Control of the foliar disease, Septoria lycopersici, in organic tomato production

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Control of the foliar disease, *Septoria lycopersici*, in organic tomato production

by

Karen Roger Marie Joslin

A thesis submitted to the graduate faculty

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This is to certify that the master's thesis of

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has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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CHAPTER 1. GENERAL INTRODUCTION AND LITERATURE REVIEW

Organic Agriculture

It is difficult to trace the organic movement back to its inception. Contrary to the belief of many consumers, the organic movement began prior to the 1960s. However, one can attribute much of the inspiration to the present day philosophies of the organic movement to a number of scientists who began connecting plant health with soil fertility in Europe in the early 1900’s.

In 1918 Sir Albert Howard began to investigate the link between soil, plant, and animal health where animal manure increased soil fertility, which in turn increased soil health and crop yield. In his book, *An Agricultural Testament*, Sir Albert Howard claimed that farming systems should resemble nature, integrating livestock and a mixed cropping system and converting animal and crop waste into humus. Additionally, all attempts to maintain soil fertility and prevent soil erosion should be undertaken. These philosophies still provide the basis for much of the organic practices used today. Rudolf Steiner, a German scientist and philosopher also played a role in the movement of organic agriculture when he developed biodynamic farming in the 1920’s. Biodynamic farming is based on the notion that there are two forces acting upon agriculture, ‘terrestrial’ and ‘cosmic’. While his agronomic methods are not always taken seriously, because they include practices such as planting according to lunar phases and astrological cycles, they also include the use of crop rotations, compost, animal manure and other ideas central to the organic practices. In 1946, the Soil Association formally registered in Britain with Lady Balfour as their first president. The objective of the association was to facilitate communication among scientists researching the relationships between soil, plant, animal and human health, to assist in field
research and disseminate information in order “to create a body of informed public opinion” (Conford, 2001). The Soil Association is currently U.K.’s largest organic certifier and campaigner for organic food and farming.

The term “organic” was first used to describe agricultural practices in the U.S. in 1946 when Jerome Rodale published *Pay Dirt*, in which he introduced organic production principles to American farmers. These production principles emphasized soil as a biological entity, the importance of compost for soil structure and fertilizer, and the dangers of chemical fertilizer, toxic pesticides and the impact of over mechanization (Rodale, 1946). In 1947 he founded the Soil and Health Foundation, which lead to the Rodale Institute, which is still active today in researching organic and low-input crop production (Conford, 2001). While the organic movement was already well under way by the 1960’s, Rachael Carson’s book, *Silent Spring*, published in 1962 informed the public about the devastating effects pesticides, particularly DDT, can have on wildlife and the environment. Her book triggered an outcry of concern from the public, which eventually led to a ban on DDT as well as the formation of the Environmental Protection Agency in 1970. *Silent Spring’s* focus on the dangers of overuse of pesticides caused many consumers to demand pesticide free foods.

In 1990 the U.S. Department of Agriculture (USDA) passed the Organic Foods Production Act (OFPA) as part of the 1990 Farm Bill (Title XXI of the Food, Agriculture, Conservation and Trade Act). The OFPA required the USDA to develop national standards for organically produced agricultural products. On October 21, 2002 the National Organic Program went into effect requiring that all products labeled organic must come from farms or operations that have been certified by a State or private group that has been accredited by the USDA. They went on to define organic production as “a system that integrates cultural,
biological, and mechanical practices that foster cycling of resources, promote ecological 
balance, and conserve biodiversity" (NOP, 2001). Prohibited in organic production are the 
use of synthetic chemicals, sewage sludge, animal growth hormones, antibiotics, irradiation, 
and crops that have been genetically engineered.

World wide there is a total of 24,070,010 hectares in organic production; Australia 
has the most hectares in organic production (10,000,000) followed by Argentina (2,960,000), 
Italy (1,168,212) then the US with 950,000 hectares (Willer and Yussefi, 2004). In the US, 
organic production has continued to grow at a rate of 20% per year as projected in the early 
90’s. Sales in 2003 reached $10.8 billion, representing 1.9% of the total food sales in the U.S. 
Fruit and vegetables accounted for 42% of total organic sales (OTA, 2004). In the US there 
are 6,949 organic farms that account for 2.3% of the total agriculture land in production 
(Willer and Yussefi, 2004). Prior to 2000, 68% of organic foods were sold through natural 
grocery stores and only 7% was sold through conventional grocery stores. However, since 
then, sales have shifted and 49% of organic products are sold through conventional grocery 
stores, 48% through natural grocery stores, and 3% is direct marketed through farmers 
markets or community supported agriculture venues (Dimitri and Greene, 2002).

**Organic Tomato Production**

In Iowa there are 39 organic fruit and vegetable farms, 21 of which grow tomatoes 
(*Lycopersicon lycopersicon* (L.) Karsten) (IDALS, 2004). In 2001, 1,397 hectares of US 
tomatoes were managed organically, accounting for almost one percent of the total tomato 
production (Greene and Kremen, 2001). California is the largest organic tomato producer, 
supplying half of the world’s organic processing tomato demands. Organic tomato 
production in California has increased 12% since 2000 and 72% since 1997 with 1346
hectares in production (Greene and Kremen, 2001). A survey funded by the Organic Farming Research Foundation (OFRF) found the median organic tomato yield was 16.8 Mgha\(^{-1}\) with a low of 2.2 Mgha\(^{-1}\) and a high of 35.8 Mgha\(^{-1}\) and that the median price received was $2.65 per kg with a high of $11.00 per kg and a low of $0.08 per kg (Walz, 2004). Expected fresh market tomato yields in the Midwest are 29 to 33 Mgha\(^{-1}\) (Foster et al., 2003). Fresh market organic tomatoes are typically grown by market gardeners who direct market either through farmers’ markets or community supported agriculture. They are often produced on less than 1-acre units. A common practice among these producers is to combat yield loss from diseases by increasing plant population. This practice could explain why the median yield of organically produced tomatoes is lower than the expected fresh market tomato yields in the Midwest. Furthermore, many organic producers grow heirloom tomatoes which are typically lower yielding than hybrid varieties.

Native to the Peru-Ecuador region of South America, the tomato (\textit{Lycopersicon lycopersicum} (L.) Karsten) was first introduced to the U.S. in 1710 but was not recognized as a food crop until 1779 (Pierce, 1987). The tomato belongs to the Solanaceae family with related crops such as potato, pepper, eggplant and tobacco. Naturally a warm season perennial, the tomato is cultivated as an annual crop. Maximum yield is achieved when the mean day temperature is 24 C with a night temperatures below 16 C (Pierce, 1987).

There are two types of tomato growth habits, determinate and indeterminate. Indeterminate varieties will continue to grow vertically and set fruit throughout the summer and into the fall. Determinate varieties fruit and ripen with in a few weeks. Indeterminate varieties are favored by producers who sell at farmers’ markets, while determinate varieties are favored by large commercial growers. There are many varieties of tomatoes bred
specifically for large scale commercial growers that are disease resistant, and they have characteristics that make transportation less damaging to the fruit such as a longer shelf life or thicker skins. However, there are many older varieties that have been maintained, called heirloom varieties that are more typically found at farmers' markets and in homeowners' backyards. While there is debate over the definition of an heirloom variety, it typically refers to a plant variety that is open-pollinated and that is not a hybrid. Heirlooms are typically more difficult to grow than hybrid tomato varieties because they lack characteristics such as disease tolerance and cold hardiness. However, their popularity and demand at farmer's markets makes them popular among organic producers.

Disease management in organic tomato production poses challenges for producers in humid climates. The Organic Farming Research Foundation found that management of plant diseases ranked 8th as an area of organic farming research most important to individual farmers (Walz, 1999). Some major tomato diseases include early blight caused by Alternaria solani Auct., anthracnose caused by Colletotrichum coccodes (Wallr.) Hughes, septoria leaf spot caused by Septoria lycopersici Speg, bacterial spot caused by Xanthomonas campestris pv. Vesicatoria (Xav), and bacterial speck caused by Pseudomonas syringae pv. tomato (Okabe). Because synthetic chemicals are not allowed in organic tomato production, producers rely on five types of management practices that include site selection, cultural control, variety selection, the use of biological control agents, and non-synthetic fungicides.

Tomato production should be located on well drained soils with adequate air movement and should not be located near fields containing related crops. Production is typically highest on loamy soils; however, with high inputs of organic matter any soil type
can produce desirable fruit (Decoteau, 2000). Because many pathogens can remain in soils for two to three years production sites should be determined based on a three year rotation.

Cultural practices should include the use of disease free transplants, two to three year crop rotations, and good sanitation. Because many diseases that infect tomatoes are spread by splashing water, the use of plastic mulch or straw mulch with drip irrigation are commonly used for disease control. Plastic mulch is also used to obtain earlier harvests in certain parts of the U.S. by warming the soil. Early harvest not only attracts a premium at farmers’ markets but can also build customer loyalty. A method of supporting plants, either with cages or a system of staking and weaving is also common to increase air movement through the plants, thus reducing relative humidity, which is often necessary for pathogen production. Plant spacing is also important in facilitating air movement. When plastic mulch is used plants rows are six ft wide with 18 to 24 inches between plants within rows (Decoteau, 2000).

The use of resistant varieties is also an effective way of controlling diseases, however, it may be difficult to find varieties that are resistant to problem diseases and also meet market demands (Miller, 2002). The most common diseases in which tomato varieties have shown resistance or tolerance to include verticillium wilt, fusarium wilt, early blight, tobacco mosaic virus, alternaria stem canker, bacterial speck, gray leaf spot, and spotted wilt virus.

Biological control is the use of natural enemies to control crop pests. There are three main types of biological control; classical, augmentation, and conservation. Classical biological control is when a natural enemy is introduced from the country where the crop originated. Augmentation is when the native natural enemy population is supplemented, and conservation biological control employs management tactics that maintain the current natural
enemy populations. Compost tea provides biological control by changing the microbial community on the leaf surface to one that favors biological control agents and discourages pathogens (Andrews, 1992). Microorganisms responsible for biological control of foliar pathogens include yeasts and phylosphere fungi, *Trichoderma* spp., and a number of bacteria species (Fokkema, N., 1993). Knowledge of the complex interactions between plant pathogens and biological control agents has been enhanced in recent years through extensive research. Many seed, damping-off and stem rot diseases caused by various *Pythium* spp. have been controlled by a number of antagonistic microorganisms including *Enterobacter cloacae* (Jordan), *Bacillus cerus*, and other rhizosphere bacteria (Kokalis-Burelle, 2002). Asaka and Shoda (1996) found that *Bacillus subtilis* RB14 produces antibiotics that can suppress *Rhizoctonia solani* Kuhn. *Gliocladium virens* combined with solarization reduced southern stem blight (*Sclerotium rolfsi*) by 49% the first year and 60% the second year (Ristaino et al., 1991). This increased understanding will enable producers to adjust management practices to optimize disease control from natural enemies.

There are a number of non-synthetic pesticides that are either derived from plants or microorganisms or from natural elements. However, there is little independent research to support product efficacy. While organic farmers rely heavily on biological pesticides the market is still small, accounting for less than 1% or the total pesticide market worth over $30 billion (Marrone, 1999).

**Septoria Leaf Spot Epidemiology and Disease Control**

*S. lycopersici* is an imperfect fungus (asexual reproduction) that produces long, colorless, filamentous conidia within pycnidia that can survive on tomato plant residue in the field for two years (Agrios, 1997). While the pycnidia require moisture to release the conidia,
disease development can occur under a wide range of temperatures from 10°C to 27°C (Agrios, 1997). *S. lycopersici* is an unspecialized necrotrophic pathogen, which means that it can grow saprophytically on leaf surfaces prior to the formation of infection structures. It obtains nutrients from either stored nutrients within the spore or from nutrients leaked out of the plant leaf (Blakeman, 1985).

Disease symptoms include small, yellow leaf spots that gradually enlarge turning light brown. Spots vary in size but usually range from one to two cm in diameter. As the disease progresses, pycnidia appear as dots in the center of leaf lesions (Agrios, 1997). When plant leaf damage exceeds 50% by the middle of August tomato yield can be reduced by 34-53% (Ferrandino and Elmer, 1992).

There are many factors that can impact disease severity including leaf age, spore density, temperature, moisture, and distance from inoculum source. Disease symptoms usually start at the base of the plant and move upwards (Agrios, 1997). When disease pressure is high older leaves are more susceptible then younger ones (Elmer and Ferrandino, 1995). As spore density increases, disease severity decreases (Sugha and Kumar, 2000), likely a factor of intraspecific competition for infection sites (Elmer and Ferrandino, 1995). Optimum temperature for disease development is between 20 and 24°C (Tu and Poysa, 1990). Disease development usually requires periods of wetness ranging from 12 to 15 hours, however, disease development is possible in the absence of wetness (Elmer and Ferrandino, 1995). Rain events can also increase disease epidemics because it aids in the distribution of spores (Parker et al., 1995).

There are currently no commercially available varieties that are resistant or tolerant to *S. lycopersici*. A few evaluations have been made to identify resistant strains; however, none
have lead to a commercially available variety. Barksdale and Stoner (1978) identified a
single dominant gene responsible for resistance in line PI 422397, however, it was never
incorporated into a commercially available cultivar. Poysa and Tu (1993) evaluated over 700
tomato cultivars for disease resistance to *S. lycopersici* and found six breeding lines that
showed high levels of resistance, however, other factors such as maturing date and yield
made them undesirable for commercial development. Sugha and Kumar (1998) also
evaluated forty-one tomato genotypes for resistance and found that none of them had a high
enough level of resistance to make them commercially desirable.

Control of *S. lycopersici* depends on the use of disease free transplants, two to three
year crop rotations, plowing under plant debris, and the use of chemical fungicides (Agrios,
1997). Kumar and Sugha (2000) found that increasing row spacing decreased disease
severity. Row spacing of 45, 60, or 75 cm (within row spacing constant at 50 cm) caused
57.6, 57.8, and 51.6% diseased plants, respectively, while row spacing of 90 x 50 cm caused
28.2% diseased plants. They also found that staking and pruning plants helped minimize
disease severity when compared to treatments of staked/not-pruned, not staked/not pruned,
and not staked/pruned plants. However, this may not always be the case. Staking and
pruning plants can cause wound sites on the plants that enable pathogens to infect plants.
Incorporating cultural control practices into organic tomato production does not ensure
disease control, thus producers must rely on non-synthetic fungicides, specifically copper
(Cu) based fungicides. Widespread use of Cu-containing fungicides has been used since
1885 (Tiller and Merry, 1981). Frequent use and reliance on Cu fungicides have raised
concerns among organic growers because of the potential for Cu accumulation in the soil
causing plant and animal toxicity. Furthermore, the potential for disease resistance and replacement have lead producers to seek alternatives.

Copper is one of the least mobile heavy metals found in the soil and typically accumulates in the top of the soil profile. While it is an essential plant nutrient required for numerous plant metabolic processes including enzyme production, photosynthesis, respiration, carbohydrate distribution, and protein and cell wall metabolism it can be toxic at high levels (Kabata-Pendias and Pendias, 2001). Symptoms of Cu toxicity include small, chlorotic leaves that drop prematurely, stunted growth and poor root development (Pahlsson, 1989). Cu sensitive crops include cereals, legumes, spinach, citrus seedlings and gladiolus (Kabata-Pendias and Pendias, 2001). Damage to tomato plants can occur when Cu is added to the soil at rates above 104 mg·kg⁻¹ (Rhoads et al., 1989). For trellised field tomatoes, Cu in excess of 50 mg·kg⁻¹ is considered toxic (Mills and Jones, 1992).

Soil microorganisms play a vital role in soil fertility and have profound impacts on agriculture production. They are responsible for nutrient transformations (mineralization and nitrification), organic matter decomposition, biological control, and increased plant growth due to symbiotic relationships (Sylvia et al., 1999). Production practices that threaten the soil ecosystem do not “promote ecological balance, and conserve biodiversity” as required by the National Organic Program Regulations as defined in 7 CFR Part 205 (NOP). While Cu fungicides are currently allowed in certified organic production there is concern among some farmers in the U.S. that there use may soon be prohibited. When soil Cu concentrations are >100ppm (dry matter), soil processes such as respiration, nitrogen mineralization and nitrification may be inhibited. When soil Cu concentrations exceed 1000 ppm (dry matter) these soil processes are always inhibited (Kabata-Pendias and Pendias,
2001). Research has shown that Cu fungicides can impact soil ecosystems by reducing certain microbial populations, thus changing the "ecological balance." Burrows and Edwards (2002) found that in laboratory experiments nematode populations were reduced 5 DAT when 800 mg·kg\(^{-1}\) Cu was added to the soil and earthworms were reduced 10 DAT when 200 \(\text{mg kg}\(^{-1}\) and 400 \(\text{mg·kg}\(^{-1}\) was added to the soil and at 800 \(\text{mg·kg}\(^{-1}\) all earthworms were killed. Paoletti et al. (1998) found a significant negative regression (r=0.71) between increasing Cu concentrations (0 to 250 ppm) and earthworm populations (4 to 0 g/m\(^2\)) in a study that evaluated 72 different orchard ecosystems with varying levels of Cu inputs. Georgieva et al. (2002) found that the number of bacteria feeding nematodes decreased and the number of hyphal feeding nematodes increased in soils treated with sewage sludge containing various levels of Cu. Since there is research that supports the claim that Cu fungicides can have a negative impact on soil microorganisms, organic producers will seek alternatives.

When fungicides are used repeatedly there is concern regarding pathogen resistance. Fungicides that are site specific usually have a higher risk of resistance than broad spectrum fungicides. While copper fungicides are broad spectrum and control pathogens by denaturing enzymes and proteins there is some research that indicates pathogen resistance is possible. Resistance to copper based fungicides has been found in two common pathogens of tomatoes, *Xanthomonas campestris* pv. *Vesicatoria* (XAV), the cause of bacterial spot (Adaskaveg and Hine, 1985), and *Pseudomonas syringae* pv. *tomato* (Okabe), the cause of bacterial speck (Bender and Cooksey, 1986). Low concentrations of Cu were also found to cause resistance in soil microorganisms, primarily in Gram-negative, rod-shaped bacteria (Huysman et al., 1994). Disease replacement can also be a problem with Cu fungicides because Cu fungicides can reduce the antagonistic microbial soil population allowing other
pathogens to cause disease. For example, the use of Cu fungicide lead to coffee berry disease caused by *Colletotrichum coffeum* (Noack) in coffee production and dieback of apricot trees caused by *Eutypa armeniacae* (Hansford). Copper reduced *Fusarium lateritium* (Nees ex Fr.) populations, a saprophytic fungus that was antagonistic to both *C. coffeanum* and *E. arminiacae* (Blakeman, 1985).

Disease forecasting, first introduced as a disease management tool in the early 1950’s, may be a way to reduce Cu fungicide applications. Madden et al. (1978) designed one of the first computerized forecasting systems (FAST) for use in tomato production to determine favorable conditions for *Alternaria solani* (Ell and G. Martin) Sor. disease development. This system combines hours of leaf wetness and mean air temperature during leaf wetness to determine a daily disease severity value (DSV). Once a predetermined DSV has been reached fungicides are applied. They found that by using the FAST system they were able to reduce the number of fungicide applications of chlorothalonil. TOMCAST is another weather based disease forecasting system that when incorporated into integrated pest management programs can reduce the number of fungicide applications by four times per season. This results in a savings of $100 per hectare (Sikora et al., 2002). The fungicides used in this research were mancozeb or chlorothalonil plus copper hydroxide. Research investigating the efficacy of disease forecasting systems for use in organic tomato production could result in reduced applications of Cu-based fungicides. An alternative disease-management technique available to organic producers is the use of biological control agents. *Serenade®* (*Bacillus subtilis* Cohn; AgraQuest, Davis, CA) is a commercially available, broad-spectrum biofungicide registered for use on tomatoes to control foliar diseases caused by bacterial and fungal pathogens. *Soran®* (rosemary oil; EcoSmart Technologies, Franklin,
TN) is another broad spectrum organic fungicide registered for use on tomatoes. The use of compost teas is another option for organic producer might be able to control diseases on tomatoes and many commercial companies are marketing equipment for on-farm tea production. However, the efficacy of these products and other techniques available to farmers has not been evaluated. Scientific evaluation of the efficacy of pesticide products registered for use in organic agriculture is vital for growers’ success.

**Compost Tea**

Compost tea, a liquid extract with microorganisms (Diver, 1998), is a producer-created biofungicide. Organic Farming and Research Foundation found that compost, compost tea and vermicompost ranked 11th as an area of organic farming research most important to individual farmers (Walz, 1999). There are two main ways in which teas can be made; one includes aeration whereas the other does not. Researchers of non-aerated compost teas have found that control of plant pathogens on the phyllosphere from beneficial organisms is acquired through microbiostasis, induced systemic resistance, inhibition of spore germination, antagonism or competition for substrate colonization or infection sites (Stone et al. 2004). Such studies have not been performed on aerated compost tea (Scheuerell and Mahaffee, 2002). The main agents in compost tea that control foliar diseases are bacteria, specifically those belonging to the genera *Bacillus* Cohn, *Pseudomonas* van Hall, *Serratia* Sm., and some fungi, including *Penicillium* Link, and *Trichoderma* Pers. (Brinton et al., 1996). There are many factors that can affect the efficacy of compost tea including compost source and maturity, dilution ratio, and fermentation time (Scheuerell and Mahaffee, 2002).
Pathogen suppression from compost tea is largely due to the species and quantity of microorganisms present in the tea. Because different compost sources contain different species of microorganisms, compost source could affect efficacy of compost tea (Weltzien, 1991). However, there have been mixed research results. Andrews (1993) evaluated compost teas made from 32 different compost sources and found that teas made from manure based compost were more effective at controlling *Venturia inaequalis* (Cooke) Winter conidia *in vitro* than plant based compost. Liping et al. (1999) compared the efficacy of compost extracts made from pig, horse, and cow manure to control cucumber wilt (*Fusarium oxysporum* f. sp. *cucumerinum* (Owen)) and found that while each extract provided disease control, there was no difference between the three. However, El-Masry et al. (2002) found that compost tea made from composted leaves and crop waste compost was effective at controlling *F. oxysporum* f. sp. *lycopersici*, *Phythium debaryanum* (Hesse) and *Sclerotium bataticola* (Taub) and compost tea made from leafy fruit compost was not as effective.

The effect compost maturity has on efficacy of tea depends on the compost source used (Scheuerell and Mahaffee, 2002). Various investigations on compost age and tea efficacy have concluded in mixed results. Brinton et al. (1996) found that compost tea made from composted plant material was most effective when the compost was less than three months old, while tea made from composted horse or dairy manure was most effective between nine to twelve months old. However, Al-Dahmani et al. (2003) compared 5, 10, and 16 month old composted cattle manure and found no difference in tea efficacy.

Studies investigating the most effective ratio for volume: volume compost tea preparation resulted in a range of ratios from 1:1 to 1:50 with most studies now using a range from 1:3 to 1:10 (Scheuerell and Mahaffee, 2002). Optimum fermentation time for non-
aerated compost tea vary according to compost source, pathogen, and host plant. Optimal fermentation time for non-aerated compost tea ranges from 3 to 14 days and 18 to 24 hours for aerated compost tea (Scheuerell and Mahaffee, 2002).

Compost teas have been found to control some important diseases of fruits and vegetables. Al-Dahmani et al. (2003) found that compost extracts showed some efficacy in controlling bacteria spot, caused by X. vesicatoria, however, control was not comparable to a mixture of copper hydroxide and clorothalanil. Tsror (1998) found that a compost tea of commercial cattle manure incubated for 7 or 14 d controlled Alternaria solani (Elli. & Mart.) L.R. Jones & Grout on field-inoculated tomato plants. The degree of control was similar to that obtained with Kocide® (copper hydroxide; Griffin L.L.C., Valdosta, GA) or Funguran® (copperferoxychlorid; Spiess Urania, Hamburg, Germany), both Cu-based fungicides. Compost tea made from either dairy cattle manure or horse manure reduced disease caused by Botrytis cinerea Pers., on strawberries (Fragaria ananassa L) by 70 % and 48%, respectively (Stindt, 1990 reviewed in Trankner, 1992). In growth chambers, compost teas made from either composted cattle or chicken manure controlled B. cinerea. Compost tea made from composted grape marc, the waste from wine production, also controlled B. cinerea on tomato and pepper (Capsicum L.) plants and grape berries (Elad and Shtienberg, 1994).

Concerns regarding the potential of compost tea containing human pathogens, particularly when nutrients are added during the brewing process or when the tea is not aerated have been raised. This lead to the formation of the Compost Tea Task Force (CTTF) by the NOSB to address these concerns and determine what regulations needed to be applied to compost tea preparation and use in certified organic production.
There have been few peer reviewed articles documenting scientific research regarding the presence of human pathogens in compost tea. Currently, the only peer-reviewed study on this topic investigated the affect added nutrients has on human pathogens in compost tea. Duff (2004) found that there was a correlation between the concentration of molasses added to compost tea and the re-growth of E. coli O157:H7 and *Salmonella* Thompson. The CTTF recommends that if compost teas made with additives are used in certified organic production the tea from the compost tea brewing system (compost source, additives, and equipment) must be pre-tested to make sure the tea from that system meets EPA recreational water quality guidelines. If compost tea has not been pre-tested it can only be applied 90 days prior to harvest of above ground crops and 120 days for root crops (NOSB, 2004).

The increasing demand for organic foods will result in an increase in organic tomato production. This will increase the use of Cu-fungicides unless alternative fungicides are used. Scientific evaluation of the efficacy of pesticide products registered for use in organic agriculture is vital for growers’ success.

**Thesis Organization**

This thesis is organized into four chapters. The first is an introduction to organic production, specifically tomato production and a review of the literature regarding disease control and potential problems associated with current practices. The second chapter is a manuscript describing my field research in which the efficacy of organic fungicides to control *Septoria lycopersici* was evaluated. The third chapter is a manuscript describing a growth chamber experiment in which the impact of compost tea recipes on disease control of *Septoria lycopersici* on tomatoes was evaluated. The fourth and final chapter contains an
economic analysis of the management practices used in my field research, a summarization of conclusions based on my two experiments and recommendations for organic tomato producers.

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CHAPTER 2. CHEMICAL CONTROL OF SEPTORIA LYCOPERSICI IN ORGANIC TOMATO PRODUCTION

A paper to be submitted for publication

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Abstract

Disease management in organic tomato (Lycopersci esculentum Mill.) production poses challenges for producers in humid climates. Septoria leaf spot (Septoria lycopersici Speg.) is a common disease of tomatoes in areas with high humidity and temperatures from 20 to 25 °C. New commercial products and techniques are becoming available to control S. lycopersici, but their efficacy has not been tested adequately. Our objective was to evaluate the efficacy of organic fungicides and compost tea from either windrow-composted cattle manure (WCCM) or vermicomposted cattle manure (VCCM). We also compared the efficacy of organic and conventional fungicides. Tomato plants ('Mountain Spring') were transplanted into black plastic mulch in May of 2003 and 2004, inoculated with 7.5 x 10^8 conidia•ha⁻¹ and treated with: (i) control (no foliar spray), (ii) alternated applications of chlorothalonil plus copper hydroxide and mancozeb plus copper hydroxide (iii) Copper hydroxide only, (iv) Bacillus subtilis only, (v) WCCM tea, and (vi) VCCM tea. In 2003 the primary disease was Xanthomonas campestris pv. vesicatoria Diodge. The only treatments effective in reducing disease severity were copper hydroxide and copper hydroxide plus chlorothalonil or mancozeb. Copper based fungicides reduced disease severity by 50% in 2003 and 75% in 2004 and increased marketable yield by 64 and 150% in 2003 and 2004, respectively. While the addition of conventional fungicides to copper hydroxide reduced disease severity by 22% in 2004 this did not result in a difference in marketable yield.
Treatments that received *B. subtilis* or compost extracts were not effective at controlling *S. lycopersici*. The method by which the cattle manure was composted did not affect disease severity. Plants treated with copper hydroxide remained disease free, and there was no effect on disease severity of adding conventional fungicides to copper hydroxide.

**Introduction**

Managing diseases of tomatoes organically poses challenges for producers in humid climates. *Septoria lycopersici* is a common fungal disease of tomatoes. Asexual spores produced in conidia are spread by splashing rain or irrigation water. Resistant or tolerant cultivars are not available; therefore growers must rely on cultural and chemical control practices, including the use of copper (Cu) fungicides for disease control (Jones et al., 1991). There are currently five Cu based fungicides allowed in certified organic production. Concerns regarding the use of Cu fungicides have been expressed due to their potential to reduce yield (Rhoads et al., 1989) and to cause toxicity to earthworms, nematodes (Burrows and Edwards, 2002), and entomopathogenic fungi (Ropek and Para, 2002). Furthermore, the potential for Cu accumulation in the soil surface (Kabata-Pendias and Pendias, 1992) and concerns about pathogen resistance also have led producers to seek alternatives. The application of low concentrations of Cu on a continuous basis can cause the development of resistant microorganisms, primarily in Gram-negative, rod-shaped bacteria such as *Psuedomonas, Alcaligenes,* and *Flavobacterium* (Huysman et al., 1994).

An alternative disease-management technique available to organic producers is the use of biological control agents that are commercially available or producer created. *Bacillus subtilis*® (*Bacillus subtilis* Cohn; AgraQuest, Davis, CA) is a commercially available, broad-spectrum biofungicide registered for use on tomatoes to control foliar diseases caused by
bacterial and fungal pathogens. However, independent research regarding its efficacy in controlling *S. lycopersici* has not been repeated.

Compost tea, a liquid extract with microorganisms (Diver, 1998), is a producer-created biofungicide. There are two main ways in which teas can be made; one includes aeration whereas the other does not. Research on non-aerated compost teas has found that control of plant pathogens in the phyllosphere from beneficial organisms is acquired through induced resistance, inhibition of spore germination, antagonism, or competition. Such studies have not been performed on aerated compost tea (Scheuerell and Mahaffee, 2002). Bacteria and fungi are the agents in compost tea that control foliar diseases, specifically those belonging to the genera *Bacillus* Cohn, *Pseudomonas* van Hall, *Serratia* Sm., *Penicillium* Link, and *Trichoderma* Pers. (Brinton et al., 1996). There are many factors that affect the efficacy of compost tea including compost source, dilution ratio, and organism extraction and application methods (Scheuerell and Mahaffee, 2002).

The efficacy of many new commercial organic products and techniques available to farmers has not been evaluated. Scientific evaluation of the efficacy of pesticide products registered for use in organic agriculture is vital for growers’ success. Our objectives were to evaluate the efficacy of organic fungicides and compost tea from either windrow-composted cattle manure (WCCM) or vermicomposted cattle manure (VCCM). We also compared the efficacy of organic and conventional fungicides.

**Materials and Methods**

Research was conducted for two seasons at the Iowa State University Horticulture Station near Gilbert, IA. The field site was a Clarion loam soil defined as a fine loamy,
mixed, superactive, mesic Typic Hapludoll. The 2003 field site was planted in muskmelons (Cucumis melo L.) in 2001 and soybeans [Glycine max (L.) Merr.] in 2002. The 2004 field site was planted in muskmelons in 2003 and tomatoes, squash, and green beans in 2002.

For 2003 the average temperature close to normal at the beginning of the season and rainfall was below normal. The deviation from normal temperature in May, June, July, and August was +0.1, -0.5, -0.7, and +2.0 °C, respectively (Figure 1). Rainfall deviation from normal for May, June, July, and August was -14, -45, +10, and -73 mm, respectively (Figure 2).

For the 2004 growing season fruit ripening was delayed because of lower than normal temperatures. The deviation from normal temperature in May, June, July, and August was +1.6, -1.0, -2.0, and -2.4 °C respectively, below average for June, July, and August. Temperatures reached 32 °C only twice during the growing season and did not exceed 32 °C. This resulted in delayed fruit set. Average rainfall in 2004 was greater than normal at the beginning of the season. Rainfall deviation from normal for May, June, July, and August was +89, -71.0, -12.5, and +6.0 mm, respectively.

'Mountain Spring' tomato plants were transplanted on 16 May 2003 and 12 May 2004 into black plastic mulch. All treatments except for the conventional treatment received 8 Mg·ha⁻¹ of compost that contained 1.4% nitrogen and 27% moisture in 2003 and 22 Mg·ha⁻¹ of compost that contained 0.52% nitrogen and 27% moisture in 2004. Compost used in 2003 was windrow composted cornstalk bedded cattle manure from Terra Fact, Corp. near Lake Park, IA. Compost used in 2004 was windrow sand bedded cattle manure from the Iowa State University dairy farm. The nitrogen (N) applied by compost in each year was 83 kg·ha⁻¹. The conventional treatment received 67 kg·ha⁻¹ of N as urea in both 2003 and 2004.
Compost and urea were broadcast uniformly and incorporated to a 20-cm depth before laying plastic mulch. Plants were pruned once at the first flower cluster on 12 June 2003 and 17 June 2004 and staked and tied according to the Florida method. Plants were irrigated with a trickle system to maintain the 20-cm-depth tensiometer readings at \(< -3 \text{ MPa}\).

Each treatment row was 7 m long with ten plants plus two guard plants at each end. Guard rows of ‘Mountain Spring’ were planted between each treatment row. Treatments were (i) control (no foliar spray), (ii) alternated applications of chlorothalonil (Bravo\textsuperscript{®}; tetrachloroisophthalonitrile; Syngenta Crop Protection, Greensboro, NC) plus copper hydroxide (Champion\textsuperscript{®}; Nufarm Americas, Sugar Land, TX) with mancozeb (Dithane DL\textsuperscript{®}; methyl (E) \(2\)-(2-[6-(2-cyanophenoxy) pyrimidin \(- 4\)-XY] phenyl) \(- 3\)- methoxyacrylate; Syngenta Crop Protection, Greensboro, NC) plus copper hydroxide, (iii) copper hydroxide only, (iv) B. subtilis only, (v) windrow composted cattle manure compost tea (WCCM), and (vi) vermicomposted cattle manure compost tea (VCCM). A rosemary oil based certidifed organic fungicide (Sporan\textsuperscript{TM}; EcoSmart Technologies Inc, Franklin, TN) was added in 2004. Commercial fungicides were applied according to label recommendations. Compost teas were made at a 10:1 water/compost ratio, by weight, in SoilSoup\textsuperscript{™} compost brewers, (SoilSoup Inc., Seattle, WA), aerated for 24 h and applied at 2000 L·ha\(^{-1}\). The adjuvant Nu-Film 17\textsuperscript{TM} (Miller Chemical & Fertilizer Corp, Hanover, PA) was added to all treatments prior to application. All treatments were applied once weekly from 19 June to 13 August 2003 and 17 June to 10 August 2004. All plants except those in the data rows were inoculated with \(7.5\times10^8\) conidia·ha\(^{-1}\) of S. lycopersici on 28 July 2003 and 6 July 2004. The inoculum source (infected foliage) was collected from field-infected plants in Ames, IA, in 2002 and stored in a freezer. To increase the amount of inoculum, leaves were macerated in
water that was filtered and then sprayed onto tomato plants in a greenhouse. The field was overhead-irrigated immediately after inoculation to disperse the conidia. Treatments and inoculum were applied with a backpack sprayer.

Weekly disease severity ratings began on 28 July 2003 and 27 July 2004 and were taken by using a modified version of the scale of Horsfall and Barratt (1945). Disease rating began one week after the first disease symptoms appeared from infection caused by naturally occurring pathogens, and the same day that inoculum was applied in 2003. In 2004, disease ratings began three weeks after inoculation when disease symptoms began to show. Weather conditions in 2003 were particularly favorable for *Xanthomonas campestris pv. vesicatoria* Doidge, which resulted in an epidemic of bacterial spot before we inoculated with *S. lycopersici* (Jones et al, 1991). It was impossible to distinguish between symptoms caused by the two pathogens on leaves in the field. In fact, symptoms were primarily bacteria spot. Consequently, disease severity ratings reflect both *X. campestris* and *S. lycopersici* for 2003. In 2004, however, disease symptoms were caused primarily by *S. lycopersici*. Weekly harvests of ripe fruit were from 29 July to 2 Sept 2003 and 11 August to 8 Sept 2004. All green fruit was harvested at the end of the season. Fruits were sorted as marketable or unmarketable (diseased, cracked, or zippered) and then counted and weighed.

Six mature leaves per plant were collected at mid-bloom, 10 July 2003 and 22 July 2004, for tissue analysis in 2003 and 2004. Plant samples were dried in a forced-air oven at 67 °C for 72 h and ground through a 1 mm-mesh screen in a Wiley mill. Tissue concentrations of P, K, Na, Ca, Mg, S, B, Cu, Mo, Mn, and Zn were measured by using inductively coupled argon plasma techniques (ICAP) (Jones, 1977; Munter and Grande, 1981) after ashing at 490 °C and digesting in 1N aqua-regia. The instrument was a Thermo Jarrell-
Ash ICP/IRIS model with a charged injection device (Epperson et al., 1988). Total leaf N was determined using a modified-Kjeldahl digestion procedure in conjunction with a nitroprusside-salicylate assay using flow ingestion analysis (Jones, 1991; Smith and Scott, 1990).

The experimental design was a randomized complete block with four replications and seven treatments. Data were analyzed by using the general linear model procedure and Tukey’s multiple comparisons and orthogonal contrasts option of SAS (SAS Institute Inc., 1988).

**Results**

Differences in disease severity occurred early and were consistent throughout the 2003 growing season. Plants in the two treatments that received copper hydroxide remained disease-free and there was no additional effect on disease severity of adding conventional fungicides to copper hydroxide® (Table 1). Treatments that received copper hydroxide had 50% lower disease severity than the untreated control by the end of the season. There was no difference in disease severity between plants that received *B. subtilis* or compost extracts and the control treatment as 50% of leaves on plants in all four treatments showed disease symptoms by the end of the season. The composting method did not affect disease severity between the two types of compost teas, VCCM and WCCM. Again, 50% of leaves on plants that received compost tea applications showed disease symptoms.

Differences in disease severity in 2004 showed a similar trend to that of 2003; disease severity was less in treatments that received copper hydroxide than those that did not (Table 2). However, unlike the 2003 growing season there was a significant difference in disease severity between plants that received copper hydroxide only, and those that received copper...
hydroxide plus conventional fungicides. Plants in treatments that received copper hydroxide only, were < 25% diseased, whereas plants in treatments that received copper hydroxide plus conventional fungicides were 25 to 50% diseased. However, plants that received copper hydroxide fungicides were 75% less diseased than plants that did not. There was no difference in disease severity between plants that received B. subtilis, rosemary oil or the compost teas and the unsprayed control, as all plants in these treatments were 100% diseased by the end of the season.

In 2003, plants that received copper hydroxide fungicides yielded 64% more marketable fruit than plants that did not (Table 3). There was no difference between plants that received copper hydroxide only, and plants that received copper hydroxide plus conventional fungicides. Plants in treatments that received copper hydroxide only, had the least amount of culled fruit; however, this was not different than culled fruit weight from plants in treatments that received copper hydroxide plus conventional fungicides, B. subtilis, or WCCM compost tea. But plants in treatments that received copper hydroxide only, had 75% less culled fruit than plants that were treated with VCCM compost tea or the control (Table 3). Plants in treatments that received copper hydroxide fungicides produced the largest fruit; however, this fruit size was similar to plants that received B. subtilis or plants in the control (Table 3).

Plants that received copper hydroxide fungicides plus conventional fungicides produced the most fruit (P<.05). The number of green fruit harvested was highest from plants in the conventional treatment. Plants that received copper hydroxide plus conventional fungicides had 326% more green fruit at the last harvest compared with other treatments. Plants in treatments that received copper hydroxide only, had 200% more green
fruit than those that did not. However, there was 54% more green fruit on plants that received copper hydroxide plus conventional fungicides than plants that received only copper hydroxide (Table 3).

In 2004, plants that received copper hydroxide fungicides yielded 150% more marketable fruit weight than plants that did not (Table 4). There was no difference between plants that received copper hydroxide only, and plants that received copper hydroxide plus conventional fungicides. There was no difference in cull weight among the treatments. There was no difference in marketable fruit size among all the treatments. On average, fruits weighed 290 g each; fruit from plants that received copper hydroxide only, produced the largest fruit, 332 g each, while plants in the control yielded the smallest fruit at 276 g each (Table 4). Plants in treatments that received copper hydroxide fungicides produced 122% more fruit per hectare than plants in treatments that did not. When green fruit was harvested during the last harvest in 2004, plants in treatments that received copper hydroxide fungicides had an average of 56 more green fruit per plot than plants in all the other treatments (Table 4).

There were differences in nutrient leaf concentrations for Cu, Mn, and Na. Plants in treatments that received only copper hydroxide were different than plants in all other treatments (Table 5). Leaves from plants that received only copper hydroxide contained 340 mg·kg⁻¹ of Cu, whereas leaves of plants from other treatments contained between 17 and 132 mg·kg⁻¹ of Cu. Differences in leaf concentrations of Mn were statistically significant; however, none of the concentrations were beyond the sufficiency range of 50 to 250 ppm (Mills and Jones, 1996). There were also differences in Na leaf concentrations; however, there is no data available regarding sufficient ranges of Na concentrations in tomatoes (Mills
and Jones, 1996). Total leaf N concentration was similar for the conventional treatment compared with the control both years, 4.1% vs. 3.77% in 2003 and 3.11 vs. 2.90% in 2004, respectively (Table 6).

**Discussion**

Neither *B. subtilis* nor rosemary oil was effective at controlling *S. lycopersici*, and *B. subtilis* was not effective at controlling *X. campestris*. The *B. subtilis* product label recommends its use for control of *X. campestris* in conjunction with Cu-based fungicides. Results from this research indicate that *B. subtilis* alone cannot control *X. campestris* and *S. lycopersici* when disease pressure is high. There was phytotoxic damage on plants that received rosemary oil, however, it is possible that during the first treatment application plants may have received a concentrated amount of fungicide because of inadequate sprayer mixing.

Compost tea was not effective at controlling *S. lycopersici* or *X. c. pv. vesticatoria*. Furthermore, there was no difference in disease severity between compost tea made from window-composted cattle manure or VCCM, indicating that composting method did not affect efficacy of the compost tea. These results are consistent with those of Plotkin (2002), who showed compost tea was ineffective at controlling *Alternaria solani* (Elli. & Mart.) L.R. Jones & Grout and *Septoria* spp. on field tomatoes. However, compost teas have been found to control some important diseases of fruits and vegetables. Tsror (1998) found that a compost tea of commercial cattle manure incubated for 7 or 14 d controlled *A. solani* on field-inoculated tomato plants. The degree of control was similar to that obtained with Kocide® (copper hydroxide; Griffin L.L.C., Valdosta, GA) or Funguran® (copperferroxychlorid; Spiess Urania, Hamburg, Germany), both Cu-based fungicides. Compost tea made from dairy cattle manure reduced disease caused by *Botrytis cinerea* Pers.,
on grapes (*Vitis* L. spp.) by 48% (Trankner, 1992). In growth chambers, compost teas made from either composted cattle or chicken manure controlled *B. cinerea* on tomato and pepper plants and grape berries (Elad and Shtienberg, 1994). Further research is necessary to determine what preparation and application factors affect the efficacy of compost teas on *S. lycopersici*. Investigating other composting sources, adjusting the dilution ratio, or changing application rate and timing may increase efficacy.

Copper hydroxide controlled both *X. campestris* and *S. lycopersici*. To our knowledge, the efficacy of this product for both pathogens on tomatoes has not been demonstrated previously. This information is useful for organic producers because copper hydroxide is one of six Cu fungicides allowed in certified organic production.

In both 2003 and 2004 plants in treatments that received copper hydroxide fungicides were the only ones in which expected yields the region were obtained, between 29 and 33 Mg·ha\(^{-1}\) (Foster et al., 2003). While there were differences in culled fruit weight, marketable fruit size, and the number of marketable fruit in 2003, a lack of differences in culled fruit weight and marketable fruit size in 2004 indicates that marketable fruit number is likely the main factor affecting yield. Fruit number is a result of flower production and/or percent of flowers that set fruit. On determinate tomato plants, such as ‘Mountain Spring’, flower clusters are often found at the end of plant branches. A healthier plant, i.e. one with less disease, would result in a bushier plant with more branches, and thus more flowers. In 2003 plants in treatments that did not receive copper hydroxide fungicides were 5-25% diseased by the second harvest and 25-50% diseased by the third and fourth harvest. In 2004 plants were 25% diseased by 27 July, two weeks before the first harvest and 85% diseased by the first harvest. Plants in these treatments had less green leaf area for photosynthesis, thus
they were smaller and less branched, which could have resulted in less flower production, leading to decreased yields.

Copper hydroxide applications increased leaf Cu concentrations above the normal range of 5 to 20 Mg kg\(^{-1}\) to concentrations that may be toxic to the plant (Rhoads et al., 1989). There was no difference in yield between plants in treatments that received copper hydroxide, but there were differences in Cu concentrations between the two treatments. This indicates that increased Cu concentrations did not decrease plant yield in this experiment. Because leaf samples were not washed before ICAP analysis, results would include any Cu on the leaf surface that did not affect the plants physiologically. While both the conventional treatment and the copper hydroxide-only treatment received the same amount of Cu in foliar application, there was less foliar Cu among plants in the conventional treatment than the copper hydroxide treatment. The reason for this difference is unclear.

Evaluation of leaf N showed that there was no difference between the compost (control) and the urea (conventional) sources of N either year. However, plant N concentration was considerably less at mid-bloom in 2004 than in 2003. Furthermore, the N values were below the accepted sufficiency range of 4 to 6\% (Mills and Jones, 1996). The Mtn. Spring variety should have amid-bloom N concentration of 4 to 4.5\% for top production (Taber, 2001). Thus, the planting could have benefited from additional soil N both years.

The use of compost tea to control \textit{S. lycopersici} should not be promoted in tomato production at this time. However, further investigations are warranted because there are many factors that can affect the tea efficacy. Future research should focus on compost source, using compost with known populations of beneficial species. Populations of beneficial
species should be tracked throughout the entire brewing/application process to determine methods that favor beneficial species. Finally, composting methods should select for beneficial organisms specific to a particular pathogen if the information is available. The use of chlorothalonil and mancozeb is only necessary when resistance to Cu-fungicides by *X. campestris* and *S. lycopersici* is a concern. This is beneficial because consumers are becoming increasingly aware of the impacts agricultural chemicals have on the environment. Producers will benefit from marketing their tomatoes as either organic, sustainable produced, or "low input", providing them with a competitive advantage over conventional producers.

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Figure 1. Average monthly temperature for the 2003 and 2004 growing seasons compared with the mid-Iowa 40 year annual average. Average weather data from *The Climate of Iowa*, ISUAG Report No. 38. Weather data for 2003 and 2004 were recorded from Gilbert, IA.
Figure 2. Average monthly temperature for the 2003 and 2004 growing seasons compared with the mid-Iowa 40 year annual average. Average weather data from *The Climate of Iowa*, ISUAG Report No. 38. Weather data for 2003 and 2004 were recorded from Gilbert, IA.
Table 1. Effect of five fungicidal agents, applied weekly, on disease severity caused by *Septoria lycopersici* and *Xanthomonas campestris pv. vesicatoria* on 'Mountain Spring' tomatoes grown near Gilbert, IA. in 2003. The field was inoculated with *Septoria lycopersici* at a rate of $7.5 \times 10^8$ conidia·ha$^{-1}$ on 28 July. Values are means of four replications.

| Treatment                        | Disease Severity |
|----------------------------------|------------------|
|                                  | 29-Jul | 5-Aug | 12-Aug | 19-Aug | 26-Aug |
| Control                          | 3a$^2$   | 4a     | 5a     | 6a     | 7a     |
| Conventional$^y$                 | 1b      | 1b     | 1b     | 1b     | 1b     |
| Copper hydroxide                 | 1b      | 1b     | 1b     | 1b     | 1b     |
| *Bacillus subtilis*              | 3a      | 4a     | 4a     | 6a     | 6a     |
| Vermicomposted cattle manure tea | 3a      | 4a     | 5a     | 6a     | 7a     |
| Windrow-composted cattle manure tea | 3a     | 5a     | 5a     | 6a     | 6a     |
| Coefficient of variability, %    | 18      | 21     | 19     | 12     | 8      |

$^2$Values followed by the same letter are not significantly different (Tukey's HSD P=0.05).

$^y$Conventional = alternated either chlorothalonil plus copper hydroxide or mancozeb plus copper hydroxide.

NS, *, Nonsignificant or significant at $P < 0.05$, respectively.
Table 2. Effect of six fungicidal agents, applied weekly, on disease severity caused by *Septoria lycopersici* on ‘Mountain Spring’ tomatoes grown near Gilbert, IA. in 2004. The field was inoculated with *Septoria lycopersici* at a rate of 7.5 x 10^8 conidia·ha^-1 on 6 July. Values are means of four replications.

| Treatment                                      | 27-Jul | 3-Aug | 10-Aug | 17-Aug | 24-Aug |
|------------------------------------------------|--------|-------|--------|--------|--------|
| Control                                        | 4a      | 4ab   | 8a      | 8a     | 9a     |
| Conventional\(^b\)                             | 1c      | 2b    | 2b      | 3b     | 5b     |
| Copper hydroxide                               | 2bc     | 2b    | 2b      | 3b     | 4c     |
| Rosemary oil                                   | 4a      | 6a    | 8a      | 8a     | 9a     |
| *Bacillus subtilis*                            | 3ab     | 6a    | 8a      | 8a     | 9a     |
| Vermicomposted cattle manure tea               | 4a      | 6a    | 8a      | 8a     | 9a     |
| Windrow-composted cattle manure tea            | 4a      | 7a    | 8a      | 8a     | 9a     |
| Coefficient of variability, %                  | 24      | 32    | 20      | 11     | 5      |

\(^a\)Values followed by the same letter are not significantly different (Tukey's HSD P=0.05).

\(^b\)Conventional = alternated either chlorothalonil plus copper hydroxide or mancozeb plus copper hydroxide.

NS, *, Nonsignificant or significant at P < 0.05, respectively.
Table 3. Effect of five fungicidal agents, applied weekly, on yield of 'Mountain Spring' tomatoes grown near Gilbert, IA. in 2003. The field was inoculated with *Septoria lycopersici* at a rate of $7.5 \times 10^8$ conidia ha$^{-1}$ on 28 July.

Values are means of four replications.

| Treatment                              | Yield (Mg·ha$^{-1}$)$^a$ | Marketable fruit | Green fruit |
|----------------------------------------|---------------------------|------------------|-------------|
|                                        | Marketable | Culled$^b$ | Mean fruit wt (g) | No./ha$^{-1} \times 10^4$ | No./plot$^c$ |
| Control                                | 21b$^w$   | 7a            | 289ab         | 7.2b           | 10c         |
| Conventional$^v$                       | 35a        | 5ab           | 321a          | 11.0a          | 75a         |
| Copper hydroxide                       | 33a        | 4b            | 312a          | 10.5ab         | 49b         |
| *Bacillus subtilis*                    | 21b        | 5ab           | 289ab         | 7.4b           | 31bc        |
| Vermicomposted cattle manure tea       | 20b        | 7a            | 250b          | 8.1ab          | 15c         |
| Windrow-composted cattle manure tea    | 21b        | 6ab           | 263b          | 8.1ab          | 10c         |
| Coefficient of variability, %          | 18         | 25            | 7             | 17             | 35          |

$^a$Total yield collected from five harvest dates: 29 July, 5 Aug., 12 Aug., 19 Aug., 26 Aug.

$^b$Includes fruits affected by disease, insect, and cosmetic damage from zippering or cracking.

$^c$Data collected from last harvest when all green fruit were collected.

$^w$Values followed by the same letter are not significantly different (Tukey's HSD $P=0.05$).

$^v$Conventional = alternated either chlorothalonil plus copper hydroxide or mancozeb plus copper hydroxide.

NS, *, Nonsignificant or significant at $P < 0.05$, respectively.
Table 4. Effect of five fungicidal agents, applied weekly, on yield of 'Mountain Spring' tomatoes grown near Gilbert, IA.

| Treatment                  | Control | Conventional | Copper hydroxide | Rosemary oil | Bacillus subtilis | Vermicomposted cattle manure tea | Windrow-composted cattle manure tea | Coefficient of variability, % |
|----------------------------|---------|--------------|------------------|--------------|------------------|----------------------------------|------------------------------------|-------------------------------|
| Marketable Mean fruit wt (g) | 7a      | 34a          | 32a              | 11b          | 12b              | 14b                             | 16b                               | 18                           |
| Marketable fruit           | 15b     | 34a          | 32a              | 11b          | 12b              | 14b                             | 16b                               | 23                           |
| Marketable fruit wt (g)    | 27/6a   | 29/7a        | 33/2a            | 27/9a        | 26/3a            | 28/9a                           | 29/6a                             | 33                           |
| Marketable fruit wt x 10^3 | 4.6b    | 11.4a        | 9.9a             | 4.1b         | 4.6b             | 5.0b                            | 5.5b                              | 16                           |
| No./plot                   | 1b      | 51a          | 65a              | 2h           | 2h               | 0h                              | 2h                                | 10                           |

Values are means of four replications.

Key:
- **NS**: Non-significant
- *****: Significant at P < 0.05

| Treatment                  | Conventional = alternated either chlorothalonil plus copper hydroxide or mancozeb plus copper hydroxide.
|----------------------------|--------------------------------------------------|
| Total yield collected from five harvest dates: 11 Aug., 17 Aug., 24 Aug., 31 Aug., and 8 Sept. | Includes fruits affected by disease, insect, and cosmetic damage from zipper or cracking.
| Total yield collected from last harvest when all green fruit were collected | Values followed by the same letter are not significantly different (Tukey's HSD P=0.05).

*Data collected from last harvest when all green fruit were collected.

Values followed by the same letter are not significantly different (Tukey's HSD P=0.05).
Table 5. Nutrient concentrations in leaf samples collected at mid-bloom in 2003.

| Treatment                                | Nutrient (ppm)$^a$ |       |       |
|------------------------------------------|--------------------|-------|-------|
|                                          | Copper             | Manganese | Sodium |
| Control                                  | 17b                | 70b     | 87c    |
| Conventional$^b$                         | 132b               | 110a    | 223a   |
| copper hydroxide                         | 340a               | 92ab    | 124c   |
| *Bacillus subtilis*                      | 19b                | 85ab    | 185ab  |
| Vermicomposted cattle manure tea         | 19b                | 76b     | 150abc |
| Windrow-composted cattle manure tea      | 21b                | 95ab    | 198ab  |

$^a$Nutrients were measured by using inductively coupled argon plasma techniques.

$^b$Conventional = altered either Bravo® plus copper hydroxide or mancozeb plus copper hydroxide.
Table 6. Nitrogen concentration (%) in leaf samples collected at mid-bloom in 2003 and 2004.

| Treatment    | 2003  | 2004  |
|--------------|-------|-------|
| Control\(^y\) | 3.7a\(^z\) | 3.0a  |
| Conventional\(^x\) | 4.1a | 3.1a  |
| Compost\(^w\) | 3.8a | 2.8a  |

\(^z\)Nitrogen content was determined using a modified-Kjeldahl digestion procedure in conjunction with a nitroprusside-salicylate assay using flow ingestion analysis.

\(^y\)Control treatments received 83 kgxha\(^{-1}\) nitrogen as compost.

\(^x\)Conventional treatments received 67 kgxha\(^{-1}\) nitrogen as urea.

\(^w\)Compost treatments received 83 kgxha\(^{-1}\) nitrogen as compost.
CHAPTER 3. CONTROL OF THE TOMATO DISEASE, *SEPTORIA LYPERSICI*, WITH COMPOST TEAS – A GROWTH CHAMBER STUDY.

A paper to be submitted for publication

Karen R.M. Joslin, Sara Helland, Henry G. Taber, and Mark L. Gleason

Abstract

Interest in the use of compost tea to control foliar diseases organically is increasing among producers and researchers because it is a disease management tool allowed in organic production that can be integrated into current production practices. Many factors such as the type of brewing and application equipment, compost and water source, brewing time, and the use of additives can influence efficacy. The objectives of this research were to evaluate the efficacy of compost tea from either windrow-composted cattle manure (WCCM) or vermicomposted cattle manure (VCCM) with or without nutrient additives, i.e. a food source for microorganisms, to control *Septoria lycopersici* Speg on *Lycopersicon lycopersicon* (L.) Karsten. The efficacy of compost tea made from a SoilSoup™ brewer was also tested. Tomato plants (‘Mountain Spring’) were started in a greenhouse and then moved into three growth chambers, inoculated with 1000 conidia/mL, at the fifth leaf stage and treated with: (i) control (no foliar spray), (ii) WCCM, (iii) WCCM tea plus a nutrient solution, (iv) VCCM tea, (v) VCCM tea plus a nutrient solution, and vi) SoilSoup™ compost tea. The experiment was repeated once. In experiment I there were no differences between plant lesion counts for the control compared with the rest of the treatments but there were significant differences among compost teas. Plants that received WCCM had 64% more lesions than plants that received VCCM without nutrients. Plants that received SoilSoup™ compost tea had 60% less lesions than plants in the WCCM treatments. In experiment II the effect was opposite;
the tea treatments reduced lesion number by 32% compared to the control. There was no difference between plants that received SoilSoup™ and the control. Plants that received VCCM compost teas and WCCM compost teas had 35% and 43% fewer lesions than plants in the SoilSoup™ treatment, respectively. There was no difference between plants that received either VVCM or WCCM only, nor did the addition of nutrients cause a difference. Inconsistency observed between experiment I and II indicates that further research is needed to determine if compost teas are a viable disease control option for organic farmers.

**Introduction**

The successful use of compost tea to control foliar diseases was first reported in 1986 when control of *Plasmopara viticola* was observed after infected grape leaves were sprayed with horse manure compost tea (Weltzien and Ketterer, 1986). Additional research has found that compost tea can be used to control many foliar disease organisms including *Botrytis cinerea* on detached leaves of tomato (*Lycopersicon lycopersicum* Mill.), pepper (*Capsicum* L.) and grape (*Vitaceae* L.) (Elad and Shtienberg, 1994) and field strawberries (*Fragaria ananassa* L) (Welke, 1999). Compost tea was also found to control *Alternaria solani* (Elli. & Mart.) L.R. Jones & Grout on field tomatoes (Tsror, 1999) and *Phytophthora infestans* on greenhouse tomatoes and detached leaves of tomato and grape (reviewed by Scheuerell and Mahaffee, 2000). In other experiments, however, compost tea has been found to be ineffective at controlling some of those same pathogens (reviewed in Scheuerell and Mahaffee, 2000). Compost tea efficacy is influenced by many factors including brewing and application equipment, compost and water source, brewing time and the addition of compost tea additives (Scheuerell and Mahaffee, 2000).
Pathogen suppression from compost tea is largely the result of microorganism species and quantity present in the tea. Bacteria are the main agent in compost tea that provides control, especially those belonging to the genera *Bacillus, Pseudomonas, Serratia,* and the fungi *Penicillium,* and *Trichoderma* (Brinton et al., 1996). Because different compost sources contain different species of microorganisms, compost source could influence compost tea efficacy (Weltzien, 1991).

Two main factors that can differ in compost source are the materials that were composted and the method by which they were composted. Animal manure and bedding, agricultural residues, and biosolids (sewage sludge) are common materials used in composting. There have been several investigations into the influence compost material type has on compost tea efficacy; however, results have been inconsistent. Brinton and Trankner (1996) found that composted horse manure was more effective at suppressing *Fusarium oxysporum* (Owen) of tomatoes than composted commercial yard waste. El-Masry et al. (2002) found that compost tea made from composted leaves and crop waste compost was effective at controlling *F. oxysporum* f. sp. *lycopersici,* *Phythium debaryanum* (Hesse) and *Sclerotium bataticola* (Taub) whereas compost tea made from leafy fruit compost was not.

There are multiple methods by which organic materials can be composted. To our knowledge, the influence of composting method on compost tea efficacy has not been investigated. Windrow-composting is a common practice in which organic materials are piled in long rows, usually 1.5 to 3 m high, 3 to 6 m wide, and of variable length. Windrows are usually aerated by physically turning the pile. Much of the decomposition of organic matter in windrow-composting systems is done by thermophilic organisms, mainly bacteria, that require temperatures between 45 and 65 C. Vermicomposting is another method in
which worms ingest organic materials and excrete a substance referred to as worm castings, which are than used to make compost tea. Because worms can not tolerate high temperatures, vermicomposting occurs at lower temperatures, between 20 and 40 C, where mesophillic organisms are dominant.

There are procedures where by microorganism populations can be altered during the composting process to produce a tea with desirable species populations. Compost tea additives are any material, other than compost and water, added to the compost tea at the beginning of the brewing process. Many additives are thought to increase microbial populations. For example, adding complex and simple sugar selects for bacteria, protein and grain selects for fungi, and yeast selects for both bacteria and fungi (Ingham, 2003). However, it is possible that nutrients not utilized by beneficial organisms will feed pathogenic ones, particularly those that have a saprophytic stage. Furthermore, there is concern that certain nutrients, specifically simple sugars, increase the risk of *E. coli* and *Salmonella* in the tea (Scheuerell, 2003). Although there have been no reported cases of illness caused by compost tea many food borne illnesses go unreported. The National Organic Standards Board (NOSB) convened a Compost Tea Task Force in 2003 to address the use of compost tea in organic production with a focus on human health concerns regarding its use. The Task Force determined that unless additives were used, there is no risk of elevated levels of *E. coli* and *Salmonella* in compost tea made from compost and vermicompost that had been made according to NOSB standards (NOSB, 2004).

The objective of this experiment was to evaluate the efficacy of compost tea from several sources to control *S. lycopersici* on tomatoes.
Materials and Methods

Research was conducted at the Iowa State University Horticulture greenhouse and growth chambers in Ames, IA. ‘Mountain Spring’ tomato plants were seeded in 50-plug flats in a greenhouse on 15 Dec. and 11 Feb 2003 for two experimental runs. Plants were transplanted into 1-gallon pots with LC-1® (SunGro Ltd., Bellevue, WA) growing media consisting of peat, perlite, and gypsum, on 5 Jan. and 3 March when they were at the third leaf stage. All plants received 30 mL Excel 15-5-15 Cal-Mag® fertilizer (Scotts Company, Marysville, OH) at the first and fourth leaf stage. Plants were moved into growth chambers, with 16 h light at 21 C, on 13 Jan. and 16 March when plants reached the fifth leaf stage.

Compost tea was made from WCCM, VCCM, or vermicompost provided by SoilSoup™ (Table 1). Treatments were (i) control (no foliar spray), (ii) WCCM tea, (iii) WCCM tea a plus nutrient solution, (iv) VCCM tea, (v) VCCM tea plus a nutrient solution, and vi) SoilSoup™ compost tea. The nutrient solution added was SoilSoup™ nutrient solution at 0.3 oz/L. The main ingredient in the nutrient solution was molasses. Compost teas were made at a 10 water: 1 compost ratio, by weight, in plastic containers and aerated through diffusion stones for 24 h. The SoilSoup™ compost tea was made according to manufacturer’s directions; 0.5 L vermicompost plus 7.5ml/L water. Distilled water was used to make all compost teas. The adjuvant Nu-Film 17™ (Miller Chemical & Fertilizer Corp, Hanover, PA) was added to all treatments prior to application at a rate of 5 mls/L. All treatments were applied once weekly from 13 Jan. to 17 Feb. for the first experiment and 16 March to 20 April for the second experiment.

Plants in the first experiment were inoculated 16 Jan. and 19 March in the second experiment with 1 x 10^3 conidia/mL of S. lycopersici. The inoculum was collected from
field-infected plants in Ames, IA. in 2002, stored in a freezer. To increase the amount of inoculum, leaves were macerated in water that was filtered and then sprayed onto tomato plants in a greenhouse. Treatments and inoculum were sprayed to run-off with a handheld spray bottle. Plants were bagged for 48 h after inoculation in order to maintain leaf wetness.

Three weekly disease severity ratings began three weeks after inoculation on 5 Feb. and 16 March and were taken by counting the number of lesions per leaf per plant. At the end of each experiment, when plants were at the 10th or 11th leaf stage, plants were cut near the cotyledon scares, dried for 48 h and weighed. Compost concentrations of P, K, Na, Ca, Mg, S, B, Cu, Mo, Mn, and Zn were measured by using inductively coupled argon plasma techniques (ICAP) (Jones, 1977; Munter and Grande, 1981;) after ashing a 0.5 g sample at 490 °C and digesting in 1N aqua-regia. Compost tea concentrations of the same elements were also determined.

The experimental design was a randomized complete block (single growth chamber) with three replications and six treatments. Data were analyzed by using the mixed procedure model and orthogonal contrasts (α < 0.05) option of the Statistical Analysis System software (SAS Institute Inc., 1996).

Results

While the elemental characteristics of the compost and compost teas used in this experiment were not statistically analyzed for differences, there are some notable variations in nutrient concentrations. The WCCM compost at 5.61 % Ca had 2.5x more calcium (Ca) than the VCCM compost and 3.4x more Ca than the SoilSoupTM compost (Table 1). The SoilSoupTM contained the highest Cu concentration, 49.7 mg·kg⁻¹. However, these differences were not seen in the compost tea. Calcium concentration was 47, 74, and 27
mg·kg⁻¹ for WCCM, VCCM, and SoilSoup™, respectively (Table 2). Copper concentration of all the teas was ≤ 0.01 ppm. In general, the WCCM compost tea had the highest nutrient concentration (Table 2). Compost teas ranged in pH from 4.8 to 6.8 (Table 2). There was a small reduction in pH in compost teas with added nutrients.

In experiment I there were no differences between the number of lesions on plants in the control and the number of lesions on plants in the rest of the treatments. Nor was there a difference between plants that received the VCCM and WCCM only, or plants that received the teas or the teas plus nutrients (Table 3). However, there was a significant difference in efficacy between VCCM and WCCM. Plants that received WCCM had 64% more lesions than plants that received VCCM without nutrients. There was also a significant difference in number of lesions between plants that received SoilSoup™ compost tea and plants that received either of the WCCM compost teas. Plants in the SoilSoup™ treatment had 40% less lesions that plants the WCCM treatments, 30 vs. 50 respectively (Table 3). There was no difference in plant dry weight among the treatments (data not presented).

In experiment II there was a significant (P<0.05) difference between plants in the control and plants in the rest of the treatments. The tea treatments reduced lesion number by 32% compared to the control. There were differences between plants in the SoilSoup™ treatments and plants that received either the VVCM compost teas or the WCCM compost teas. There was no difference between plants that received SoilSoup™ and the control, Plants that received VCCM compost teas and WCCM compost teas had 35% and 43% less lesions than plants in the SoilSoup™ treatment, respectively (Table 3). There was no difference between plants that received either VVCM or WCCM only, nor did the addition of
nutrients cause a difference. There was no difference in plant dry weight among the treatments (data not presented).

Discussion

The presence of lesions initiated data collection in both experiments, which began three weeks after inoculation. There was a noticeable difference in the number of lesions present during each experiment; there were noticeably less lesions on plants in experiment II than there was in experiment I. In experiment I there was no efficacy from any of the compost teas. However, in experiment II all the compost teas, except the tea made from the SoilSoup™ equipment, begin to provide some level of disease control. The compost material used for the two experiments was from the same batch. A possible difference that may have influenced efficacy was the temperature difference in the greenhouse where the compost teas were made. Teas in the first experiment were made between 15 Jan. and 16 Feb. while teas in experiment II were from 15 Mar. to 14 April. Also, plant growth, particularly leaf cuticle development may have been different during the two time periods, possibly affecting the ability of the pathogen to cause infection. Temperature during the 24 h aeration process was not recorded.

*S. lycopersici* is a facultative saprophyte that can grow epiphytically on tomato leaf surfaces. Nutrients added to the leaf surface with the compost tea may have provided an energy source for the pathogen. This could explain why plants in some treatments, particularly the WCCM in exp. I, had more lesions than plants in the control.

There is a limited amount of research investigating the affect added nutrients has on compost tea efficacy. Our results showed no benefit of adding additional nutrients (primarily molasses) to the teas. Other researcher shows inconsistent results; Elad and Schtienberg
(1994) found added nutrients to be ineffective at increasing tea efficacy, whereas Ketterer (1990, reviewed in Scheuerell and Mahaffee, 2000) and Urban and Trankner (1993, reviewed in Scheuerell and Mahaffee, 2000) observed increases in compost tea efficacy from added nutrients. The most notable difference in compost tea composition from added nutrients was the pH. Adding nutrients reduced the pH by 0.5-0.6 units.

Research has found that pH can influence compost tea efficacy in *in vitro* assays. Yohalem et al (1994) found that they could reliably suppress conidia germination of *Venturia inaequalis* (Cooke) Winter with non-aerated compost tea with a pH between 8.0 and 8.5. Urban and Trankner (1993, reviewed in Scheuerell and Mahaffee, 2002) found that control of *Botrytis cinerea* Pers. was greatest with compost tea with a pH above six. It is possible that compost tea efficacy was reduced in these experiments because the pH of the compost used may have been too low (4.9 to 6.8).

The SoilSoup™ compost tea equipment retails for $299. In both experiments SoilSoup™ compost tea was ineffective at reducing lesion numbers. Furthermore, better control was achieved by making compost tea in a plastic container with forced air through a diffusion stone than with the SoilSoup™ equipment. Thus, at this time, use of this product for control of *S. lycopersici* is not recommended.

While the data in exp. II indicates that applying compost teas provided some disease control, without yield data it is difficult to determine whether the decrease in leaf surface loss was enough to mediate yield loss due to *S. lycopersici*. Because there was no difference in plant dry weight, it is possible that the lesion differences would not result in a yield effect. Field research should be done to test this. Whether or not compost teas used in experiment II would have prevented yield loss due to *S. lycopersici*, the inconsistency observed between
experiment I and II indicates that further research is needed to determine if compost teas are a viable disease control option for organic farmers. Research should focus on identifying the presence of beneficial organisms in the compost source and monitoring their populations throughout the brewing and application process. Tea components, such as salt, pH and other elements should be evaluated for their impact on microorganism survival. Finally, because added nutrients may increase disease severity and human pathogens (Urban and Trankner, 1993 cited in Scheuerell and Mahaffee, 2002) their use should not be promoted until further research is performed.

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Table 1. Elemental characteristics of composts, as mg/kg, dry weight basis.

|                              | P    | K    | Na   | Ca   | Mg   | S    | B    | Cu   | Mn   | Zn   | Mo  |
|------------------------------|------|------|------|------|------|------|------|------|------|------|-----|
| SoilSoup Compost™            | 5470 | 5120 | 2080 | 16400| 4350 | 2920 | 32   | 49.7 | 290  | 136  | 1.24|
| Vermicomposted manure compost| 4730 | 6300 | 1650 | 22100| 5740 | 2270 | 13.4 | 12.3 | 352  | 77.4 | 0.83|
| Windrow-composted manure compost | 6260 | 3840 | 790  | 56100| 4330 | 3080 | 18.9 | 23.2 | 343  | 172  | 3.21|
Table 2. Chemical characteristics of compost tea solutions. Elements expressed as mg/L

|                          | pH | Salt (ds/m) | P  | K  | Na | Ca | Mg | S  | B  | Cu | Mn | Zn | Mo |
|--------------------------|----|-------------|----|----|----|----|----|----|----|----|----|----|----|
| SoilSoup Compost™        | 4.9| 4.7         | 0.4| 69 | 18 | 27 | 12 | 14 | 0.04| <0.02| 0.09| 0.04| <0.02|
| Vermicomposted           | 6.8| 2.1         | 22 | 74 | 17 | 74 | 33 | 9  | 0.1 | 0.01 | 0.16 | 0.03| <0.01|
| Vermicomposted plus      |    |             |    |    |    |    |    |    |    |      |      |    |    |
| nutrients²               | 6.3| 2.7         | 21 | 102| 23 | 105| 40 | 18 | 0.1 | 0.01 | 0.55 | 0.09| <0.01|
| Windrow-composted        | 5.4| 1.5         | 10 | 426| 139| 47 | 50 | 74 | 0.18| 0.05 | 0.04 | 0.06| 0.03|
| Windrow-composted plus   |    |             |    |    |    |    |    |    |    |      |      |    |    |
| nutrients                | 4.8| 2.3         | 3  | 481| 148| 98 | 70 | 86 | 0.15| 0.05 | 0.28 | 0.11| 0.03|

²SoilSoup™ nutrient solution was added at 0.3 oz/L. The main ingredient in the nutrient solution was molasses.
Table 3. Effect of five compost teas on disease severity cause by Septoria lycopersici on 'Mountain Spring' tomatoes

Grown in growth chambers, 2004. Values are means from three replications.

| Treatments                                                      | Number of lesions per plant<sup>2</sup> |
|-----------------------------------------------------------------|----------------------------------------|
|                                                                | Exp. I | Exp. II |
| Control (CT)                                                    | 30     | 25      |
| SoilSoup                                                        | 30     | 24      |
| Vermicomposted cattle manure tea (VCCM)                        | 28     | 17      |
| Vermicomposted cattle manure tea plus nutrients (VCCM+)        | 33     | 14      |
| Windrow-composted cattle manure tea (WCCM)                     | 46     | 16      |
| Windrow-composted cattle manure tea plus nutrients (WCCM+)     | 53     | 12      |
| Estimates<sup>2</sup>                                           |        |         |
| CT vs. Rest                                                    | NS     | *       |
| VCCM vs. WCCM                                                  | **     | NS      |
| VCCM/WCCM vs. VCCM+/WCCM+                                      | NS     | NS      |
Table 3. (continued)

|                      | Number of lesions per plant$^2$ |
|----------------------|----------------------------------|
| SoilSoup vs. VCCM/VCCM+ | NS                               |
| SoilSoup vs. VCCM/VCCM+ | NS                               |
| SoilSoul vs. WCCM/WCCM+ | *                                |

$^2$Total number of lesions averaged from three plants at the final data collection date.

$^3$Estimates calculated by partitioning the treatment effects using SAS, proc mixed.

NS, *, **, Nonsignificant or significant at the $P < 0.05$, or $P < 0.01$, respectively.
CHAPTER 4. GENERAL CONCLUSIONS

Yield reduction in organic production is often offset by higher premiums received for organic produce that can be 10 to 30% higher than conventional prices (Sok and Glaser, 2001). The Boston Wholesale Fruit and Vegetable Report (2004) listed organic tomato premiums 2.5x that of conventional tomatoes. Therefore, many organic tomato producers do not apply fungicides for disease control. Moreover, in areas where land is not a limiting factor many producers make up for yield loss from disease by increasing the number of plants grown. However, because organic tomatoes are a high value crop many producers will continue to rely on copper fungicides for disease control. Since there are currently no other viable alternatives in certified organic production future research should focus on ways producers can reduce Cu fungicide applications to address concerns regarding soil accumulation, yield loss, microorganism toxicity and disease resistance associated with Cu.

The use of compost tea to control S. lycopersici should not be promoted in tomato production at this time. Even so, further investigations are warranted because there are many factors that can affect the tea efficacy, including the age of the compost source. The composts used in this experiment were cured, meaning that most of the easily degradable organic substrates were already decomposed. Thus, it is likely that the diversity of organisms present in the compost was low. At this stage, the bacterial population within the compost is low, particularly when compared to the fungi population. There is some skepticism as to how well fungi can reproduce and survive in an aqueous environment. Furthermore, thermophilic bacteria, those that can survive temperatures between 60 and 65 C, such as Bacillus sp. may not present in cured compost (CIWMB, 2001). Previous research has
observed that compost tea made from 6 month old horse compost was more effective at controlling *Pseudoperonospora cubense* (Berk. and M.A. Curtis) Rostorzhev than tea made from 1-year old compost (Winterscheidt et al, 1990) cited in Weltzien, 1991). Andrews (1993) also found that compost maturity impacted compost tea efficacy; control of *Venturia inaequalis* decreased as compost age increased. Thus, compost tea efficacy may have been greater if non-cured compost was used.

Added nutrients were not found to increase compost tea efficacy in growth chamber experiments. Furthermore, we found that in some cases the addition of fermentation nutrients increased the number of disease lesions. This indicates that pathogenic organisms can benefit from the addition of fermentation nutrients and that further research should address this concern before their use is promoted. Moreover, because there are concerns they should not be used at this time.

Future research into compost teas should focus on identifying the beneficial organisms present in the compost source used to make the tea and monitoring their populations throughout the brewing and application process. Tea components, such as salt, pH and other elements should be evaluated for their impact on microorganism survival. Also, making adjustments to how the tea is prepared, such as dilution ratio or fermentation time may increase efficacy. Application rate and timing may also increase efficacy.

The SoilSoup™ compost tea equipment retails for $299. Based on both the field and growth chamber research we performed this product is not recommended for control of *S. lycopersici*. If producers want to experiment with compost teas they can save money by purchasing commercial aerators for use in any type of container for a fraction of the cost.
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