EFFECTS OF COMPOST AND LIME APPLICATION ON SOIL CHEMICAL PROPERTIES, SOIL MICROBIAL COMMUNITY, AND FUSARIUM WILT IN FLORIDA-GROWN TOMATOES

John Gum

May 2012

Chair: Amy L. Shober
Major: Soil and Water Science

Abstract: Soils used for vegetable production in Florida are sandy, have low organic matter content and fertility, and can support the growth of soil-borne pathogens. Some growers choose to apply compost as an antagonistic suppression approach to combat soil-borne disease effects on crop yields or to increase organic matter and improve soil fertility. The objective of this on-farm study was to determine the effect of compost and lime on soil chemical properties, the soil microbial community (including *Fusarium* spp.), and the incidence and severity of fusarium wilt in commercially produced tomato with a history of fusarium wilt. Seasonal trials were conducted in spring and fall of 2010, where soil treatments (composted yard waste and lime) were applied to plots in a randomized complete block design with three replications using a calibrated tractor spreader. Composite soil samples were collected immediately following application of soil treatments, at flowering, and at fruit set and analyzed for soil chemical properties (e.g., organic matter, pH, soil test nutrients, etc.) and soil microbes (e.g., total bacteria, *Fusarium oxysporum* spp., etc.). Incidence of fusarium wilt was assessed on a periodic basis over the course of tomato production. Data showed that the application of compost and/or lime to soils prior to bedding had no effect on soil pH, EC, or Mehlich 3 nutrients, with the exception of organic matter and Mehlich 3-Mg in fall 2010. Soil organic matter increased when compost was applied at the 30 ton/acre application rate in the fall season, while Mehlich 3 Mg increased when

compost was applied at the 20 and 30 ton/acre application rate. Bacteria colony counts were higher at the beginning of each season, but fungal colony counts increased and bacteria colony counts decreased as the season progressed. Wilt incidence was seen much earlier in the fall season than in the spring trial due to climatic differences between seasons; however, fusarium wilt incidence was not affected by soil treatment. Single applications of organic amendments at high rates (>20 tons/acre) can increase soil organic matter in the short-term, but may not decrease the occurrence of fusarium wilt.

Introduction and Literature Review

The U.S. tomato industry (fresh market and processed) was valued at 1.39 billion dollars in 2010 (USDA-NASS, 2011). Approximately two-thirds of U.S. fresh market tomatoes are produced in Florida and California (USDA, 2009). Other major tomato producing states are Ohio, Virginia, Georgia, and Tennessee. In 2009, fresh-market tomatoes were grown on 34,600 acres in Florida, with an average yield of 366 hundredweight (cwts) and overall value of 5.2 million dollars (National Agricultural Statistics Service, 2009).

Vegetable production in the southeastern U.S., including Florida, commonly occurs on sandy coastal plains soils, which are acidic with low organic matter content, soil fertility, water holding capacity, and biological activity (Muchovej et al., 2008). Soil fertility in these soils is typically managed by applying inorganic fertilizers and lime as needed (Kirkham et al., 2008), while soil diseases, nematodes, and weeds have traditionally been controlled by fumigation with methyl bromide (Martin, 2003).

Since the late 1960’s, tomato growers have relied on the use of soil fumigation, principally methyl bromide, for broad spectrum control of weeds, soil-borne pests, and pathogens. The use of methyl bromide effectively sterilizes soils, reducing the level of soil-borne pests and pathogens as well as beneficial microorganisms that function to cycle plant nutrients and potentially suppresses the effects of harmful organisms (Martin 2003). In the U.S., Florida and California accounted for more than 75% of methyl bromide use in 2000 (Osteen, 2000). According to the National Center for Food and Agricultural Policy (2000), 30% of methyl bromide use was for pre-plant applications to tomatoes. While methyl bromide has traditionally provided good control of weeds and soil-borne pests in agriculture, its use was linked to ozone depletion (Martin 2003). As a result, the use of methyl bromide in developed countries was phased out by 2005 (with the exception of critical uses) under the Montreal Protocol (Osteen, 2000). Methyl bromide is still being used in Florida for tomato production under critical usage allotments. Because there currently are no economical and efficacious alternatives to methyl bromide (Osteen 2000), continued reductions in methyl bromide use are expected to result in lower crop yields. In addition, chemical alternatives to methyl bromide may cost more or have to be applied more frequently, thereby, cutting into the profit margins of tomato producers (Osteen, 2000). In addition, agricultural transition from methyl bromide has led to a resurgence of diseases caused by soil-borne pathogens, especially wilt caused by *Fusarium oxysporum* f.sp. *lycopersici* (FOL).

Fusarim oxysporum has been classified as a *forma specialis* (Gordon and Martyn, 1997). According to Alabouvette et al. (2007), strains of *F. oxysporum* that are isolated from the soil but are not able to infect potential hosts are considered non-pathogenic. Another way of explaining non-pathogenic is that the saprophytic isolates can be taken from many hosts, which may be healthy or diseased. The presence of *F. oxysporum* in soil does not necessarily indicate that host plants will be infected. To be considered a pathogenic strain of *F. oxysporum*, the isolates must be able to infect the host and that host must show signs of being diseased (Alabouvette et al., 2007).

Three pathogenic races of FOL have been described (Larkin and Fravel, 2002). These races can only be distinguished by inoculating tomato lines that carry the corresponding resistance gene to each specific race. Physiology of the host plant and the ability of the *F. oxysporum* to infect the host are influenced by environmental conditions including temperature, soil moisture, sunlight, and soil physical and chemical characteristics (Larkin and Fravel, 2002). These soil physical and chemical characteristics can encompass one or many of the following: pH, electrical conductivity, organic matter, or soil test phosphorus (P), potassium (K), calcium (Ca), or magnesium (Mg). *Fusarium oxysporum* f.sp *lycopersici* persists in soils at temperatures up to approximately 80ºF and under extremely dry conditions (Kennelly, 2007). Once the pathogen is present in the soil, it is nearly impossible to eradicate. Distribution of pathogen occurs via seed, tomato stakes, soil, infected transplants, or infested soil clinging to transplants (Jones, 1991). *Fusarium oxysporum* infection starts in the roots of the host plant. Early stages of fusarium wilt on young plants are not initially visible as the fungus invades the xylem vessels of the plant (Mai and Abawi, 1987). In more mature plants, symptoms consist of stunting, yellowing of the lower leaves, formation of adventitious roots, wilting of leaves and young stems, and defoliation; marginal necrosis of remaining leaves may also occur (Jones, 1991). In tomatoes, these disease characteristics are most evident during blossoming and fruit maturation (Gonsalves and Ferreira, 1993). Ultimately, infection with *F. oxysporum* will result in death of the plant.

Because current chemical and non-chemical alternatives to methyl bromide lack broad-spectrum control and require additional inputs for disease, weed, and nematode control, growers have a renewed interest in cultural approaches for the management of soil-borne pests and pathogens (Chellemi 2002). While it is unlikely that any single cultural approach will totally replace the use of soil fumigants in conventional agriculture, the integrated use of such practices could possibly offset fumigant rates or augment fumigants with lower activity against certain soil-borne pests and pathogens. On the other hand, organic growers have little recourse for the management of soil-borne pests and pathogens, other than the use of cultural practices and resistant cultivars. While tomato cultivars with resistance to all three races of FOL are available, they lack the horticultural traits desired by the industry and are more susceptible to other pathogens that are problematic in Florida.

The management of soil pH with lime has been shown to reduce the occurrence of fusarium wilt, when nitrate-based N fertilizers are used in place of ammonium-based sources (Jones and Woltz, 1967, 1969, 1972). Such practices were paramount for the control of FOL race 2 (Jones and Woltz, 1967, 1969), but efficacy has not been assessed for race 3 isolates. However, soil pH management varies among tomato growers and is not currently used as a disease management tool because of widespread soil fumigant use (Geraldson et al., 1966; Jones et al., 1966). Previous studies found that raising the pH of Florida field soils to neutral or higher reduced the incidence of fusarium wilt on tomato by 50% to 80% (Jones and Woltz, 1972; Jones and Overman, 1976).

Research suggests that repeated applications of organic amendments, such as animal manures, biosolids, and composted materials, can increase soil organic matter level (Darby et al., 2006; Tester, 1990), even in the southeastern U.S., where the organic matter oxidation is rapid (Ozores-Hampton et al., 1998). Soil organic matter has many known benefits, such as increased water holding capacity, improved soil aeration (through reduced bulk density), and increased soil fertility (Tester, 1990). Increasing soil organic matter can also enhance microbial activity, which can improve plant nutrient uptake and suppression of certain plant diseases (Darby et al., 2006; Stone et al., 2003; Vallad et al., 2003). Producer reliance on inorganic fertilizers to meet crop nutrient requirements does nothing to enhance soil organic matter levels. In addition, fields are commonly left fallow between crop cycles allowing the loss of organic matter as topsoil is eroded by wind or water. There are also many references in the literature that support the idea that *F. oxysporum* can be suppressed using composted materials (Gordon and Martyn, 1997; Noble and Conventry, 2005). However, evidence that suppression occurs in a field environment is limited. A majority of the research related to compost and disease suppression has been done in a controlled greenhouse environment using peat-based potting mixes in pots (Aldahmani et al., 2005; Rose et al., 2003).

Research clearly indicates that the use of organic amendments and lime can improve soil physical and chemical properties and increase overall crop growth (Baligar et al., 2001; McGeehan, 2012). However, it is unclear whether these practices alone or in combination can sufficiently control soil-borne pathogens, such as FOL, when vegetables are produced in sandy soils within a humid, sub-tropical climate regime. The objective of this on-farm study was to determine the effect of compost and lime on soil organic matter, the soil microbial community (including *Fusarium* spp.), and the incidence and severity of diseases caused by FOL.

Materials and Methods

Experimental design. Field trials were established at a commercial tomato production farm in Manatee County, FL in 2010 spring and fall. Composted yard waste (compost) and lime (pulverized calcium carbonate; Hi-CAL) were applied as soil treatments to all field trials to manipulate soil organic matter and pH on 18 Jan. 2010 and 20 July 2010 for the spring and fall seasons, respectively. Soil treatments during the spring 2010 trial included: 1) 5 tons/acre compost + 0.50 tons/acre SuperMag; 2) 10 tons/acre compost + 0.25 tons/acre SuperMag; 3) 1 ton/acre Hi-CAL + 0.50 tons/acre SuperMag; and 4) 0.25 tons/acre SuperMag (unamended control). In fall 2010, soils treatments were: 1) 10 tons/acre compost + 0.25 tons/acre SuperMag; 2) 20 tons/acre compost + 0.50 tons/acre SuperMag; 3) 30 tons/acre compost + 0.75 tons/acre SuperMag; 4) 1 ton/acre Hi-CAL + 0.50 tons/acre SuperMag; and 5) 0.25 tons/acre SuperMag (unamended control). Soil treatments were applied to individual 35 ft × 600 ft field plots in a randomized complete block design with three replications (total = 15 plots; approx. 9 acres total) using a calibrated tractor spreader. Lime (Hi-CAL) was applied (when designated as part of the soil treatment) at an appropriate rate needed to raise the soil pH from native levels (approximately pH 6.0) to pH 7.0 based on the buffer pH test (Adams-Evens buffer) (Mylavarapu, 2009). Mulched, raised beds (6 beds per plot) were prepared with 5 ft center-to-center bed spacing. Tomatoes were produced on an approximately 110-day production cycle. The planting dates were 3 Mar. 2010 and 1 Sept. 2010 for the spring and fall seasons, respectively. Other aspects of land preparation, fertility and water management, pest and disease control, and harvest were performed using best management practices at the discretion of the grower cooperator.

Compost and soil samples. Composted municipal yard waste was prepared by the grower from municipal yard waste collected by the city of St. Petersburg, FL. The composted material was set in windrows of 12 to 15 ft tall by 20 to 25 ft wide, which were turned once per month on average. Windrow temperatures were monitored weekly and were never allowed to exceed 145°F. The windrow was turned 6 to 8 times and screened prior to application to field plots. Compost pH, electrical conductivity (EC), moisture content, organic C, organic matter (OM), carbon to nitrogen (C:N) ratio, total Kjeldahl N, total digestible P, total digestible K, and maturity were determined using standard test methods for the examination of compost and composting (TMECC) (US Composting Council, 2002) at the Soil Control Lab (Watsonville, CA).

Soil samples were collected three times per season: at bedding (immediately following the application of soil treatments), at flowering, and at fruit set. Soil samples were not taken at final harvest due to early termination of the field trials by the cooperating grower due to low market prices. Composite soil samples were collected by randomly collecting 24 to 30 cores from the top 15 cm of soil in each plot and stored in coolers until transported back to the laboratory for processing. A portion of each soil sample was air-dried, sieved to pass a 2-mm screen, and analyzed for soil pH (1:2 soil to deionized water ratio), EC (1:2 soil to deionized water ratio), and OM (loss on ignition) using standard methods (Mylavarapu, 2009). Soil test P, K, Ca, and Mg were determined by analyzing Mehlich 3 soil extracts (Mehlich, 1984) using inductively coupled plasma-atomic emission spectroscopy (ICP-AEP) (Perkin Elmer, Waltham, MA).

Soil-borne fungi and bacteria. The remaining (field moist) portion of each composite soil sample was used to assess soil microbial populations using standard dilution plating techniques. Total culturable aerobic bacteria and *Pseudomonas* spp. were enumerated on 0.3% tryptic soy agar and King's B medium (King et al., 1954), respectively, each amended with cyclohexamide (10 $mg \cdot L^{-1}$) and pentachloronitrobenzene (1 $g \cdot L^{-1}$) to suppress fungal growth. Total culturable fungi were enumerated on potato dextrose agar and a V-8 medium amended with rifampicin (50 $mg \cdot L^{-1}$), streptomycin (200 $mg \cdot L^{-1}$), and chloramphenicol (250 $mg \cdot L^{-1}$) to suppress bacterial growth. *Fusarium oxysporum* were assessed by dilution plating dried 1-g soil samples onto a modified Komada's medium (Hansen et al., 1990). The colony forming units (cfu) per gram of soil were collected from each dilution series and converted to a logarithmic scale prior to statistical analysis.

Disease ratings. Both trials were established on land with a history of vascular wilt disease caused by FOL, race 3 (G. Vallad, personal communication), with an average disease incidence of 20%, but as high as 80% in some areas of the field. However, the incidence of any soil-borne disease issues was assessed on a periodic basis over the course of tomato production. Fusarium wilt was confirmed through standard aseptic isolation of FOL from stem and petioles. Several collected isolates from randomly selected colonies of both morphology types were selected to verify pathogenic status (Attitalla et al., 2011).

Statistical analysis. Soil chemical properties were analyzed by season using a repeated measures model, with soil treatment and sampling date as fixed effects and block as a random effect using PROC MIXED in SAS (SAS Institute, 2003). Normality was checked by examining histograms and normality plots of the conditional residuals (generated by the command "plots = pearsonpanel"). No significant soil treatment × date effects were reported for soil chemical properties allowing data to be pooled over each trial. All pairwise comparisons were completed on transformed data using the Tukey's honestly significant difference (HSD) test with a significance level of $\alpha = 0.05$.

Generalized linear models in the PROC GLIMMIX procedure of SAS, Version 9.2 (SAS Institute, Inc., Cary, NC) were used to determine the effect of compost and lime treatments on disease incidence and culturable soil bacteria and fungi counts. Soil amendment treatment was considered a fixed effect, while block and block × treatment were treated as random effects in the model. Disease incidence data were square root transformed, while culturable soil bacteria and fungi counts were log base 10 transformed prior to statistical analyses. Fisher's protected LSD ($\alpha = 0.05$) test was used to compare least squares means among treatments at each date.

Results and Discussion

Compost and soil samples. Compost that was applied to the soil was fully mature and supported plant growth (data not shown). The pH of the compost applied during the spring 2010 and fall 2010 seasons was slightly alkaline (Table 1). Chemical properties of the yard waste compost used in our study were much lower than the properties of a composted yard waste that was used in vegetable production in central Florida (Ozores-Hampton et al., 2011), with the exception of the C:N ratio (Table 1). Ozores-Hampton et al. (2011) reported a C:N ratio of 14.5 compared to the C:N ratio of 25 and 22 for compost applied in the spring and fall seasons of our study, respectively. The lower C:N ratio and higher nutrient contents reported by Ozores-Hampton et al. (2011) is probably a result of compost feedstock that consisted of biosolids in addition to yard waste. Compost applied as part of our study contained only yard waste materials. However, both composts would oxidize readily and N would be mineralized and available for plant uptake during the growing season.

In spring 2010, the application of compost and/or lime to soils prior to bedding had no effect on soil pH, EC, OM, or Mehlich 3 nutrients (Table 2). Similarly, no significant soil treatment effects were reported for pH, EC, or Mehlich 3 P, K, and Ca in fall 2010 production cycle (Table 3). Our results differed from those of Ozores-Hampton et al. (2011), who reported an increase in soil OM, pH, and Mehlich 1-extractable P, K, Ca, and Mg. However, Ozores-Hampton et al. (2011) measured soil parameters following repeated composted applications over a 10-year time frame, whereas compost in our study was applied in a single application during one growing season. Also, Ozores-Hampton et al. (2011) reported an initial compost application rate of 180 $Mg \cdot ha^{-1}$ (80.4 ton/acre), which was approximately three times higher than our highest application rate.

Application of compost affected soil OM and Mehlich 3 Mg in the fall 2010 season (Table 3). The application of compost at the 30 tons/acre rate led to significant increases in soil OM compared to soils that did not receive compost (Table 3). In the spring growing season, temperatures were much higher and application rates were lower than in the fall season, which could have had an affect on the rate of OM decomposition. Loper et al. (2010) reported a significant increase in soil OM when composted dairy manure solids were applied to simulated residential landscapes at an application rate of 256 $Mg \cdot ha^{-1}$ that was three times higher than the highest rate (30 ton/acre) in our study. In contrast, Hanlon et al. (2009) reported a modest 2.2 % increase in soil organic matter when compost was applied at a rate of 5 to 7 tons/acre to a sandy soil over a 10-year period (Ed Hanlon, personal communication). The U.S. Compost Council (2001) states that applications of compost at rates up to 50 or 60 dry tons/acre can be beneficial to vegetable production, but application rates that are that high are rarely used. The average compost application rate for vegetables is 1 to 2 tons/acre (U.S. Compost Council, 2001). Therefore, it may take repeated applications of compost over a longer time period to see a significant increase in soil OM, unless high rates are applied during a single compost application.

We also observed an increase in Mehlich 3 Mg when compost was applied to soil at the 20 and 30 tons/acre rates (Table 3). Our compost contained 31 lbs of Mg per ton; therefore, application at the 20 and 30 tons/acre rates added 620 and 930 lbs of Mg, respectively. Stoffella and Kahn (2001) reported that Mg concentrations in compost ranged from 1 to 5 $g \cdot kg^{-1}$ (2 to 10 lb/ton). The increase in Mehlich 3 Mg may also be related to the application of Super MAG in combination with the compost at the higher rates.

Soil-borne fungi and bacteria. During the spring 2010 season, soil treatments had no effect on total soil bacteria or total fungi (data not shown). However, compost and lime applications led to an increase in the total soil bacteria during the fall 2010 season, with an increase in the total soil bacteria and a decrease in the total fungi only for the 7 Oct. 2010 collection date (Table 4). We suggest that that the higher counts of bacteria initially, followed by succession of fungi (increased fungi counts) could be due to an increase in soil organic matter that occurred with application of compost at high application rates (20 to 30 tons/acre). Kornillowicz-Kowalska and Bohacz (2010) reported similar results following land application of composted feather waste, where an initial spike in bacteria was succeeded by higher counts of fungi. We did not find a re-colonization of *F. oxysporum* in the soil regardless of the compost amendments despite the fact that *F. oxysporum* persists in soil as chlamdospores and lives off of organic matter (Olivain et al., 2006).

Our data showed that the amount of fluorescent pseudomonads counts increased numerically over the course of the fall season for some of the treatments (Table 4). *Pseudomonads* are antagonistic microbes that have been shown to be suppressive against the fungal pathogen *Fusarium* (Sylvia et al., 2005). There were no effects of soil treatments seen on *F. oxysporum* population. We were unable to determine if *F. oxysporum* re-colonized the soil beds over the course of the study due to the fact that our counts were near the limit of detection. Based on our data (Table 4), none of the soil treatments influenced the presence of *F. oxysporum* in the soil.

Disease ratings. The greatest number of symptomatic plants with fusarium wilt was identified toward the end of the spring 2010 trial, regardless of soil treatment (Figure 1). In fall 2010, we found that beds receiving compost at the 20 ton/acre rate produced tomato plants with the lowest number of fusarium wilt symptoms when compared with other treatments (Figure 2). By the end of the trial, tomatoes produced on beds that were composted at the 30 tons/acre rate showed the highest incidence of wilt (Figure 2); however, these treatment effects were not statistically significant. Wilt incidence was seen much earlier in the fall season than in the spring trial (Figures 1 and 2). This trend for earlier disease occurrence could be because optimal temperature conditions were reached earlier in the fall growing season than that of the spring season. Larkin and Fravel (2002) reported that fusarium wilt disease incidence were apparent at the tested range of temperatures of 22 to 32°C, but the greatest incidence rates occurred at an ambient air temperature of 27°C. According to Florida Automated Weather Network (Balm Station) for the months of May through November, air temperatures fell within the 22 to 32°C range (University of Florida, 2012). In both seasons, the temperature exceeded 27°C, which was a possible reason why an increase of disease incidence was seen.

Researchers have shown that amending soils with composted materials can suppress certain diseases (Hadar, 2011; Hoitink and Boehm, 1999; Noble, 2011). However, we were not able to demonstrate suppression of fusarium wilt during our on-farm trials. Our field trials were terminated about two weeks prior to first harvest, which makes it difficult to establish the role of compost or lime in the suppression of fusarium wilt in our field trials. Rapid degradation of compost (related to the temperature and moisture regime in Florida) may be another possible reason why we observed no soil treatment effect on fusarium wilt suppression.

Conclusions. Based on results from our on-farm trials, we cannot recommend the addition of compost on a large scale for the commercial production of tomato to achieve suppression of fusarium wilt in a single year or season. Large application of organic amendments can increase overall organic matter within a short amount of time; however, it is unclear if the increase in soil OM will translate to increased tomato yields, have an effect on future seasons, or reduce the incidence of fusarium wilt. Future studies should determine if repeated applications of organic amendments and/or lime have a long-term effect on soil chemical and physical properties or incidence of fusarium wilt in tomato.

Literature Cited

Alabouvette, C., C. Olivain, F. L'Haridon, S. Aime, and C. Steinberg. 2007. Using strains of *fusarium oxysporum* to control fusarium wilts: dream or reality? INRA Umr Microbiologie Geochimie des Sols.157-77.

Aldahmani, J.h., P.a. Abbasi, F. Sahin, H.a.j. Hoitink, and S.a. Miller. 2005. Reduction of bacterial leaf spot severity on radish, lettuce, and tomato plants grown in compost-amended potting mixes. Canadian Journal of Plant Pathology 27(2):186-93.

Attitalla, I. H., Z. Latiffah, B. Salleh, and S. Brishammar. 2011 Biology and partial sequencing of an endophytic fusarium oxysporum and plant defense complex. American Journal of Biochemistry and Molecular Biology 1:121-44.

Baligar, V. C., N. K. Fageria, and Z. L. He. 2001. Nutrient use efficiency in plants. Communications in Soil Science and Plant Analysis 32(7-8):921-50.

Chellemi, D. O. 2002. Nonchemical management of soilborne pests in freah market vegtable production systems. Phytopathology 92:1367-1372.

Darby, H.M., A.G. Stone, and R.P. Dick. 2006. Compost and manure mediated impacts on soil-borne pathogens and soil quality. Soil Science Society of America Journal 70(2):347-358.

Geraldson, C.M., A.J. Overman, and J.P. Jones. 1966. Combination of high analysis fertilizers, plastic mulch and fumigation for tomato production on old agricultural land. Proceedings of the Soil Science Society of Florida 25:18-24.

Gonsalves, A.K. and S.A. Ferreira. 1993. Fusarium oxysporum. *Knowledge Master*. 15 Oct. 2011. <http://www.extento.hawaii.edu/kbase/crop/type/f_oxys.htm>.

Gordon, T.D. and R.D. Martyn. 1997. The evolutionary biology of *Fusarium oxysporum*. Annual Review of Phytopathology 35: 111-128.

Hadar, Yitzhak. 2011. Suppressive compost: when plant pathology met microbial ecology. Phytoparasitica 39: 311-314.

Hanlon, E.A., R.M. Muchovej, M. Ozores-Hampton, S. Shukla, F.M. Roka, H. Yamataki. 2009. Sugarcane production in southwest Florida: Mineral soils and amendments. Univ. Florida Inst. Food Agric. Sci. 10 Apr. 2012. <http://edis.ifas.ufl.edu/sc073>.

Hoitink, H.A.J. and M.J. Boehm. 1999. Biocontrol within the context of soil microbial communities: a substrate-dependent phenomenon. Annual Review of Phytopathology 37: 427-46.

Jones, J.P., A.J. Overman, and C.M. Geraldson. 1966. Effect of fumigants and plastic film on control of several soil-borne pathogens of tomato. Phytopathology 56: 929-930.

Jones, J.P. and S.S. Woltz. 1967. Fusarium wilt (race 2) of tomato: Effect of lime and micronutrient soil amendments on disease development. Plant Disease Reporter 51: 645-648.

Jones, J.P. and S.S. Woltz. 1969. Fusarium wilt (race 2) of tomato: Calcium, pH, and micronutrient effects on disease development. Plant Disease Reporter 53: 276-279.

Jones, J.P. and S.S. Woltz. 1972. Effect of soil pH and micronutrient amendments on verticillium and fusarium wilt of tomato. Plant Disease Reporter 56: 151-153.

Jones, J.P. and A.J. Overman. 1976. Tomato wilts, nematodes, and yields as affected by soil reaction and a persistent contact nematicide. Plant Disease Reporter 60: 913-917.

Jones, J. B., J.P. Jones, R.E. Stall, and T.A. Zitter, eds. 1991. Compendium of tomato diseases. American Phytopathological Society, St. Paul, MN.

Kennelly, M. 2007. Wilt, nematode, and virus diseases of tomato. Kansas State University. Bul. 723.

King, E.O., M.K. Ward and D.E. Raney. 1954. Two simple media for the demonstration of pyocyanin and fluorescein. Journal of Laboratory and Clinical Medicine 44: 301-307

Kirkham, F., J. Tallowin, R. Sanderson, A. Bhogal, B. Chambers, and D. Stevens. 2008. The impact of organic and inorganic fertilizers and lime on the species-richness and plant functional characteristics of hay meadow communities. Biological Conservation 141(5): 1411-1427.

Korniłłowicz-Kowalska, T., and J. Bohacz. 2010. Dynamics of growth and succession of bacterial and fungal communities during composting of feather waste. Bioresource Technology 101(4): 1268-276.

Larkin, R.P., and D.R. Fravel. 2002. Effects of varying environmental conditions on biological control of fusarium wilt of tomato by non- pathogenic *Fusarium* spp. Phytopathology 92: 1160-1166.

Loper, S., A.L. Shober, C. Wiese, G.C. Denny, C.D. Stanley, and E.F. Gilman. 2010. Organic soil amendment and tillage affect soil quality and plant performance in simulated residential landscapes. HortScience 45(10): 1522-528.

Mai, W.F. and G.S. Abawi. 1987. Interactions among root-knot nematodes and fusarium wilt fungi on host plants. Annual Review of Phytopathology 27: 317-38.

Martin, F.N. 2003. Development of alternative strategies for management of soil-borne pathogens currently controlled with methyl bromide. Annual Review of Phytopathology 41: 325-50.

McGeehan, S.M. 2012. Impact of waste materials and organic amendments on soil properties and vegetative performance. Applied and Environmental Soil Science 2012: 1-11. doi: 10.1155/2012/907831

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communication Soil Science. Plant Analytical. 15: 1409-416.

Muchovej, R.M., E.A. Hanlon, E. McAvoy, M. Ozores-Hampton, F.M. Roka, S. Shukla, H. Yamataki, and K. Cushman. 2008. Management of soil and water for vegetable production in Southwest Florida. Univ. Florida Inst. Food Agric. Sci. Gainesville. 10 Apr. 2012. <http://edis.ifas.ufl.edu/ss452>.

Mylavarapu, R.S. 2009. UF/IFAS Extension soil testing laboratory (ESTL) analytical procedures and training manual. Univ. Florida Inst. Food Agric. Sci. Gainesville. 10 Apr. 2012 <http://edis.ifas.ufl.edu/ss312>.

Noble, R., and E. Coventry. 2005. Suppression of soil-borne plant diseases with composts: A review. Biocontrol Science and Technology 15(1): 3-20.

Noble, R. 2011. Risks and benefits of soil amendment with composts in relation to plant pathogens. Australasian Plant Pathology 40(2): 157-67.

Olivain, C., C. Humbert, J. Nahalkova, J. Fatehi, F. L'Haridon, and C. Alabouvette. 2006. Colonization of tomato root by pathogenic and nonpathogenic *Fusarium oxysporum* strains inoculated together and separately into the soil. Applied and Environmental Microbiology 72(2): 1523–31.

Osteen, C. 2000. Economic implications of the methyl bromide phaseout. USDA. Bul. 756.

Ozores-Hampton, M., P.A. Stansly, and T.P. Salame. 2011. Soil chemical, physical, and biological properties of a sandy soil subjected to long-term organic amendments. Journal of Sustainable Agriculture 35(3): 243-59.

Ozores-Hampton, M., T.A. Obreza, and G. Hochmuth. 1998. Using composted wastes on Florida vegetable crops. HortTechnology 8: 130-137.

Rose, S., M. Parker, and Z. K. Punja. 2003. Efficacy of biological and chemical treatments for control of fusarium root and stem rot on greenhouse cucumber. Plant Disease 87(12): 1462-470.

Stoffella, P.J., and B.A. Kahn. 2001. Plant nutrition benefits of phosphorus, potassium, calcium, magnesium, and micronutrients from compost. Utilization. Compost Utilization in Horticultural Cropping Systems. Boca Raton, FL: Lewis, pp. 307-17.

Stone, A.G., G.E. Vallad, L.R. Cooperband, D. Rotenberg, H.M. Darby, R.V. James, W.R. Stevenson, and R.M. Goodman. 2003. Effect of organic amendments on soilborne and foliar diseases in field-grown snap bean and cucumber. Plant Disease 87: 1037-1042.

Sylvia, D.M., J.J. Fuhrmann, P.G. Hartel, and D.A. Zuberer. 2005. Composting or organic wastes, p. 587-606. Principles and Applications of Soil Microbiology. 2nd ed. Upper Saddle River, N. J.

Tester, C.F., 1990. Organic amendment effects on physical and chemical properties of a sandy soil. Soil Science Society of America Journal 54: 827-831.

University of Florida. 2012. Report generator. Florida automated weather network report generator. Univ. Florida inst. Agric. Sci., Gainesville. 9 Apr. 2012. <<http://fawn.ifas.ufl.edu/scripts/reportrequest.asp>>.

U.S. Compost Council. 2001. Field guide to compost use. 11 March 2012. <http://compostingcouncil.org/admin/wp-content/plugins/wp-pdfupload/pdf/1330/Field_Guide_to_Compost_Use.pdf>.

U.S. Composting Council. 2002. Test methods for the examination of composting and compost. The Composting Council Research and Education Foundation. Rokonkoma, NY.

U.S. Deptartment of Agriculture. 2010. National Agricultural Statistics Service. Florida fresh tomatoes: Area, yield, production, and value, 1960-2009.

USDA-NASS, 2001. Crop Values 2010 Summary (February 2011).Available at: Web. <http://usda.mannlib.cornell.edu/usda/current/CropValuSu/CropValuSu-02-16-2011.pdf>.

Vallad, G.E., L. Cooperband, and R.M. Goodman. 2003. Plant foliar disease suppression mediated by composted forms of paper mill residuals exhibits molecular features of induced resistance. Physiological and Molecular Plant Pathology 63: 65-77.

Tables and Figures

Table 1. Chemical and physical characteristics of compost applied as a soil treatment during two commercial production seasons of tomato in a sandy soil in Florida.

Parameter [z]	Spring 2010	Fall 2010	Ozores-Hampton et al. (2011)
Moisture (%)	37.5	24.5	30.3
pH	7.78	8.12	7.3
EC[y] (mmhos/cm)	1.4	1.4	0.5
Organic matter (%)	30.9	26.5	--[x]
Organic C (%)	15.0	16.0	--
Total Kjeldahl N (%)	0.62	0.71	1.9
C:N ratio[w]	25	22	14.5
Total digestible P ($g \cdot kg^{-1}$)	1.30	1.20	10.0
Total digestible K ($g \cdot kg^{-1}$)	2.90	2.70	5.00
Total digestible Ca (%)	3.3	3.3	4.1
Total digestible Mg (%)	0.15	0.15	0.27

[z]Reported values based on analysis by Soil Control Lab (Watsonville, CA) using the standard Test Methods for the Examination of Compost and Composting (U.S. Composting Council, 2002).

[y]EC = electrical conductivity ($1\ dS \cdot m^{-1}$ = 1 mmhos/cm).

[x]-- Not reported.

[w]C:N ratio = carbon to nitrogen ratio.

Table 2. Effect of soil compost and lime treatments (n = 12) on selected soil chemical properties when applied to sandy soils prior to bedding at a commercial tomato production facility in Florida during the spring 2010 season.

Soil treatment	Super MAG (ton/acre)	pH	Electrical conductivity ($dS\cdot m^{-1}$)	Organic matter ($g\cdot kg^{-1}$)	Mehlich 3-P ($mg\cdot kg^{-1}$)	Mehlich 3-K ($mg\cdot kg^{-1}$)	Mehlich 3-Ca ($mg\cdot kg^{-1}$)	Mehlich 3-Mg ($mg\cdot kg^{-1}$)
Compost, 20 ton/acre	0.50	7.05 a[z]	292 a	10.6 a	180 a	68.4 a	516 a	105 a
Compost, 10 ton/acre	0.25	6.94 a	551 a	10.5 a	177 a	131 a	555 a	139 a
Hi-CAL, 1.0 ton/acre	0.50	6.99 a	596 a	9.90 a	174 a	138 a	500 a	179 a
Unamended control	0.25	7.14 a	318 a	10.5 a	189 a	69.4 a	516 a	108 a

[z]Means within column followed by different letters are significantly different based on Tukey's honestly significant difference (HSD) test at $P \leq 0.05$.

Table 3. Effect of soil compost and lime treatments (n = 12) on selected soil chemical properties when applied to sandy soils prior to bedding at a commercial tomato production facility in Florida during the fall 2010 season.

Soil treatment	Super MAG (ton/acre)	pH	Electrical conductivity ($dS \cdot m^{-1}$)	Organic Matter ($g \cdot kg^{-1}$)	Mehlich 3-P ($mg \cdot kg^{-1}$)	Mehlich 3-K ($mg \cdot kg^{-1}$)	Mehlich 3-Ca ($mg \cdot kg^{-1}$)	Mehlich 3-Mg ($mg \cdot kg^{-1}$)
Compost, 30 ton/acre	0.75	6.88 a[z]	502 a	12.3 a	181 a	86 a	864 a	143 a
Compost, 20 ton/acre	0.50	6.86 a	553 a	11.5 ab	182 a	86 a	822 a	142 a
Compost, 10 ton/acre	0.25	6.88 a	549 a	11.2 ab	179 a	87.5 a	781 a	120 ab
Hi-CAL, 1.0 ton/acre	0.50	7.01 a	438 a	10.6 b	161 a	61.7 a	779 a	107 b
Unamended control	0.25	6.93 a	467 a	10.6 b	177 a	78.3 a	780 a	113 b

[z]Means within column followed by different letters are significantly different based on Tukey's honestly significant difference (HSD) test at $P \leq 0.05$.

Table 4. Effect of soil compost and lime treatments (n = 12) on total culturable bacteria, fluorescent pseudomonads, total fungi, and *Fusarium oxysporum* in sandy soils collected from a commercial tomato, fall 2010.

Soil microbial community/soil treatments	Super MAG (ton/acre)	Culturable colonies ($\log_{10}$ CFU g^{-1})[z]		
		16 Sept.	7 Oct.	19 Nov.
Total bacteria				
Compost, 30 ton/acre	0.75	6.12 a[y]	5.20 b	5.45 a
Compost, 20 ton/acre	0.50	6.13 a	5.20 b	5.38 a
Compost, 10 ton/acre	0.25	6.12 a	4.94 a	5.39 a
Hi-CAL, 10 ton/acre	0.25	5.91 a	4.85 a	5.37 a
Unamended control	0.50	5.97 a	5.03 ab	5.44 a
Fluorescent pseudomonads				
Compost, 30 ton/acre	0.75	3.86 a	3.06 a	3.76 a
Compost, 20 ton/acre	0.50	3.86 a	3.28 a	3.67 a
Compost, 10 ton/acre	0.25	3.80 a	3.61 a	4.27 a
Hi-CAL, 10 ton/acre	0.25	3.58 a	3.40 a	4.03 a
Unamended control	0.50	3.91 a	3.19 a	4.35 a
Total fungi				
Compost, 30 ton/acre	0.75	3.86 a	1.30 a	2.24 a
Compost, 20 ton/acre	0.50	1.97 a	1.33 a	2.23 a
Compost, 10 ton/acre	0.25	1.27 a	1.85 b	2.25 a
Hi-CAL, 10 ton/acre	0.25	1.33 a	1.85 b	2.29 a
Unamended control	0.50	1.31 a	1.95 b	2.17 a

Fusarium oxysporum				
Compost, 30 ton/acre	0.75	0.88 a	0.50 a	0.98 a
Compost, 20 ton/acre	0.50	1.28 a	0.00 a	0.94 a
Compost, 10 ton/acre	0.25	0.40 a	0.65 a	0.80 a
Hi-CAL, 10 ton/acre	0.25	1.44 a	0.00 a	1.56 a
Unamended control	0.50	0.65 a	0.37 a	1.19 a

[z]$\log_{10}$ CFU g^{-1}= culturable forming units

[y]Means within column followed by different letters are significantly different based on LSD ($\alpha = 0.05$) test was used to compare least squares means among treatments at each date.

[x]Level of detection (LOD)= 1 x 10^4 cfu/g (equivalent to log 10 = 4.0) for total bacteria and fluorescent pseudomonads = 20 cfu/g (equivalent to log 10 = 1.3) for total fungi and for Fusarium oxysporum

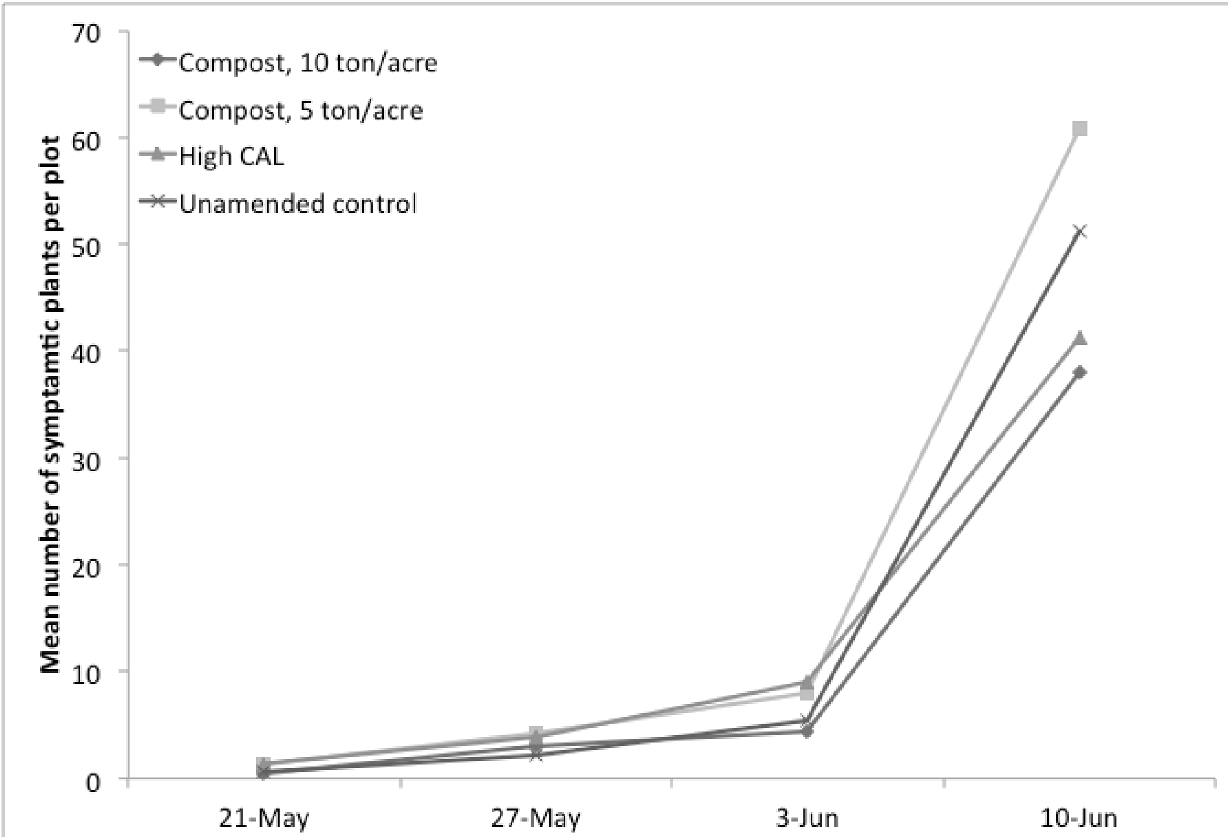

Figure 1. Incidence of fusarium wilt in commercial tomato where compost and lime treatments were applied to sandy soils prior to bedding in Florida during the spring 2010 growing season.

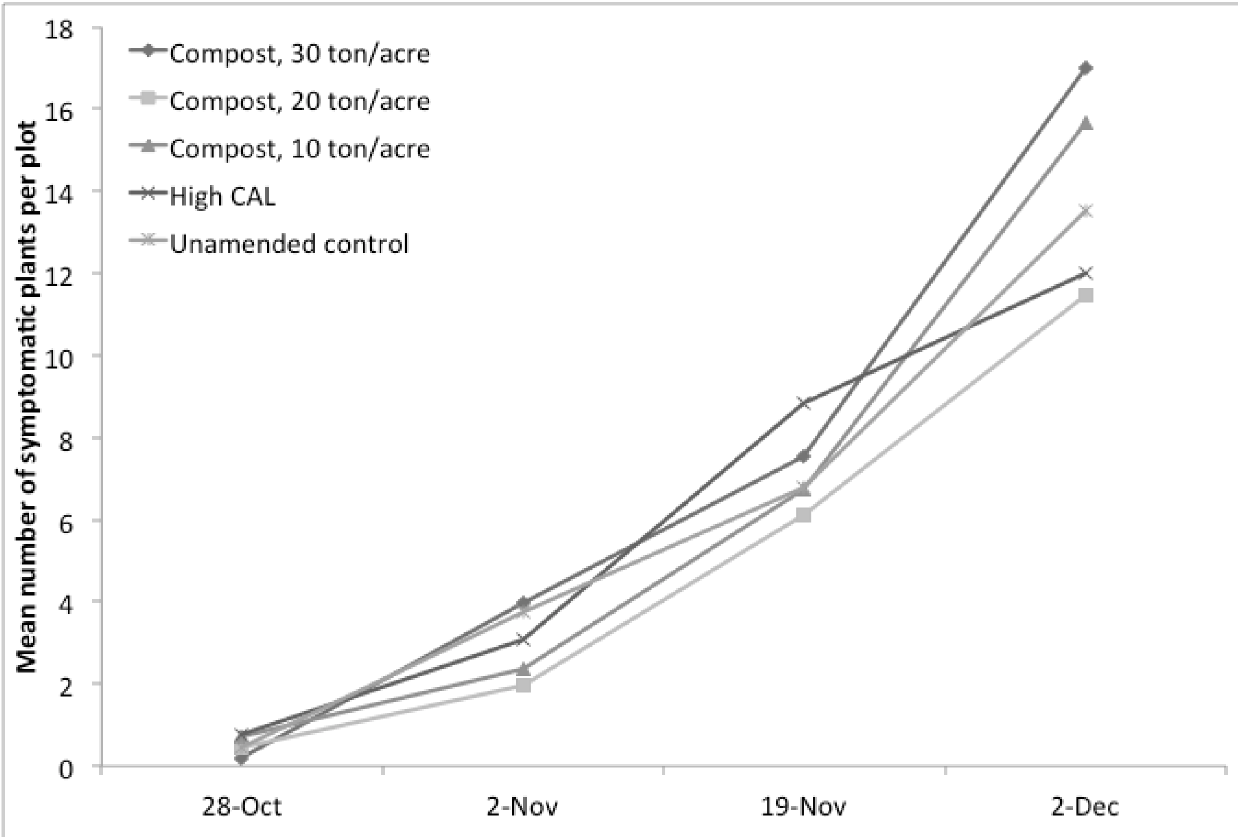

Figure 2. Incidence of fusarium wilt in commercial tomato where compost and lime treatments were applied to sandy soils prior to bedding during the fall 2010 growing season.