FLORIDA TOMATO INSTITUTE

PROCEEDINGS

SEPTEMBER 9, 2009

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CITRUS+ VEGETABLE

UNIVERSITY OF FLORIDA IFAS EXTENSION

THE GROWER

2009 FLORIDA TOMATO INSTITUTE

The Ritz-Carlton, Naples, Florida | September 9, 2009 | PRO 526

MODERATOR: MARY LAMBERTS, MIAMI-DADE COUNTY EXTENSION SERVICE, HOMESTEAD

9:00 **Welcome –** *Millie Ferrer, UF/IFAS Interim Extension Dean and Director, Gainesville*

9:05 **State of the Industry –** *Reggie Brown, Florida Tomato Committee, Maitland*

9:20 **Heating the water used in dump tanks, flumes and washers: Where did this originate? –** *Jerry Bartz, UF/IFAS Plant Pathology Dept., Gainesville* ***page 6***

9:40 **Assessment of microbes in tomato packinghouses –** *Fred Bonilla, UF Dept. of Infectious Diseases and Pathology, Gainesville* ***page 8***

10:00 **Can we use CRF in tomato production? –** *Monica Ozores-Hampton, UF/IFAS SWFREC, Immokalee* ***page 10***

10:15 **Sulfur fertilization in tomato production –** *Bielinski Santos , UF/IFAS GCREC, Wimauma* ***page 14***

10:30 **The effect of TYLCV on tomato yield depends upon age of the plant at time of inoculation –** *M. Lapidot, UF/IFAS Plant Pathology Dept., Gainesville* ***page 16***

10:45 **Progress in making TYLCV and bacterial spot resistance breeding more efficient and the latest variety outlook –** *Jay Scott, UF/IFAS GCREC, Wimauma* ***page 20***

11:05 **Breeding for disease resistance in fresh market tomatoes –** *Jeremy Edwards, UF/IFAS GCREC, Wimauma*

11:25 **Lunch** *(on your own)*

MODERATOR: ALICIA WHIDDEN, HILLSBOROUGH COUNTY EXTENSION SERVICE, SEFFNER

1:00 **CUE and fumigant assessment update –** *Dan Botts, Florida Fruits and Vegetables Association, Maitland*

1:20 **Fumigation for tomato today: Methyl bromide alternatives, the future of drip fumigation and outcomes and impacts of EPA reassessments of soil fumigants –** *Joe Noling, UF/IFAS CREC, Lake Alfred* ***page 22***

1:40 ***Ralstonia solanacearum*** **Race 3 biovar 2 causing bacterial wilt of tomato: Strategies for best management of a Select Agent pathogen –** *Patrice Champoiseau, UF/IFAS Plant Pathology Dept., Gainesville* ***page 25***

2:00 **The economic impact of Bacterial Spot on the tomato industry –** *John Vansickle, UF/IFAS Food & Resource Economics Dept., Gainesville* ***page 30***

2:20 **Identification of weed reservoirs of tomato yellow leaf curl virus in florida -** *Jane Polston, UF/IFAS Plant Pathology Dept., Gainesville* ***page 32***

2:40 **Industry updates –** *Crystal Snodgrass, Manatee County Extension, Palmetto*

3:30 **Adjourn**

PRODUCTION GUIDES

Tomato varieties for Florida – *Steve Olson, UF/IFAS NFREC, Quincy, and Gene McAvoy, UF/IFAS Hendry County Extension, LaBelle* ***page 34***

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Selected insecticides approved for use on insects that attack tomatoes – *Susan Webb, Entomology and Nematology Dept., Gainesville* ***page 49***

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HEATING THE WATER USED IN DUMP TANKS, FLUMES AND WASHERS: WHERE DID THIS ORIGINATE?

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CASE STUDY

In July, 1978 a 30-lb box of packed tomatoes (variety 'Improved Walter') was sent from a receiver in Orlando to the postharvest Pathology Laboratory in Gainesville (Bartz, 1980). The fruit had been grown and packed in the Quincy region. Since the area was new to tomato production back then, ripening rooms had not yet been constructed. So, this box had not been gassed. The shipment had been rejected by the receiver in Orlando due to progressive decay. When opened a day later, 60% of the fruit in the box had primary decay lesions. The survivors were stored at 68°F for 1 week and an additional 5% of the original contents had developed lesions. At this point, the survivors were more or less fully red and were discarded. An investigation of the shipment revealed:

- 59% of the lesions observed were directly beneath or beside the stem scar and internal.
- 10% of the lesions were adjacent to or beneath the blossom scar and internal.
- 29% of the lesions were midway between the blossom and stem scar and internal.
- 2% of the lesions were directly connected with a wound on the fruit surface.
- ≥ 6 different pathogens were isolated from lesions.
- Fruit in the field were not affected.
- Tank capacity was limited in this new packing shed operation.
- Ambient air temperatures were high.
- Calcium hypochlorite was periodically added to the water system but free chlorine concentration was not measured.
- Symptoms could be reproduced if a suspension of one of the pathogens was vacuum-infiltrated into fruit.

The pathogens were isolated, identified and proven to be the causal agents with Koch's postulates. Each one was strictly a wound invader; none could penetrate directly through the tomato cuticle. Since only 2% of the lesions were clearly associated with wounds, the pathogens had to have entered the fruit, which is called internalization. An infiltration of fruit by dump tank or washer water was implicated since fruit that were vacuum infiltrated with water suspensions of bacteria developed symptoms like those in the outbreak box.

The question then became: how this could have happened? Tomato fruits are filled with air-spaces. Mature-green tomatoes float when dumped into water. They do not normally absorb water and certainly do not absorb any through their waxy surfaces. Gas exchange between the air outside a fruit and that inside of it is mostly through the stem scar (Brooks, 1937), which is precisely where a majority of the lesions began. But the stem scar surface is normally dry and does not act like a sponge; on the contrary, water added to a dry stem scar beads and does not penetrate. However, according to the laws of physics, if a fruit is covered with water and sufficient pressure is exerted on the water, some will be forced into openings on the fruit surface. This situation could occur if the fruit is submerged deeply in a dump tank, is struck by a pressurized stream of water or if it cools while submerged.

PREVIOUS REPORTS ABOUT TOMATOES AND INFILTRATION

Aqueous suspensions of microorganisms have long been used in plant pathology laboratories and field plots to inoculate plants with plant pathogens. The water provides a vehicle that carries the suspended microbe into wounds, stomata or other openings in the plant surface. Once in contact with plant cells, the pathogen begins its attack. As noted above, vacuum infiltration of tomato fruit with bacteria isolated from internal lesions in fruit from a rejected shipment led to a reproduction of the symptoms (Bartz, 1980).

The concept of internalizing inocula in this manner was borrowed from Hall et al. (1970) who evaluated tomato lines for susceptibility to graywall by vacuum infiltrating the fruit with aqueous suspensions of bacteria. However, one of the first reports where wash water was reported to carry spoilage bacteria into an agricultural commodity did not involve tomato fruit, but rather hen's eggs (Haines and Moran, 1940). The authors carefully analyzed the egg shell, determined that it had pores connecting the shell surface with internal membranes surrounding the white and yolk. They reasoned that if the egg cooled while submerged, vacuums would develop in the air bubble within the membrane and airspaces within the shell, which could suck spoilage bacteria into the egg. Indeed, warm eggs soaked for 1 hour in cool water containing a spoilage bacterium, internalized the inocula and spoiled during subsequent storage. Similar soaks in water at the same temperature or greater than that of the egg led to much lower rates of spoilage.

The first report of tomatoes being soaked in water came from California and involved the use of warm water in dump tanks during colder harvest seasons (Kasmire, 1971). The fruit surfaces were warmed, which reduced pitting and scuffing during packing operations. A 1-minute immersion in warm water (85 to 90°F) led to the least surface damage, whereas a 30-second dip into hot water (135°F) exacerbated the damage. He further noted that tomatoes at 85°F immersed for 10 minutes in water at 50°F increased in weight by 0.17%, whereas a similar immersion in water at 85°F did not result in a weight increase due to water uptake.

Studer and Kader (1977) investigated the possibility of using water in 10-ton gondolas or bulk bins to cushion tomatoes that were mechanically harvested for fresh market. They found a high degree of splitting (due to water uptake) in fruit that were immersed for 2 hours soon after harvest. The splitting was increased if the water was cooler than the fruit at the time of submersion. Even fruits submerged for 15 minutes were subject to splitting. However, if the fruits were stored overnight before being dumped into the water, splitting was not observed.

RESEARCH ON WATER UPTAKE AND DECAY

The initial research related to water uptake accompanied by an internalization of suspended bacteria by freshly harvested tomato fruits focused on temperature differences between tomato and water (Bartz and Showalter, 1981). Because decay problems were reported more frequently when air temperatures were high, it was reasoned that fruits may have cooled after being dumped into unheated water. The research concentrated on proving that bacteria and fungi could be forced into tomato fruits if the fruits cooled while submerged in suspensions of decay pathogens. Immersion periods ranged from 10 to 30 minutes. Weight increases ranged from 0 to 3.6% and were generally proportional to the temperature difference between fruits and water as well as the contact duration. Fruits initially at the same temperature as the water did not increase in weight and rarely developed decay during subsequent storage. By contrast, when mature green fruits at 104°F were submerged into an aqueous suspension of soft rot bacteria at 68°F for 10 minutes, a decay incidence rate of 100% was observed within 2 days of storage. Water uptake increased when certain surfactants were added to the water (Bartz, 1982). Depth of submersion, period of submersion and fruit temperature were also implicated in increasing water uptake and subsequent decay development. Unusually warm fruits were prone to absorb water when the water was at the same temperature or even cooler than the fruit temperature. These observations led to the recommendation that the water in dump tanks and flumes be warmed 10°F higher than the highest incoming pulp temperature and that harvested fruits be kept out of direct sunlight, which could increase pulp temperatures (Sherman et al., 1981). Packinghouse managers were admonished to measure the pulp temperature of each incoming lot of fruit and not to make assumptions.

Bartz (1981) noted that a 2-minute immersion of fruit at 98°F in an aqueous suspension of soft rot bacteria at the same temperature did not lead to a weight increase, although 5% of the fruit developed bacterial soft rot during a subsequent 8-day period of storage. If the water was 17°F cooler than the pulp temperature, 15% of the fruit developed soft rot after a 2-minute exposure and 98% after a 10-minute exposure. Ogawa et al. (1980) reported preliminary tests where tomatoes contaminated with spores of *Botrytis cinerea* (causal agent of gray mold) were dipped into water at 100°F or at 65°F for 3 minutes. More decay developed among the fruits that had been treated with the cool as compared with warm water. Thus, a 3-minute immersion of a warm tomato in cool water may be long enough to establish infiltration. The increase in decay incidence caused by a fungal pathogen also implied that fungal spores could be carried into the fruits along with water. Vigneault et al. (2000) observed a 100% incidence of *Rhizopus* rot among fruits hydrocooled in water containing spores of *Rhizopus stolonifer* and then stored for 10 days at 68°F. By contrast, if the hydrocooler water also contained 50 ppm free chlorine at pH 7.0, no decay developed. Thus, maintenance of a rapidly acting sanitizer in the water also affects the decay risk associated with immersing tomatoes in water.

RESEARCH NEEDS

In a visit to several packinghouses, Mahovic (2007) noted that the residence times for fruits in dump tanks ranged from 30 to 120 seconds. Whether water uptake and subsequent decay risk driven by a temperature difference could occur during a 30- to 120-second exposure, is unclear. However, what is becoming increasingly clear is that water uptake by fruit caused by physical phenomena should not be allowed due to food safety concerns. Zhuang et al. (1995) noted that *Salmonella* could be internalized into stem scar tissues like soft rot bacteria. Once inside the fruits, this human pathogen could not be successfully eliminated with current sanitation methods. By contrast, soft rot bacteria must be in living tissues in order to cause decay; cells that merely contaminate upper levels of a dry stem scar are not able to infect the entire fruit. But, cells of *Salmonella* in upper levels of the stem scar are protected from exposure to sanitizers and may survive for several days. Thus, methods that protect fruits from postharvest pathogens may be only partially successful in a sanitation program for *Salmonella*. Before the water temperature requirement can be modified, evidence must be developed that a combination of an approved sanitizer and a short immersion period will preclude internalization of *Salmonella*. ❋

REFERENCES

Bartz, J. A. 1981. Ingress of suspensions of Erwinia carotovora subsp. carotovora into tomato fruit. Pages 452-460 in: Proc. Int. Conf. Plant Pathog. Bact. 5th. J. C. Lozano, ed. Centro Internacional de Agricultra Tropical, Cali. Colombia. 640 pp.

Bartz, J. A. 1982. Infiltration of tomatoes immersed at different temperatures to different depths in suspensions of Erwinia carotovora subsp. carotovora. Plant Dis. 66:302-306.

Bartz, J. A., Mahovic, M., Hermle, C. M., Concelmo, D. 2003. Internalization of microorganisms into tomato fruit through water congested tissues, Abstracts, 8th International Congress of Plant Pathology, 2003, p.316.

Bartz, J. A., and Showalter, R. K. 1981. Infiltration of tomatoes by bacteria in aqueous suspension. Phytopathology 71:515-518.

Brooks, C. 1937. Some effects of waxing tomatoes. Proc. Am. Soc. Hort. Sci. 35:720.

Haines, R. B., and Moran, T. 1940. Porosity of, and bacterial invasion through, the shell of the hen's egg. J. Hyg. 40:453-461.

Hall, C. B., Stall, R. E., and Strobel, J. W. 1970. Differential graywall development in tomato stocks infiltrated with bacteria. Proc. Fla. State Hort. Soc. 83:179-182.

Kasmire, R. F. 1971. Hot water treatments for tomatoes. Fruit and Veg. Perishables Handling 29:3-4. Univ. Cal., California Agric. Ext. Serv., Davis.

Mahovic, M. J. 2007. Use of chlorine, chlorine compounds and alternatives to chlorination in the sanitation of tomato water flume dump tanks. Ph.D. dissertation, University of Florida.

Ogawa, J. M., Hoy, M. W., Manji, B. T., and Hall, D. H. 1980. Proper use of chlorine for postharvest decay control of fresh market tomatoes. Calif. Tomatorama Inf. Bull. No. 27, Fresh Market Tomato Advis. Board, Bakersfield, CA.

Sherman, M., Showalter, R. K., Bartz, J. A., and Simone, G. W. 1981. Tomato packinghouse dump tank sanitation. Veg. Crops Fact Sheet VC-31, Fla Coop. Ext. Serv. Univ. Fla., Inst. Food Agric. Sci., Gainesville.

Studer, H. E. and Kader, A. A. 1976-1977. Handling tomatoes in water. Ann. Rep. Fresh Market Tomato Res. Prog. Fresh Market Tomato Advisory Board, Bakersfield, CA 93303. p. 84.

Vigneault, C., Bartz, J. A., and Sargent, S. A. 2000. Postharvest decay risk associated with hydrocooling tomatoes. Plant Dis. 84:1314-1318.

Zhuang, R. Y., Beuchat, L. R., and Angulo, F. J. 1995. Fate of Salmonella montevideo on and in raw tomatoes as affected by temperature and treatment with chlorine. Appl. Environ. Microbiol. 61:2127-2131.

ASSESSMENT OF MICROBES IN TOMATO PACKINGHOUSES

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INTRODUCTION

The United States enjoys one of the safest food supplies in the world. Nevertheless, infectious diseases spread through food and beverages are a common, distressing and sometimes life-threatening problem for millions of people in the United States. The Center for Disease Control and Prevention estimates that 76 million people suffer from foodborne illnesses in the United States each year, which accounts for 325,000 hospitalizations and more than 5,000 deaths. The economical toll from foodborne disease is heavy as health experts estimate a yearly cost of 5 to 6 billion dollars in direct medical expenses and lost productivity (CDC, 2009). To this end, food safety programs are important to address important health issues related to food sources, production and consumption.

The agriculture community has important economic reasons to be concerned and informed about food safety requirements and issues (Lynch et al., 2009). To be accepted in the marketplace, agricultural products must meet governmental food safety standards, and maintain a safety level that inspires continued consumer confidence. There are more than 250 known foodborne diseases caused by bacteria, viruses or protozoa. Some diseases are caused by toxins from the disease-causing microbe, others by the human body's reaction to the microbial infection. The sources of food contamination are almost as numerous and varied as the contaminants themselves. Bacteria, and other infectious organisms, are pervasive in the environment and foods may become contaminated at many stages of food production, including in the home. Of the numerous human pathogens transmitted through contaminated food, *Salmonella* spp. and *Escherichia coli* bacteria represent two of the most common (and often serious) foodborne infections in the US with approximately 40,000 and 73,000 cases of infection reported annually to the CDC (Frenzen et al., 2005, Chang et al., 2009).

TABLE 1. Summary of analytical techniques used.

Technique	Target
mHPC agar	Heterotrophic plate count
mTEC agar	E. coli
Tetrathionate Broth	Salmonella-enrichment prior to PCR
Rappaport-Vassiliadis R10 Broth	Salmonella-enrichment prior to PCR
PCR	Salmonella spp. hilA and sdiA genes
PCR	E. coli O157:H7 rfbE gene
PCR	Universal 16s rRNA gene

The goal of the study was to assess the microbial concentration in the wash tanks at two South Florida tomato packinghouses and assay the packinghouse water samples for specific pathogens important to the industry using advance molecular biology techniques. Our first objective was to assay the water using traditional membrane filtration methods and determine the level of total heterotrophic bacteria and *E. coli* in the wash tanks over a period of 4 to 6 hours of heavy operation. Secondly, we assayed the water and grab samples of tomatoes (before and after packaging) for *Salmonella* spp. and *E. coli* O157:H7 using the polymerase chain reaction (PCR) method, a highly sensitive DNA amplification technique for specifically identifying the presence of a microorganism.

MATERIALS AND METHODS

Ninety one water samples were collected over 4 sampling events and analyzed for total heterotrophic bacteria and E.coli using standard membrane filtration methods as described in "Standard Methods for the Examination of Water and Wastewater" (APHA, 2005; Table 1) and U.S. Environmental Protection Agency publications (2000). Briefly, water samples were collected from wash tanks every 30 min. and filtered through 47-mm filters with a 0.45-µm pore size to entrap the bacteria. The filters were placed onto mHPC agar for the enumeration of total heterotrophic bacteria (THB) and on mTEC agar for the enumeration of thermotolerant *E. coli*. The agar plates were analyzed at 24 and 48 hrs. of incubation and the number of colony-forming units (CFU)/100 ml was determined. The concentration of chloride was also determined for every water sample collected.

For the genetic analysis of the water, 25 ml from 32 of the water samples were filtered through a 25° mm filter with a 0.45 µm pore size, the bacterial population on the filter was lysed in a SDS/ProK/CTAB lysis solution, and the DNA was extracted and purified. Two PCR primer sets for *Salmonella* spp. (targeting the *sdi*A and *hil*A genes), one primer set for *E. coli* O157:H7 (targeting the rfbE gene), and one primer set for 'universal' bacteria (16s rRNA gene) were used as previously described (Guo et al., 2000; Halatsi et al., 2006; Omiccioli et al., 2009).

In an attempt to increase the sensitivity of the PCR detection of *Salmonella,* 8 of the water samples processed for DNA analysis as described above were also subjected to an enrichment procedure. Bacteria-containing filters were placed into culture-grade tubes with Rappaport-Vassiliadis R10 broth and Tetrathionate broth and incubated overnight at 37oC. The broth sample was centrifuged at 10,000 × g for 10 min., the pellet was lysed in a SDS/ProK/CTAB lysis solution, and the DNA was extracted and purified.

Grab samples of tomatoes (approximately 500 g) were collected from the

truck bins prior to dumping (pre-processed) and from the final 25-pound packing boxes (post-processed). A total of 10 tomato samples were analyzed directly by PCR and by PCR after the enrichment procedure. The tomatoes were collected in a sterile bag and 100 ml of phosphate-buffered saline (PBS) was added. The bag was shaken and agitated every 5 min. for 30 min. to remove and collect bacteria off the surface of the tomatoes. The PBS wash of the pre-processed and post-processed tomatoes was also analyzed for THB by membrane filtration.

RESULTS AND DISCUSSION

Analysis of total heterotrophic bacteria (THB) and *E. coli* bacteria. The concentrations of THB and *E. coli* enumerated by the membrane filtration method were very low in all wash tank samples analyzed (Fig. 1). For THB, less than 10 CFU per 100 ml of wash tank water was detected in nearly all samples throughout the 5-6 hrs. of tomato processing. While some samples were positive for presumptive coliform bacteria, upon confirmation tests, *E. coli* was not detected in any of the water samples. An initial concern was the travel time from collection of the sample, to transport and analysis in the laboratory. The samples were analyzed within 8 hrs. of collection. However, to investigate whether the extended contact time was affecting the microbial concentration in the water samples, we decided to process the water sample for membrane filtration onto the agar plates at the packinghouses and immediately after collection. The results were comparable, with very few THB CFU/100ml and no *E. coli* CFU/100ml detected in the water. Fig. 1 shows the average CFU/100ml of total heterotrophic bacteria and the average chloride levels detected at the 2 packinghouses. Importantly, the lower chloride levels used at packinghouse B did not result in an increase in bacterial levels.

The pre-processed and post-processed tomato grab samples had detectable levels of THB. The THB in the pre-processed tomatoes ranged from 6.1×10^4 to 3.4×10^5 CFU/100ml of the PBS wash used on ~500 g of tomatoes. The post-processed samples had, on average, an 81% reduction (range 73% to 93%) in THB concentration. The EPA "acceptable" level for total heterotrophic bacteria per 100 ml of drinking water is 5.0×10^4 CFU. Therefore, the concentrations detected in this study

FIGURE 1. Total heterotrophic bacteria (CFU/100ml) and chloride levels (mg/L) in wash tank samples collected over 6 hrs at 2 South Florida packinghouses. Each packinghouse was sampled at least twice and the averages are reported.

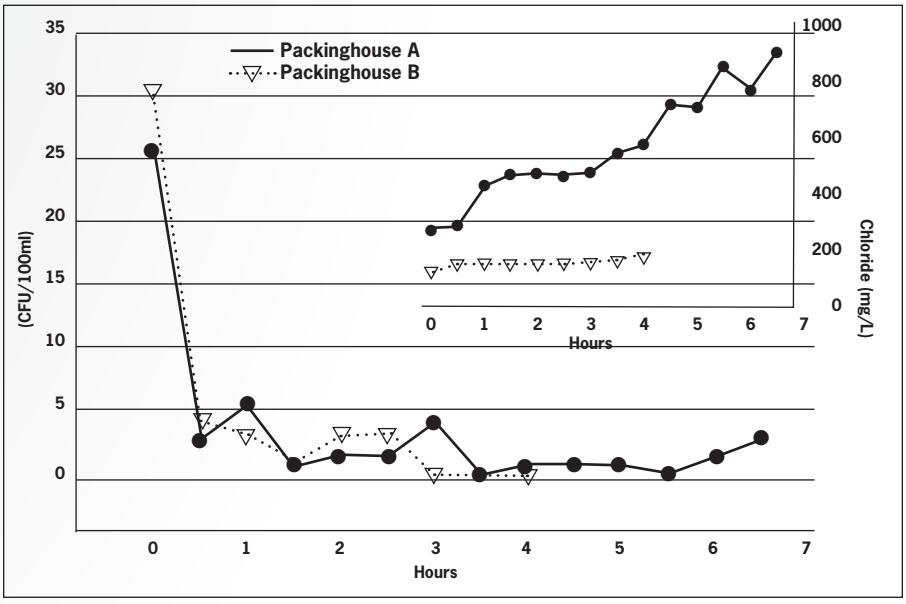
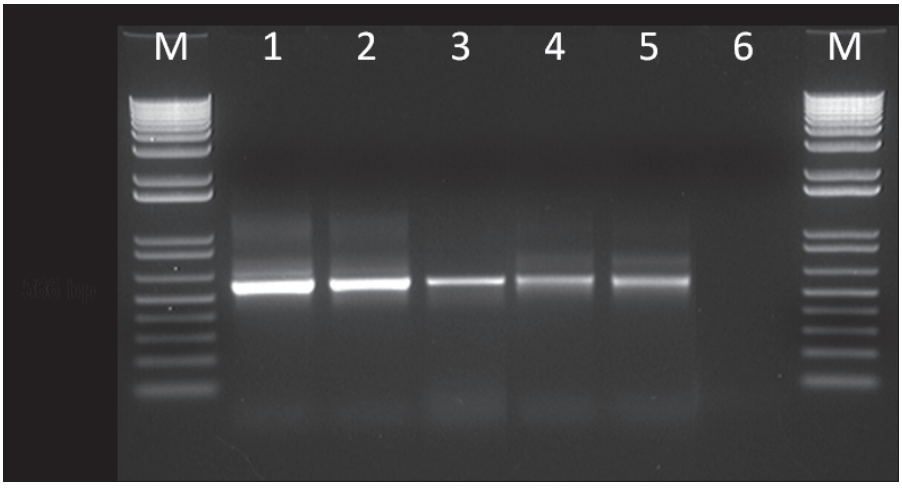


FIGURE 2. Representative samples of 16s rRNA gene fragments isolated from DNA samples. Lane M, DNA marker. Lanes 1-2, tomato wash samples. Lanes 3-5, sash tank samples. Lane 6, negative control.



were relatively low, and the presence of THB did not correlate with the presence of human pathogens in the absence of other indicators of fecal contamination. To this end, there was no *E. coli* detected in the final tomato samples by membrane filtration or PCR (*E. coli* O157:H7).

PCR analysis of *Salmonella* spp. and *E. coli* O157:H7. Despite the low levels of bacteria detected in the water samples by membrane filtration, the PCR reaction for the universal 16s rRNA gene demonstrated a robust amplification of this gene fragment (Fig. 2). The PCR assay is a highly sensitive assay using a DNA amplification procedure to detect the presence of organism-specific genes. This assay is not quantitative, but the positive reactions observed (Fig. 2) demonstrate that there is not a significant level of PCR inhibition in the reaction. This is a particularly important point as environmental samples can contain numerous inhibitors of PCR such as humic acids and complex polysaccharides that can lead to false-negative results being reported. All of the samples analyzed by PCR were positive for the 16s rRNA gene, as would be expected. However, none of the samples was positive for *Salmonella* spp. or *E. coli* O157:H7 by PCR.

Samples subjected to the *Salmonella*-enrichment procedure remained negative for *Salmonella* spp. by PCR suggesting that a direct analysis of 25 ml of water by PCR is not below a particular detection limit, but that the sample is truly negative for *Salmonella* spp.

REFERENCES

APHA. 2005. Standard methods for the examination of water andwWastewater, 20th Ed. Am. Public Health Assoc./Am. Water Works Assoc./Water Environment Fed., Washington, DC.

CDC. 2009. Surveillance for foodborne disease outbreaks - United States, 2006. MMWR Morb Mortal Wkly Rep 58: 609-615.

Chang, M., S.L. Groseclose, A.A. Zaidi, and C.R. Braden. 2009. An ecological analysis of sociodemographic factors associated with the incidence of salmonellosis, shigellosis, and E. coli O157:H7 infections in US counties. Epidemiol Infect 137: 810-820.

Frenzen, P. D., A. Drake, and F.J. Angulo. 2005. Economic cost of illness due to Escherichia coli O157 infections in the United States. J Food Prot 68: 2623-2630.

Guo, X., J. Chen, L.R. Beuchat, and R.E. Brackett. 2000. PCR detection of Salmonella enterica serotype Montevideo in and on raw tomatoes using primers derived from hilA. Appl Environ Microbiol 66: 5248-5252.

Halatsi, K., I. Oikonomou, M. Lambiri, G. Mandilara, A. Vatopoulos, and A. Kyriacou. 2006. PCR detection of Salmonella spp. using primers targeting the quorum sensing gene sdiA. FEMS Microbiol. Lett. .259: 201-207.

Lynch, M. F., R.V. Tauxe, and C.W. Hedberg. 2009. The growing burden of foodborne outbreaks due to contaminated fresh produce: Risks and opportunities. Epidemiol. Infect. 137: 307-315.

Omiccioli, E., G. Amagliani, G. Brandi and M. Magnani. 2009. A new platform for Real-Time PCR detection of Salmonella spp., Listeria monocytogenes and Escherichia coli O157 in milk. Food Microbiol. 26: 615-622.

CAN WE USE CONTROLLED RELEASE FERTILIZERS (CRF) IN TOMATO PRODUCTION?

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INTRODUCTION

Increased environmental concerns and the development of Best Management Practices (BMP) for vegetable crops have emphasized the need to better manage fertilizer, increase fertilizer efficiency, and reduce N loss to the environment (Shaviv, 2000). Slow-release and controlled-release fertilizers (CRF) are recognized in the BMP manual for vegetables (www.floridaagwaterpolicy.com) as one of the main nutrient BMPs for crops grown with seepage irrigation. Synthetic CRN (controlled-release nitrogen) can be separated into two general groups: 1) those that are slow-release as a byproduct of a chemical reaction (such as urea-formaldehyde), and, 2) those that are slow release via a sulfur, wax or resin coating around the fertilizer prill (Morgan et al., 2009). If the CRN fertilizer has a release pattern that matches with crop needs, N uptake by the growing tomato crop may become more efficient, thus resulting in greater yield or reduced need for fertilizer N (Shaviv, 2000; Simonne and Hutchinson, 2005). Additionally, if CRN can be applied as a pre-plant application, the need for multiple applications of soluble N fertilizer under leaching rain events would be eliminated, resulting in reduced production costs (Hutchison et al., 2003; Hutchison and Simonne, 2003).

Most previous work has focused on use of sulfur coat urea (SCU) and urea-formaldehyde (UF), as they have been in the fertilizer market for thirty years (Lacascio and Fiskell, 1979; Csizinszky, 1989; Csizinszky et al., 1992; 1993). Recently, research has evaluated resin-coated products (Du et al., 2006). In Florida, yields were improved with CRF compared with multiple soluble fertilizer application in potato production (Hutchison et al., 2003). However, studies with tomatoes with older CRF materials when compared to soluble fertilizer application have shown conflicting results (Csizinszky et al., 1994; Morgan et al., 2003). Based on available research, benefits of using CRN fertilizers in tomato production will come from reduced environmental risk and savings in production costs (Hutchison and Simonne, 2003). Therefore, testing is needed to determine sources, rate and release pattern of N under south Florida growing conditions before growers can adapt these slow-release sources of N as part of their fertilizer BMP programs.

MATERIALS AND METHODS

Four trials were conducted with different combination of CRN sources, bed placement and N rates with seepage irrigation in southwest Florida at the University of Florida, Southwest Florida Research and Education Center (UF/SWFREC) and on commercial farms in the Immokalee area on Immokalee fine sand and EauGallie fine sand, respectively. Both soils have sandy surface layers that are prone to NO3-N leaching. Seepage irrigation is possible in this area because vertical water movement is decreased by an impervious Spodic layer at an average depth of 3 feet resulting in a perched water table. In each trial, tomatoes were grown following industry standards for production practices (Table 1) and UF/IFAS recommendations for pest and disease control (Olson et al., 2006a,b).

Trial 1 - CRN sources and rates with placement in the "hot mix" (Spring 2006). This trial was conducted at UF/SWFREC, Immokalee, FL (Table 1). We compared three CRN sources applied as a hot mix with a control of soluble ammonium nitrate placed in two grooves on the bed shoulders at rates of 160, 230 and 300 lb/A. The three CRFs sources were Nitamin®

TABLE 1. Summary of cultural practices used in testing controlled-release fertilizers rates and placement effect on tomato grown with seepage irrigation in Southwest Florida.

Cultural practice	Trial 1 SWFREC	Trial 2 SWFREC	Trial 3 Commercial field	Trial 4 Commercial field
Variety	Hazera 3073	Florida 47	BHN 832	BHN 832
Plant spacing (inch)	18	18	20	20
Bed spacing (feet)	6	6	6	6
Methyl Bromide: Chloropicrin	67:33@355lb/A	67:33@355lb/A	50:50 @ 100lb/A	50:50 @ 100lb/A
Mulch	Black polyethylene	White polyethylene	Silver VIF[2]	Silver VIF
Planted plot length (feet)	30	30	400	400
Harvest plot length (feet)	21	21	17	17
Number of beds in plot	3	3	3	3
Replications	4	4	3	3
Bed width (inch)	42	42	32	32
Transplant date	20 Feb., 2006	7 Sept., 2006	13 Dec., 2007	23 Oct., 2008
Harvest dates	16 May, 24 May, and 5 June, 2006	27 Nov., 11 Dec., and 20 Dec., 2006	12 Mar., 26 Mar., and 9 April, 2008	3 Feb., 19 Feb., and 5 Mar., 2009

2 VIF - VIRTUALLY IMPEMEABLE FILM

[granular (23-0-0), methylated urea and derivatives; Georgia-Pacific Resins, Inc.], Multicote® [polymer-coated urea (40-0-0); Haifa Chemical Ltd.], and AgroCote® [polymer-coated sulfur-coated urea (38-0-0); The Scotts Company]. At bedding, 40 lb/A of soluble N (mostly ammonium nitrate), 64 lb/acre P2O5, 64 lb/acre K2O, and a blend of micronutrients were broadcast incorported in the bed as a bottom mix. Total fertilizer N rates were 200, 270 and 340 lb/acre.

Trial 2 - CRN (polymer-coated urea) release time and rates with placement in the "bottom mix" (Fall 2006). This trial was conducted at UF/SWFREC, Immokalee, FL (Table 1). This trial compared one CRN source, Multicote [polymer-coated urea (40-0-0); Haifa Chemical Ltd.], with a 2 or 4 month release rate, and the combination of the two release rates at the rates of 120, 180, and 240 lb/A total N. Total N rates were a combination of CRN at 100, 150 and 200 and soluble (mostly ammonium nitrate) at 20, 30 and 40 lb/acre of N broadcast application (bottom mix) before bedding and were compared with a control hot mix consisting of ammonium nitrate (Pro-Source, Immokalee, FL). The bottom mix also included 64 lb/acre P2O5, 64 lb/acre K2O, and a blend of micronutrients.

Trial 3 - CRN sources (polymer-coated urea), release time mix and rates with placement in the "bottom mix" (Winter 2007). The trial was conducted in a commercial farm near Immokalee, FL (Table 1). We compared two CRN sources: Polyon, [polymer-coated urea (43-0-0), Agrium Advance Technology, AL], and Multicote Agri [polymer-coated urea (43-0-0), Haifa Nutritech, FL], in a combination of 50% 2-month and 50% 4-month time release and at two N rates of 120 and 170 lb/acre of CRN. Total N rates were a combination of CRN plus 30 lb/A of soluble N (mostly ammonium nitrate) applied broadcast (bottom mix) before bedding and compared to a control hot mix consisting of 200 (IFAS rate) and 266 (grower rate) lb/A of ammonium nitrate and 390 lb/acre of K2O (Howard Fertilizer, Immokalee, FL). The bottom mix also included 190 lb/acre P2O5, 40 lb/acre K2O, and a blend of micronutrients.

Trial 4 - Combination of CRN (polymer coated-potassium nitrate) rates and soluble N fertilizer with placement in the "bottom mix" (Winter 2008). The trial was conducted in a commercial farm near Immokalee, FL (Table 1). We compared one CRN source Multicote Agri [polymer-coated potassium nitrate (12-0-43), Haifa Nutritech, FL], a combination of 50% 2-month and 50% 4-month time release at three N rates 50, 100 and 150 lb/acre applied broadcast (bottom mix) before bedding plus 100 lb/acre of soluble N (ammonium nitrate) as a hot mix. The total N treatments were 150, 200 and 250 lb/acre and compared to a control hot mix consisting of 200 (IFAS) and 266 (Grower) lb/acre of N (ammonium nitrate) and 390 lb/acre of K2O, (Howard Fertilizer, Immokalee, FL). In all treatments the bottom mix also included 100 lb/acre P2O5, 40 lb/acre K2O, and a blend of micronutrients.

Data collection. On-farm plots were clearly marked to prevent unscheduled harvest by commercial crews. Marketable green and colored tomatoes were graded in the field according to USDA specifications of number and weight of extra-large (5x6), large (6x6), and medium (6x7) green and colored fuit (USDA, 1997). Cull fruits were those blemished or defective and thus unmarketable. Trial 1 and 2 were analyzed by SAS as a two factor experiment. Statistical significances were determined for product, rate, and the product by rate interaction. Trial 3 and 4 yield data were subjected to analysis of variance (ANOVA) and mean separation using LSD (trial 1) and Duncan's Multiple Range Test (trial 2, 3 and 4) at the 5% level.

RESULTS AND DISCUSSION

Weather conditions during the trials. Overall, South Florida weather recorded by the Florida Automated Weather Network (FAWN) was hot and dry throughout the fall, and cool and dry during the spring of 2006 (Table 2). The two winter seasons were cool and dry with one (3 Jan.) and five (21-23, Jan., 5 Feb. and 3 Mar.) freeze events during 2007 and 2008, respectively.

Cumulative rainfall amounts during the 2006, 2007 and 2008 seasons were 6, 5.1, 8.8 and 2.5 inches for spring, fall, and the two winter seasons, respectively. The IFAS tomato fertilizer recommendation (Olson et al., 2006b) and the BMP manual (FDACS, 2005) allow for supplemental N and K fertilizer applications after a qualified leaching rain, a documented "low" plant nutrient concentration, and during extended harvest seasons. Under this provision, 30 lb/acre of N and 20 lbs/A of K2O can be added for each qualifying leaching rain event. Based on rainfalls during these trials, no supplemental application was justified in these trials.

In seepage irrigated fields, freeze protection may be done by raising the water table near the soil surface. During these trials, water tables were raised 7 to 9 inches during freeze events from depths of 19 to 24 inches prior to the freeze events to a depth 12 to 15 inches during the day freezing temperatures were expected. After the threat of freeze has past, the water table were lowered to the original 19-24- inch depth. This cultural practice is necessary to protect the crops in circumstances beyond the control of the grower. After the surge in water table, some soluble nutrients may leach (Sato et al., 2009ab), but this is not considered a qualified event for supplemental fertilizer application.

Trial 1. The interactions between fertilizer source and N rate were not significant. Fertilizer sources had a significant effect on plant biomass, yield, and leaf tissue nutrient content. CRN sources produced significantly lower yields in the extra-large (5X6), large (6X6), and medium (6X7) size categories, and total yield, compared with the soluble control (Table 3). Also, grower standard treatment, using soluble fertilizers, produced more biomass and higher leaf

TABLE 2. Summary total rainfall and number of leaching rain events in South Florida during the 2006 and 2008 tomato seasons.

Trial	Year	Season	Temperature Min (°F)		Temperature Max (°F)		Total rainfall (inch)	Number leaching rainfalls	Possible[z] and applied supplemental N (lb/acre)
			Reported	Average	Reported	Average			
1	2006	Spring	38.6	54.0	99.5	93.8	6.0	0	0/0
2	2006	Fall	36.8	53.9	95.7	90.6	5.1	0	0/0
3	2007	Winter	29.4	55.0	89.8	81.6	8.8	0	0/0
4	2008	Winter	24.7	49.1	90.3	78.6	2.5	0	0/0

[z] SOURCE: UF/IFAS SUPPLEMENTAL FERTILIZER APPLICATION IS ALLOWED AFTER A LEACHING RAIN DEFINED AS 3 INCHES IN 3 DAYS OR 4 INCHES IN 7 DAYS FOR TOMATOES (OLSON ET AL., 20069,b)

TABLE 3. Effects of CRN sources and rates incorporated as a hot mix on total tomato yields combined over four harvests and according to size categories of extra-large (5x6), large (6x6), medium (6x7), total of all size categories of marketable fruit and unmarketable yield during Spring 2006 (Trial 1).

Factor[z]		Total Marketable Yield[y] (25-lb boxes/acre)				Culls[y]
N source	Rate (lb/acre)	5/6	6/6	6/7	Total	
Soluble		1,531 a	354 a	333 a	2,218 a	463 a
Nitamin®		901 b	197 b	204 b	1,303 b	345 a
Multicote		1,020 b	204 b	207 b	1,431 b	385 a
AgroCote®		1,087 b	224 b	214 b	1,524 b	345 a
P value		0.006	0.001	0.001	0.002	0.70
	200	1,246 a	280 a	258 a	1,784 a	424 a
	270	1,172 a	252 ab	238 a	1,663 a	365 a
	340	986 a	202 b	222 a	1,410 a	364 a
P value		0.23	0.05	0.45	0.17	0.31

[z] NITAMIN® [GRANULAR (23-0-0), METHYLATED UREA AND DERIVATIVES; GEORGIA-PACIFIC RESINS, INC.], MULTICOTE [POLYMER-COATED UREA (40-0-0); HAIFA CHEMICAL LTD.].
AGROCOTE® [POLYMER-COATED SULFUR-COATED UREA (38-0-0); THE SCOTTS COMPANY].
[y] WITHIN COLUMNS AND FACTOR, MEANS FOLLOWED BY DIFFERENT LETTERS ARE STATISTICALLY DIFFERENT ACCORDING TO THE LEAST SIGNIFICANT DIFFERENCE (LSD) TEST AT 5%.

TABLE 4. Effects of CRN [Multicote, polymer-coated urea (40-0-0)] release time and rates incorporate as a bottom mix on total tomato yields combined over four harvests and according to size categories of extra-large (5x6), large (6x6), medium (6x7), total of all size categories of marketable fruit and unmarketable yield during the Fall season 2006 (Trial 2).

Factor		Total Marketable Yield (Boxes/acre)[y]				Culls [y]
N source[z]	Rate (lb/acre)	5/6	6/6	6/7	Total	
Soluble		2,041 a	325 a	410 a	2,776 b	319 a
2-mo/4-mo (Multicote)		2,213 a	328 a	448 a	2,989 ab	276 a
2-month (Multicote)		2,293 a	379 a	502 a	3,179 a	282 a
4-month (Multicote)		2,304 a	387 a	511 a	3,201 a	320 a
P value		0.19	0.50	0.53	0.10	0.18
	120	2,093 a	333 a	462 a	2,888 a	293 a
	180	2,,209 a	315 a	445 a	2,950 a	297 a
	240	2,340 a	416 a	516 a	3,271 a	308 a
P value		0.12	0.07	0.41	0.05	0.79
Linear Contrast (rate)[w]		ns	ns	ns	*	ns

[z] MULTICOTE [POLYMER-COATED UREA (40-0-0); HAIFA CHEMICAL LTD.].
[y] WITHIN COLUMNS AND FACTOR, MEANS FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT ACCORDING TO THE LEAST SIGNIFICANT DIFFERENCE (LSD) TEST AT 5%.
[w] * = SIGNIFICANCE AT P ≤ 0.05; NS = NOT SIGNIFICANT

N content than any of the CRN fertilizers treatments (data not shown). Nitrogen rate had little effect on plant growth or performance. It can be concluded that CRN fertilizers are not well suited to the type of placement used in this study. More specifically, CRN products appeared ineffective when used as a "hot mix" and placed in grooves at the top and outside edges of the plant bed. Hence, CRN were broadcast incorporated on the cold mix in the other trials.

Trial 2. There were no significant interactions among release time and N rates (Table 4). Higher total marketable yield (all harvest and size combined) were produced with the 2-month or 4-month release materials alone than with the soluble N treatment, but the yields with the 50-50 2-month + 4-month combination treatment were not significantly different from those with either release time alone or the soluble-N treatments ($P \leq 0.10$). Total X-large (5X6), large (6X6), medium (6X7), and unmarketable (culls) were not significantly affected by N release time (2 and 4-months or the combination of both products). Total marketable yield (all harvest and size combined) increased linearly as N rate increased from 120 to 240 lb/acre ($P \leq 0.05$). Total X-large (5X6), large (6X6), medium (6X7), and unmarketable (culls) were not significantly affected by N rate.

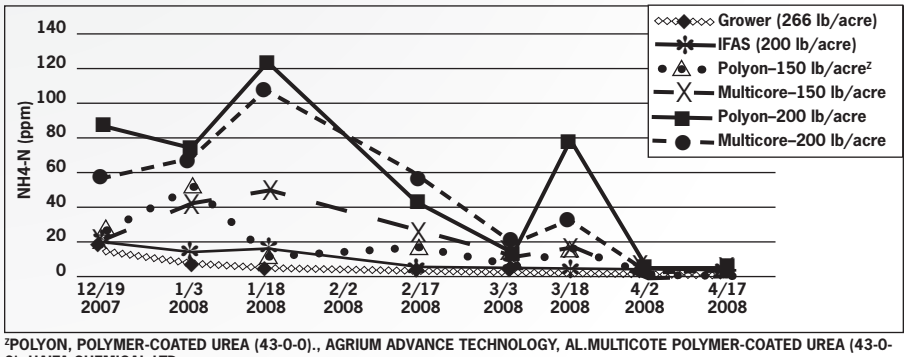
Trial 3. Soluble fertilizer application of 200 (IFAS) and 266 (Grower) lb/acre of N resulted in higher extra-large (5X6) fruit at first harvest than the two CRN products at 120 lb/acre CRN rate (150 lb/acre of total N; [Table 5; $P \leq 0.05$). Soluble fertilizer application at 266 lb/acre (grower) rate produced greater total yield (three harvest and sizes combined) than the two CRN products at 120 lb/acre CRN rate (150 lb/acre of total N) but these differences were not significant ($P \leq 0.10$). There were no differences between 266 and 200 lb/acre or 200 lb/acre and the CRN products in total yields ($P \leq 0.10$). Yield reduction with both CRN products at 150 lb/acre of total of N extra-large (5X6) fruit at first harvest and total yield was probably due to a smaller plant biomass and lower petiole sap NO3-N concentrations probably induced by lower N rates (compared with IFAS and grower rates) and ammonium (NH4-N) toxicity (Figure 1). High soil NH4-N levels of 32 ppm in the center of the bed at 35 days after planting (DAP) compared with 8 ppm from soluble N grower rate of 266 lb/acre (Figure 1). Ammonium toxicity may occur when fertilizers containing urea are applied to cold wet soils that have been fumigated. The conversion of NH4-N to NO3-N (nitrifcation) is carried out by soil nitrifying bacteria that may be absent due to soil fumigation (methyl bromide/chloropicrin). Secondly, the cool wet soils with poor aeration due to freeze protection practices (Table 1) would lead to increased soil ammonium retention. Also, the utilization of VIP high barrier plastic films to reduce fumigation rates may have trapped volatile ammonium in the soil. Ammonium toxicity can produce symptoms similar to phosphorous deficiency, primarily reducing plant biomass and causing extreme toxicity symptoms that can lead to plant mortality.

TABLE 5. Effects of CRN [Polyon and Multicote@ Agri polymer-coated urea (43-0-0)] sources and rates incorporated as a bottom mix on total tomato yields over 3 harvests and according to size categories of extra-large (5x6), large (6x6), medium (6x7), total of all size categories of marketable fruit and unmarketable yield during winter 2007 (trial 3).[z]

N program (lb/acre)				Total Marketable Yield (Boxes/acre)									
				First harvest					Second harvest				
N program[y]	CRN	Soluble N	Total N	5/6	6/6	6/7	Total	Culls	5/6	6/6	6/7	Total	Culls
Grower	0	266	266	492a	197b	138	828	108	981	652	623	2,256	421
IFAS	0	200	200	515a	233b	128	877	124	984	622	578	2,184	493
Polyon	120[x]	30	150	370b	304a	154	828	98	672	632	596	1,900	374
Multicote@	120[x]	30	150	434b	282a	174	889	125	810	586	500	1,896	372
P value				0.03	0.04	0.68	0.51	0.52	0.13	0.51	0.19	0.09	0.25

[z] WITHIN COLUMNS, MEANS FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST AT 5%.
[y] POLYON, POLYMER-COATED UREA (43-0-0)., AGRIUM ADVANCE TECHNOLOGY, AL. MULTICOTE [POLYMER-COATED UREA (43-0-0); HAIFA CHEMICAL LTD.].
[x] 120 LB/A = 60 LB/A OF A 2-MONTH + 60 LB/A OF A 4-MONTH CRN

FIGURE 1. Center of the bed soil (NH4-N) ammonium content at four inches depth during winter 2007 season.



[z] POLYON, POLYMER-COATED UREA (43-0-0)., AGRIUM ADVANCE TECHNOLOGY, AL.MULTICOTE POLYMER-COATED UREA (43-0-0); HAIFA CHEMICAL LTD.

TABLE 6. Effects of combination of CRN [Multicote Agri polymer-coated potassium nitrate (12-0-43), Haifa Nutritech, FL] rates and soluble N fertilizer on total tomato yields over three harvests and according to size categories of extra-large (5x6), large (6x6), medium (6x7), total of all size categories of marketable fruit and unmarketable yield during winter 2008 (trial 4).[z]

N program (lb/acre)			Marketable Yield (Boxes/acre)									
			First harvest					Second harvest				
CRN Bottom mix	Soluble N Hot mix	Total N	5/6	6/6	6/7	Total	H1+H2 Total	5/6	6/6	6/7	Total	Culls
0	255 (Grower)	255	783	359	138	1,280	2,042ab	1,152	837	625	2,614	404
0	200 (IFAS)	200	861	286	95	1,243	2,119a	1,182	737	739	2,658	350
50	100	150	791	325	124	1,240	2,042ab	1,170	767	624	2,561	347
100	100	200	877	284	108	1,269	2,209a	1,296	740	580	2,616	399
150	100	250	672	282	117	1,070	1,852b	1,024	703	716	2,443	360
P value			0.25	0.35	0.60	0.08	0.05	0.40	0.33	0.10	0.38	0.82
Contrast Linear (CRN only)			0.23	0.33	0.80	0.08	0.07	0.31	0.30	0.33	0.34	0.83

[z] WITHIN COLUMNS, MEANS FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST AT 5%.

Higher CRN rate of 170 lb/acre or 200 lb/acre of total N resulted in plant mortality of 54% for Polyon and 29% for Multicote probably due to higher NH4-N soil concentration in the center of the bed of 91 and 75 ppm, respectively, as compared of 8 ppm NH4-N where the soluble N grower rate of 266 lb/acre 35 DAP was applied (Figure 1).

Trial 4. Soluble fertilizer application 200 (IFAS), 266 (Grower) lb/acre, CRN (Multicote) at 50 and 100 lb/acre N rate or 150 and 200 lb/acre of total N, respectively, resulted in higher total first harvest than CRN (Multicote) at 150 lb/acre N rate or 250 lb/acre of total N [Table 6 ($P \leq 0.10$)].

Soluble fertilizer application 200 (IFAS) and CRN (Multicote) at 100 or 200 lb/acre N rate resulted in higher total first and second harvest (all sizes combined) than CRN (Multicote) at 150 lb/acre N rate or 250 lb/acre of total N (Table 6; $P \leq 0.10$). There was no response to N treatment by other tomato size categories in any harvest. Total first harvest (all sizes combined) and total first and second harvest (all sizes combined) tended to increase linearly as CRN (Multicote) rate increased from 50 to 150 lb/acre of N or 150 to 250 lb/acre of total N ($P \leq 0.10$). There was no response to CRN treatment by other tomato size categories in any harvest. Combination of 50 or 100 lb/acre of CRN (Multicote) and 100 lb/acre of soluble N fertilizer can produced similar results than 100% soluble N fertilizer during winter season.

SUMMARY:

a. When different CRN sources were tested as a "top mix", their performance was lower than that of the control soluble fertilizer (trial 1) most likely because their placement in the bed reduced the rate of N released into the soil thereby reducing plant growth and yield. CRN products may perform better when placed in the bed and incorporated into the soil so the CRN particles are in close contact with soil and soil moisture.

b. In the Fall of 2006, one CRN source (polymer-coated urea) was thoroughly mixed with the soil during bedding in what is commonly called the "bottom mix" (Trial 2). The CRN (polymer-coated urea) performed well in this placement, with yields greater than or equal to the control or soluble N treatments.

c. Trial 3 illustrated the need for more research regarding the use and placement of polymer-coated urea on mulched crops during the winter in South Florida because of risks associated with ammonium toxicity. In this case, it is possible an extreme cold temperature event, saturated soil conditions resulting from the use of surface water as freeze protection, and the reduction of microbe activity in converting NH4-N due to fumigation (methyl bromide/chloropicrin) all worked to increase the risk of plant NH4-N toxicity. In our trial, two CRN products at 120 lb/acre (150 lb/acre of total N) resulted in lower yield in major tomato categories compared with soluble N probably due to lower than optimal N rate and high NH4-N soil content (32 ppm at the center of the bed). Higher CRN rates of 170 lb/acre or 200 lb/acre total N of the same two products resulted in plant mortality of 29% and 54%, probably due to higher NH4-N soil concentration in the center of the bed of 91 and 75 ppm, respectively. This further indicates optimum performance of urea-based CRN fertilizers in Fall and Winter tomatoes in South Florida appears to depend on avoiding fertilizer placement and other cultural practices which lead to temperature extremes or water saturation. Optimal soil temperatures with a minimum of 50°F and maximum of 94°F are suitable for the conversion of NH4-N to NO3-N (a process called nitrification; Sabey et al., 1956), therefore, extreme temperatures can lead to an accumulation

of excessive and damaging NH4-N in the soil, especially when used under VIF-type film. Utilizing other CRN sources, such as polymer coated potassium nitrate, may lead to better results.

d. CRN as polymer-coated potassium nitrate (trial 4) can be a more suitable source of N for tomato production during the winter in South Florida to minimize the risk of high soil NH4-N. Also, the combination of 50 or 100 lb/acre of CRN as (polymer-coated potassium nitrate) broadcast in the bed and 100 lb/acre of soluble N fertilizer as 'hot mix' pre-plant produced comparable yields in the major tomato categories (total first harvest, total first and second harvest combined, and total harvest (all sized and harvest combined). Based on these results, the use of polymer-coated potassium nitrate needs to be investigated in multiple winters and other seasons. ✻

REFERENCES

Csizinszky A. A. 1994.Yield response of bell pepper and tomato to controlled release fertilizer on sand. J. Plant Nutr.9:1535-1549.

Csizinszky, A. A., C. D. Stasley, and G. A. Clark. 1993. Evaluation of controlled-release urea for fresh-market tomato. Proc. Fla. State Hort. Soc. 106:183-187.

Csizinszky, A. A., G. A. Clark and C. D. Stasley. 1992. Evaluation of methylene urea for fresh-market tomato, with seepage irrigation. Proc. Fla. State Hort. Soc. 105:370-372.

Csizinszky, A. A. 1989. Effect of controlled (slow) release nitrogen sources on tomato, Lycopersicon esculentum Mill. cv. 'Solar Set'. Proc. Fla. State Hort. Soc. 102:348-351.

Du, C., J. Zhou, and A. Shaviv. 2006. Release characteristic of nutrients from polymer-coated compound controlled release fertilizers. J. Polym. Environ. 14:223-230.

FDACS. 2005. Florida Vegetable and Agronomic Crop Water Quality and Quantity BMP Manual. Florida Department of Agriculture and Consumer Services http://www.floridaagwaterpolicy.com/PDFs/BMPs/vegetable&agronomicCrops.pdf.

Hutchinson, C., E. Simonne, P. Solano, J. Meldrum, and P. Linvingston-Way. 2003. Testing of controlled release fertilizers programs for seep irrigated Irish potato production. J. Plant Nutr. 26:1709-1723.

Hutchinson, C. M. and E.H. Simonne. 2003. Controlled-release fertilizer opportunities and cost for potato production in Florida, EDIS HS-941, http://edis.ifas.ufl.edu/HS187.

Locascio, S.J. and J.G. Fiskell. 1979. Pepper response to sulfur-coated urea, mulch and nitrogen rate. Proc. Fla. State Hort. Soc. 92:112-115.

Morgan, K., K. Cushman, and S. Sato. 2009. Release mechanisms for slow- and controlled- release fertilizer and strategies for their use in vegetable production. J. Hort. Technology 19(1):10-12.

Olson, S.M., E.H. Simonne, W.M. Stall, K.L. Pernezny, S.E. Webb, T.G. Taylor, S.A. Smith, and D.M. Parmenter. 2006a. Pepper production in Florida, pp. 331-343 In: S.M. Olson and E. Simonne (Eds.) 2006-2007 Vegetable Production Handbook for Florida, Vance Pub., Lenexa, KS.

Olson, S.M., W. M. Stall, M.T. Momol, S.E. Webb, T.G. Taylor, S. A. Smith, E. H. Simonne, and E. McAvoy. 2006b. Tomato production in Florida, pp. 407-426 In: S.M. Olson and E. Simonne (Eds.) 2006-2007 Vegetable Production Handbook for Florida, Vance Pub., Lenexa, KS.

Sato, S, K. T. Morgan, M. Ozores-Hampton, and E.H. Simonne. 2009a. Spatial distributions in sandy soils with seepage irrigation: Nitrogen. Soil Sci. Soc. Am. J. 73(3):1044-1052.

Sato, S., K.T. Morgan, M. Ozores-Hampton, and E.H. Simonne. 2009b. Spatial distributions in sandy soils with seepage irrigation: Phosphorus and potassium. Soil Sci. Soc. Am. J. 73(3):1053-1060.

Simonne, E.H. and C.M. Hutchinson. 2005. Controlled release fertilizer for vegetable crops: Teaching new tricks to an old dog. HortTechnology 15(1):14-24.

USDA. 1997. United States standards for grades of fresh tomatoes. Agr. Markt. Serv. http://www.ams.usda.gov/standards/tomatfrh.pdf.

Savey B. R., W. V. Bartholomew, R. Shaw and J. Pseek. 1956. Influence of temperature on nitrification in soils. Soil Sci. Soc. Am. J. 20(3)357-360.

Shaviv, A. 2000. Advances in controlled release fertilizers. Adv.Agron. 71: 1-49.

SULFUR FERTILIZATION IN TOMATO PRODUCTION

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BACKGROUND

Sulfur (S) is an essential plant nutrient for crops and it is required for the synthesis of the amino acids cysteine and methionine, which are building blocks of certain plant proteins and enzymes. In the past, S was supplied indirectly in two ways: a) through the application of fertilizers, such as triple superphosphate; and b) through atmospheric deposition from acid rain resulting from fossil fuel burning. However, this situation has changed during the last two decades. Granular and liquid fertilizers no longer contain high amounts of sulfates, and stringent federal and state environmental regulations have reduced the incidence of acid rain. Therefore, S deficiencies are more likely to occur today.

Typical S deficiencies are often confused with those of other deficient elements, such as nitrogen (N), and they show as generalized leaf yellowing or light green foliage with weak plants. These symptoms frequently confound the ability of growers, researchers and Extension personnel to diagnose correctly S deficiencies. This element occurs in the soil in both organic and inorganic forms, but in most soils, the majority of S is in diverse organic forms. Most plants absorb S through the roots as the inorganic sulfate (SO4) form, although limited amounts can be absorbed through the leaf stomata as the gas SO2.

Tomato production in Florida mostly occurs on deep Spodosols (fine sand) with low organic matter (<2%) content. These soils have low capacity for S retention and thus S leaching is likely to occur before root absorption takes place. Preliminary field observations indicated that several crops, including tomato, bell pepper and strawberry could respond to S fertilization, increasing plant vigor and marketable yields. But more research is needed on the subject. Hence, a four-year project was initiated in 2005 at the Gulf Coast Research and Education Center in Wimauma Florida, to: a) determine the tomato response to S fertilization, b) revaluate its sufficiency range, c) reformulate application rates, d)

examine the effect of S-containing irrigation water on the total S contribution for tomato, and e) determine a valid analytical test to determine S availability in soils.

PAST AND CURRENT RESEARCH

Effects of S source on tomato. This first study was conducted twice between 2006 and 2007 and examined the impact of several S-containing fertilizer sources on tomato yields and leaf S concentrations. Fertilizer-source treatments were: a) ammonium nitrate (AN; 34% N) at a rate of 300 lb/acre of N; b) AN + potassium sulfate (PS; 23% S and 55% K) at rates of 300 + 343 lb/acre of N and S; c) ammonium sulfate nitrate (ASN; 26% N and 14% S) at a rate of 300 + 343 lb/acre of N and S; and d) a non-treated control. Muriate of potash (KCl, 60% K) was used to balance total K amounts in each treatment to ensure that this nutrient was non-limiting. Fertilizers were applied 21 days before transplanting on two, 3-inch-deep, 14-inches-apart bands on bed tops. Planting beds were 32 inches wide at the base, 28 inches wide at the top, 8-inch high, and 5-ft apart. Finished beds were fumigated with methyl bromide plus chloropicrin (67:33 v/v) at a rate of 175 lb/acre to eliminate soilborne diseases, nematodes, and weeds. Beds were covered with 0.6-mil-thick silver-on-black polyethylene mulch, and drip irrigation tubing was buried 1 inch deep in the bed center. 'Florida 47' tomato transplants were established 2-ft apart on single rows on the center of each bed. Irrigation was supplied via subsurface irrigation at an approximate rate of 8,000 gal/acre/day, and the soil was maintained at field capacity. The water table was maintained between 18 and 24 inches deep and constantly monitored with observations wells located in the fields. Plant nutrients, other than N and S, were supplied under non-limiting conditions. The four treatments were arranged in a randomized complete block design with four replications. Experimental units were 30-ft long with a 10-ft long non-treated buffer zone at the end of each plot. Recently mature leaves were collected from each plot 12 weeks after transplanting (WAT) to determine foliar S concentration. Tomato fruits were harvested twice (10 and 12 WAT) and graded as marketable or non-marketable. Data were analyzed with General Linear Model procedure of SAS to determine treatments effects (P=0.05) and treatment means were separated with single degree-of-freedom orthogonal contrasts.

TABLE 1. Effects of sulfur (S) fertilizer sources on tomato foliar S concentrations and marketable yields[z].

Fertilizer sources	N rates	S rates	Foliar S concentrations	Marketable yields
	(lb/acre)		(%)	(ton/acre)
Control	0	0	0.53 b	12.4 c
AN	300	0	0.55 b	18.7 b
AN + PS	300	343	0.79 a	28.2 a
ASN	300	343	0.72 a	27.5 a

[z] *MEANS FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT AT THE 5% LEVEL.

FIGURE 1. Effect of preplant sulfur (S) application rates on the foliar S concentration in mature tomato leaves at 5 weeks after transplanting.

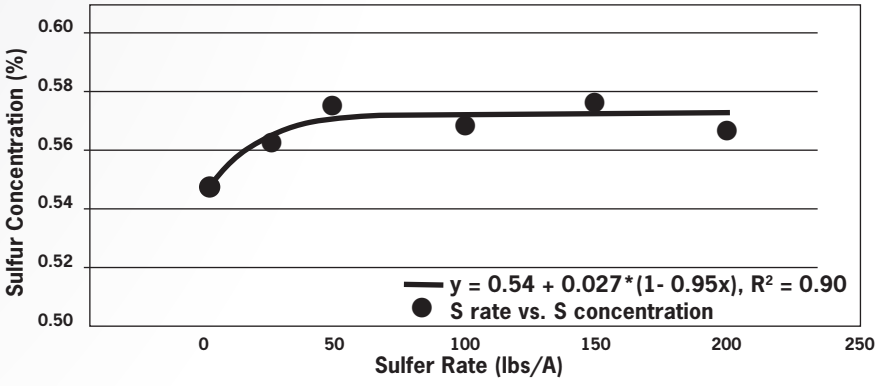
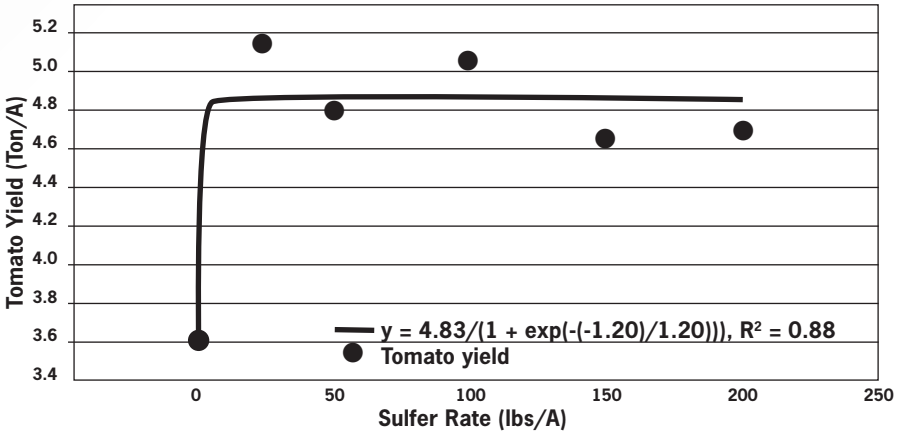


FIGURE 2. Effects of preplant sulfur (S) application rates on the early tomato yields at 10 weeks after transplanting.



Fertilizer treatments affected tomato foliar S concentration and marketable fruit weight. Plots treated with either rate of AN or non-treated had the lowest foliar S concentration, ranging between 0.55% and 0.53% (Table 1). However, plots treated with S-containing fertilizers caused significant foliar S concentration increases when compared with the non-treated control and AN-treated plots. Average S concentration was about 0.74%, which was 40% higher than the concentration in non-treated control plots. There were no significant differences on foliar S concentration between AN + PS and ASN when compared within the same rates (Table 1). Therefore, adding S to the fertilization programs, regardless of S sources, increased S concentration.

Marketable fruit weight followed a similar pattern as that for S concentration in the tomato leaves (Table 1). There were no significant marketable yield differences in plots treated with either AN + PS or ASN, suggesting that different S sources caused no different response on tomato production. Average marketable yield ranged between 27.5 and 28.2 ton/acre in the S-treated plots. In contrast, average yield in the AN-treated plots was 18.7 ton/acre, which was 44% and 42% less than the yields in the AN + PS and ASN-treated plots. The AN-treated plots had higher yields than the non-treated control, which

can be attributed to the increased N rates.

It has been indicated that the sufficiency S range for tomato is between 0.3% and 0.8% on a dry weight basis, which appears to be excessively wide for specific S recommendations in tomato. In this case, there was a positive tomato yield response as concentration increased from about 0.53% in the non-treated control to 0.7% in the S-treated plots, demonstrating that application of S in tomato fertilization programs is essential to increase marketable yields.

Influence of S rates on Tomato. This second study was conducted twice between 2008 and 2009 to determine the appropriate preplant S rate needed to increase tomato yields. Similar cultural practices were used as previously described. Elemental S (90% S) was used as the preplant fertilizer source and it was applied on bed tops between 15 days before transplanting as described for the previous study. Application rates were 0, 25, 50, 100, 150, and 200 lb/acre of S. Other plant nutrients were supplied under non-limiting conditions. Foliar S concentration was measured between 4 and 5 WAT using recently mature leaves. Tomato fruits were harvested on 10 and 12 WAT and graded as marketable or non-marketable. Data were analyzed using regression analysis.

There was a significant effect of S rates on foliar S concentrations and early yields, but not on total yields (data not shown). Foliar S concentration increased sharply from 0 to 50 lb/acre of S, with no significant changes afterwards (Fig. 1). Early total yields increased with the application of 25 lb/acre of S, with no significant early yield response between 25 and 200 lb/acre of S (Fig. 2). These results indicated that there is a significant response of tomato to preplant S fertilization, regardless of the S source utilized. Growers seeking to include S into their current fertilization programs might need to explore using between 25 and 50 lb/acre of S, depending on the preplant application procedure and considering either in-bed or broadcast rates of this nutrient. More research is needed to validate these results in large-scale plots in grower fields. ✻

THE EFFECT OF TYLCV ON TOMATO YIELD DEPENDS UPON AGE OF THE PLANT AT TIME OF INOCULATION

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INTRODUCTION

Tomato Yellow Leaf Curl Virus (TYLCV) is currently one of the most devastating viruses of cultivated tomatoes in tropical and subtropical regions. Although originally found in the eastern Mediterranean (Cohen and Harpaz, 1964), it is now a worldwide problem in tomato cultivation (Polston and Anderson, 1997; Moriones and Navas-Castillo, 2000). The virus is a monopartite begomovirus, transmitted by the whitefly *Bemisia tabaci* (Gennadius) whose severe population outbreaks are usually associated with high incidence of the disease. Control measures in infected regions are traditionally based on limiting vector populations. Chemical control has been only partially effective, especially under high disease pressure, and in addition to its deleterious effects on the environment, the vector has been shown to develop pesticide resistance. The use of physical barriers such as fine-mesh screens and UV-absorbing plastic sheets and screens has become widespread in the Mediterranean basin as a means of crop protection (Antignus et al. 2001). However, these screens also result in overheating and poor ventilation. Genetic resistance in the host plant is the best defence against whitefly-transmitted viruses, since it requires no chemical input and/or plant seclusion and may be stable and long-lasting. Thus, the best way to reduce the spread of TYLCV is by breeding tomatoes that are resistant or tolerant to the virus (Lapidot and Friedmann, 2002).

Over the last 25 years, extensive effort has been invested in breeding tomato cultivars resistant to TYLCV. Since all cultivars of tomato (*Lycopersicon esculentum*) are extremely susceptible to TYLCV, wild *Lycopersicon* species were screened for their response to the virus to identify genes for resistance. Breeding programs have been based on the transfer of resistance genes from accessions of wild origin into the cultivated tomato. However, progress in breeding for TYLCV resistance has been slow, due in part to the complex genetics of the resistance and the presence of interspecific barriers between the wild and domesticated tomato species (Lapidot and Friedmann, 2002).

Another setback in the development of TYLCV resistance is that while most screening assays rely on severity of TYLCV-induced disease symptoms, the most relevant evaluation of resistance level is TYLCV-induced yield reduction (Lapidot et al. 1997, 2006). Thus it is recommended that in addition to monitoring symptoms, the effect of infection on total yield and yield components be tested and compared to that in equivalent, non-infected plants. Usually, tests comparing different varieties are carried out under field inoculation, and no comparison is made to the full yield potential of uninfected plants, which has a direct bearing on the yields of the infected plants. Nevertheless, such expensive and time-consuming tests can only be carried out on the most promising resistant varieties, and not on segregating populations.

Another obstacle in the development of TYLCV resistance has been the lack of a standard method for the assessment of

resistance. Variability in assay conditions has led to contradictory results, where different resistance levels have been attributed to the same genetic sources (Pico et al., 1998; Vidavsky et al., 1998). The response of a plant to infection by a pathogen may be affected by test conditions such as temperature, light, growth conditions, inoculation pressure and plant age (or developmental stage) at the time of infection. This latter phenomenon has been referred to as age-related or mature-plant resistance (Loebenstein, 1972). In some instances, it has been shown that mature plants resist or tolerate virus infection much better than plants infected at an early stage of development, leading to what appears to be increased viral resistance (Garcia-Ruiz and Murphy, 2001; Moriones et al. 1998).

In this study, we tested for the possible effects of plant age on the expression of genetic resistance to TYLCV. Tomato plants expressing different levels of resistance to TYLCV were inoculated at three different ages—14, 28 and 45 days after sowing (DAS). Resistance was assayed mainly by comparing yield components of inoculated plants to those of control, non-inoculated plants of the same line or variety.

MATERIALS AND METHODS

Virus and whitefly maintenance. Culture of the Israeli isolate of TYLCV (GenBank Acc. No. X15656) were maintained in tomato (*Lycopersicon esculentum* L.) in an insect-proof greenhouse. Whitefly (*Bemisia tabaci*, biotype B) colonies were reared on cotton (*Gossypium hirsutum* L.) plants grown in muslin-covered cages maintained inside an insect-proof greenhouse.

Plant material. Lines: A TYLCV-susceptible 'Marmande' type tomato line, Rehovot-13 (R-13; Hazera Genetics Ltd., Brurim, Israel), and a highly TYLCV-resistant tomato line, TY-199 (Volcani Center), were used.

F1 hybrids. The TYLCV-susceptible tomato, 144, and TYLCV-resistant tomatoes—3193, 3205 and 3209 (Hazera Genetics Ltd.), Tyjoco (Sluis & Groot/Syngenta, Enkhuizen, The Netherlands) and Anastasia (Bruinsma Seeds, Enkhuizen, The Netherlands), were used.

Test plants were sown in 128-cell Todd Planter Flats (also known as "speedling" trays) and kept in the trays for 30 days until transplanted to the field.

TYLCV inoculation. Adult whiteflies were provided a 48-h acquisition access period (AAP) on TYLCV-infected tomato source plants. Following the AAP, whiteflies were allowed a 24-h inoculation access period (IAP) on tomato test plants. Tomato plants inoculated at 14 and 28 DAS were inoculated in the greenhouse, whereas plants inoculated at 45 DAS were inoculated in the field.

Greenhouse inoculation. To ensure 100% infection, inoculation was performed at a density of about 50 whiteflies per plant. The different tomato varieties were inoculated at 14 or 28 DAS. Control, non-inoculated plants of the same varieties were exposed to virus-free whiteflies for 24 h. Following the IAP, whiteflies were removed by treating plants with imidacloprid (Confidor, Bayer, Leverkusen, Germany). The plants were maintained in an insect-proof greenhouse at 26-32°C prior to transplant to the field at 30 DAS.

Inoculation in the field. Adult whiteflies were provided a 48-h AAP on TYLCV-infected tomato source plants, after which the source plants containing the whiteflies were moved into sealed buckets. In the field, the target plants for inoculation were covered with non-woven polypropylene (Agril) sheets (Sodoca, Biesheim, France) mounted on a wooden frame. The buckets were taken to the field, positioned under the Agril sheets and then opened to release the whiteflies. The whiteflies were allowed a 24-h IAP on the test tomato plants followed by application of imidacloprid. The Agril sheets were removed 24 h after imidacloprid application.

TYLCV symptom-severity rating. Symptom development was evaluated according to the symptom-severity scale described by Friedmann et al. (1998): 0 = no visible symptoms, inoculated plants show same growth and development as non-inoculated plants; 1 = very slight yellowing of leaflet margins on apical leaf; 2 = some yellowing and minor curling of leaflet ends; 3 = a wide range of leaf yellowing, curling and cupping, with some reduction in size, but plants continue to develop; 4 = very severe plant stunting and yellowing, pronounced leaf cupping and curling, and plant growth stops. Symptom severity was evaluated in the field, 5 weeks after transplanting. Plant height was measured a month later.

Field trial. Following controlled inoculation in the greenhouse, plants were treated with imidacloprid before establishement in the field in April, and grown through the spring and summer seasons. Plants of each variety were planted in paired rows—inoculated and non-inoculated (control), on 1-m wide beds, five plants per row. The within-row and between-row spacing were 0.5 and 1.2 m, respectively. Each pair of rows served as a replicate for the experiment, and a total of 10 randomly distributed replicates were planted in the field. Imidacloprid was applied through the drip-irrigation system on 4 and 8 weeks after transplanting. Fruits were picked three times: in the first and second harvests, only mature-red fruits were collected; in the third harvest, all mature-red and immature green fruits were collected. Culls were discarded. The following parameters were assayed: total yield, total number of fruits and average fruit weight. Data were taken per row and were averaged for all rows.

RESULTS

Effect of age on TYLCV-induced yield reduction. To test the effect of plant age on genetic resistance to TYLCV, plants were inoculated at 14, 28 or 45 days after sowing (DAS). At 14 and 28 DAS the plants were inoculated in the greenhouse, and at 30 DAS the plants were transplanted in the field. Inoculation at 45 DAS was done in the field, following transplanting. The highest level of resistance, as reflected by the lowest yield reduction induced by TYLCV, was expressed by the resistant line TY-199 (Table 1). Following inoculation at 14 DAS (the first true leaf stage), TY-199 plants showed no disease symptoms, but nonetheless produced only 45.5% of the yield of the non-inoculated control plants. TY-199 was followed by the F1 hybrid 3205 which produced 42% of the yield of its non-inoculated control. The resistant F1 hybrids 3193, 3209 and 'Anastasia' expressed practically the same level of resistance, which was much lower than that expressed by TY-199 and 3205, producing 27.4%, 26.4% and 25.4%, respectively, of the yield of their non-inoculated counterparts. Of all the resistant varieties tested, 'Tyjoco' showed the lowest level of resistance following inoculation, producing only 18% of the yield of its non-inoculated control (Table 1). However, all the resistant varieties performed much better than the two susceptible controls, R-13 and 144, both of which barely produced any fruit following inoculation (0.0% and 2.6%, respectively, compared to the yield of their non-inoculated counterparts). The TYLCV-

TABLE 1. The effect of plant age at time of inoculation with Tomato Yellow Leaf Curl virus on yield components of selected tomato cultivars.

Cultivar	Plant age at inoculation (DAS)[z]	Symptom severity score[y]	Plant height (cm)[x]	Yield (kg/plant)	Fruit weight (g/fruit)
R-13	Non-inoculated	0.0	131.0 a	4.2 a	128.5 a
	14	4.0	47.8 b	0.0 b	86.3 b
	28	4.0	73.5 c	0.1 c	70.3 c
	45	4.0	75.6 c	0.9 d	85.4 c
144	Non-inoculated	0.0	150.0 a	6.7 a	94.7 a
	14	4.0	52.5 b	0.2 b	52.2 b
	28	4.0	85.5 c	0.6 c	60.0 b
	45	4.0	92.7 c	1.4 d	68.2 c
TY-199	Non-inoculated	0.0	164.4 a	4.4 a	80.1 a
	14	0.1	144.5 b	2.0 b	77.6 a
	28	0.1	160.0 a	3.1 c	74.8 a
	45	0.0	157.8 a	4.0 a	76.7 a
3205	Non-inoculated	0.0	159.4 a	6.7 a	65.6 a
	14	0.7	128.6 b	2.8 b	60.0 a
	28	0.3	149.4 c	4.3 c	62.0 a
	45	0.0	153.8 a,b	5.5 d	61.7 a
3193	Non-inoculated	0.0	161.9 a	6.2 a	106.0 a
	14	1.1	121.9 b	1.7 b	96.7 a
	28	1.0	145.0 c	3.4 c	103.8 a
	45	0.4	142.5 c	4.4 d	98.4 a
3209	Non-inoculated	0.0	157.5 a	7.2 a	155.9 a
	14	1.3	131.3 b	1.9 b	120.2 b
	28	1.3	146.3 a,b	3.3 c	118.1 b
	45	0.3	151.3 a	5.5 d	146.2 a
Tyjoco	Non-inoculated	0.0	154.4 a	6.1 a	95.8 a
	14	2.3	113.8 b	1.1 b	62.7 b
	28	1.9	131.1 c	2.7 c	75.5 c
	45	1.4	142.9 d	3.9 d	74.3 c
Anastasia	Non-inoculated	0.0	161.9 a	5.9 a	103.6 a
	14	2.4	111.3 b	1.5 b	88.9 b
	28	2.2	127.5 c	2.3 c	91.4 b
	45	1.9	140.0 d	3.5 d	89.3 b

[z]DAS = days after sowing; [y]Symptom severity was evaluated in the field, 5 weeks after transplanting; [x]Plant height was measured a month later.
Means with different letters differ significantly at $P < 0.05$ when analyzed by one-way ANOVA.

induced yield reduction was mainly due to the strong reduction in the number of fruits per plant, although in the case of the susceptible varieties, there was also a strong reduction in fruit size—ranging from 57% of the size of the control fruits for 144 to 66.5% of the size of the control fruits for R-13. Only two of the resistant varieties, 'Tyjoco' and 3209, suffered a significant reduction in fruit size following inoculation: 'Tyjoco' fruit size was 69% of that of its non-inoculated controls, and 3209 fruit size was 77% of that of its non-inoculated controls. The other resistant varieties suffered minor reductions in fruit size due to TYLCV inoculation, ranging from 'Anastasia' which lost only 14% of its fruit size to TY-199, 3205 and 3193, which showed no significant reduction in fruit size at all (Table 1).

Disease-severity score was in essence correlated to yield reduction: the higher the score, the higher the yield reduction. Both susceptible varieties had the highest disease severity score of 4, followed by 'Anastasia' and 'Tyjoco' (2.4 and 2.3, respectively), 3209 and 3193 (1.3 and 1.1, respectively), and finally 3205 with 0.7 and TY-199 which showed practically no disease symptoms (Table 1).

Plant heights of the susceptible plants were the most affected, both showing a severe reduction in plant height due to the virus (only 35% to 36% of the height of their control counterparts). The most affected resistant variety was 'Anastasia', which reached 68% of the height of its control, while the height of the other resistant varieties ranged from 74% for 'Tyjoco' to 96% (not statistically significant) for 3209, 3205 and TY-199 (Table 1).

When the different varieties (resistant and susceptible) were inoculated with TYLCV at 28 DAS, all produced higher yields compared to inoculation at 14 DAS. The yield increase (or actually smaller TYLCV-induced yield reduction) was substantial, ranging from 50% for TY-199 and 3205, to 100% or more for 3193 and 'Tyjoco' (Table 1). In all cases, the plants that were inoculated later were also taller. However, regardless of the large increase in yield, the symptom-severity score barely changed between plants inoculated at 14 DAS and those inoculated 2 weeks later (Table 1). A further substantial decrease in TYLCV-induced yield reduction (a yield increase) was achieved by all the tested varieties (resistant and susceptible alike) following inoculation at 45 DAS. The yield increase for the variety expressing the highest level of TYLCV resistance, TY-199, was from 2 kg/plant following inoculation at 14 DAS, 3.1 kg/plant following inoculation at 28 DAS, to 4 kg/plant following inoculation at 45 DAS (Table 1). For varieties expressing a lower level of TYLCV resistance, the yield increase was even greater: 'Tyjoco' yield, which was 1.1 kg/plant following inoculation at 14 DAS, more than doubled to 2.7 kg/plant following inoculation at 28 DAS, and reached 3.9 kg/plant following inoculation at 45 DAS (Table 1). The susceptible varieties showed a more marked increase in yield due to the effect of plant age at time of infection. R-13, which produced 0.01 kg/plant following inoculation at 14 DAS, reached 0.9 kg/plant following inoculation at 45 DAS—quite a substantial increase. The same was true for 144—its yield increased from 0.2 kg/plant following inoculation at 14 DAS to 1.4 kg/plant following inoculation at 45 DAS (Table 1).

DISCUSSION

In the present work, we examined whether plant age at time of inoculation has any effect on the expression of genetic resistance to TYLCV. Tomato plants were inoculated at three different ages—14, 28 and 45 DAS. We chose to inoculate at 14

DAS since this is the first true leaf stage—in practice, the earliest stage for efficient inoculation of TYLCV. Inoculation at 28 DAS was selected to represent inoculation just prior to transplant to the field—transplanting tomato plants 30 DAS is a common agricultural practice. Inoculation at 45 DAS was selected to represent inoculation of plants following transplant to the field, but not too long after transplant, since in many whitefly-stricken areas, the plants are infected shortly after exposure to open-field conditions. At the two earlier dates (14 and 28 DAS), inoculation was performed in the greenhouse, while at the later date of 45 DAS, the plants were inoculated in the field.

Six different TYLCV-resistant tomato varieties, as well as two susceptible varieties, were tested. Plant age at time of inoculation had no effect on the disease-severity score of the susceptible varieties, and a very small effect (if any) on the disease-severity score of the resistant varieties. In contrast, plant age at time of inoculation had a significant effect on the total yield of all of the varieties tested, susceptible and resistant alike. However, it should be noted that although inoculation of older susceptible plants did result in increased yield, the yield of the TYLCV-infected susceptible plants was very low for all of the ages tested.

The different resistant and susceptible tomato varieties were tested for TYLCV-induced yield reduction, which is the ultimate test for viral (or any other pathogen) resistance. The yield of each infected entry was compared with that of its control, uninfected counterpart. All tested varieties suffered a significant yield reduction due to inoculation with TYLCV, at all three tested ages. The lowest yield was produced by plants inoculated at 14 DAS. The susceptible varieties produced practically no yield following inoculation at 14 DAS, whereas the yield produced by the resistant varieties varied according to their resistance level, ranging between 18% and 45% of the yield of their non-inoculated counterparts. A smaller TYLCV-yield reduction—a substantial yield increase of between 50% and 100%, depending on the resistance level displayed by the tomato variety, was achieved following inoculation at 28 DAS. A further decrease in TYLCV-induced yield reduction (yield increase of 30% to 40%) was achieved following inoculation at 45 DAS. Moreover, the yield produced by TYLCV-resistant tomato plants inoculated at 45 DAS was from 100% to 300% higher than that produced by plants inoculated at 14 DAS (Table 1).

Like total yield, the number of fruits produced by the inoculated plants increased markedly following inoculation at later age. Plant height was also affected by plant age at time of inoculation—all tested varieties that were inoculated at 28 DAS were taller than their counterparts inoculated at 14 DAS. This was not necessarily the case for plants inoculated at 45 DAS—four varieties reached the same height, while two varieties showed increases in this parameter. Interestingly, the two varieties showing a statistically significant effect of inoculation at 45 DAS on plant height were those showing the lowest level of TYLCV resistance (Table 1).

In conclusion, the results from this study clearly demonstrate the occurrence of mature-plant resistance in tomato plants that are susceptible and resistant to TYLCV. However, while plant age at time of inoculation had a strong effect on yield, it barely affected the disease-severity score. This may indicate that older plants are not necessarily more resistant per se to TYLCV than younger plants, but are merely able to dampen down the devastating effect of the virus since they are in an advanced developmental stage, or are simply stronger than the younger plants.

These results raise another question—when is the "correct" or best time to inoculate tomato plants when screening for TYLCV resistance? This may depend on the genetic material being screened: if segregating populations are being screened for individual resistant plants, then it is best to inoculate at the earliest possible stage, when the effect of the viral infection is most severe. This way the selected plants will indeed be those showing the highest level of TYLCV resistance. If, on the other hand, commercial varieties are being tested for level of resistance, then inoculation at 28 DAS may be most suitable as it represents inoculation just prior to transplanting to the field. Since most commercial tomato plants are sown in specialized and protected nurseries, from an agricultural point of view, 28 DAS may be the most relevant stage for testing commercial hybrids. ✻

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REFERENCES

Antignus Y, Nestel D, Cohen S, Lapidot M (2001) Ultraviolet-deficient greenhouse environment affects whitefly attraction and flight-behavior. Environ. Entomol. 30:394-399.

Cohen S, Harpaz I (1964) Periodic rather than continual acquisition of a new tomato virus by its vector, the tobacco whitefly (Bemisia tabaci Gennadius). Entomol. Exp. and Appl. 7:155-166.

Friedmann M, Lapidot M, Cohen S, Pilowsky M (1998) A novel source of resistance to tomato yellow leaf curl virus exhibiting a symptomless reaction to viral infection. J. Am. Soc. Hortic. Sci. 123:1004-1007.

Garcia-Ruiz H, Murphy JF (2001) Age-related resistance in bell pepper to Cucumber mosaic virus. Ann. Appl. Biol. 139:307-317.

Lapidot M, Ben Joseph R, Cohen L, Machbash Z, Levy D (2006) Development of a scale for evaluation of Tomato yellow leaf curl virus-resistance level in tomato plants. Phytopathology 96:1404-1408.

Lapidot M, Friedmann M (2002) Breeding for resistance to whitefly-transmitted geminiviruses. Ann. Appl. Biol. 140:109-127.

Lapidot M, Friedmann M, Lachman O, Yehezkel A, Nahon S, Cohen S, Pilowsky M (1997) Comparison of resistance level to tomato yellow leaf curl virus among commercial cultivars and breeding lines. Plant Dis. 81:1425-1428.

Loebenstein G (1972) Localization and induced resistance in virus-infected plants. Ann. Rev. Phytopathol. 10:177-206.

Moriones E, Aramburu J, Riudavets J, Arno J, Lavina A (1998) Effect of plant age at time of infection by tomato spotted wilt tospovirus on the yield of field-grown tomato. Eur. J Plant Pathol. 104:295-300.
Moriones E, Navas-Castillo J (2000) Tomato yellow leaf curl virus, an emerging virus complex causing epidemics worldwide. Virus Res. 71:123-134.

Pico B, Diez M, Nuez F (1998) Evaluation of whitefly-mediated inoculation techniques to screen Lycopersicon esculentum and wild relatives for resistance to Tomato yellow leaf curl virus. Euphytica 101:259-271.

Polston JE, Anderson PK (1997) The emergence of whitefly-transmitted geminiviruses in tomato in the western hemisphere. Plant Dis. 81:1358-1369.

Vidavsky F, Leviatov S, Milo J, Rabinowitch HD, Kedar N, Czosnek H (1998) Response of tolerant breeding lines of tomato, Lycopersicon esculentum, originating from three different sources (L. peruvianum, L. pimpinellifolium and L. chilense) to early controlled inoculation by tomato yellow leaf curl virus (TYLCV). Plant Breeding 117:165-169.

PROGRESS IN MAKING TYLCV AND BACTERIAL SPOT RESISTANCE BREEDING MORE EFFICIENT AND THE LATEST VARIETY OUTLOOK

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Of the many tomato (*Solanum lycopersicum* L.) breeding projects being covered by the University of Florida, three of the major priorities are to develop varieties with resistance to Tomato Yellow Leaf Curl Virus (TYLCV), tolerance to bacterial spot, and improved fruit flavor and color. These projects will be the major focus of this presentation.

TOMATO YELLOW LEAF CURL VIRUS RESISTANCE

The TYLCV resistance project started in 1990 and resistance genes have been introgressed into tomato from the wild tomato species *S. chilense*. Several breeding lines have been released in the last few years to provide seed companies with germplasm for their TYLCV resistance breeding programs. With this material, a line has to have two resistance genes to attain a high level of resistance to TYLCV and to other begomoviruses. It has been difficult to attain lines with the horticultural type desired because some undesirable traits are linked to the resistance genes (linkage drag). Also, it is more difficult to incorporate more than one resistance gene than a single gene. Multiple disease resistant varieties have resistance from single dominant genes. Present TYLCV resistant varieties such as 'Tygress,' 'SecuriTY 28', and newer ones have resistance conferred by a dominant gene Ty-1 or Ty-2. So far, these genes have been effective in Florida but the virus has overcome these resistances in some areas of the world. If Ty-1 resistant varieties were widely deployed in Florida it is possible that virulent virus strains would emerge that would render these varieties susceptible. Thus, development of improved germplasm with other genes is necessary to provide long term, durable resistance. These genes can be used alone or in combination with existing genes such as Ty-1 or Ty-2.

To facilitate the incorporation of our resistance genes we have been working intensively with molecular markers since 1996. If molecular markers tightly linked to resistance genes can be identified, resistance can be incorporated by marker assisted selection (MAS). MAS would accelerate the breeding process four-fold: without markers we can make one backcross every two years utilizing disease inoculation and selection for resistance in the field; with MAS, one can make four crosses in two years without growing any plants in the field. Developing markers for MAS however has been expensive and time consuming. The good news is that there have been tremendous advancements in marker technology and many things are possible now that were not available in 1996. So far, we have identified two resistance genes in our breeding program. From accessions LA2779 and LA1932, the Ty-3 gene is located on chromosome 6 in a region near the Ty-1 gene (Ji et al., 2007). More recently, from some lines derived from LA1932, the Ty-4 gene is located on chromosome 3 (Ji et al., 2009). We have good markers for both genes and tomato breeders can now use MAS in their breeding programs for Ty-3 and Ty-4. Thus, incorporation of these genes into acceptable tomato varieties for Florida will be greatly facilitated. Beyond this, there are other resistance genes that we have yet to locate; experiments are presently underway to find these genes so they too can be utilized in developing durable resistant varieties. We are also using molecular markers concentrated near the Ty-3 gene to fine map the resistance gene and reduce linkage drag.

BACTERIAL SPOT RESISTANCE

Breeding for bacterial spot tolerance (*Xanthomonas spp.*) has been a priority in the breeding program since 1982 and not a single tolerant variety has yet been released. This has been discouraging for the breeder and tomato growers in Florida who are threatened by this disease which is ubiquitous in Florida. The first breeding problem has been that the pathogen has evolved virulent races even in the absence of tolerant varieties. There are at least four races (T1, T2, T3, and T4) of the pathogen and all but T2 have been prevalent in Florida. Today, it appears that the major race is T4 with T3 still present as well. We need to develop varieties with tolerance to both these races, and the tolerance genes should not be race specific, so as to help prevent the emergence of another virulent race that overcomes the tolerance. Whereas past breeding efforts have not resulted in an acceptable variety, knowledge gained has put us in a position to move forward more expediently. Sam Hutton studied resistance to race T4 utilizing three breeding lines with resistance genes from several accessions including 'Hawaii 7998,' our main sources of resistance to race T1. Other resistance came from PI 114490 and S. pimpinellifolium accessions PI 128216 and PI 126932 (the two latter accessions having resistance to race T3). Resistance from each of the three breeding lines was partial (hence the term tolerance) and multigenically controlled by additive, dominant, and epistatic gene action (Hutton, 2008).

A major effort was also made to find molecular markers linked to the tolerance genes. Markers representing several chromosomal regions were identified as being associated with tolerance. Follow-up experiments were done in fall 2008 to verify these associations of markers with tolerance. From this work, markers on chromosomes 11 and 3 were positively associated with tolerance while markers on chromosomes 12 and 7 were associated with susceptibility. The marker on chromosome 7 was linked to the I-3 gene that confers resistance to fusarium wilt

(*Fusarium oxysporum f.sp. lycopersici*) race 3. This confirms observations that varieties with fusarium wilt race 3 resistance have been more susceptible to bacterial spot than other varieties. We have been backcrossing bacterial spot tolerance into fusarium wilt race 3 resistant breeding lines. In spring 2009, we found one of the lines being developed did have a high level of bacterial spot tolerance and that our markers on chromosomes 3 and 11 were present in this line. From here we can use MAS in future backcrossing and this should greatly facilitate development of fusarium wilt resistant lines with bacterial spot tolerance. These markers will also be used for MAS in other breeding lines. At present, we are not sure how tightly linked our markers are with the tolerance genes, but we will learn more about that as we proceed. It will be necessary to monitor tolerance along with MAS to insure the tolerance is not lost to some degree. If possible, given funding constraints, we hope to develop more markers to identify tolerance genes. Useful molecular markers have been limited in the genetic material we have been working with, but we are part of a national USDA project called SolCap that is developing new markers. This project should prove useful in expanding our marker library, and quite possibly, be of use in verifying the precise location of bacterial spot tolerance genes. In summary, breeding for bacterial spot has been difficult, but we now have better tools for making progress. In the meantime, we have been testing bacterial spot tolerant hybrids and continue to be interested in Fla. 8555 which has performed well in three yield trials so far. Otherwise, some bacterial spot tolerance has been evident within the bacterial wilt (*Ralstonia solanacearum*) resistance program for reasons we do not yet fully understand. An inbred that looks interesting as a parent in initial testing is Fla. 8626. This inbred has huge fruit along with bacterial disease tolerance.

'TASTI-LEE' AND OTHER FLAVOR RESEARCH

Fla. 8153 was released in 2006 as 'Tasti-LeeTM ' (Scott et al., 2008) and seed is now available from Bejo Seeds. For seeds, contact Greg Styers: G.styers@bejoseeds.com, phone 805-689-1627. This variety has been described at previous Tomato Institutes and details will not be given here. This crimson variety boasts about 25% more lycopene than the average tomato variety, providing superior red interior color. It has performed well in numerous taste panels and was released as a premium variety to be labeled for better competition with greenhouse tomatoes in the supermarket (where Florida tomatoes have lost market share in recent years). To ensure maturity and the desired quality to compete, fruit should be picked at the breaker stage. Test marketing is underway this fall and results should be available at next year's Tomato Institute. Growers with produce stands and/or U-pick operations might try planting 'Tasti-Lee' and see if they get a positive response from their customers. It has been a reliable yielder in numerous trials and on grower farms with fruit size being a little smaller overall than varieties typically grown in Florida.

We have identified a fruity-floral flavor note that is appealing, and we are backcrossing it into the parents of 'Tasti-Lee' for further flavor improvement of this hybrid. This flavor note has been difficult to fix for good expression but one of the lines in this procedure, Fla. 8629, has been rated at the top of all four taste panels where it has been tested. Furthermore, hybrids heterozygous for Fla. 8629 have also done well suggesting that 'Tasti-Lee' could be improved for flavor by improving only one of the parents for the fruity floral trait. Horticultural improvement is needed as Fla. 8629 needs greater fruit size and firmness. If 'Tasti-Lee' can find a market niche, we hope to be able to follow it with a fruity-floral version of the same variety. Otherwise, emphasis on good flavor is stressed in the whole breeding program. One new inbred that has had good flavor is Fla. 8735. This line has large, firm fruit with excellent locule formation, the latter likely relating to the ability of this line to carry a nice acid level (since acids are more prevalent in locules than pericarp). Numerous test crosses are being made with Fla. 8735 to attain improved hybrids for the Florida market.

'TRIBECA', A 2007 RELEASE

This variety (Scott et al., 2009) was tested as Fla. 8363 and Gulf Stream but was named 'Tribeca' due to some trade mark issues with the name Gulf Stream. Vilmorin Inc. is the seed company producing seed of this variety. Some germination problems have delayed seed availability, but this problem should be resolved by switching the direction of the cross. Seed will be available from Caroline Cordier: Caroline.cordier@vilmorin.com, phone 520-940-1539. The main features of this variety are that it is resistant to tomato spotted wilt virus and it has heat-tolerant fruit setting ability. The major production region will be North Florida and the southeast where tomato spotted wilt is a problem and where 'Tribeca' has done well in several trials over multiple years. On the peninsula of Florida, it is suggested that growers try 'Tribeca' in their early fall plantings for its heat-tolerant setting ability as it has performed well under these conditions. Seed should be plentiful for next fall and JW Scott can be contacted to obtain smaller seed samples for testing.✻

REFERENCES

Hutton, S.F. 2008. Inheritance and mapping of resistance to bacterial spot race T4 (Xanthomonas perforans) in tomato, and its relationship to race T3 hypersensitivity, and inheritance of race T3 hypersensitivity from PI 126932. (PhD dissertation, University of Florida).

Ji, Y., D.J. Schuster, and J.W. Scott. 2007. Ty-3, a begomovirus resistance locus near the tomato yellow leaf curl virus resistance locus Ty-1 on chromosome 6 of tomato. Molecular Breeding 20:271-284.

Ji, Y. J.W. Scott, D.J. Schuster, and D.P. Maxwell. Molecular mapping of Ty-4, a new tomato yellow leaf curl virus resistance locus on chromosome 3 of tomato. J. Amer. Soc. Hort. Sci., 134:281-288.

Scott, J.W., S.M. Olson, and J.A. Bartz. 2009. 'Tribeca' hybrid tomato; Fla. 8124C and Fla. 8249 breeding lines. HortScience 44:471-473.

Scott, J.W., E.A. Baldwin, H.J. Klee, J.K. Brecht, S.M. Olson, J.A. Bartz, and C.A. Sims. 2008. Fla. 8153 hybrid tomato; Fla. 8059 and Fla. 7907 breeding lines. HortScience 43:2228-2230.

NOTES

FUMIGATION FOR TOMATO TODAY: METHYL BROMIDE ALTERNATIVES, THE FUTURE OF DRIP FUMIGATION AND OUTCOMES AND IMPACTS OF EPA REASSESSMENTS OF SOIL FUMIGANTS

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Drip fumigation is defined simply as the application of a soil fumigant through a drip irrigation system. Some soil fumigants, like Vapam® (metam sodium) and K-Pam® (metam potassium), are readily soluble in water and can be applied directly into irrigation water, while others require special emulsified concentrate (EC) formulations for application (Table 1). For example, chloropicrin and Telone (1,3-dichloropropene or 1,3-D) are not highly soluble in water and must be premixed with special emulsifying agents to enhance solubility in water and to promote the uniform suspension of the fumigant in water before delivery into the irrigation lines. Considerable research is currently underway to optimize application technologies to improve performance consistency with drip applied alternative fumigants. In California and Florida, drip applied chloropicrin EC or Inline® (a mixture of 1,3-D and chloropicrin with a emulsiftying agent) has provided satisfactory soil-borne pest control and yields of a variety of crops which were equivalent to that of in-row, shank applied methyl bromide and chloropicrin. Currently, over 55% of the California strawberry acreage is drip fumigated with either chloropicrin EC or Inline®.

Prior to EPA completion and release of the Fumigant Re-registration Eligibility Decisions (RED's) on June 3, 2009, drip fumigation was being proposed as an alternative to chisel application to minimize fumigant-excluded buffer zones, personal protective equipment (PPE) and costly worker certifications, as well as for in-field monitoring requirements for use of chisel applied fumigants. It was fortunate for Florida agriculture that EPA did not ultimately demand such exorbitant standards and requirement within the fumigant RED's. This is not to say that drip fumigation with the alternative fumigants should not be considered to be an effective, economical, and environmental and worker safe approach to fumigant use compared to that of standard shank injections. With drip approaches, fewer, more fuel-efficient tractor operations are expected to reduce overall fumigant application and production costs. Fewer workers in the field at the time of application also translates into a safer environment for workers with reduced grower liabilities, and with some fumigants it has the potential to significantly reduce costs for PPE (boots, gloves, coveralls, respirators, etc.) when needed.

Safe and effective drip fumigation requires an understanding of how different physical, chemical and environmental factors affect water and gas phase movement of the different soil fumigants. Additionally, it requires new chemical injection equipment with proper safety devices, a leak-free drip-irrigation system with uniform water distribution, and fumigant application and dilution into the proper amount of water. A brief discussion of these factors follows.

TABLE 1. Soil fumigant product dilutions (volume:volume) to achieve various parts per million (ppm) concentrations in irrigation water[z]. To achieve 1000 ppm Chloropicrin EC in irrigation water requires a mixture of 1 gallon Chloropicrin EC into 1507 gallons of irrigation water.

Fumigant	Formulation	lb a.i. / gal	Product Dilution in Water (vol. product : vol. water)		
			500 ppm	1000 ppm	1500 ppm
Chloropicrin EC	94% chloropicrin	12.58	1: 3015	1: 1507	1: 1005
Pic-Clor 60 EC	56.7% chloropicrin 37.1% 1,3-D	6.73 4.49	1: 1613 -	1: 807 -	1: 538 -
Telone EC	93.6% 1,3-D	9.45	1: 2265	1: 1133	1: 740
Telone Inline	60.8% 1,3-D 33.3% chloropicrin	6.57 3.73	1:1575 -	1: 787 -	1: 540 -
Vapam HL	42% metam sodium	4.26	1: 1021	1: 510	1: 340
Kpam HL	54% metam potassium	5.8	1: 1390	1: 695	1: 463

[z]Concentrations of chloropicrin or 1,3-D which exceed 1500 ppm may result in precipitation of the fumigant (when solubility limits are exceeded ~2000 mg/l) and to damage to PVC pipelines of the irrigation system. For this reason, irrigation lines must be thoroughly flushed of fumigant to prevent damage. Due to product inconsistency and ineffectiveness, none of the above fumigants should be applied below 500 ppm. Growers assume final responsibility for determining irrigation flow rates and for achieving desired product concentration irrigation water.

SOIL CONSIDERATIONS

Most of the soils of peninsular Florida are Spodosols, defined as poorly drained fine sands (96%-98% sand, <2% silt, clay, and organic fractions) with an underlying impermeable (spodic) horizon 18 to 24 inches below the soil surface. Above the spodic layer soil water holding capacity is low, typically in the range of 4% to 8%, with water permeability of 6 to 20 inches per hour. Water tables are shallow, and, in many fields, water may pond or flood after heavy rains, enforcing the need for a drainage system of ditches and canals. Water movement in soil is principally vertical, with very little lateral movement. Seepage and drip irrigation are the principal means of irrigation used in the raised bed, plasticulture system of Florida. The sandy nature of our soils has constrained our ability to move and uniformly distribute a drip fumigant away from its point of application.

WATER-PHASE MOVEMENT

A significant amount of research has been conducted to characterize the dynamics of drip irrigation water movement and use of the drip system for chemical delivery. These studies have relied upon tracking the movement and spatial distribution of water soluble colored dye, introduced into the irrigation stream. Movements of water-borne dye and fumigant have been investigated for varying injection periods and total water volumes, drip tube num-

bers per bed, flow rates, emitter spacings, soil compaction regimes, and bed dimensions. The overall results of these studies, as well as generalized summary of field results of drip fumigation trials, form the basis for the following recommendations for maximizing water phase movement of alternative fumigants, such as Vapam®, K-Pam® and chloropicrin EC and Inline®. A separate discussion of gas phase movement will follow.

In general, the results of all of the previous dye studies have repeatedly shown that the average width, depth, and cross-sectional area of the wetted zone generally increases with irrigation water volume, typically forming a hemispherical shape until water fronts from adjacent emitters along the drip tape collide. As these fronts collide, a wetted strip of no more than 12 to 15 inches develops parallel to the drip line. Measured laterally from the drip emitter, outward water movement was seldom measured more than 6 to 7 inches. Depending on the width of the bed, these studies demonstrated that it was virtually impossible to wet more than 40% to 60% of the raised plant bed with a single drip tube. With two drip tapes, it was possible to wet from 75% to 95% of the bed. In general, the wetting front is typically two- to threefold greater with use of two drip tubes rather than with a single tube per bed. But even with two tapes per bed, it is always more difficult to wet a high proportion of a wide bed compared to a narrow bed.

For a given water volume, the use of two tapes per bed increased spatial distribution of irrigation water simply because of the spacing between drip tubes and the increased number of emission points along the bed. In the overall analysis of the relationship between total irrigation water volume and spatial distribution of the wetted zone, it appears that most bed wetting occurs in the time to deliver the first 300 gallons of water per 100 linear feet of row. If a maximum rooting depth of 16-20 inches from the top of the bed is assumed, then irrigation run times required to deliver water volumes of 100 to 200 gallons per 100 feet of row should not be exceeded so as to contain the wetting front within the future rooting zone of the plant.

GAS-PHASE MOVEMENT

Upon drip delivery to soil, the fumigant moves through the soil within a radially advancing water front. Differences in soil type can significantly affect water flow which controls the solution-phase transport of dissolved soil fumigants. Faster movement and vertical drainage of fumigant solutions occurs in our fine sandy soils compared to other soils with higher percentages of silts and clays. Soil air spaces are also restored more quickly in sandy soils which then promotes earlier gas diffusion and rates of flow through open air passages in soil. As water moves downward in the soil, a corresponding increase in the volume of soil air space occurs. In order to restore the dynamic equilibrium between water and gas phase concentrations, more molecules of the fumigant must therefore enter into the vapor or gas phase. In general, field research has demonstrated that fumigants move in gas phase approximately 3 to 5 inches beyond the wetting front. Metam products may only move only a few inches from the wetted front; whereas, Inline may move as much as 6 to 8 inches beyond the wetted zone due to the stronger vapor pressure of 1,3-D and chloropicrin.

In general, fumigant concentrations decrease with time after application and with distance from the drip tapes emitters (Fig. 1). Lowest measured fumigant concentrations and highest pest survivorship are generally observed at the bed shoulders, particularly with wide beds. Higher rates of fumigant application which require more water to apply, in many circumstances are needed to laterally move the fumigant wetting front at lethal concentration to the shoulders of the bed. In many Georgia and Florida studies on fine sandy soils, the rapid drainage and poor lateral movement of Inline® (25-30 gal/acre), Vapam® (75 gal/acre) or K-Pam® (60 gal/acre) have resulted in poor nutsedge control on bed shoulders when a single drip tape was used. Even with two tapes per bed, some drip-applied fumigants with low vapor pressure and low diffusivity have failed to control nutsedge on the bed shoulders or even in areas between the dual tapes. Nematodes are usually much easier to kill than nutsedge and effective control is often observed at the bed shoulders.

In general, reduced effectiveness and consistency can be observed with any fumigant product when applied through a single drip tape per bed. Increasing rates of applications have helped to overcome this problem, but oftentimes not entirely. Previous research has also demonstrated that fumigant concentrations (and their efficacy) could be enhanced across the bed by using highly retentive mulches, such as virtually impermeable films (VIF) or metalized mulches. Fumigant retention under these mulches are prolonged at higher concentrations which results in higher overall exposure to lethal concentrations and improve lateral spread of the fumigant across the bed.

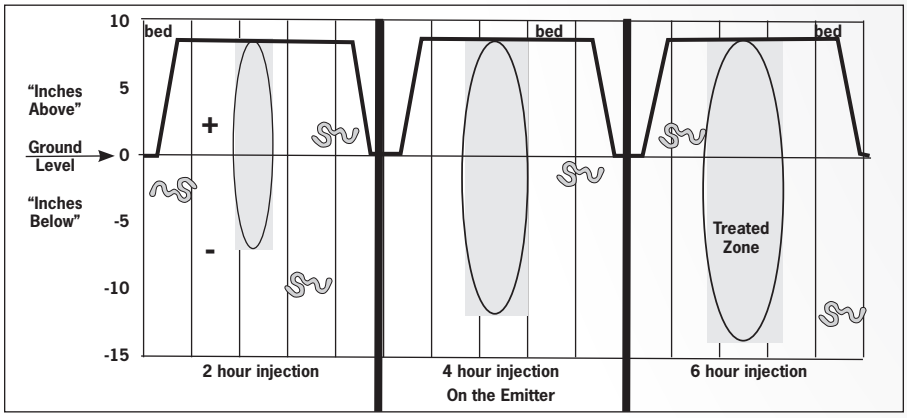
LETHAL DOSAGE

After a fumigant is applied to soil as a liquid, it then converts into a gas, once open air passages in the soil redevelop. As indicated previously, fumigant movement in soil begins in the water phase, advancing within the water front, and then after irrigation is stopped and gravitational water moves downward to restore soil air spaces, through gas phase diffusion. To achieve satisfactory pest control, the fumigant must remain in contact with the target pest for sufficient time to kill the organism. The pesticidal effect of the fumigant on the target organism is thus a function of both fumigant concentration (C) and time (T). That is to say that the level of pest control achieved is related primarily to pesticide concentration, outward radial movement of both water and gas phase fumigant, which determines total treated soil volume, and residence time of the chemical in the soil. Unfortunately, lethal concentrations expressed as fumigant concentrations over time have not been developed, primarily due to the high cost and sophistication required to monitor gas concentrations in soil, at diverse depths and bed locations. There also are many different soil factors and conditions capable of influencing C x T values, so it may not be possible to measure their separate influences on pest control efficacy. In Florida's sandy soils, Inline® is usually applied at rates between 20 and 30 gal/acre, Telone EC® at 10 to 12 gal/acre, Vapam® at 30 to 35 gal/acre, and K-pam® 25 to 30 gal/acre. Typical dilution rates result in fumigant concentrations of 500 to 1500 ppm.

PRACTICAL CONSIDERATIONS

Based on grower demonstration trials, soils and grower production practices differ markedly, and the resulting differences in soil type, compaction and depth of restrictive layers, can affect water movement and the final distribution of chemicals

FIGURE 1. Cross-section of a raised plant bed illustrating the results of a grower field chemigation trial using a Water soluble dye to map the resultant water front. The results illustrate the principally vertical and very limited lateral spreading of a water front throughout a raised plant bed as the irrigation run time (volume) is increased from 2 to 6 hours. The results demonstrate the potential difficulties in achieving pest control efficacy with a chemigated pesticide when less than 50% of the bed is wetted during a 6 hour injection period.



in soil. This was clearly demonstrated in some grower trials where only very limited lateral spreading of the water front occurred as irrigation run time (volume) was increased from 2 to 6 hours (Fig. 1). Given the soil characteristics at these sites, it becomes apparent that the drip system cannot be effectively and universally used for delivery of alternative fumigants, at least through a single drip tube. To determine the suitability of any field site, growers are encouraged to conduct their own dye studies to optimize the utility of the drip system for their own purposes. Growers also should be reminded of the possible effects of applying such large volumes of water on bed architecture, leaching of preplant fertilizers and plant nutrition and health. Surely, some adjustments in the fertility program, such as exclusive reliance on postplant fertigation, must be developed to minimize nutrient leaching impacts from use of the drip system for preplant soil fumigation.

Even though our knowledge and understanding of the dynamics of drip water movement in soil increases, it does not mean that growers, armed with this information, will achieve immediate success without cost or change. For example, it was shown that flaws in irrigation system design could significantly compromise treatment efficacy of chemigating compounds such as Telone EC or Vapam®. The principal problem involved lack of delivery uniformity throughout the entire field. In one field trial, significant drops in drip line water pressure from one end of the field to the other, established a gradient of diminishing volume of water output and hence of treated soil volume. The results of this dye trial clearly demonstrated that use of pressure regulators across the entire field with adequate water flow sizing requirements is a must to insure distribution uniformity. In this regard, the irrigation system should be designed to maintain a minimum line pressure of 8 to 10 psi along the entire drip line within each row to assure uniform delivery of fumigant product.

The proximity of the plant to the drip tube has also been demonstrated to be very important in terms of defining pest control efficacy and plant growth response with a drip fumigant. In separate experiments, it was observed that Vapam® application rates as low as 10-15 gal/acre could be effectively used for both tomato and pepper crop destruction purposes, if established plants were within two inches of individual drip emitters. Identical studies with plants positioned 6 to 8 inches from the drip line required a rate of 20-30 gal/acre and a longer irrigation run to achieve the same level of plant mortality. Presumably, a two-fold increase in application rate was needed to compensate for the additional distance required to contact the primary root zone of the plant. The problem is even further amplified when one considers typical production practice of laying the drip tape on one side of the bed and planting the crop on the bed center. On a wide bed (36 inches), the bed shoulder opposite that of the drip tape is typically untreated. Ideally the tape would be placed in the center of the bed and the crop planted offset of the tape. Growers also should consider a change in bed width since narrower beds could be covered more uniformly than wider 32-36 inch-wide beds. Given the sandy nature of Florida soils, narrower beds, drip tubes with closer drip emitter spacing (likely in the range of 8-12 inches), and planting practices which place plants closer to the drip tube may need to be adopted to more effectively utilize the drip tape for application of alternative fumigants. Unless two tubes per bed are installed, drip fumigation may be better suited for crop destruction and pest control protection of the double crop rather than as relying upon it as the preplant fumigant treatment of the primary crop.

DRIP FUMIGATION

Before considering drip fumigation as a pest management tool, an evaluation of irrigation system design and distribution uniformity should be conducted to ensure even water distribution and operating pressure uniformity, and thus drip emitter discharge rates within the field and entire length of row. Any inconsistency in drip flow will be reflected in variability in fumigation rates, pest control efficacy, and crop yield response. Other drip fumigation considerations include:

- Placard the Field and ensure that the irrigation system has functional back flow prevention (required by law).
- Soil Preparation: Properly till the soil and ensure adequate moisture to construct a firm, compressed, raised bed. For seepage-irrigated fields, some adjustment in water table after bed formation may be needed to allow application of additional water.
- Avoid wet soils since the performance of fumigants are negatively impacted by excessive soil moisture.
- In fields without seepage irrigation, consider deep tillage to destroy compacted traffic pan layers to insure fumigant penetration (both liquid and gas phase) to depths directly below the raised bed. In seepage fields, a deep tillage practice could damage the spodic layer with resultant loss in the ability to perch a water table.
- Install the drip tape(s) to a depth of 1-2 inches to avoid tape movement (vertical or horizontal) along the row. Drip tapes subject to heating and cooling are capable of considerable movement

unless buried to a soil depth of at least 1 inch. Spread the tapes as far apart as possible to ensure wetting of the bed center and shoulders. In general, research has demonstrated that fumigants move in gas phase 3 to 5 inches beyond the wetting front. On beds wider than 36 inches, it may not be possible to distribute fumigant to the bed shoulders even with 2 tapes spaced 12 to 15 inches apart.

• Since pump capacity with irrigation zones is frequently limiting, two low-flow drip tapes (0.2 to 0.25 gpm / 100 row feet) should be used to match previous flows used for the single drip tape. Use of drip tape(s) for end of season crop termination or double cropping treatment requires proper filtration and tape cleaning programs.

• Install a high barrier / VIF mulch to reduce field emissions and to enhance cross bed diffusion of fumigant gases and pest control efficacy, particularly of weeds, at reduced rates of fumigant use.

• Maintain adequate soil moisture prior to and after application to maintain biological activity in soil and susceptibility to fumigant treatment.

• After installation of the drip tape and plastic mulch, pressurize the irrigation system and inspect the system for leaks within irrigation lines, manifold connections, end drains, or damaged drip tape within rows causing puddling in the row middles. Repeat the irrigation process to avoid problems from developing at the time of fumigant injection.

• Repeated operation of the irrigation system prior to drip fumigation will help to ensure uniformity of chemical application across the treated area.

• To ensure water (and fumigant) distribution uniformity throughout the field and within individual rows, pressure variation within the drip tape should be minimized. Poor pressure and flow uniformity is generally caused by pressure and flow variability in drip tape emitters throughout the field. ✻

RALSTONIA SOLANACEARUM RACE 3 BIOVAR 2:

DESCRIPTION AND STRATEGIES FOR BEST MANAGEMENT OF A SELECT AGENT PATHOGEN AS A POTENTIAL INCITANT OF BACTERIAL WILT OF TOMATO

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Bacterial wilt caused by *Ralstonia solanacearum* is one of the major diseases of tomato and other solanaceous plants worldwide. Bacterial wilt in commercial tomato fields may result in significant yield reductions and even complete losses under favorable disease conditions (Boshou, 2005). The disease generally occurs in lowlands in tropical and subtropical areas. In the United States, *R. solanacearum* phylotype II (race 1 biovar 1) occurs naturally and causes bacterial wilt in states south of Maryland, including Florida (McCarter, 1991).

One subgroup of *R. solanacearum* designated race 3 biovar 2 (R3b2) attacks plants at higher altitudes in tropical, subtropical, and warm-temperate areas. Initially described as pathogenic on potato and tomato, R3b2 can also wilt eggplant, pepper, and geranium (where it causes Southern wilt disease). Other solanaceous and non-solanaceous plants also may act as alternative hosts for R3b2 (Lemay et al., 2003). This pathogen is extremely destructive; on potato alone, R3b2 is responsible for an estimated $1 billion US in losses each year on the global scale (Elphinstone, 2005).

Because of its host range, worldwide distribution, and aggressiveness, R3b2 is considered a serious threat to agriculture production in the US and Canada, where it is not known to be established. In order to prevent its introduction and establishment in the US, R3b2 was listed in 2002 as a "Select Agent plant pathogen", and is subject to the strictest biosecurity regulations (Lambert, 2002). R3b2 has been accidentally introduced into the US several times on imported and infected geranium cuttings, resulting in millions of dollars in losses due to regulatory eradication protocols (Kim et al., 2003; Williamson et al., 2002).

Along with a description of the disease and causal organism, we will discuss below diagnostic methods and strategies for best management of bacterial wilt of tomato and control of *R. solanacearum*, with emphasis on R3b2. These strategies include exclusionary practices to prevent introduction of the pathogen to disease-free locations and prevent spread from infested to healthy fields, as well as effective field sanitary cultural practices for locations where the pathogen is known to be established.

DESCRIPTION OF THE DISEASE

Symptoms. Symptoms induced by R3b2 cannot be distinguished from wilt symptoms caused by other *R. solanacearum* strains. The first visible symptom is wilting of the youngest leaves during the hottest part of the day, often on just one side of a leaflet or on a single branch. At this stage, plants may appear to recover at night when temperatures are cooler. Under favorable conditions, the entire plant may wilt quickly, leading to general wilting and yellowing of foliage and eventually plant death. Another common symptom associated with bacterial wilt in the field is plant stunting. This symptom may appear at any stage of plant growth; sometimes, infected tomato plants

will not show symptoms until just before fruit ripening, when they undergo rapid collapse. A longitudinal slice of infected stems will reveal vascular browning, visible as long, narrow, dark-brown streaks. In succulent young plants of highly susceptible varieties, the stem can collapse, and grey-white bacterial ooze may be visible on stem surfaces (McCarter, 1991).

Symptom expression is favored by high temperatures (85-95°F). Under cool temperatures or when tolerant or moderately tolerant tomato cultivars are grown, plants may remain latently infected (symptomless) for extended periods of time. Latent infections are of major importance in the epidemiology of the disease as the absence of visible symptoms makes detection of *R. solanacearum* very difficult.

Cycle and epidemiology. *R. solanacearum* is primarily a soilborne and waterborne pathogen. No aerial spread of the pathogen has been reported so far. It primarily infects host plants through their roots, entering through wounds formed by lateral root emergence or by root damage caused by soilborne organisms (e.g., the root-knot nematode). The bacterium can also enter plants by way of stem injuries from insects, handling, or tools. Once inside the roots or stems, the bacterium colonizes the plant through the xylem in the vascular bundles (Denny, 2006).

R3b2 is most severe on plants between 75 and 95°F and decreases in aggressiveness when temperatures exceed 95°C or fall below 60°F. Active disease at temperatures below 60°F is rare (Ciampi and Sequeira, 1980; Hayward, 1991).

The pathogen can be spread from infested to healthy fields by soil transfer on machinery and surface runoff water after irrigation or rainfall. It also can be disseminated from infested ponds or rivers to healthy fields by flooding or irrigation. Plant-to-plant infection can occur when bacteria shed from infected roots move to roots of nearby healthy plants. Long-distance spread of the pathogen can occur with transportation of latently infected transplants (McCarter, 1991).

The bacterium can survive for days and up to years in infested water, wet soils or deep soil layers (> 30 inches), from where it can be dispersed. Diverse biological (such as antagonist microorganisms) and environmental factors (mainly temperature, soil type and moisture) can affect survival of *R. solanacearum* in soil and aquatic habitats (Denny, 2006).

In natural habitats, R3b2 can survive moderate winters in plant debris in soil, in weed hosts or in the rhizosphere of non-host plants, which act as inoculum reservoirs. Infected semi-aquatic weeds, such as Solanum dulcamara (bittersweet nightshade, also known as climbing or woody nightshade) can release large populations of the bacterium from roots into river water when temperatures start to increase after winter.

TABLE 1. Characteristics of races and their relationship to biovars of *Ralstonia solanacearum* (from Denny and Hayward, 2001; Daughtrey, 2003).

Race	Primary hosts	Geographical distribution	Biovar
1	Wide (tobacco, tomato, solanceous and nonsolanaceous weeds, diploid bananas, groundnut, potato, pepper, eggplant, olive, ginger, strawberry, geranium, Eucalyptus, other plants…)	Asia, Australia, Americas	3, 4 1
2	Triploid bananas, other *Musa spp.*	Caribbean, Brazil, Philippines	1
3	Potato and tomato	Worldwide except US and Canada	2 (or 2A)[z]
4	Ginger Unknown	Australia, China, Hawaii, India, Japan, Mauritius, South Asia India	4 3
5	Mulberry tree	China	5

[z] Typical race 3 strains are sometimes referred to as biovar 2A. New race 3 strains from the Amazon basin have been placed in a new biovar, designed as 2T or N2 (their relation to races is unclear).

TABLE 2. Hosts of *Ralstonia solanacearum* race 3 biovar 2 (from Floyd, 2008; Lemay, 2003).

Primary hosts	Lycopersicon esculentum (tomato) Solanum tuberosum (potato)
Other cultivated hosts	Beta vulgaris (beet) Capsicum spp. (peppers) Momoridica charantia (bittergourd) Pelargonium spp. (geraniums) Phaseolus vulgaris (bean) Solanum melongena (eggplant)
Weed hosts	Brassica spp. (mustards), Cerastium glomeratum (sticky chickweed) Chenopodium album (lambsquarters) Datura stramonium (Jimson weed) Drymaria cordata (whitesnow) Melampodium perfoliatum (perfoliate blackfoot) Polygonum capitatum (pinkhead smartweed) Portulaca oleracea (purslane) Solanum carolinense (horsenettle) Solanum dulcamara (bittersweet or climbing nightshade) Solanum nigrum (black nightshade) Stellaria media (common chickweed) Tropaeolum majus (garden nasturtium) Urtica dioica (stinging nettle)

DESCRIPTION OF THE PATHOGEN

A "species complex". *Ralstonia solanacearum* (Smith 1986; Yabuuchi et al., 1996; formerly called *Pseudomonas solanacearum*) is considered a "species complex," due to significant variation within the group (Fegan and Prior, 2005). It was historically subdivided into five races, based loosely on host range, and five biovars, based on the different ability of *R. solanacearum* strains to produce acid from a panel of 5 to 8 carbohydrate substrates, including disaccharides and sugar alcohols (Table 1). There are no laboratory tests to define the "race" of an isolate because host ranges of strains are broad and often overlap. Recently, a phylogenetically meaningful classification scheme was developed based on DNA sequence analysis (Prior and Fegan, 2005). This scheme divides the species complex into four major groups called phylotypes that broadly reflect the ancestral relationships and geographical origins of the strains.

R. solanacearum R3b2 strains belong to phylotype II and sequevars 1 and 2 (Fegan and Prior, 2005). The R3b2 strains distributed outside South America belong to sequevar 1.

Culture, identification and conservation. *R. solanacearum* is a Gram-negative, rod-shaped, largely aerobic bacterium that is 0.5-0.7 × 1.5-2.0 μm^2 in size. Liquid and solid (agar) growth media are commonly used for culturing the bacterium. For most strains, the optimal growth temperature is between 82 and 90°F (Denny and Hayward, 2001; Hayward, 1991). R3b2 strains have a lower optimal growth temperature of 80.5°F. On solid agar media, individual bacterial colonies are usually visible after 36 to 48 hours of growth at 82°F, and colonies of the normal or virulent type are white or cream-colored, irregularly shaped, highly fluidal, and opaque. Occasionally, colonies of the mutant or non-virulent type appear; these

TABLE 3. USDA-APHIS validated test kids for *Ralstonia solanacearum* (from Floyd, 2007).

Rs Immunostrip® Test Agdia Inc. 30380 County Road 6 Elkhart, IN 46514 Website: http://www.agdia.com Phone: 800-622-4342
Potato Brown Rot Pocket ™Diagnostic Central Science Laboratory (CSL) Sand Hutton, York, Y041 1 LZ Website: http://www.csl.gov.uk Phone: 44 1904 462600
Ralstonia solanacearum SPOTCHECK LF™ Adgen, Ltd. Nellie's Gate, AYR Scotland, KA6 5AW Website: http://www.agden.co.uk Phone: 44 1292 525275

are uniformly round, smaller, and butyrous (or dry). A tetrazolium chloride (TZC) medium (Kelman, 1999) can differentiate the two colony types. On this medium, virulent colonies appear white with pink centers and non-virulent colonies are a uniform dark red.

R. solanacearum can be stored for many years at room temperature in sterilized tap, distilled or deionized water. It will also survive long-term at -80°C in liquid culture broth containing 40% glycerol (Denny and Hayward, 2001).

Hosts. *R. solanacearum* race 3 biovar 2 has a smaller host range than race 1 (Denny, 2006). Although primary hosts of the pathogen are potato and tomato, R3b2 also was shown to induce symptoms on eggplant, geranium, and pepper. Some other solanaceous and non-solanaceous plants can be hosts of R3b2 (Table 2).

Sign. Bacterial streaming is a common sign of *R. solanacearum* (McCarter, 1991). When cut stem sections from infected plants are placed in water, threads of a viscous white slime can be observed streaming from the cut end of the stem within minutes. These threads are bacterial ooze exuding from the infected xylem vascular bundles. This streaming test is a valuable diagnostic tool for quick detection of bacterial wilt diseases in the field. However it may not be useful early in disease development.

Detection and identification. The first step in pathogen identification consists of observation of sign and disease symptoms. Symptomatic plants in the field or in the greenhouse can be tested for R. solanacearum using screening tests that can facilitate early detection of the pathogen. These screening tests include bacterial streaming, plating on a semi-selective medium such as modified SMSA (Elphinstone, 1996), and immunodiagnostic assays using species-specific antibodies. The USDA-APHIS-PPQ has tested and recommends the use of commercially available immunostrips for rapid detection of *R. solanacearum* in the field or lab (Table 3). Screening tests are inexpensive, fast and require minimum equipment. However, they cannot be used to identify the "race" or biovar.

Several microbiological and molecular methods can be used to identify *R. solanacearum* at the sequevar, race and biovar level, following recovery from asymptomatic plants, or from water or soil samples. These methods include immunodiagnostic assays using species-specific antibodies, polymerase chain reaction (PCR) with species-specific primers, and biovar test (Denny, 2006).

The biovar test, a bacteriological assay based on the differential ability of *R. solanacearum* strains to produce acid from a panel of disaccharides and sugar alcohols, requires specialized media and takes several weeks (Denny and Hayward, 2001). Unequivocal identification of R3b2 must rely on at least two distinct methods, including the biovar test and one of the DNA-based tests that use PCR to amplify an R3b2-specific DNA fragment. Because of current United States regulations, the only laboratory legally permitted to conclusively identify R3b2 is the USDA-APHIS-PPQ National Plant Germplasm and Biotechnology Laboratory in Beltsville, MD. A diagnostician who identifies R. solanacearum in samples from tomato, potato or geranium should consider the possibility that the strain may be R3b2 and immediately contact the APHIS-PPQ lab in Beltsville.

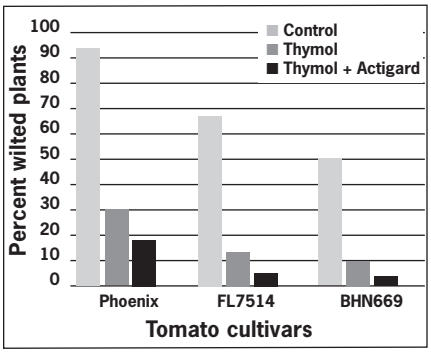
USDA-APHIS-PPQ-National Plant Germplasm and Biotechnology Laboratory (NPGBL)
BARC-East, Bldg. 580
Powder Mill Road • Beltsville, MD 20705
301-504-7100 • Fax: 301-504-8539

DISEASE MANAGEMENT

Because *R. solanacearum* is a soilborne pathogen and host resistance is limited, bacterial wilt is very difficult to control (Hayward, 1991; Saddler, 2005). Moreover, R. solanacearum is widely distributed and has an unusually broad host range (Denny 2006; Hayward, 1991). Thus, no single strategy has shown 100% efficiency in control of the disease.

In locations where the pathogen is present or established. In locations where *R. solanacearum* is established, some level of bacterial wilt control is possible by using a combination of diverse control methods. These methods should be used as part of an integrated management strategy for most effective control of the disease, and include:

FIGURE 1. Effect of the integrated application of Actigard (acibenzolar-S-methyl) and Thymol on bacterial wilt of tomato after artificial inoculation of three tomato cultivars in a field experiment (2006) in North Florida (Quincy).



Host resistance. Some level of bacterial wilt control is possible using resistant or moderately resistant tomato cultivars, such as 'FL7514' and 'BHN 466'. Resistance in these cultivars may vary with location and temperature, because of strain differences (Hanson et al., 1996; Wang et al., 1998).

Grafting susceptible tomato cultivars onto resistant tomato or other solanaceous rootstocks is effective against Asian strains of *R. solanacearum* and is used on the commercial scale in different locations worldwide (Saddler, 2005). Effectiveness of grafting for use against R3b2 has not been tested yet. Additionally, some reports suggest that bacterial wilt-resistant tomato cultivars and breeding lines may have poor resistance to R3b2 (P. Prior, personal communication).

Chemical control and soil treatment. Chemical control by soil fumigation or application of phosphorous acid has been reported to be effective for controlling bacterial wilt of tomato in the field (Chellemi et al., 1994; Ji et al., 2007). Similarly, soil treatments, such as modification of soil pH, heat treatment by solarization, and the application of stable bleaching powder have been shown to reduce bacterial populations and disease severity on a small scale (Saddler, 2005).

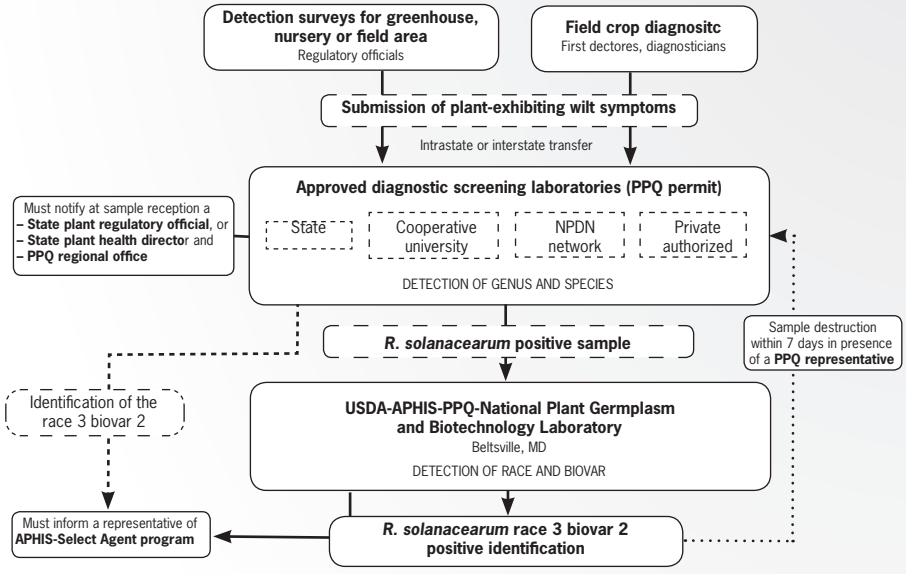
Drawbacks of these methods may include environmental damage, cost, and high labor input. Additionally, most of these methods still have to be tested against R3b2 strains of *R. solanacearum*. When used, chemical control should be integrated with other methods to reduce selection pressure for pathogen resistance.

Recently, the use of Thymol, a plant-

TABLE 4. Recommended management strategies for bacterial wilt on tomato caused by *Ralstonia solanacearum* (from Momol, 2005).

Before planting	• Consider an effective weed control program for use in and around tomato fields and for aquatic weed control around irrigation ponds. • Apply 3-4 years rotation and cover crops for infested fields to reduce *R. solanacearum*, weeds and nematodes. • Do not irrigate rotation and cover crops with *R. solanacearum* contaminated pond or surface water, avoid reinfestation. • Use well drained and leveled fields and do not use low-lying areas of the field. • Raise soil pH to 7.5-7.6 and increase available calcium (liming). • Consider using infested fields (after 3-4 years rotation) during cooler months for tomato production (i.e., spring season for north Florida).
During production	• Exclude the pathogen by applying strict sanitation practices (pathogen-free irrigation water, transplants, stakes, machinery, etc.). • Chlorinate irrigation water continuously when surface water or *R. solanacearum* infested pond water is used. • Continue an effective weed control in and around tomato fields and irrigation ponds. • Irrigate based on water need, avoid over irrigation. • Apply plant resistance inducer, such as Actigard (Syngenta) if you are using moderately resistant cultivars (i.e., FL 7514). Actigard enhances resistance against this disease if it is used in combination with moderately resistant cultivars.
After harvest	• Exclude the pathogen by applying strict sanitation practices (pathogen free irrigation water, transplants, stakes, machinery, etc.). • Chlorinate your irrigation water continuously if you are using surface water or *R. solanacearum* infested pond water. • Continue an effective weed control in and around tomato fields and irrigation ponds. • Irrigate based on water need, avoid over irrigation.

FIGURE 2. Regulatory procedure pathway for identification of Ralstonia solanacearum race 3 biovar 2 in the United States (from Floyd, 2008).



derived volatile biochemical (currently not commercially available), was shown to reduce disease incidence and increase yield in field experiments in Florida (Ji et al., 2005). Similarly, the application of the plant resistance inducer, acibenzolar-S-methyl (Actigard, Syngenta), in combination with moderately resistant cultivars, was shown to enhance resistance against bacterial wilt of tomato in the field (Anith et al., 2004; Pradhanang et al., 2005). In a 2006 field experiment in Quincy, FL, integrated application of Thymol and Actigard showed significant reduction in the percentage of wilted tomato plants, on cultivars that showed susceptibility to the disease after artificial inoculation with the pathogen (T.M. Momol, personal communication; Fig. 1).

Biological control. Biological control based on suppressive soils or known *R. solanacearum* antagonists has shown promising results in small scale experiments, but still needs to be validated on a larger scale and against R3b2 (Saddler, 2005).

Phytosanitation and cultural practices. The best strategy for controlling bacterial wilt in the field consists primarily of phytosanitation and cultural practices. In regions where bacterial wilt of potato is endemic or in locations where *R. solanacearum* is present but not yet established, these methods may be effective. These practices include crop rotation with non-host plants such as grasses, intercropping, control of weed and root-knot nematode populations, planting at non-infested production sites, removal of weeds or crop residue where inoculum persists, selection of appropriate planting time to avoid heat, deep plowing of crop residues, satisfactory soil drainage, and early- and late-season irrigation management (Hayward, 1991; Saddler, 2005). Recommendations for best management of bacterial wilt of tomato are listed in Table 4.

In locations where the pathogen is not present. In US tomato-producing states, it is important to prevent introduction and, if inadvertently introduced, subsequent movement of race 1 of *R. solanacearum* from infested to healthy locations or fields. Effective cultural sanitation practices are critical to keep non-infested areas clean. Sanitation efforts include planting only certified disease-free plantlets, disinfesting all equipment before moving it between fields, controlling floodwater flow, and never using surface water for irrigation. At the greenhouse, sanitary practices for tomato transplant production may include avoidance of sub-irrigation, wide separation of greenhouses from field production areas, disinfestation of all frames, trays and tools, use of pathogen-free soils or potting mix, control of weeds, and limited handling of plants (Mc Carter, 1991)

Because of its status as a Select Agent, government regulations in the US include zero tolerance for R3b2. This zero tolerance includes reinforcement of quarantine regulations, exclusionary practices, sanitary protocols, and inspections designed to prevent introduction of infected geranium cuttings produced off-shore. A "New pest response guidelines for *R. solanacearum* race 3 biovar 2" (Floyd, 2008) presents current information for detection, control, containment, and eradication of this pathogen in compliance with regulations. APHIS-PPQ (2005) also developed "Minimum sanitation protocols for offshore geranium cutting production" for use by off-shore geranium suppliers. It mandates implementation of sanitation procedures to prevent accidental introduction of R3b2 and to ensure that, if it is introduced, the pathogen does not spread within greenhouses, or on equipment or vehicles.

In addition to establishing exclusionary strategies, growers should monitor potentially infested sites for early detection and subsequent eradication of R3b2. Key sites for monitoring include soils in which R3b2-infected plants have been identified, rivers and other surface water used for irrigation, particularly when infected weed hosts may be present, and tomato production fields in the vicinity of geranium production greenhouses.

Regulatory response to detection of R3b2 in the US. Confirmed infestations of tomato (or other solanaceous crops) by R3b2 will require quarantine of fields, tomato trans-

plants, seedlings, or other plant material associated with infested lots, including processing facilities, storage bins, means of conveyance, soil, and irrigation water. Host removal and destruction is required along with disinfestation, as well as several years of non-host production in infested fields or associated growing areas before the quarantine can be removed. In case of contamination of water by the pathogen, irrigation with surface water should be prohibited, and water treatments, such as filtration or chemical disinfection, may be applied under control of legal authorities. Any permission to irrigate would be subject to results from sampling and testing water samples.

According to government regulations, any positive detection of *R. solanacearum* from a diagnostic screening laboratory following detection survey by a regulatory official should be sent to the USDA-APHIS-PPQ NPGB Laboratory in Beltsville for identification of the race and biovar (Floyd, 2008). Upon receiving the sample, a state plant regulatory official (or a state plant health inspector) and the PPQ regional office should be notified as requested (Fig. 2).

CONCLUSIONS

R3b2 is an important crop pathogen in both developing and industrialized countries, responsible for millions of dollars losses yearly and the direct cause of hunger and economic hardship in the tropical highlands of Asia, Africa, and South/Central America. Therefore, effective management of bacterial wilt diseases worldwide is critical and requires additional research for development of new diagnostic tools for R3b2. It also requires effective training of growers, official regulators, diagnosticians and other individuals responsible for first detection and management of this pathogen. Hence, a Ralstonia solanacearum/bacterial wilt dedicated website (http://plantpath.ifas.ufl.edu/rsol/) that aims to provide up-to-date information on *R. solanacearum* for best management of the diseases it causes on potato, tomato, and geranium, is now available. ✻

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SELECTED REFERENCES

Anith, K. N., Momol, M. T., Kloepper, J. W., Marois, J. J., Olson S. M., and Jones, J. B. 2004. Efficacy of plant growth-promoting rhizobacteria, acibenzolar-S-methyl, and soil amendment for integrated management of bacterial wilt on tomato. Plant Dis. 88:669-673.

APHIS-PPQ. 2005. Minimum sanitation protocols for offshore geranium cutting production 2005. Issued Dec. 1, 2005. USDA-APHIS-PPQ Pest Detection and Management Programs, Riverdale, MD.

Boshou, L. 2005. A broad review and perspective on breeding for resistance to bacterial wilt. Pages 225-238 in: Bacterial Wilt Disease and the Ralstonia solanacearum Species Complex. C. Allen, P. Prior, and A. C. Hayward, eds. American Phytopathological Society, St. Paul, MN.

Chellemi, D. O., Olson, S. M., and Mitchell, D. J. 1994. Effects of soil solarization and fumigation on survival of soilborne pathogens of tomato in north Florida. Plant Dis. 78:1167-1172.

Ciampi, L., and Sequeira, L. 1980. Influence of temperature on virulence of Race 3 strains of Pseudomonas solanacearum. Am. Potato J. 57:307-317.

Daughtrey, M. 2003. New and Re-emerging Diseases in 2003. Department of Plant Pathology, Cornell University, Long Island Horticultural Research & Extension Center.

Denny, T. P. 2006. Plant pathogenic Ralstonia species. Pages 573-644 in: Plant-associated bacteria. S. S. Gnanamanickam, ed. Springer Publishing, Dordrecht, The Netherlands.

Denny, T. P. and Hayward, A. C. 2001. Gram-negative bacteria: Ralstonia. Pages 151-174 in: Laboratory guide for identification of plant pathogenic bacteria, 3rd ed. Schaad, N. W., Jones, J. B., and Chun, W., eds. APS Press, St. Paul, MN.

Elphinstone, J. G. 2005. The current bacterial wilt situation: A global overview. Pages 9-28 in: Bacterial Wilt: The Disease and the Ralstonia solanacearum Species Complex. C. Allen, P. Prior, and A. C. Hayward, eds. American Phytopathological Society, St. Paul, MN.

Elphinstone, J. G., Hennessey, J., Wilson, J. K., and Stead, D. E. 1996. Sensitivity of different methods for the detection of Ralstonia solanacearum in potato tuber extracts. EPPO Bull. 26:663-678.

Fegan, M., and Prior, P. 2005. How complex is the "Ralstonia solanacearum species complex"? Pages 449-461 in: Bacterial Wilt Disease and the Ralstonia solanacearum Species Complex. C. Allen, P. Prior, and A. C. Hayward, eds. American Phytopathological Society, St. Paul, MN.

Floyd, J. 2008. New Pest Response Guidelines: Ralstonia solanacearum race 3 biovar 2. USDA–APHIS–PPQ–Emergency and Domestic Programs, Riverdale, Maryland. http://www.aphis.usda.gov/import_export/plants/manuals/index.shtml.

Hanson, P. M., Wang, J. F., Licardo, O., Hanudin, Mah, S. Y., Hartman, G. L., Lin, Y. C., and Chen, J. T. 1996. Variable reactions of tomato lines to bacterial wilt evaluated at several locations in Southeast Asia. HortScience 31:143-146.

Hayward, A. C. 1991. Biology and epidemiology of bacterial wilt caused by Pseudomonas solanacearum. Ann. Rev. Phytopathol. 29:65-87.

Ji, P., Momol, T., Olson, S., Meister, C., Norman, D., and Jones, J. 2007. Evaluation of phosphorous acid-containing products for managing bacterial wilt of tomato. Phytopathology 97:S52.

Ji, P., Momol, M. T., Olson, S. M., and Pradhanang, P. M. 2005. Evaluation of thymol as biofumigant for control of bacterial wilt of tomato under field conditions. Plant Dis. 89:497-500.

Kelman, A. 1954. The relationship of pathogenicity of Pseudomonas solanacearum to colony appearance in a tetrazolium medium. Phytopathology 44:693-695.

Kim, S. H., Olson, T. N., Schaad, N. W., and Moorman, G. W. 2003. Ralstonia solanacearum Race 3, biovar 2, the causal agent of brown rot of potato, identified in geranium in Pennsylvania, Delaware, and Connecticut. Plant Dis. 87:450.

Lambert, C. D. 2002. Agricultural Bioterrorism Protection Act of 2002: Possession, Use, and Transfer of Biological; Agents and Toxins; Interim and Final Rule (7 CFR Part 331). Federal Register 67:76908-76938.

Lemay, A., Redlin, S., Fowler, G., and Dirani, M. 2003. Pest data sheet: Ralstonia solanacearum race 3 biovar 2. Published Feb., 12. USDA-APHIS-PPQ. Center for plant health science and technology. Plant epidemiology and risk analysis laboratory, Raleigh, NC.

McCarter, S. M. 1991. Bacterial wilt. Pages 28-29 in: Compendium of tomato diseases. Jones, J. B., Jones, J. P., Stall, R. E., and Zitter, T. A., eds. APS Press Publisher: St. Paul, MN.

Momol, T., Ji, P., Jones, J., and Olson, S. 2005. Recommended management strategies for bacterial wilt on tomato caused by Ralstonia solanacearum. NFREC Extension Report No: 2005-8.

Pradhanang, P.M., Ji, P., Momol, M.T., Olson, S.M., Mayfield, J. L. and Jones, J.B. 2005. Application of acibenzolar-S-methyl enhances host resistance in tomato against Ralstonia solanacearum. Plant Dis. 89: 989-993.

Prior, P., and Fegan, M. 2005. Recent developments in the phylogeny and classification of Ralstonia solanacearum. Acta Hort. 695:127-136.

Saddler, G. S. 2005. Management of bacterial wilt disease. Pages 121-132 in: Bacterial Wilt Disease and the Ralstonia solanacearum Species Complex. C. Allen, P. Prior, and A. C. Hayward, eds. American Phytopathological Society, St. Paul, MN.

Wang, J. F., Hanson, P., and Barnes, J. A. 1998. Worldwide evaluation of an international set of resistance sources to bacterial wilt in tomato. Pages 269-275 in: Bacterial Wilt Disease: Molecular and Ecological Aspects. P. Prior, C. Allen, and J. Elphinstone, eds. Springer Verlag, Berlin, Germany.

Williamson, L., Hudelson, B. D., and Allen, C. 2002. Ralstonia solanacearum strains isolated from geranium belong to Race 3 and are pathogenic on potato. Plant Dis. 86:987-991.

THE ECONOMIC IMPACT OF BACTERIAL LEAF SPOT ON THE TOMATO INDUSTRY

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Bacterial spot on tomatoes is a serious disease that is caused by a mobile bacterium *Xanthomonas campestris pv. vesicatoria* (Xcv). Disease development is favored by temperatures of 24-32˚C, high humidity and rain (Momol et al., 2008). Disease symptoms include dark brown and circular spots on the leaves, stems and fruit spurs. Fruit lesions caused by the disease will cause the fruit to not be marketable. The disease causes serious problems every year on tomatoes in Florida.

Bacterial spot will impact the productivity of the crop and could result in additional expenses to control its development. The impact of this disease is significant given the regularity with which it impacts the Florida tomato industry and the severity of its impact in fields that suffer from it. It could have effects that range from a modest impact on marketable fruit yield to total plant collapse and total crop loss. It is important to understand these impacts to estimate the severity of the disease and the potential returns to programs that lead to its control. It is important that growers understand the risk associated with this disease and the impact the disease can have on the profitability of their farming operation.

This research estimates the impact of bacterial spot on tomatoes for a representative farm in southwest Florida. Budgets developed at the University of Florida (VanSickle et al., 2009) were used to model a farm that grows 272 acres of fresh-market, round tomatoes. This representative farm model is a risk-based model that accounts for risk associated with yield and price. For this project, the risk that bacterial spot adds to yield risk is accounted for by estimating the incidence and impact of bacterial spot on farms in southwest Florida from the 1998/99 to 2007/08 seasons. Those disease incidence measures are then correlated with yield to develop the risk-based model that is used to estimate the impact of bacterial spot on the returns to growing tomatoes over a 10 year period. The model allows us to estimate a baseline for an operation that does not suffer from bacterial spot and to compare actual experience with that baseline.

REPRESENTATIVE FARM MODEL

A representative farm model for a grower of fresh-market, round tomatoes in southwest Florida was developed to assess the impact of bacterial spot in Florida. The model was developed using Simetar© (Richardson, et al., 2006), an Excel add-in that was developed explicitly for stochastic simulation modeling. Here, Simetar is used to model the representative activities of a Florida tomato grower located in Southwest Florida. The model simulates the farm's financial results over a ten-year period based on production costs estimated by VanSickle and Smith (2009) for a fall tomato crop of 272 acres. This grower is expected to incur variable costs of $6,400.52 for growing tomatoes in 2007/08 and harvest and marketing costs of $5,235 per acre for a yield of 1,500 25-lbs cartons per acre. Based on annual cash operating and fixed costs and expected prices and yields an annual income statement, an annual cash flow statement, and balance sheets are forecast. Since this is a stochastic simulation, pseudo-random prices and yields are drawn from a multivariate empirical distribution. The random yields and prices are correlated based on historical correlations. Yields are estimated for the simulation based on recorded yields as reported by a grower who produced on 19 different fields in southwest Florida from 1998/99 to 2007/08. Because fields were not always planted and also because of missing data, the total number of observations provided by the grower was 71. The grower also provided scouting data for the incidence of bacterial spot in the fields over the course of the crop in each of these fields. The data allowed us to estimate a probability distribution function for bacterial spot in fresh market tomatoes and to correlate bacterial spot with yields within those fields.

The scouting data provided by the grower provided a measure of incidence and severity for bacterial spot in the fields. A Bacterial Spot (BS) index of 0 to 5 was used to measure the severity of bacterial spot incidence in the field (Table 1). The index corresponds to the Horsfall Barrattt scale for measuring plant disease (Horsfall and Barrett, 1945). Weekly measures were observed for 1 to 6 weeks after planting. These measures were used to estimate a slope coefficient for the spread of bacterial spot in the field over the first six weeks after planting. The slope coefficients ranged in value from -0.0002 (meaning a small incidence was reported that was not present at the end of the six weeks) to 0.614, with an average value of 0.2174. Yield data in the fields ranged from 483 to 2,319 25-lbs cartons per acre, with an average yield over this period of 1,454 cartons/acre.

TABLE 1. Bacterial spot index as related to the Horsfall Barratt (HB) scale for measuring the incidence of plant disease.

BS Index	HB Scale	Relative Leaf Area Affected (%)
0	1	0
0.25 - 1	2	0 to 3
1.25-1.5	3	3 to 6
1.75-2	4	6 to 12
2.25-2.5	5	12 to 25
2.75-3.25	6	25 to 50
3.5-3.75	7	50 to 75
4	8	75 to 87
4.25-4.5	9	87 to 94
4.75-5	10	94 to 97
5	11	97 to 100
5	12	100

Correlation coefficients were estimated for yield with both the slope coefficient and the absolute scouting index measure for the sixth week after planting. The correlation coefficient for the slope measure was -0.397 while the correlation coefficient for the sixth week scouting index measure was -0.416. For purposes of the impact analysis the sixth week scouting measure was used to simulate the inci-

dence and severity of bacterial spot.

Prices for fresh market tomatoes are modeled from price data for southwest Florida provided by the Florida Tomato Committee (Florida Tomato Committee, Annual Reports 1999 – 2008). A probability distribution function for price was estimated from this data and correlated with yields to produce price and yield estimates for a simulation of the grower's returns over a 10 year horizon given the state of technology that evolved from 1998/99 to 2007/08.

The simulation provides an estimate of the net worth provided by growing tomatoes given the current state of technology and incidence of bacterial spot. The model is then altered to remove the incidence of bacterial spot to provide an estimate of net worth should the farmer operate with no risk associated with bacterial spot. The difference between the simulations provides an estimate of the cost of bacterial spot within this representative farm.

RESULTS

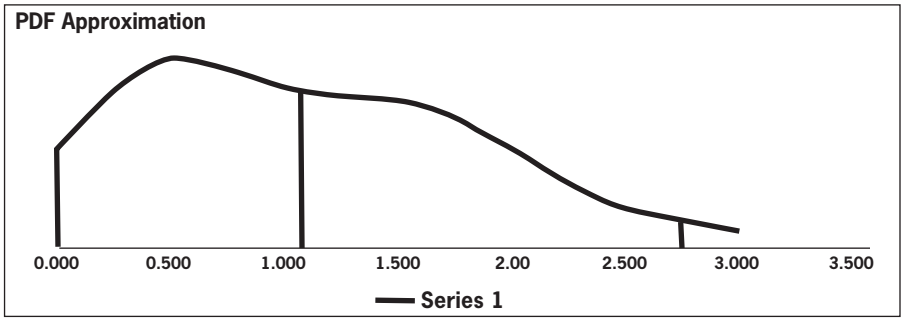
A simple regression of yield on trend and the sixth week scouting measure indicates that yields will decrease by 214.7 cartons per acre for each unit increase in the sixth week scouting index for bacterial spot (Table 1). The average bacterial spot measure in this data is 1.05 (Fig. 1), indicating that bacterial spot has caused an average decrease in yields of 225 cartons per acre over the period 1998/99 to 2007/08 (equal to the BS scout parameter 214.7 multiplied by the average BS index observation of 1.05). Given average prices of $13.71/25-lb carton experienced in 2007/08, the total revenues lost from this type of impact was $3,090 per acre. A representative grower with 272 acres who experienced an average incidence of bacterial spot in 2007/08 lost $892,704 in total revenues from this disease.

The simulation for the 272 acre farm that grows tomatoes with the risk of bacterial spot continuing shows that the change in the net present value of net worth is expected to be a loss of $172,190. The model indicates that there is an 87% probability that this grower will lose net worth if he continues to grow 272 acres over the next 10 years. If the risk of bacterial spot is eliminated, then that expected loss in net worth is reduced to $51,037, a gain of $121,190 for this representative grower. The risk of losing net worth is still significant at 62%, but the probability is lowered by 25% as a result of removing bacterial spot as a threat.

TABLE 2. Regression results for field yield regressed on sixth week bacterial spot index.

Coefficient	Parameter estimate	Standard error	t-test
Intercept	1,675	74.7	22.43
BS Index	-214.7	57.2	-3.75
R^2	0.173		

FIGURE 1. Probability distribution for observed bacterial spot (BS) index for farm operating in southwest Florida.



The simulation was also used to evaluate the investment that could be made to eliminate the threat of bacterial spot in tomatoes. The model was run with increased costs where the threat of bacterial spot is eliminated, but where the financial result (change in net worth) is the same as with the threat of bacterial spot. The results indicate that a farm could invest as much as $537.50 per acre in technology and production practices to eliminate the threat of bacterial spot, with the expected outcome on net worth as good as or better than it is without any new technology or production practice that eliminates the threat that exists today.

CONCLUSIONS

Bacterial spot is a serious threat to fresh tomato growers in Florida. The objective of this study was to estimate the cost of bacterial spot to a representative tomato grower in southwest Florida. A stochastic farm level simulation model was used to model the production and financial activities of a representative grower over a ten-year horizon, using production budgets developed from growers in southwest Florida, and scouting data for incidence of bacterial spot on farms in southwest Florida. The results suggest there is an incentive to implement production practices and technology that could control the incidence of bacterial spot in tomato production. A farm could absorb up to $537.50 in added production costs to control bacterial spot and be equally as well off as they are without that investment. Not only will the farmer likely experience an increase in net worth as a result of technology that controls bacterial spot, but the risk of suffering negative returns in the operation would be diminished with this technology. The results indicate that the threat of losing net worth in the operation is reduced by 25% by eliminating the threat to this disease. ✻

ACKOWLEDGEMENT

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REFRENCES

Florida Tomato Committee. 1999-2008. "Florida tomato committee annual report", Florida Tomato Committee, Maitland, FL.

Horsfall, J.G. and R.W. Barratt. 1945. An improved grading system for measuring plant disease (abstract). Phytopathology 35:655.

Momol, T., J. Jones, S. Olson, A. Obradovic, B. Balogh and P. King. 2008. Integrated management of bacterial spot on tomato in Florida." UF/IFAS EDIS PP192. Gainesville, FL.

Richardson J.W., K.D. Schumann, and P.A. Feldman. 2006. Simetar© simulation for applied risk management, Version 2006 Texas A&M University, College Station, TX.

VanSickle, John, Scott Smith and Eugene McAvoy. 2009. Production budget for tomatoes in the Southwest Florida area, 2007/08. UF/IFAS EDIS (submitted), Gainesville, FL.

IDENTIFICATION OF WEED RESERVOIRS OF TOMATO YELLOW LEAF CURL VIRUS IN FLORIDA

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The recognition of wild plant reservoirs can be a very important component of the management of plant viruses. The role and relative importance of weed reservoirs in virus ecology varies with the virus, the crop and the location. The ecology of Tomato Yellow Leaf Curl virus (TYLCV), a virus which appeared in Florida in 1997 (Polston et al., 1997), is not well understood. The whitefly vector has a very wide reported range of plants upon which it will feed (more than 500 plant species). While we do know that there are alternative crop hosts for TYLCV, we do not know if wild plant species play any role as reservoirs. This information is important for the improvement of the management of TYLCV. One option that has been proposed is a crop-free period in the summer, between the spring and fall crops. This crop-free period will not be effective if there are wild plant species present during the summer that will serve as reservoirs of TYLCV.

We conducted a survey of possible TYLCV reservoirs and collected plants in 2008-2009. This is a challenging project because there are hundreds of wild plant species in the Manatee-Hillsborough Counties area. Many species are widely dispersed. In addition, we are expecting that only a small percent of the plants of a susceptible species would be infected. To focus our collection and keep within the budget allotted, we did not collect from grasses or plants known not to be hosts of the whitefly vector. Most of the plant species were selected based on their ability to serve as hosts for whiteflies, and/or the presence of virus-like symptoms. We were looking for plants that could serve as sources of virus for young tomato plants. Different species of wild plants are present at different times of the year so we collected samples from plants at the early part of the spring season, and then at the end of the spring season in the Ruskin tomato production region. Five sites in Manatee Co. and one in Hillsborough Co. were sampled. Plants were sampled in and around tomato fields and came from the following types of locations: tomato field, ditch bank, edges of tomato fields, edges of other fields, woody field edge, fallow fields, and fence rows. The sites selected were those where we had observed TYLCV-infected tomatoes early in the season, and therefore where it was likely a weed host might exist.

RESULTS TO DATE

Samples were collected, identified, and frozen for laboratory analyses for the presence of TYLCV. All samples were assayed for the presence of TYLCV using a nucleic acid spot hybridization assay (NASHA). Briefly, nucleic acid was extracted from frozen samples, blotted onto nylon membranes, and hybridized with a radioactively-labeled probe made from the genome of TYLCV. While this assay allows the rapid processing of many samples, it is known to give false positive results, especially on plant samples that have a lot of latex and polysaccharides (present in many tropical wild plants). Therefore, the more specific and sensitive polymerase chair reaction (PCR) using primers which will amplify TYLCV, was conducted on all samples that gave a positive result in the NASHA. DNA was extracted from samples that were positive in the dot spot assay and a PCR was run using appropriate primers. Samples positive by this assay will be retested using a different set of primers to confirm the first results.

Between February 2008 and February 2009, we collected 1,920 plants from 45 known species of wild plants from 15 different plant families (Table 1). We are in the process of identifying the species of approximately 227 of those samples. All of the samples have been tested by NASHA for the presence of TYLCV. Approximately 326 samples gave a positive result in the NASHA. Of those 103 have already been tested by PCR and the rest are in the process of being tested. TYLCV was not detected in any of the plants tested. We conclude that the samples which were positive by NASHA were probably the result of non-specific binding of the probe to the sample.

This study will be completed within the next few months. As of today, we do not have any evidence that would suggest that there is a wild plant species that is an important reservoir for TYLCV in the summer months. If our data continue along this trend, it would suggest that there are no obvious impediments, in terms of wild plant species, to the success of a tomato-free period. This is not to say that there are no wild plant hosts, since our study was not exhaustive, but that we did not find any likely candidates. At this point, it might be worth implementing a host free period in the summer months on a trial basis. ✻

REFERENCE

Polston, J.E., R. J. McGovern, and L.G. Brown. 1999. Introduction of Tomato yellow leaf curl virus in Florida and implications for the spread of this and other geminiviruses of tomato. Plant Disease 83:984-988.

TABLE 1. Wild plants sampled from the fields and tested for presence of TYLCV in and around tomato fields in Manatee and Hillsborough Counties, Florida.

Family	Species	Common Name	County	No. of Samples Tested	No. Positive by NASHA
Amaranthaceae	*Amaranthus viridis*	Slender amaranth	Manatee	40	10
	Amaranthus. spp.			10	0
Anacardiaceae	*Schinus terebinthifolius*	Brazilian pepper	Manatee	20	0
Asteraceae	*Ambrosia artemisiifolia*	Common ragweed	Manatee	50	0
	Bidens pilosa L.	Spanish needle	Manatee, Hillsborough	170	0
	Bidens spp.		Manatee	61	0
	Heterotheca subaxillaris	Camphorweed	Manatee	40	0
	Lactuca canadensis	Wild lettuce	Manatee	20	0
	Pseudognaphalium sp.	cudweed	Manatee	20	0
Chenopodiaceae	*Chenopodium album L.*	Lambs quarters	Manatee	19	0
	C. ambrosioides L.	Mexican tea	Manatee	80	0
	C. sp.	chenopodium	Manatee	40	0
Commelinaceae	*Commelina diffusa Burm. f.*	Spreading dayflower	Manatee	20	0
Euphorbaceae	*Euphorbia hirta L.*	Garden spurge	Manatee	10	0
	Euphorbia spp.	spurge	Manatee	40	0
	Poinsettia cyanthophero (Murray) Bartling	Wild poinsettia	Manatee	30	0
	Ricinus communis L.	Castorbean	Manatee	14	0
Fabaceae	*Crotalaria spectabilis Roth*	showy crotalaria	Manatee	10	0
	Indigofera hirsuta L.	Hairy indigo	Manatee, Hillsborough	127	71
	Melilotus alba	White sweet clover	Manatee	40	0
	Phaseolus sp.	(narrow leaf) phasebean		20	0
	Phaseolus sp.	(broad leaf) phasebean		10	7
	Sesbania sp. Scop	Hemp sesbania	Manatee	71	40
	Trifolium sp.	Clover sp.	Manatee	21	0
Lythraceae	*Lagerstroemia sp.*	Crape myrtle	Manatee	11	0
Malvaceae	*Abutilon permolle*	coastal indian mallow	Manatee	7	0
	Abutilon sp.	Indian mallow	Manatee	20	0
	Sida spinosa L.	Sida	Manatee	31	0
	S. rhombifolia L.	Indian hemp	Manatee	20	1
	Sida. sp.	Sida	Manatee, Hillsborough	50	0
	Urena lobata	Caesar-weed	Manatee	111	23
Myricaceae	*Myrica cerifera*	wax myrtle	Manatee	5	4
Onagraceae	*Ludwigia peruviana*	Primrose willow	Manatee, Hillsborough	70	20
	Ludwigia spp.“	“	Hillsborough	63	26
	Oenothera laciniata	Cutleaf primrose	Manatee	60	3
Polygonaceae	*Rumex crispus*	curly dock	Manatee	20	20
Rubiaceae	*Richardia brasiliensis*	Brazilian pusley	Manatee	30	0
	R. scabra L.	Florida pusley	Manatee, Hillsborough	65	10
Solanaceae	*Physalis spp.*		Manatee	20	0
	Solanum americanum Mill.	Nightshade	Manatee	42	0
	Solanum esculentum L.	Cultivated tomato	Manatee	10	10
	S. ptycanthum Dun.	Eastern nightshade	Manatee	21	0
	S. viarum Dunal	Tropical soda apple	Manatee	10	0
Verbenaceae	*Lantana sp.*	Lantana	Manatee	28	0
	Phyla nodiflora	Mat lippia	Manatee	10	0
Unknown	Unknown	unknown	Manatee	233	80

TOMATO VARIETIES FOR FLORIDA

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Variety selections, often made several months before planting, are one of the most important management decisions made by the grower. Failure to select the most suitable variety or varieties may lead to loss of yield or market acceptability. The following characteristics should be considered in selection of tomato varieties for use in Florida.

Yield. The variety selected should have the potential to produce crops at least equivalent to varieties already grown. The average yield in Florida is currently about 1400 25-pound cartons per acre. The potential yield of varieties in use should be much higher than average.

Disease Resistance. Varieties selected for use in Florida must have resistance to Fusarium wilt, race 1, race 2 and in some areas race 3; Verticillium wilt (race 1); Gray leaf spot; and some tolerance to Bacterial soft rot. Available resistance to other diseases may be important in certain situations, such as Tomato Yellow Leaf Curl in south and central Florida and Tomato spotted wilt and Bacterial wilt resistance in northwest Florida.

Horticultural Quality. Plant habit, stem type and fruit size, shape, color, smoothness and resistance to defects should all be considered in variety selection.

Adaptability. Successful tomato varieties must perform well under the range of environmental conditions usually encountered in the district or on the individual farm.

Market Acceptability. The tomato produced must have characteristics acceptable to the packer, shipper, wholesaler, retailer and consumer. Included among these qualities are pack out, fruit shape, ripening ability, firmness, and flavor.

CURRENT VARIETY SITUATION

Many tomato varieties are grown commercially in Florida, but only a few represent most of the acreage. In years past we have been able to give a breakdown of which varieties are used and predominantly where they were being used but this information is no longer available through the USDA Crop Reporting Service.

TOMATO VARIETY TRIAL RESULTS

Table 1 shows results of Spring 2008 tomato trial conducted at the North Florida Research and Education Center.

TOMATO VARIETIES FOR COMMERCIAL PRODUCTION

The following varieties are currently popular with Florida growers or have done well in university trials. It is by no means a comprehensive list of all varieties that may be adapted to Florida conditions. Growers should try new varieties on a limited basis to see how they perform for them.

LARGE-FRUITED TOMATO VARIETIES

Amelia. Vigorous determinate, main season, jointed hybrid. Fruit are firm and aromatic suitable for green or vine ripe. Good crack resistance. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2,3), root-knot nematode , Gray leaf spot and Tomato spotted wilt. (Harris Moran).

Bella Rosa. Midseason maturity. Heat tolerant determinate type. Produces large to extra-large, firm, uniformly green and globe shaped fruit. Variety is well suited for mature green or vine-ripe production. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Tomato spotted wilt. (Sakata)

BHN 586. Midseason maturity. Fruit are large to extra-large, deep globed shaped with firm, uniform green fruits well suited for mature green or vine-ripe production. Determinate, medium to tall vine. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2) Fusarium crown rot and root-knot nematode. (BHN)

BHN 602. Early-midseason maturity. Fruit are globe shape but larger than BHN 640, and green shouldered. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2,3) and Tomato spotted wilt. (BHN).

BHN 640. Early-midseason maturity. Fruit are globe shape but tend to slightly elongate, and green shouldered. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2,3) and Tomato spotted wilt. (BHN).

Crista. Midseason maturity. Large, deep globe fruit with tall robust plants. Does best with moderate pruning and high fertility. Good flavor, color and shelf-life. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2,3), Tomato spotted wilt and root-knot nematode. (Harris Moran)

Crown Jewel. Uniform fruit have a deep oblate shape with good firmness, quality and uniformly-colored shoulders. Determinate with medium-tall bush. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2) Fusarium crown rot, Alternaria stem canker and Gray leaf spot. (Seminis)

Fletcher. Midseason maturity. Large, globe to deep oblate fruit with compact plants. Does best with moderate pruning and high fertility. Good flavor, color and shelf-life. For vine ripe use only due to nipple characteristic on green fruit. Replacement for 'Mountain Spring' where Tomato spotted wilt is a problem. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2,3), Tomato spotted wilt and root-knot nematode.

Flora-Lee. It was released for the premium tomato market. A midseason, determinate, jointed hybrid with moderate heat-tolerance. Fruit are uniform green with a high lycopene content and deep red interior color due to the crimson gene. Resistant: Fusarium wilt (race 1,2,3), Verticillium wilt (race 1), and Gray leaf spot. For Trial.

Florida 47. A late midseason, determinate, jointed hybrid. Uniform green, globe-shaped fruit. Resistant: Fusarium wilt (race 1,2), Verticillium wilt (race 1), Alternaria stem canker, and Gray leaf spot. (Seminis).

Florida 91. Uniform green fruit borne on jointed pedicels. Determinate plant. Good fruit setting ability under high temperatures. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Alternaria stem canker, and Gray leaf spot. (Seminis)

HA 3073. A midseason, determinate, jointed hybrid. Fruit are large, firm, slightly oblate and are uniformly green. Resistant: Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Gray leaf spot, Tomato yellow leaf Curl and Tomato mosaic. (Hazera)

Linda. Main season. Large round, smooth, uniform shouldered fruit with excellent firmness and a small blossom end scar. Strong determinate bush with good cover. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Alternaria stem canker and Gray leaf spot. (Sakata)

Phoenix. Early mid-season. Fruit are large to extra-large, high quality, firm, globe-shaped and are uniformly-colored. "Hot-set" variety. Determinate, vigorous vine with good leaf cover for fruit protection. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Alternaria stem canker and Gray leaf spot. (Seminis)

Quincy. Full season. Fruit are large to extra-large, excellent quality, firm, deep oblate shape and uniformly colored. Very strong determinate plant. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Alternaria stem canker, Tomato spotted wilt and Gray leaf spot. (Seminis)

RPT 6153. Main season. Fruit have good eating quality and fancy appearance in a large sturdy shipping tomato and are firm enough for vine-ripe. Large determinate plants. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2) and Gray leaf spot. (Seedway)

Sanibel. Main season. Large, firm, smooth fruit with light green shoulder and a tight blossom end. Large determinate bush. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), root-knot nematodes, Alternaria stem canker and Gray leaf spot. (Seminis)

Sebring. A late midseason determinate, jointed hybrid with a smooth, deep oblate, firm, thick walled fruit. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2,3), Fusarium crown rot and Gray leaf spot. (Syngenta)

SecuriTY 28. An early season determinate variety with a medium vine and good leaf cover adapted to different growing conditions. Produces extra large, round and firm fruit. Resistant: Alternaria stem canker, Fusarium wilt (race 1 and 2), Gray leaf spot, Tomato yellow leaf curl and Verticillium wilt (race 1). (Harris Moran)

Solar Fire. An early, determinate, jointed hybrid. Has good fruit setting ability under high temperatures. Fruit are large, flat-round, smooth, firm, light green shoulder and blossom scars are smooth. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1, 2 and 3) and gray leaf spot. (Harris Moran)

Solimar. A midseason hybrid producing globe-shaped, green shouldered fruit. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), Alternaria stem canker, gray leaf spot. (Seminis).

Soraya. Full season. Fruit are high quality, smooth and tend toward large to extra-large. Continuous set. Strong, large bush. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2,3), Fusarium crown rot and Gray leaf spot. (Syngenta, Rogers Seed)

Talladega. Midseason. Fruit are large to extra-large, globe to deep globe shape. Determinate bush. Has some hot-set ability. Performs well with light to moderate pruning. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Tomato spotted wilt and Gray leaf spot. (Syngenta, Rogers Seed)

Tygress. A midseason, jointed hybrid producing large, smooth firm fruit with good packouts. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), gray leaf spot, Tomato mosaic and Tomato yellow leaf curl. (Seminis).

PLUM-TYPE TOMATO VARIETIES

BHN 410. Midseason. Large, smooth, blocky, jointless fruit tolerant to weather cracking. Compact to small bush with concentrated high yield. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Bacterial speck (race 0) and Gray leaf spot. (BHN Seed)

BHN 411. Midseason. Large, smooth, jointless fruit is tolerant to weather cracks and has reduced tendency for graywall. Compact plant with concentrated fruit set. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Bacterial speck (race 0) and Gray leaf spot. (BHN Seed)

BHN 685. Midseason. Large to extra-large, deep blocky, globe shaped fruit. Determinate, vigorous bush with no pruning recommended. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2,3) and Tomato spotted wilt. (BHN Seed)

Mariana. Midseason. Fruit are predominately extra-large and extremely uniform in shape. Fruit wall is thick and external and internal color is very good with excellent firmness and shelf life. Determinate, small to medium sized plant with good fruit set. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), root-knot nematode, Alternaria stem canker and tolerant to Gray leaf spot. (Sakata)

Monica. Midseason. Fruit are elongated, firm, extra-large and uniform green color. Vigorous bush with good cover. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Bacterial speck (race 0) and Gray leaf spot. (Sakata)

Plum Dandy. Medium to large determinate plants. Rectangular, blocky, defect-free fruit for fresh-market production. When grown in hot, wet conditions, it does not set fruit well and is susceptible to bacterial spot. For winter and spring production in Florida. Resistant: Verticillium wilt, Fusarium wilt (race 1), Early blight, and rain checking. (Harris Moran).

Sunoma. Main season. Fruit are medium-large, elongated and cylindrical. Plant maintains fruit size through multiple harvests. Determinate plant with good fruit cover. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Bacterial speck (race 0), root-knot nematodes, Tomato mosaic and Gray leaf spot. (Seminis)

CHERRY-TYPE TOMATO VARIETIES

BHN 268. Early. An extra firm cherry tomato that holds, packs and ships well. Determinate, small to medium bush with high yields. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1). (BHN Seed)

Camelia. Midseason. Deep globe, cocktail-cherry size with excellent firmness and long shelf life. Indeterminate bush. Outdoor or greenhouse production. Verticillium wilt (race 1), Fusarium wilt (race

TABLE 1. Tomato variety trial results, Spring, 2008. North Florida Research and Education Center, Quincy, FL.[z]

Entry	Source	Marketable Yield (25lb cartons/A) Extra Large	Extra Large	Marketable (%)	Fruit Size (oz)
Tous 91	Hazera Seeds	2108 a	2179 a	75.9 a-c	8.4 a
Inbar	Hazera Seeds	1365 b	1996 a	75.7 a-c	6.0 de
BHN 602	BHN	1001 b-d	1478 b	77.2 a	6.0 de
*Quincy	Seminis	912 c-e	1463 bc	77.7 a	6.0 de
Fla. 8363	GCREC	1147 bc	1438 bc	78.1 a	6.5 b-d
NC 086	NCS	928 c-e	1280 b-d	70.4 a-d	6.1 c-e
Finishline	Syngenta	928 c-e	1225 b-d	71.1 a-d	6.5 b-d
Nico	Harris Moran	792 c-e	1216 b-d	71.1 a-d	5.7 e
Red Defender	Harris Moran	811 c-e	1215 b-d	73.1 a-d	6.1 c-e
NC 07246	NCS	893 c-e	1198 b-d	76.5 ab	6.2 c-e
Amelia	Harris Moran	903 c-e	1186 b-d	74.5 a-d	6.2 c-e
Mountain Glory	NCS	834 c-e	1148 b-d	72.5 a-d	6.2 c-e
Redline	Syngenta	874 c-e	1139 b-d	74.9 a-d	6.3 c-e
SecuriTY 28	Harris Moran	890 c-e	1058 b-d	72.2 a-d	7.1 b
Fla. 8153	GCREC	653 d-f	1029 b-d	72.7 a-d	5.7 e
NC 07235	NCS	666 d-f	1014 b-d	73.0 a-d	5.7 e
Fla. 8612	GCREC	836 c-e	995 cd	75.1 a-c	6.8 bc
Fletcher	NCS	692 d-f	992 cd	72.6 a-d	5.9 de
Bella Rosa	Sakata	700 d-f	923 de	67.4 b-d	6.3 c-e
NC 0694	NCS	553 ef	894 de	70.3 a-d	5.7 e
Crista	Harris Moran	501 ef	802 de	71.1 a-d	5.7 e
Florida 47	Seminis	326 f	496 e	66.8 cd	5.9 de
Fla. 8413	GCREC	308 f	492 e	65.6 d	5.8 e

[z] Mean separation by Duncan's Multiple Range Test, 5% level. Comments: In-row spacing 20 inches, 6-ft between-row spacing. Trickle irrigation under blackpolyethylene mulch. Fertilizer applied 196-56-196 lb/A N-P205-K20. Seeded: 18 February, transplanted: 7 April, 3 harvests between 24 June and 9 July.

1) and Tobacco mosaic. (Siegers Seed)

Cherry Blossom. 70 days. Large cherry, holds and yields well. Determinate bush. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1,2), Bacterial speck (race 0), root-knot nematodes, Alternaria stem canker and Gray leaf spot. (Seedway)

Mountain Belle. Vigorous, determinate type plants. Fruit are round to slightly ovate with uniform green shoulders borne on jointless pedicels. Resistant: Fusarium wilt (race 2), Verticillium wilt (race 1). (Syngenta Rogers Seed).

Shiren. Compact plant with high yield potential and nice cluster. Resistant: Fusarium wilt (race 1,2), root-knot nematodes and Tomato mosaic. (Hazera)

Super Sweet 100 VF. Produces large clusters of round uniform fruit with high sugar levels. Fruit somewhat small and may crack during rainy weather. Indeterminate vine with high yield potential. Resistant: Verticillium wilt (race 1) and Fusarium wilt (race 1). (Siegers Seed, Seedway)

GRAPE-TYPE TOMATO VARIETIES

Brixmore. Very early. Indeterminate. Very uniform in shape and size, deep glossy red color with very high early and total yield. High brix and excellent firm flavor. Resistant: Verticillium wilt (race 1), root-knot nematodes and Tomato mosaic. (Harris Moran)

Cupid. Early. Vigorous, indeterminate bush. Oval-shaped fruit have an excellent red color and a sweet flavor. Resistant: Fusarium wilt (race 1,2), Bacterial speck (intermediate resistance race 0) and Gray leaf spot. (Seminis)

Jolly Elf. Early season. Determinate plant. Extended market life with firm, flavorful grape-shaped fruits. Average 10% brix. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 2) and cracking. (Siegers Seed, Seedway)

Red Grape. 68 days. Vigorous indeterminate bush. Firm excellent shaped fruit weighing 8-15 g.

Santa. 75 days. Vigorous indeterminate bush. Firm elongated grape-shaped fruit with outstanding flavor and up to 50 fruits per truss. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1), root-knot nematodes and Tobacco mosaic. (Thompson and Morgan)

St. Nick. Mid-early season. Indeterminate bush. Oblong, grape-shaped fruit with brilliant red color and good flavor. Up to 10% brix. (Siegers Seed)

Smarty. 69 days. Vigorous, indeterminate bush with short internodes. Plants are 25% shorter than Santa. Good flavor, sweet and excellent flavor. (Seedway)

Sweethearts. Indeterminate bush with intermediate internodes. Brilliant red, firm, elongated grape-shaped fruit. Matures between 70 and 75 days. Good flavor, crack-resistant and high brix. Resistant: Tobacco mosaic virus.

Tami G. Early season. Indeterminate, medium tall. Small fruits with nice shape. ✻

WATER MANAGEMENT FOR TOMATO

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Water and nutrient management are two important aspects of tomato production in all production systems. Water is used for wetting the fields before land preparation, transplant establishment, and irrigation. The objective of this article is to provide an overview of recommendations for tomato irrigation management in Florida. Irrigation management recommendations should be considered together with those for fertilizer and nutrient management.

Irrigation is used to replace the amount of water lost by transpiration and evaporation. This amount is also called crop evapotranspiration (ETc). Irrigation scheduling is used to apply the proper amount of water to a tomato crop at the proper time. The characteristics of the irrigation system, tomato crop needs, soil properties, and atmospheric conditions must all be considered to properly schedule irrigations. Poor timing or insufficient water application can result in crop stress and reduced yields from inappropriate amounts of available water and/or nutrients. Excessive water applications may reduce yield and quality, are a waste of water, and increase the risk of nutrient leaching.

A wide range of irrigation scheduling methods is used in Florida, which correspond to different levels of water management (Table 1). The recommended method to schedule irrigation for tomato is to use together an estimate of the tomato crop water requirement that is based on plant growth, a measurement of soil water status and a guideline for splitting irrigation (water management level 5 in Table 1; Table 2). The estimated water use is a guideline for irrigating tomatoes. The measurement of soil water tension is useful for fine tuning irrigation. Splitting irrigation events is necessary when the amount of water to be applied is larger than the water holding capacity of the root zone.

TABLE 1. Levels of water management and corresponding irrigation scheduling methods for tomato.

Water Management		Irrigation scheduling method
Level	Rating	
0	None	Guessing (no specific rule is followed to irrigate)
1	Very low	Using the "feel and see" method
2	Low	Using systematic irrigation (example: 2 hrs every day from transplanting to harvest)
3	Intermediate	Using a soil moisture measuring tool to start irrigation
4	Advanced	Using a soil moisture measuring tool to schedule irrigation and apply amounts based on a budgeting procedure
5	Recommended	Using together a water use estimate based on tomato plant stage of growth, a measurement of soil moisture, determining rainfall contribution to soil moisture, having a guideline for splitting irrigation and keeping irrigation records.

TABLE 2. Summary of irrigation management guidelines for tomato.

Irrigation management component	Irrigation system[z]	
	Seepage[y]	Drip[x]
1- Target water application rate	Keep water table between 18 and 24 inch depth	Historical weather data or crop evapotranspiration (ETc) calculated from reference ET or Class A pan evaporation
2- Fine tune application with soil moisture measurement	Monitor water table depth with observation wells	Maintain soil water tension in the root zone between 8 and 15 cbar
3- Determine the contribution of rainfall	Typically, 1 inch rainfall raises the water table by 1 foot	Poor lateral water movement on sandy and rocky soils limits the contribution of rainfall to crop water needs to (1) foliar absorption and cooling of foliage and (2) water funneled by the canopy through the plan hole.
4- Rule for splitting irrigation	Not applicable	Irrigations greater than 12 and 50 gal/100ft (or 30 min and 2 hrs for medium flow rate) when plants are small and fully grown, respectively are likely to push the water front being below the root zone
5-Record keeping	Irrigation amount applied and total rainfall received[w] Days of system operation	Irrigation amount applied and total rainfall received[w] Daily irrigation schedule

[z] Efficient irrigation scheduling also requires a properly designed and maintained irrigation systems
[y] Practical only when a spodic layer is present in the field
[x] On deep sandy soils
[w] Required by the BMPs

TOMATO WATER REQUIREMENT

Tomato water requirement (ETc) depends on stage of growth, and evaporative demand. ETc can be estimated by adjusting reference evapotranspiration (ETo) with a correction factor call crop factor (Kc; equation [1]). Because different methods exist for estimating ETo, it is very important to use Kc coefficients which were derived using the same ETo estimation method as will be used to determine ETc. Also, Kc values for the appropriate stage of growth and production system (Table 3) must be used.

By definition, ETo represents the water use from a uniform green cover surface, actively growing, and well watered (such as a turf or grass covered area). ETo can be measured on-farm using a small weather station. When daily ETo data are not available, historical daily averages of Penman-method ETo can be used (Table 4). However, these long-term averages are provided as guidelines since actual values may fluctuate by as much as 25%, either above the average on hotter and drier than normal days, or below the average on cooler or more overcast

TABLE 3. Crop coefficient estimates (Kc) for tomato[z].

Tomato Growth Stage	Corresponding Weeks After Transplanting[y]	Kc for Drip-Irrigated Crops
1	1-2	0.30
2	3-4	0.40
3	5-11	0.90
4	12	0.90
5	13	0.75

[z] Actual values will vary with time of planting, length of growing season and other site-specific factors. Kc values should be used with ETo values in Table 2 to estimated crop evapotranspiration (ETc)
[y] For a typical 13-week-long growing season

TABLE 4. Historical Penman-method reference ET (ETo) for four Florida locations (in gallons per acre per day)[z].

Month	Tallahassee	Tampa	West Palm Beach	Miami
January	1,630	2,440	2,720	2,720
February	2,440	3,260	3,530	3,530
March	3,260	3,800	4,340	4,340
April	4,340	5,160	5,160	5,160
May	4,890	5,430	5,160	5,160
June	4,890	5,430	4,890	4,890
July	4,620	4,890	4,890	4,890
August	4,340	4,620	4,890	4,620
September	3,800	4,340	4,340	4,070
October	2,990	3,800	3,800	3,800
November	2,170	2,990	3,260	2,990
December	1,630	2,170	2,720	2,720

[z] Assuming water application over the entire area with 100% efficiency

days than normal. As a result, SWT or soil moisture should be monitored in the field.

Eq. [1] Crop water requirement = Crop coefficient x Reference evapotranspiration

ETc = Kc x ETo

Tomato crop water requirement may also be estimated from Class A pan evaporation using:

Eq. [2] Crop water requirement = Crop factor x Class A pan evaporation

ETc = CF x Ep

Typical CF values for fully-grown tomato should not exceed 0.75 (Locascio and Smajstrla, 1996). A third method for estimated tomato crop water requirement is to use modified Bellani plates also known as atmometers. A common model of atmomter used in Florida is the ETgage. This device consists of a canvas-covered ceramic evaporation plate mounted on a water reservoir. The green fabric creates a diffusion barrier that controls evaporation at a rate similar to that of well water plants. Water loss through evaporation can be read on a clear sight tube mounted on the side of the device. Evaporation from the ETgage (ETg) was well correlated to ETo except on rainy days, but overall, the ETgage tended to underestimate ETo (Irmak et al., 2005). On days with rainfall less than 0.2 inch/day, ETo can be estimated from ETg as: ETo = 1.19 ETg. When rainfall exceeds 0.2 inch/day, rain water wets the canvas which interferes with the flow of water out of the atmometers, and decreases the reliability of the measurement.

TOMATO IRRIGATION REQUIREMENT

Irrigation systems are generally rated with respect to application efficiency (Ea), which is the fraction of the water that has been applied by the irrigation system and that is available to the plant for use. In general, Ea is 20% to 70% for seepage irrigation and 90% to 95% for drip irrigation. Applied water that is not available to the plant may have been lost from the crop root zone through evaporation, leaks in the pipe system, surface runoff, subsurface runoff, or deep percolation within the irrigated area. When dual drip/seepage irrigation systems are used, the contribution of the seepage system needs to be subtracted from the tomato irrigation requirement to calculate the drip irrigation need. Otherwise, excessive water volume will be systematically applied. Tomato irrigation requirement are determined by dividing the desired amount of water to provide to the plant (ETc), by Ea as a decimal fraction (Eq. [3]).

Eq. [3] Irrigation requirement = Crop water requirement / Application efficiency

IR = ETc/Ea

IRRIGATION SCHEDULING FOR TOMATO

For seepage-irrigated crops, irrigation scheduling recommendations consist of maintaining the water table near the 18-inch depth shortly after transplanting and near the 24- inch depth thereafter (Stanley and Clark, 2003). The actual depth of the water table may be monitored with shallow observation wells (Smajstrla, 1997).

Irrigation scheduling for drip irrigated tomato typically consists in daily applications of ETc, estimated from Eq. [1] or [2] above. In areas where real-time weather information is not available, growers use the "1,000 gal/acre/day/string" rule for drip-irrigated tomato production. As the tomato plants grow from 1 to 4 strings, the daily irrigation volumes increase from 1,000 gal/acre/day to 4,000 gal/acre/day. On 6-ft centers, this corresponds to 15 gal/100lbf/day and 60 gal/100lbf/day for 1 and 4 strings, respectively.

SOILS MOISTURE MEASUREMENT

Soil water tension (SWT) represents the magnitude of the suction (negative pressure) the plant roots have to create to free soil water from the attraction of the soil particles, and move it into its root cells. The dryer the soil, the higher the suction needed, hence, the higher SWT. SWT is commonly expressed in centibars (cb) or kiloPascals (kPa; 1cb = 1kPa). For tomatoes grown on the sandy soils of Florida, SWT in the rooting zone should be maintained between 6 (field capacity) and 15 cb.

The two most common tools available to measure SWT in the field are tensiometers and time domain reflectometry (TDR) probes, although other types of probes

are now available (Muñoz-Carpena, 2004). Tensiometers have been used for several years in tomato production. A porous cup is saturated with water, and placed under vacuum. As the soil water content changes, water comes in or out of the porous cup, and affects the amount of vacuum inside the tensiometer. Tensiometer readings have been successfully used to monitor SWT and schedule irrigation for tomatoes. However, because they are fragile and easily broken by field equipment, many growers have renounced to use them. In addition, readings are not reliable when the tensiometer dries, or when the contact between the cup and the soil is lost. Depending on the length of the access tube, tensiometers cost between $40 and $80 each. Tensiometers can be reused as long as they are maintained properly and remain undamaged.

It is necessary to monitor SWT at two soil depths when tensiometers are used. A shallow 6-inch depth is useful at the beginning of the season when tomato roots are near that depth. A deeper 12-inch depth is used to monitor SWT during the rest of the season. Comparing SWT at both depths is useful to understand the dynamics of soil moisture. When both SWT are within the 4-8 cb range (close to field capacity), this means that moisture is plentiful in the rooting zone. This may happen after a large rain, or when tomato water use is less than the irrigation applied. When the 6-inch-depth SWT increases (from 4-8 cb to 10-15cb) while SWT at 12-inch depth remains within 4-8 cb, the upper part of the soil is drying, and it is time to irrigate. If the 6-inch-depth SWT continues to rise above 25cb, a water stress will result; plants will wilt, and yields will be reduced. This should not happen under adequate water management.

A SWT at the 6-inch depth remaining with the 4-8 cb range, but the 12-inch depth reading showing a SWT of 20-25cb suggest that deficit irrigation has been made: irrigation has been applied to re-wet the upper part of the profile only. The amount of water applied was not enough to wet the entire profile. If SWT at the 12-inch depth continues to increase, then water stress will become more severe and it will become increasingly difficult to re-wet the soil profile. The sandy soils of Florida have a low water holding capacity. Therefore, SWT should be monitored daily and irrigation applied at least once daily. Scheduling irrigation with SWT only can be difficult at times. Therefore, SWT data should be used together with an estimate of tomato water requirement.

TABLE 5. Estimated maximum water application (in gallons per acre and in gallons/100lfb) in one irrigation event for tomato grown on 6-ft centers (7,260 linear bed feet per acre) on sandy soil (available water holding capacity 0.75 in/ ft and 50% soil water depletion). Split irrigations may be required during peak water requirement.

Wetting width (ft)	Gal/100ft to wet depth of 1 ft	Gal/100ft to wet depth of 1.5 ft	Gal/100ft to wet depth of 2 ft	Gal/acre to wet depth of 1 ft	Gal/acre to wet depth of 1.5ft	Gal/acre to wet depth of 2 ft
1.0	24	36	48	1,700	2,600	3,500
1.5	36	54	72	2,600	3,900	5,200

Time domain reflectometry (TDR) is another method for measuring soil moisture. The availability of inexpensive equipment ($400 to $550/unit) has recently increased the potential of this method to become practical for tomato growers. A TDR unit is comprised of three parts: a display unit, a sensor, and two rods. Rods may be 4 inches or 8 inches in length based on the depth of the soil. Long rods may be used in all the sandy soils of Florida, while the short rods may be used with the shallow soils of Miami-Dade county.

The advantage of TDR is that probes need not be buried permanently, and readings are available instantaneously. This means that, unlike tensiometers, TDR can be used as a hand-held, portable tool.

TDR actually determines percent soil moisture (volume of water per volume of soil). In theory, a soil water release curve has to be used to convert soil moisture in to SWT. However, because TDR provides an average soil moisture reading over the entire length of the rod (as opposed to the specific depth used for tensiometers), it is not practical to simply convert SWT into soil moisture to compare readings from both methods. Tests with TDR probes have shown that best soil monitoring may be achieved by placing the probe vertically, approximately 6 inches away from the drip tape on the opposite side of the tomato plants. For fine sandy soils, 9% to 15% appears to be the adequate moisture range. Tomato plants are exposed to water stress when soil moisture is below 8%. Excessive irrigation may result in soil moisture above 16%.

GUIDELINES FOR SPLITTING IRRIGATION

For sandy soils, a one square foot vertical section of a 100-ft long raised bed can hold approximately 24 to 30 gallons of water (Table 5). When drip irrigation is used, lateral water movement seldom exceeds 6 to 8 inches on each side of the drip tape (12 to 16 inches wetted width). When the irrigation volume exceeds the values in Table 5, irrigation should be split into 2 or 3 applications. Splitting will not only reduce nutrient leaching, but it will also increase tomato quality by ensuring a more continuous water supply. Uneven water supply may result in fruit cracking.

UNITS FOR MEASURING IRRIGATION WATER

When overhead and seepage irrigation were the dominant methods of irrigation, acre-inches or vertical amounts of water were used as units for irrigations recommendations. There are 27,150 gallons in 1 acre-inch; thus, total volume was calculated by multiplying the recommendation expressed in acre-inch by 27,150. This unit reflected quite well the fact that the entire field surface was wetted.

Acre-inches are still used for drip irrigation, although the entire field is not wetted. This section is intended to clarify the conventions used in measuring water amounts for drip irrigation. In short, water amounts are handled similarly to fertilizer amounts, i.e., on an acre basis. When an irrigation amount expressed in acre-inch is recommended for plasticulture, it means that the recommended volume of water needs to be delivered to the row length present in a one-acre field planted at the standard bed spacing. So in this case, it is necessary to know the bed spacing to determine the ex-

act amount of water to apply. In addition, drip tape flow rates are reported in gallons/hour/emitter or in gallons/hour/100 ft of row. Consequently, tomato growers tend to think in terms of multiples of 100 linear feet of bed, and ultimately convert irrigation amounts into duration of irrigation. It is important to correctly understand the units of the irrigation recommendation in order to implement it correctly.

EXAMPLE

How long does an irrigation event need to last if a tomato grower needs to apply 0.20 acre-inch to a 2-acre tomato field? Rows are on 6-ft centers and a 12-ft spray alley is left unplanted every six rows; the drip tape flow rate is 0.30 gallons/hour/emitter and emitters are spaced 1 foot apart.

1. In the 2-acre field, there are 14,520 feet of bed (2 x 43,560/6). Because of the alleys, only 6/8 of the field is actually planted. So, the field actually contains 10,890 feet of bed (14,520x 6/8).

2. A 0.20 acre-inch irrigation corresponds to 5,430 gallons applied to 7,260 feet of row, which is equivalent to 75gallons/100feet (5,430/72.6).

3. The drip tape flow rate is 0.30 gallons/hr/emitter which is equivalent to 30 gallons/hr/100feet. It will take 1 hour to apply 30 gallons/100ft, 2 hours to apply 60gallons/100ft, and 2.2 hours to apply 75 gallons. The total volume applied will be 8,168 gallons/2-acre (75 x 108.9).

IRRIGATION AND BEST MANAGEMENT PRACTICES

As an effort to clean impaired water bodies, federal legislation in the 70's, followed by state legislation in the 90's and state rules since 2000 have progressively shaped the Best Management Practices (BMP) program for vegetable production in Florida. Section 303(d) of the Federal Clean Water Act of 1972 required states to identify impaired water bodies and establish Total Maximum Daily Loads (TMDL) for pollutants entering these water bodies. In 1987, the Florida legislature passed the Surface Water Improvement and Management Act requiring the five Florida water management districts to develop plans to clean up and preserve Florida lakes, bays, estuaries, and rivers. In 1999, the Florida Watershed Restoration Act defined a process for the development of TMDLs. The "Water Quality/quantity Best Management Practices for Florida Vegetable and Agronomic Crops" manual was adopted by reference and by rule 5M-8 in the Florida Administrative Code on Feb. 8, 2006 (FDACS, 2005). The manual (available at www.floridaagwaterpolicy.com) provides background on the state-wide BMP program for vegetables, lists all the possible BMPs, provides a selection mechanism for building a customized BMP plan, outlines record-keeping requirements, and explains how to participate in the BMP program. By definition, BMPs are specific cultural practices that aim at reducing nutrient load while maintaining or increasing productivity. Hence, BMPs are tools to achieve the TMDL. Vegetable growers who elect to participate in the BMP program receive three statutory benefits: (1) a waiver of liability from reimbursement of cost and damages associated with the evaluation, assessment, or remediation of contamination of ground water (Florida Statutes 376.307); (2) a presumption of compliance with water quality standards (F.S. 403.067 (7)(d)), and (3); an eligibility for cost-share programs (F.S. 570.085 (1)).

BMPs cover all aspects of tomato production: pesticide management, conservation practices and buffers, erosion control and sediment management, nutrient and irrigation management, water resources management, and seasonal or temporary farming operations. The main water quality parameters of importance to tomato and pepper production and targeted by the BMPs are nitrate, phosphate and total dissolved solids concentration in surface or ground water. All BMPs have some effect on water quality, but nutrient and irrigation management BMPs have a direct effect on it. ✻

ADDITIONAL READINGS:

Cantliffe, D., P. Gilreath, D. Haman, C. Hutchinson, Y. Li, G. McAvoy, K. Migliaccio, T. Olczyk, S. Olson, D. Parmenter, B. Santos, S. Shukla, E. Simonne, C. Stanley, and A. Whidden. 2009. Review of nutrient management systems for Florida vegetable producers. EDIS HS1156, http://edis.ifas.ufl.edu/HS1156.

FDACS. 2005. Florida Vegetable and Agronomic Crop Water Quality and Quantity BMP Manual. Florida Department of Agriculture and Consumer Services http://www.floridaagwaterpolicy.com/PDFs/BMPs/vegetable&agronomicCrops.pdf.

Irmak, S., M. Asce, M.D. Dukes, and J.M. Jacobs. 2005. Using modified Bellani plate evapotranspiration gauges to estimate short canopy reference evapotranspiration. J. Irr. Drainage Eng. (2):164-175.

Locascio, S.J. and A.G. Smajstrla. 1996. Water application scheduling by pan evaporation for drip-irrigated tomato. J. Amer. Soc. Hort. Sci. 121(1):63-68 Muñoz-Carpena, R. 2004. Field devices for monitoring soil water content. EDIS Bul. 343. http://edis.ifas.ufl.edu/AE266.

Simonne, E.H., D.W. Studstill, R.C. Hochmuth, G. McAvoy, M.D. Dukes and S.M. Olson. 2003. Visualization of water movement in mulched beds with injections of dye with drip irrigation. Proc. Fla. State Hort. Soc. 116:88-91.

Simonne, E.H., D.W. Studstill, T.W. Olczyk, and R. Munoz-Carpena. 2004. Water movement in mulched beds in a rocky soil of Miami-Dade County. Proc. Fla. State Hort. Soc 117:68-70.

Simonne, E. and B. Morgan. 2005. Denitrification in seepage irrigated vegetable fields in South Florida, EDIS, HS 1004, http://edis.ifas.ufl.edu/HS248.

Simonne, E.H., D.W. Studstill, R.C. Hochmuth, J.T. Jones and C.W. Starling. 2005. On-farm demonstration of soil water movement in vegetables grown with plasticulture, EDIS, HS 1008, http://edis.ifas.ufl.edu/HS251.

Simonne, E.H. and M.D. Dukes. 2009. Principles of irrigation management for vegetables, pp.17-23. In: S.M. Olson and E. Simonne (eds) 2009-2010 Vegetable Production Handbook for Florida, Vance Publ., Lenexa, KS.

Smajstrla, A.G. 1997. Simple water level indicator for seepage irrigation. EDIS Circ. 1188, http://edis.ifas.ufl.edu/AE085.

Stanley, C.D. and G.A. Clark. 2003. Effect of reduced water table and fertility levels on subirrigated tomato production in Southwest Florida. EDIS SL-210, http://edis.ifas.ufl.edu/SS429.

NOTES

FERTILIZER AND NUTRIENT MANAGEMENT FOR TOMATO

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Fertilizer and nutrient management are essential components of successful commercial tomato production. This article presents the basics of nutrient management for the different production systems used for tomato in Florida.

CALIBRATED SOIL TEST: TAKING THE GUESSWORK OUT OF FERTILIZATION

Prior to each cropping season, soil tests should be conducted to determine fertilizer needs and eventual pH adjustments. Obtain a UF/IFAS soil sample kit from the local agricultural Extension agent or from a reputable commercial laboratory for this purpose. If a commercial soil testing laboratory is used, be sure the laboratory uses methodologies calibrated and extractants suitable for Florida soils. When used with the percent sufficiency philosophy, routine soil testing helps adjust fertilizer applications to plant needs and target yields. In addition, the use of routine calibrated soil tests reduces the risk of over-fertilization. Over fertilization reduces fertilizer efficiency and increases the risk of groundwater pollution. Systematic use of fertilizer without a soil test may also result in crop damage from salt injury.

The crop nutrient requirements of nitrogen, phosphorus, and potassium (designated in fertilizers as N, P2O5, and K2O, respectively) represent the optimum amounts of these nutrients needed for maximum tomato production (Table 1). Fertilizer rates are provided on a per-acre basis for tomato grown on 6-ft centers. Under these conditions, there are 7,260 linear feet of tomato row in a planted acre. When different row spacings are used, it is necessary to adjust fertilizer application accordingly. For example, a 200 lbs/A N rate on 6-ft centers is the same as 240 lbs/A N rate on 5-ft centers and a 170 lbs/A N rate on 7-ft centers. This example is for illustration purposes, and only 5 and 6 ft centers are commonly used for tomato production in Florida.

TABLE 1. Fertilization recommendations for tomato grown in Florida on sandy soils testing very low in Mehlich-1 potassium (K2O).

Production system	Nutrient	Recommended base fertilization[z]							Recommended supplemental fertilization[z]		
		Total (lbs/A)	Preplant[y] (lbs/A)	Injected[x] (lbs/A/day) Weeks after transplanting[w]					Leaching rain[r,s]	Measured low plant nutrient content[u,s]	Extended harvest seasons
				1-2	3-4	5-11	12	13			
Drip irrigation, raised beds, and polyethylene mulch	N	200	0-50	1.5	2.0	2.5	2.0	1.5	n/a	1.5 to 2 lbs/A/day for 7days[t]	1.5-2 lbs/A/day[p]
	K_2O	220	0-50	2.5	2.0	3.0	2.0	1.5	n/a	1.5-2 lbs/A/day for 7days[t]	1.5-2 lbs/A/day[p]
Seepage irrigation, raised beds, and polyethylene mulch	N	200	200[v]	0	0	0	0	0	30 lbs/A[q]	30 lbs/A[t]	30 lbs/A[p]
	K_2O	220	220[v]	0	0	0	0	0	20 lbs/A[q]	20 lbs/A[t]	20 lbs/A[p]

[z] 1 A = 7,260 linear bed feet per acre (6-ft bed spacing); for soils testing "very low" in Mehlich 1 potassium (K2O).
[y] applied using the modified broadcast method (fertilizer is broadcast where the beds will be formed only, and not over the entire field). Preplant fertilizer cannot be applied to double/triple crops because of the plastic mulch; hence, in these cases, all the fertilizer has to be injected.
[x] This fertigation schedule is applicable when no N and K2O are applied preplant. Reduce schedule proportionally to the amount of N and K2O applied preplant. Fertilizer injections may be done daily or weekly. Inject fertilizer at the end of the irrigation event and allow enough time for proper flushing afterwards.
[w] For a standard 13 week-long, transplanted tomato crop grown in the Spring.
[v] Some of the fertilizer may be applied with a fertilizer wheel though the plastic mulch during the tomato crop when only part of the recommended base rate is applied preplant. Rate may be reduced when a controlled-release fertilizer source is used.
[u] Plant nutritional status may be determined with tissue analysis or fresh petiole-sap testing, or any other calibrated method. The "low" diagnosis needs to be based on UF/IFAS interpretative thresholds.

Fertilizer rates can be simply and accurately adjusted to row spacings other than the standard spacing (6-ft centers) by expressing the recommended rates on a 100 linear bed feet (lbf) basis, rather than on a real-estate acre basis. For example, in a tomato field planted on 7-ft centers with one drive row every six rows, there are only 5,333 lbf/A (6/7 x 43,560 / 7). If the recommendation is to inject 10 lbs of N per acre (standard spacing), this becomes 10 lbs of N/7,260 lbf or 0.14lbs N/100 lbf. Since there are 5,333 lbf/acre in this example, then the adjusted rate for this situation is 7.46 lbs N/acre (0.14 x 53.33). In other words, an injection of 10 lbs of N to 7,260 lbf is accomplished by injecting 7.46 lbs of N to 5,333 lbf.

LIMING

The optimum pH range for tomato is 6.0-6.5. This is the range at which the availability of all the essential nutrients is highest. Fusarium wilt problems are reduced by liming within this range, but it is not advisable to raise the pH above 6.5 because of reduced micronutrient availability. In areas where soil pH is basic (>7.0), micronutrient deficiencies may be corrected by foliar sprays.

Calcium and magnesium levels should be also corrected according to the soil test. If both elements are "low", and lime is needed, then broadcast and incorporate dolomitic limestone (CaCO3, MgCO3). Where calcium alone is deficient, "hi-cal"

(CaCO3) limestone should be used. Adequate calcium is important for reducing the severity of blossom-end rot. Research shows that a Mehlich-I (double-acid) index of 300 to 350 ppm Ca would be indicative of adequate soil-Ca. On limestone soils, add 30-40 pounds per acre of magnesium in the basic fertilizer mix. It is best to apply lime several months prior to planting. However, if time is short, it is better to apply lime any time before planting than not to apply it at all. Where the pH does not need modification, but magnesium is low, apply magnesium sulfate or potassium-magnesium sulfate.

Changes in soil pH may take several weeks to occur when carbonate-based liming materials are used (calcitic or dolomitic limestone). Oxide-based liming materials (quick lime -CaO- or dolomitic quick lime -CaO, MgO-) are fast reacting and rapidly increase soil pH. Yet, despite these advantages, oxide-based liming materials are more expensive than the traditional liming materials, and therefore are not routinely used.

The increase in pH induced by liming materials is not due to the presence of calcium or magnesium. Instead, it is the carbonate (CO3) and oxide (O) part of CaCO3 and CaO, respectively, that raises the pH. Through several chemical reactions that occur in the soil, carbonates and oxides release OH- ions that combine with H+ to produce water. As large amounts of H+ react, the pH rises. A large fraction of the Ca and/or Mg in the liming materials gets into solution and binds to the sites that are freed by H+ that have reacted with OH-.

FERTILIZER-RELATED PHYSIOLOGICAL DISORDERS

Blossom-End Rot. Growers may have problems with blossom-end-rot, especially on the first or second fruit clusters. Blossom-end rot (BER) is a Ca deficiency in the fruit, but is often more related to plant water stress than to Ca concentrations in the soil. This is because Ca movement into the plant occurs with the water stream (transpiration). Thus, Ca moves preferentially to the leaves. As a maturing fruit is not a transpiring organ, most of the Ca is deposited during early fruit growth.

Once BER symptoms develop on a tomato fruit, they cannot be alleviated on this fruit. Because of the physiological role of Ca in the middle lamella of cell walls, BER is a structural and irreversible disorder. Yet, the Ca nutrition of the plant can be altered so that the new fruits are not affected. BER is most effectively controlled by attention to irrigation and fertilization, or by using a calcium source such as calcium nitrate when soil Ca is low. Maintaining adequate and uniform amounts of moisture in the soil are also keys to reducing BER potential.

Factors that impair the ability of tomato plants to obtain water will increase the risk of BER. These factors include damaged roots from flooding, mechanical damage or nematodes, clogged drip emitters, inadequate water applications, alternating dry-wet periods, and even prolonged overcast periods. Other causes for BER include high fertilizer rates, especially potassium and nitrogen.

Calcium levels in the soil should be adequate when the Mehlich-1 index is 300 to 350 ppm, or above. In these cases, added gypsum (calcium sulfate) is unlikely to reduce BER. Foliar sprays of Ca are unlikely to reduce BER because Ca does not move out of the leaves to the fruit.

Gray Wall. Blotchy ripening (also called gray wall) of tomatoes is characterized by white or yellow blotches that appear on the surface of ripening tomato fruits, while the tissue inside remains hard. The affected area is usually on the upper portion of the fruit. The etiology of this disorder has not been fully established, but it is often associated with high N and/or low K, and aggravated by excessive amount of N. This disorder may be at times confused with symptoms produced by the tobacco mosaic virus. Gray wall is cultivar specific and appears more frequently on older cultivars. The incidence of gray wall is less with drip irrigation where small amounts of nutrients are injected frequently, than with systems where all the fertilizer is applied pre-plant.

Micronutrients. For acidic sandy soils cultivated for the first time ("new ground"), or sandy soils where a proven need exists, a general guide for fertilization is the addition of micronutrients (in elemental lbs/A) manganese -3, copper -2, iron -5, zinc -2, boron -2, and molybdenum -0.02. Micronutrients may be supplied from oxides or sulfates. Growers using micronutrient-containing fungicides need to consider these sources when calculating fertilizer micronutrient needs.

Properly diagnosed micronutrient deficiencies can often be corrected by foliar applications of the specific micronutrient. For most micronutrients, a very fine line exists between sufficiency and toxicity. Foliar application of major nutrients (nitrogen, phosphorus, or potassium) has not been shown to be beneficial where proper soil fertility is present.

FERTILIZER APPLICATION

Mulch Production with Seepage Irrigation. Under this system, the crop may be supplied with all of its soil requirements before the mulch is applied (Table 1). It is difficult to correct a deficiency after mulch application, although a liquid fertilizer injection wheel can facilitate sidedressing through the mulch. The injection wheel will also be useful for replacing fertilizer under the used plastic mulch for double-cropping systems. A general sequence of operations for the full-bed plastic mulch system is:

1. Land preparation, including development of irrigation and drainage systems, and liming of the soil, if needed.

2. Application of "cold" mix comprised of 10% to 20% of the total N and potassium seasonal requirements and all of the needed phosphorus and micronutrients. The cold mix can be broadcast over the entire area prior to bedding and then incorporated. During bedding, the fertilizer will be gathered into the bed area. An alternative is to use the "modified broadcast" technique for systems with wide bed spacings. Use of modified broadcast or banding techniques can increase phosphorus and micronutrient efficiencies, especially on alkaline (basic) soils.

3. Formation of beds, incorporation of

herbicide, and application of mole cricket bait.

4. The remaining 80% to 90% of the N and potassium is placed in one or two narrow bands 9 to 10 inches to each side of the plant row in furrows. This "hot mix" fertilizer should be placed deep enough in the grooves for it to be in contact with moist bed soil. Bed presses are modified to provide the groove. Only water-soluble nutrient sources should be used for the banded fertilizer. A mixture of potassium nitrate (or potassium sulfate or potassium chloride), calcium nitrate, and ammonium nitrate has proven successful. Research has shown that it is best to broadcast incorporate controlled-release fertilizers (CRF) in the bed with bottom mix than in the hot bands.

5. Fumigation, pressing of beds, and mulching. This should be done in one operation, if possible. Be sure that the mulching machine seals the edges of the mulch adequately with soil to prevent fumigant escape.

Water management with the seep irrigation system is critical to successful crops. Use water-table monitoring devices and tensiometers or TDRs in the root zone to help provide an adequate water table but no higher than required for optimum moisture. It is recommended to limit fluctuations in water table depth since this can lead to increased leaching losses of plant nutrients. An in-depth description of soil moisture devices may be found in Muñoz-Carpena (2004).

Mulched Production with Drip Irrigation. Where drip irrigation is used, drip tape or tubes should be laid 1 to 2 inches below the bed soil surface prior to mulching. This placement helps protect tubes from mice and cricket damage. The drip system is an excellent tool with which to fertilize tomato. Where drip irrigation is used, apply all phosphorus and micronutrients, and 20 percent to 40 percent of total nitrogen and potassium preplant in the bed. Apply the remaining N and potassium through the drip system in increments as the crop develops.

Successful crops have resulted where the total amounts of N and K2O were applied through the drip system. Some growers find this method helpful where they have had problems with soluble-salt burn. This approach would be most likely to work on soils with relatively high organic matter and some residual potassium. However, it is important to begin with rather high rates of N and K2O to ensure young transplants are established quickly. In most situations, some preplant N and K fertilizers are needed.

Suggested schedules for nutrient injections have been successful in both research and commercial situations, but might need slight modifications based on potassium soil-test indices and grower experience (Table 1).

SOURCES OF N-P2O5-K2O.

About 30% to 50% of the total applied N should be in the nitrate form for soil treated with multi-purpose fumigants and for plantings in cool soil. Controlled-release nitrogen sources may be used to supply a portion of the nitrogen requirement. One-third of the total required nitrogen can be supplied from sulfur-coated urea (SCU), isobutylidene diurea (IBDU), or polymer-coated urea (PCU) fertilizers incorporated in the bed. Nitrogen from natural organics and most controlled-release materials is initially in the ammoniacal form, but is rapidly converted into nitrate by soil microorganisms.

Normal superphosphate and triple superphosphate are recommended for phosphorus needs. Both contribute calcium and normal superphosphate contributes sulfur.

All sources of potassium can be used for tomato. Potassium sulfate, sodium-potassium nitrate, potassium nitrate, potassium chloride, monopotassium phosphate, and potassium-magnesium sulfate are all good K sources. If the soil test predicted amounts of K2O are applied, then there should be no concern for the K source or

TABLE 2. Deficient, adequate, and excessive nutrient concentrations for tomato [most-recently-matured (MRM) leaf (blade plus petiole)].

Stage of Growth				N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
				%						ppm					
Tomato	MRM leaf	5-leaf stage	Deficient	<3.0	0.3	3.0	1.0	0.3	0.3	40	30	25	20	5	0.2
			Adequate range	3.0 5.0	0.3 0.6	3.0 5.0	1.0 2.0	0.3 0.5	0.3 0.8	40 100	30 100	25 40	20 40	5 15	0.2 0.6
			High	>5.0	0.6	5.0	2.0	0.5	0.8	100	100	40	40	15	0.6
	MRM leaf	First flower	Deficient	<2.8	0.2	2.5	1.0	0.3	0.3	40	30	25	20	5	0.2
			Adequate range	2.8 4.0	0.2 0.4	2.5 4.0	1.0 2.0	0.3 0.5	0.3 0.8	40 100	30 100	25 40	20 40	5 15	0.2 0.6
			High	>4.0	0.4	4.0	2.0	0.5	0.8	100	100	40	40	15	0.6
			Toxic (>)								1500	300	250		
	MRM leaf	Early fruit set	Deficient	<2.5	0.2	2.5	1.0	0.25	0.3	40	30	20	20	5	0.2
			Adequate range	2.5 4.0	0.2 0.4	2.5 4.0	1.0 2.0	0.25 0.5	0.3 0.6	40 100	30 100	20 40	20 40	5 10	0.2 0.6
			High	>4.0	0.4	4.0	2.0	0.5	0.6	100	100	40	40	15	0.6
			Toxic (>)								250				
Tomato	MRM leaf	First ripe fruit	Deficient	<2.0	0.2	2.0	1.0	0.25	0.3	40	30	20	20	5	0.2
			Adequate range	2.0 3.5	0.2 0.4	2.0 4.0	1.0 2.0	0.25 0.5	0.3 0.6	40 100	30 100	20 40	20 40	5 10	0.2 0.6
			High	>3.5	0.4	4.0	2.0	0.5	0.6	100	100	40	40	10	0.6
	MRM leaf	During harvest period	Deficient	<2.0	0.2	1.5	1.0	0.25	0.3	40	30	20	20	5	0.2
			Adequate range	2.0 3.0	0.2 0.4	1.5 2.5	1.0 2.0	0.25 0.5	0.3 0.6	40 100	30 100	20 40	20 40	5 10	0.5 0.6
			High	<2.0	0.2	1.5	1.0	0.25	0.3	40	30	20	20	5	0.2

its associated salt index.

SAP TESTING AND TISSUE ANALYSIS

While routine soil testing is essential in designing a fertilizer program, sap tests and/or tissue analyses reveal the actual nutritional status of the plant. Therefore these tools complement each other, rather than replace one another.

When drip irrigation is used, analysis of tomato leaves for mineral nutrient content (Table 2) or quick sap test (Table 3) can help guide a fertilizer management program during the growing season or assist in diagnosis of a suspected nutrient deficiency.

For both nutrient monitoring tools, the quality and reliability of the measurements are directly related with the quality of the sample. A leaf sample should contain at least 20 most recently, fully developed, healthy leaves. Select representative plants, from representative areas in the field.

SUPPLEMENTAL FERTILIZER APPLICATIONS

In practice, supplemental fertilizer applications allow vegetable growers to numerically apply fertilizer rates higher than the standard UF/IFAS recommended rates when growing conditions require doing so. Applying additional fertilizer under the three circumstances described in Table 1 (leaching rain, 'low' foliar content, and extended harvest season) is part of the current UF/IFAS fertilizer recommendations and nutrient BMPs.

LEVELS OF NUTRIENT MANAGEMENT FOR TOMATO PRODUCTION

Based on the growing situation and the level of adoption of the tools and techniques described above, different levels of nutrient management exist for tomato production in Florida. Successful production and nutrient BMPs requires management levels of 3 or above (Table 4).*

SUGGESTED LITERATURE

Cantliffe, D., P. Gilreath, D. Haman, C. Hutchinson, Y. Li, G. McAvoy, K. Migliaccio, T. Olczyk, S. Olson, D. Parmenter, B. Santos, S. Shukla, E. Simonne, C. Stanley, and A. Whidden. 2009. Review of nutrient management systems for Florida vegetable producers. EDIS HS1156, http://edis.ifas.ufl.edu/HS1156.

Florida Department of Agriculture and Consumer Services. 2005. Florida Vegetable and Agronomic Crop Water Quality and Quantity BMP Manual. http://www.floridaagwaterpolicy.com/PDFs/BMPs/vegetable&agronomicCrops.pdf.

Gazula, A., E. Simonne and B. Boman. 2007. Update and outlook for 2007 of Florida=s BMP program for vegetable crops, EDIS Doc. 367, http://edis.ifas.ufl.edu/HS367.

Hochmuth, G., D. Maynard, C. Vavrina, E. Hanlon, and E. Simonne. 2004. Plant tissue analysis and interpretation for vegetable crops in Florida. EDIS http://edis.ifas.ufl.edu/EP081.

Muñoz-Carpena, R. 2004. Field devices for monitoring soil water content. EDIS. Bul 343. http://edis.ifas.ufl.edu/HS266.

Olson, S.M., W.M. Stall, G.E. Vallad, S.E. Webb, T.G. Taylor, S.A. Smith, E.H. Simonne, E. McAvoy, and B.M. Santos. 2009. Tomato production in Florida, pp. 291-312. In: S.M. Olson and E. Simonne (Eds.) 2009-2010 Vegetable Production Handbook for Florida, Vance Pub., Lenexa, KS.

Simonne, E.H. and G.J. Hochmuth. 2009. Soil and fertilizer management for vegetable production in Florida, pp. 3-15. In: S.M. Olson and E. Simonne (Eds.) 2009-2010 Vegetable Production Handbook for Florida, Vance Pub., Lenexa, KS.

Simonne, E., D. Studstill, B. Hochmuth, T. Olczyk, M. Dukes, R. Muñoz-Carpena, and Y. Li. 2002. Drip irrigation: The BMP era - An integrated approach to water and fertilizer management in Florida, EDIS HS917, http://edis.ifas.ufl.edu/HS172.

Studstill, D., E. Simonne, R. Hochmuth, and T. Olczyk. 2006. Calibrating sap-testing meters. EDISHS 1074, http://edis.ifas.ufl.edu/HS328.

NOTES:

TABLE 3. Recommended nitrate-N and K concentrations in fresh petiole sap for round tomato.

	Sap concentration (ppm)	
Stage of growth	NO_3-N	K
First buds	1000–1200	3500–4000
First open flowers	600–800	3500–4000
Fruits one-inch diameter	400–600	3000–3500
Fruits two-inch diameter	400–600	3000–3500
First harvest	300–400	2500–3000
Second harvest	200–400	2000–2500

TABLE 4. Progressive levels of nutrient management for tomato production.[z]

Nutrient Management		Description
Level	Rating	
0	None	Guessing
1	Very low	Soil testing and still guessing
2	Low	Soil testing and implementing "a" recommendation
3	Intermediate	Soil testing, understanding IFAS recommendations, and correctly implementing them
4	Advanced	Soil testing, understanding IFAS recommendations, correctly implementing them, and monitoring crop nutritional status
5	Recommended	Soil testing, understanding IFAS recommendations, correctly implementing them, monitoring crop nutritional status, and practice year-round nutrient management and/or following BMPs (including one of the recommended irrigation scheduling methods).

[z] THESE LEVELS SHOULD BE USED TOGETHER WITH THE HIGHEST POSSIBLE LEVEL OF IRRIGATION MANAGEMENT

WEED CONTROL IN TOMATO

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Although weed control has always been an important component of tomato production, its importance has increased with the introduction of the sweet potato whitefly and development of the associated irregular ripening problem. Increased incidence of several viral disorders of tomatoes also reinforces the need for good weed control. Common weeds, such as the difficult-to-control nightshade, and volunteer tomatoes (considered a weed in this context) are hosts to many tomato pests, including sweet potato whitefly, bacterial spot, and viruses. Control of these pests is often tied, at least in part, to control of weed hosts. Most growers concentrate on weed control in row middles; however, peripheral areas of the farm should not be neglected. Weed hosts and pests may flourish in these areas and serve as reservoirs for re-infestation of tomatoes by various pests. Thus, it is important for growers to think in terms of weed management on the entire farm, not just the actual crop area.

Total farm weed management is more complex than row middle weed control because several different sites and possible herbicide label restrictions are involved. Often weed species in row middles differ from those on the rest of the farm, and this might dictate different approaches. Sites other than row middles include roadways, fallow fields, equipment parking areas, well and pump areas, fence rows and associated perimeter areas, and ditches.

Disking is probably the least expensive weed control procedure for fallow fields. Where weed growth is mostly grasses, clean cultivation is not as important as in fields infested with nightshade and other disease and insect hosts. In the latter situation, weed growth should be kept to a minimum throughout the year. If cover crops are planted, they should be plants which do not serve as hosts for tomato diseases and insects. Some perimeter areas are easily disked, but berms and field ditches are not and some form of chemical weed control may have to be used on these areas. We are not advocating bare ground on the farm as this can lead to other serious problems, such as soil erosion and sand blasting of plants; however, where undesirable plants exist, some control should be practiced, if practical, and replacement of undesirable species with less troublesome ones, such as bahiagrass, might be worthwhile.

Certainly fence rows and areas around buildings and pumps should be kept weed-free, if for no other reason than safety. Herbicides can be applied in these situations, provided care is exercised to keep them from drifting onto the tomato crop.

Field ditches and canals present special considerations because many herbicides are not labeled for use on aquatic sites. Where herbicidal spray may contact water and be in close proximity to tomato plants, for all practical purposes, growers probably would be wise to use Diquat only. On canals where drift onto the crop is not a problem and weeds are more woody, Rodeo, a systemic herbicide, could be used. Other herbicide possibilities exist, as listed in Table 1. Growers are cautioned against using Arsenal on tomato farms because tomatoes are very sensitive to this herbicide. Particular caution should be exercised if Arsenal is used on seepage irrigated farms because it has been observed to move in some situations.

Use of rye as a windbreak has become a common practice in the spring; however, in some cases, adverse effects have resulted. If undesirable insects such as thrips build up on the rye, contact herbicide can be applied to kill it and eliminate it as a host, yet the remaining stubble could continue serving as a windbreak.

The greatest row middle weed problem confronting the tomato industry today is nightshade. Nightshade has developed varying levels of resistance to some post-emergent herbicides in different areas of the state. Best control with post-emergence (directed) contact herbicides is obtained when the nightshade is 4 to 6 inches tall, rapidly growing and not stressed. Two applications in about 50 gallons per acre using a good surfactant are usually necessary.

With post-directed contact herbicides, several studies have shown that volumes above 60 gallons per acre will actually dilute the herbicides and therefore reduce efficacy. Good leaf coverage can be obtained with volumes of 50 gallons or less per acre. A good surfactant can do more to improve the wetting capability of a spray than can increasing the water volume. Many adjuvants are available commercially. Some adjuvants contain more active ingredient than others and herbicide labels may specify a minimum active ingredient rate for the adjuvant in the spray mix. Before selecting an adjuvant, refer to the herbicide label to determine the adjuvant specifications.

POSTHARVEST VINE DESICCATION

Additionally important is good field sanitation with regard to crop residue. Rapid and thorough destruction of tomato vines at the end of the season always has been promoted; however, this practice takes on new importance with the sweet potato whitefly. Good canopy penetration of pesticidal sprays is difficult with conventional hydraulic sprayers once the tomato plant develops a vigorous bush due to foliar interception of spray droplets. The sweet potato whitefly population on commercial farms was observed to begin a dramatic, rapid increase about the time of first harvest in the spring of 1989. This increase appears to continue until tomato vines are killed. It is believed this increase is due, in part, to coverage and penetration. Thus, it would be wise for growers to continue spraying for whiteflies until the crop is destroyed and to destroy the crop as soon as possible with the fastest means available. Gramoxone Inteon and Firestorm are labeled for post-harvest desiccation of tomato vines. Follow the label directions.

The importance of rapid vine destruction cannot be overstressed. Merely turning off the irrigation and allowing the crop to die will not do; application of a desiccant followed by burning is the prudent course. ✻

Herbicide	Labeled Crops	Time of Application to Crop	Rate (lbs. AI./Acre) Mineral Soils	Muck Soils		
Carfentrazone (Aim)	Tomato	Preplant Directed-hooded Row-middles	0.031	0.031		
Remarks: Aim may be applied as a preplant burndown treatment and/or as a post-directed hooded application to row middles for the burndown of emerged broadleaf weeds. May be tank mixed with other registered herbicides. May be applied at up to 2 oz (0.031 lb ai). Use a quality spray adjuvant such as crop oil concentrate (COC) or non-ionic surfactant at recommended rates.						
Clethodim (Select 2 EC) (Arrow) (SelectMax)	Tomatoes	Postemergence	0.9-.25	—		
Remarks: Postemergence control of actively growing annual grasses. Apply at 6-16 fl oz/acre. Use high rate under heavy grass pressure and/or when grasses are at maximum height. Always use a crop oil concentrate at 1% v/v in the finished spray volume, or a non-ionic Surfactant with SelectMAX. Do not apply within 20 days of tomato harvest.						
DCPA (Dacthal W-75)	Established tomatoes	Posttransplanting after crop establishment (non-mulched)	6.0-8.0	—		
Remarks: Controls germinating annuals. Apply to weed-free soil 6 to 8 weeks after crop is established and growing rapidly or to moist soil in row middles after crop establishment. Note label precautions against replanting non-registered crops within 8 months.						
EPTC (Eptam 7E)	Tomatoes	Pretransplant	2.62-3.5	—		
Remarks: Labeled for transplanted tomatoes grown on plastic mulch. Apply 3-4 pints/A to the bed top and shoulders immediately prior to the installation of the mulch. Do not transplant the tomato plants for a minimum of 14 days following the application. A 24c special local needs label for Florida.						
Flumioxazin (Chateau)	Fruiting Vegetables Tomatoes	Directed Row-middles	0.125	—		
Remarks: Chateau may be applied up to 4 oz product/application to row middles of raised plastic mulched beds that are at least 4 inches higher than the treated row middle and the mulched bed must be a minimum of a 24-inch bed width. Do not apply after crops are transplanted. All applications must be made with shielded or hooded equipment. For control of emerged weeds, a burn down herbicide may be tank-mixed. Label is a Third-Party registration (TPR, Inc.). Use without a signed authorization and waiver of liability is a misuse of the product.						
Glyphosate (Roundup, Durango, Touchdown, Glyphomax)	Tomatoes	Chemical fallow Preplant, Preemergence, Pretransplant	0.3-1.0	—		
Remarks: Roundup, Glyphomax and Touchdown have several formulations. Check the label of each for specific labeling directions.						
Halosulfuron (Sandea)	Tomatoes	Pretransplant Postemergence Row middles	0.024-0.036	—		
Remarks: A total of 2 applications of Sandea may be applied as either one pre-transplant soil surface treatment at 0.5-0.75 oz. product; one over-the-top application 14 days after transplanting at 0.5-0.75 oz. product; and/or postemergence applications(s) of up to 1 oz. product (0.047 lb ai) to row middles. A 30-day PHI will be observed. For postemergence and row middle applications, a surfactant should be added to the spray mix.						
Lactofen (Cobra)	Fruiting vegetables	Row middles	0.25-0.5	—		
Remarks: Third Party label for use pre-transplant or post transplant shielded or hooded to row middles. Apply 16 to 32 fluid oz per acre. A minimum of 24 fl oz is required for residual control. Add a COC or non-ionic surfactant for control of emerged weeds. 1 pre and 1 post application may be made per growing season. Cobra contacting green foliage or fruit can cause excessive injury. Drift of Cobra treated soil particles onto plants can cause contact injury. Do not apply within 30 days of harvest. The supplemental label must be in the possession of the user at the time of application.						
S-Metolachlor (Dual Magnum)	Tomatoes	Pretransplant- Row middles	1.0-1.3	—		
Remarks: Apply Dual Magnum preplant non-incorporated to the top of a pressed bed as the last step prior to laying plastic. May also be used to treat row middles. Label rates are 1.0-1.33 pts/A if organic matter is less than 3%. Research has shown that the 1.33 pt may be too high in some Florida soils except in row middles. Good results have been seen at 0.6 pts to 1.0 pints especially in tank mix situations under mulch. Use on a trial basis.						
Metribuzin (Sencor DF) (Sencor 4)	Tomatoes	Postemergence Posttransplanting after establishment	0.25 - 0.5	—		
Remarks: Controls small emerged weeds after transplants are established or when direct-seeded plants reach 5 to 6 true leaf stage. Apply in single or multiple applications with a minimum of 14 days between treatments and a maximum of 1.0 lb ai/acre within a crop season. Avoid applications for 3 days following cool, wet or cloudy weather to reduce possible crop injury.						
Metribuzin (Sencor DF) (Sencor 4)	Tomatoes	Directed spray in row middles	0.25 - 1.0	—		
Remarks: Apply in single or multiple applications with a minimum of 14 days between treatments and maximum of 1.0 lb ai/acre within crop season. Avoid applications for 3 days following cool, wet or cloudy weather to reduce possible crop injury. Label states control of many annual grasses and broadleaf weeds including, lambsquarter, fall panicum, Amaranthus sp., Florida pusley, common ragweed, sicklepod, and spotted spurge.						
Napropamide (Devrinol 50DF)	Tomatoes	Preplant incorporated	1.0-2.0	—		
Remarks: Apply to well worked soil that is dry enough to permit thorough incorporation to a depth of 1 to 2 inches. Incorporate same day as applied. For direct-seeded or transplanted tomatoes.						
Napropamide (Devrinol 50DF)	Tomatoes	Surface treatment	2.0	—		
Remarks: Controls germinating annuals. Apply to bed tops after bedding but before plastic application. Rainfall or overhead-irrigate sufficient to wet soil 1 inch in depth should follow treatment within 24 hours. May be applied to row middles between mulched beds. A special Local Needs 24(c) Label for Florida. Label states control of weeds including Texas panicum, pigweed, purslane, Florida pusley, and signalgrass.						
Oxyfluorfen (Goal 2XL) (Goaltender)	Tomatoes	Fallow bed	0.25-0.5	—		
Remarks: Must have a 30-day treatment–planting interval for transplanted tomatoes. Apply as a preemergence broadcast to preformed beds or banded treatment at 1-2 pt/A or 1/2 to 1 pt/A for Goaltender. Mulch may be applied any time during the 30-day interval.						
Paraquat (Gramoxone Inteon) (Firestorm)	Tomatoes	Premergence; Pretransplant	0.62-0.94	—		
Remarks: Controls emerged weeds. Use a non- ionic spreader and thoroughly wet weed foliage.						
Paraquat (Gramoxone Inteon) (Firestorm)	Tomatoes	Post directed spray in row middles	0.47	—		
Remarks: Controls emerged weeds. Direct spray over emerged weeds 1 to 6 inches tall in row middles between mulched beds. Use a non-ionic spreader. Use low pressure and shields to control drift. Do not apply more than 3 times per season.						
Paraquat (Gramoxone Inteon) (Firestorm)	Tomatoes	Postharvest desiccation	0.62-0.93	0.46-0.62		
Remarks: Broadcast spray over the top of plants after last harvest. Gramoxone label states use of 2-3 pts. Use a non-ionic surfactant at 1 pt/100 gals to 1 qt/100 gals spray solution. Thorough coverage is required to ensure maximum herbicide burndown. Do not use treated crop for human or animal consumption.						
Pelargonic Acid (Scythe)	Fruiting vegetables (tomato)	Preplant Preemergence Directed-shielded	3-10% v/v	—		
Remarks: Product is a contact, nonselective, foliar applied herbicide. There is no residual control. May be tank mixed with several soil residual compounds. Consult the label for rates. Has a greenhouse and growth structure label.						
Pendimethalin Prowl H ,O	Tomatoes	Post-directed Row Middles	0.0475-1.43	—		
Remarks: May be applied pre-transplant but not under mulch. May be applied at 1.0 to 3 pts/A to row middles. Do not apply within 70 days of harvest.						
Rimsulfuron (Matrix)	Tomatoes	Posttransplant and directed-row middles	0.25-0.5 oz	—		
Remarks: Matrix may be applied preemergence (seeded), postemergence, posttransplant and applied directed to row middles. May be applied at 1-2 oz. product (0.25-0.5 oz ai) in single or sequential applications. A maximum of 4 oz. product per acre per year may be applied. For post (weed) applications, use a non-ionic surfactant at a rate of 0.25% v/v. for preemergence (weed) control, Matrix must be activated in the soil with sprinkler irrigation or rainfall. Check crop rotational guidelines on label.						
Sethoxydim (Poast)	Tomatoes	Postemergence	0.188 - 0.28	—		
Remarks: Controls actively growing grass weeds. A total of 4 1/2 pts. product per acre may be applied in one season. Do not apply within 20 days of harvest. Apply in 5 to 20 gallons of water adding 2 pts. of crop oil concentrate per acre. Unsatisfactory results may occur if applied to grasses under stress. Use 0.188 lb ai (1 pt.) to seedling grasses and up to 0.28 lb ai (1 1/2 pts.) to perennial grasses emerging from rhizomes etc. Consult label for grass species and growth stage for best control.						
Trifloxysulfuron (Envoke)	Tomatoes (transplanted)	Post directed	0.007-0.014	—		
Remarks: Envoke can be applied at 0.1 to 0.2 oz product/A post-directed to transplanted tomatoes for control of nutsedge, morning-glory, pigweeds and other weeds listed on the label. Applications should be made prior to fruit set and at least 45 days prior to harvest. A non-ionic surfactant should be added to the spray mix.						
Trifluralin (Treflan HFP) (Trifluralin 4EC)	Tomatoes	Pretransplant incorporated	0.5	—	(Treflan TR-10)	(except Dade County)
Remarks: Controls germinating annuals. Incorporate 4 inches or less within 8 hours of application. Results in Florida are erratic on soils with low organic matter and clay contents. Note label precautions against planting non-crops within 5 months. Do not apply after transplanting.						

TOMATO FUNGICIDES

AND OTHER DISEASE MANAGEMENT PRODUCTS (UPDATED JUNE 2009)

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BE SURE TO READ A CURRENT PRODUCT LABEL BEFORE APPLYING ANY CHEMICAL.

Chemical	Fungicide group[1]	Max. Rate/ Acre/ Applic.	Season	Min. Days to Harvest	Pertinent Diseases or Pathogens	Remarks[2]
fix copper compounds (many brands available: Badge SC, Basic Copper 50W HB, Basic Copper 53, COCS WDG, Champ DP, Champ F2 FL, Champ WG, Champion WP, COC DF, COC WP, Copper Count N, Cuprofix Ultra 40D, Kentan DF, Kocide 3000, Kocide 2000, Kocide DF, Nordox, Nordox 75WG, Nu Cop 50WP, Nu Cop 3L, Nu Cop 50DF, Nu Cop HB)	M1	-	-	1	Anthracnose Bacterial speck Bacterial spot Early blight Grey leaf mold Grey leaf spot Late blight Septoria leaf spot	Mancozeb or maneb enhances bactericidal effect of fix copper compounds. See label for details.
sulfur (many brands available: Cosavet DF, Kumulus DF, Micro Sulf, Microfine Sulfur, Microthiol Disperss, Sulfur 6L, Sulfur 90W, Super Six, That Flowable Sulfur, Tiolux Jet, Thiosperse 80%, Wettable Sulfur, Wettable Sulfur 92, Yellow Jacket Dusting Sulfur, Yellow Jacket Wettable Sulfur)	M2	-	-	1	Powdery mildew	Follow label closely, it may cause phytotoxicity.
maneb (many brands available: Maneb 75DF, Maneb 80WP, Manex,)	M3	2.4 qts.	16.8 qts.	5	Early blight Late blight Gray leaf spot Bacterial spot[3] Anthracnose Leaf mold Septoria leaf spot	See label for details
mancozeb (many brands available: Dithane DF, Dithane F45, Dithane M45, Manzate, Manzate Pro-Stik, Penncozeb 4FL, Penncozeb 75DF, Penncozeb 80WP)	M3	3 lbs.	22.4 lbs.	5		
Ziram (ziram)	M3	4 lbs	24 lbs	7	Anthracnose Early blight Septoria leaf spot	Do not use on cherry tomatoes. See label for details.
ManKocide (mancozeb + copper hydroxide)	M3 / M1	5 lbs.	112 lbs.	5	Bacterial spot Bacterial speck Late blight Early blight Gray leaf spot	See label
chlorothalonil (many brands available: Bravo Ultrex, Bravo Weather Stik, Bravo Zn, Chloronil 720, Echo 720, Echo 90 DF, Echo Zn, Equus 500 Zn, Equus 720 SST, Equus DF, Initiate 720)	M5	-	-	0	Early blight Late blight Gray leaf spot Leaf mold Target spot Botrytis Rhizoctonia fruit rot	Use higher rates at fruit set and lower rates before fruit set, see label
Allpro Exotherm Termil (20 % chlorothalonil)	M5	1 can / 1000 sq. ft.	-	7	Botrytis Leaf mold Late blight Early blight Gray leaf spot Target spot	Greenhouse use only. Allow can to remain overnight and then ventilate. Do not use when greenhouse temperature is above 75 F. See label for details.
Rally 40WSP, Nova 40 W (myclobutanil)	3	4 oz.	1.25 lbs.	0	Powdery mildew	Note that a 30 day plant back restriction exists, see label
Ridomil Gold EC (mefenoxam)	4	2 pts. / trtd. acre	3 pts / trtd. acre	28	Pythium diseases	See label for details
Ultra Flourish (mefenoxam)	4	2 qts	3 qts		Pythium and Phytophthora rots	See label for details
Ridomil MZ 68 WP (mefenoxam + mancozeb)	4 / M3	2.5 lbs.	7.5 lbs.	5	Late blight	Limit is 3 appl./crop, see label
Ridomil Gold Copper 64.8 W (mefenoxam + copper hydroxide)	4 / M1	2 lbs.		14	Late blight	Limit is 3 appl. /crop. Tank mix with maneb or mancozeb fungicide, see label
Ridomil Gold Bravo 76.4 W (chlorothalonil +mefenoxam)	4 / M5	3 lbs.	12 lbs	14	Early blight Late blight Gray leaf spot Target Spot	Limit is 4 appl./crop, see label
Endura (boscalid)	7	12.5 oz	25 oz.	0	Target spot (Corynespora cassiicola) Early Blight (Alternaria solani)	Alternate with non-FRAC code 7 fungicides, see label
Scala SC (pyrimethanil)	9	7 fl oz	35 fl oz	1	Early blight Botrytis	Use only in a tank mix with another effective fungicide (non FRAC code 9) ; 30 day plant back with off label crops ; see label
Amistar 80 DF (azoxystrobin)	11	2 oz	12 oz	0	Early blight Late blight Sclerotinia Powdery mildew Target spot Buckeye rot	Limit is 6 appl/crop. Must alternate or tank mix with a fungicide from a different FRAC group, see label.
Quadris (azoxystrobin)	11	6.2 fl.oz.	37.2. fl.oz.	0		

Cabrio 2.09 F (pyraclostro-bin)	11	16 fl oz	96 fl oz	0	Early blight Late blight Sclerotinia Powdery mildew Target spot Buckeye rot	Only 2 sequential appl. allowed. Limit is 6 appl/crop. Must alternate or tank mix with a fungicide from a different FRAC group, see label.
Flint (trifloxystro-bin)	11	4 oz	16 oz	3	Early blight Late blight Gray leaf spot	Limit is 5 appl/crop. Must alternate or tank mix with a fungicide from a different FRAC group, see label.
Evito (fluoxastrobin)	11	5.7 fl oz	22.8 fl oz	3	Early blight Late blight Southern blight Target spot	Limit is 4 appl/crop. Must alternate or tank mix with a fungicide from a different FRAC group, see label.
Reason 500SC (fenamidone)	11	8.2 oz	24.6 lb	14	Early blight Late blight Septoria leaf spot	See label for details
Tanos (famoxadone + cymoxanil)	11 / 27	8 oz	72 oz	3	Late blight Target spot Bacterial spot (suppression)	Do not alternate or tank mix with other FRAC group 11 fungicides. See label for details
Terramaster 4EC (etridiazole)	14	7 fl oz	27.4 fl oz	3	Pythium and Phytophthora root rots	Greenhouse use only. See label for details
Blocker 4F Terraclor 75 WP (PCNB)	14	See Label	See Label		Southern blight (Sclerotium rolfsii)	See label for application type and restrictions
Botran 75 W (dichloran)	14	1 lb.	4 lbs.	10	Botrytis	Greenhouse use only. Limit is 4 applications. Seedlings or newly set transplants may be injured, see label
Ranman (cyazofamid)	21	2.1-2.75 oz	16 oz	0	Late Blight	Limit is 6 appl./crop, see label
Gavel 75DF (zoaximide + mancozeb)	22 / M3	2.0 lbs	16 lbs	5	Buckeye rot Early blight Gray leaf spot Late blight Leaf mold	See label
Agri-mycin 17 (streptomycin sulfate) Ag Streptomycin (streptomycin sulfate) Fire Wall (streptomycin sulfate)	25	200 ppm	-	-	Bacterial spot Bacterial speck	See label for details. For transplant production only. Many isolates are resistant to streptomycin.
Curzate 60DF (cymoxanil)	27	5 oz	30 oz per 12 month	3	Late Blight	Do not use alone, see label for details
Previcur Flex (propamocarb hydrochloride)	28	1.5 pints (see Label)	7.5 pints	5	Late blight	Only in a tank mixture with chlorotalonil, maneb or mancozeb, see label
K-phite 7LP Fosphite Fungi-Phite Helena Prophyte Phostrol Topaz (mono-and di-potassium salts of phosphorous acid)	33	See label		0	Phythophthora spp. Pythium spp. Fusarium spp. Rhizoctonia Late Blight Powdery Mildew	Do not apply with copper-based fungicides. See label for restrictions and details
Aliette 80 WDG (fosetyl-al)	33	5 lbs.	20 lbs.	14	Phytophthora root rot	See label for warnings concerning the use of copper compounds.
Acrobat 50 WP (dimethomorph)	40	6.4 oz	32 oz	4	Late blight	See label for details
Forum (dimethomorph)	40	6 oz	30 oz	4	Late blight	Only 2 sequential appl. See label for details
Revus Top (mandipropamid + difenoconazole)	40/3	7 fl oz	28 fl oz	1	Anthracnose Black mold Early blight Gray leafspot Late blight Powdery mildew Septoria leafspot Target spot	4 apps per season; no more than 2 sequential apps; do not use on varieties with mature fruit less than 2 inches in diameter. Not labeled for transplants. See label
Presidio (Fluopicolide)	43	3-4 fl oz	12 fl oz/ per season	2	Late blight Phythophthora spp.	4 apps per season; no more than 2 sequential apps. 10 day spray interval; Tank mix with another labeled fungicide with a different mode of action; 18 month rotation with off label crops
Serenade ASO Serenade Max Sonata (Bacillus sp.)	44	See label	See label	0	Bacterial spot Early Blight Late Blight Powdery mildew Target spot Botrytis	Mix with copper compounds, see label.
Actigard (acibenzolar-S-methyl)	P	0.75 oz.	4.75 oz	14	Bacterial spot Bacterial speck Tomato spotted wilt—a viral disease (use in combination of UV-reflective mulch and vector thrips specific insecticides.	Do not use highest labeled rate in early sprays to avoid a delayed onset of harvest. See label for details.
AgriPhage (bacteriophage)	NC	2 pts	-	0	Bacterial spot Bacterial speck	See label for details.

Oxidate (hydrogen peroxide)	NC	1:100 dilution	-	0	Anthracnose Bacterial speck Bacterial spot Botrytis Early blight Late blight Powdery mildew Rhizoctonia fruit rot	See label for details.
Amicarb 100 Kaligreen Milstop (Potassium bicarbonate)	NC	See label	-	0	Powdery mildew	See label for details.
JMS Stylet-Oil (paraffinic oil)	NC	3 qts.	-	-	Potato Virus Y Tobacco Etch Virus Cucumber Mosaic Virus	See label for restrictions and use (e.g. use of 400 psi spray pressure)

[1] FRAC CODE (FUNGICIDE GROUP): NUMBERS (1-44) AND LETTERS (M, NC, U, P) ARE USED TO DISTINGUISH THE FUNGICIDE MODE OF ACTION GROUPS. ALL FUNGICIDES WITHIN THE SAME GROUP (WITH SAME NUMBER OR LETTER) INDICATE SAME ACTIVE INGREDIENT OR SIMILAR MODE OF ACTION. THIS INFORMATION MUST BE CONSIDERED FOR THE FUNGICIDE RESISTANCE MANAGEMENT DECISIONS. M = MULTI SITE INHIBITORS, FUNGICIDE RESISTANCE RISK IS LOW; NC = NOT CLASSIFIED, INCLUDES MINERAL OILS, ORGANIC OILS, POTASSIUM BICARBONATE, AND OTHER MATERIALS OF BIOLOGICAL ORIGIN; U = RECENT MOLECULES WITH UNKNOWN MODE OF ACTION; P = HOST PLANT DEFENSE INDUCERS. SOURCE: FRAC CODE LIST 2009; HTTP://WWW.FRAC.INFO/ (FRAC = FUNGICIDE RESISTANCE ACTION COMMITTEE).

[2] INFORMATION PROVIDED IN THIS TABLE APPLIES ONLY TO FLORIDA. BE SURE TO READ A CURRENT PRODUCT LABEL BEFORE APPLYING ANY CHEMICAL. THE USE OF BRAND NAMES AND ANY MENTION OR LISTING OF COMMERCIAL PRODUCTS OR SERVICES IN THE PUBLICATION DOES NOT IMPLY ENDORSEMENT BY THE UNIVERSITY OF FLORIDA COOPERATIVE EXTENSION SERVICE NOR DISCRIMINATION AGAINST SIMILAR PRODUCTS OR SERVICES NOT MENTIONED.

[3] TANK MIX OF MANCOZEB OR MANEB ENHANCES BACTERICIDAL EFFECT OF COPPER COMPOUNDS.

SELECTED INSECTICIDES

APPROVED FOR USE ON INSECTS ATTACKING TOMATOES

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Trade Name (Common Name)	Rate (product/acre)	REI (hours)	Days to Harvest	Insects	MOA Code[1]	Notes
Acramite-50WS (bifenazate)	0.75–1.0 lb	12	3	twospotted spider mite	un	One application per season.
Actara (thiamethoxam)	2.0–5.5 oz	12	0	aphids, flea beetles, leafhoppers, stinkbugs, whiteflies	4A	Maximum of 11 oz/acres per season. Do not use following a soil application of a Group 4A insecticide.
Admire Pro (imidacloprid)	7–10.5 fl oz	12	21	aphids, Colorado potato beetle, flea beetles, leafhoppers, thrips (foliar feeding thrips only), whiteflies	4A	Most effective if applied to soil at transplanting. Limited to 24 oz/acre. Admire Pro limited to 10.5 fl oz/acre.
Admire Pro (imidacloprid)	0.6 fl oz/1,000 plants	12	0 (soil)	aphids, whiteflies	4A	Greenhouse Use: 1 application to mature plants, see label for cautions.
Admire Pro (imidacloprid)	0.44 fl oz/10,000 plants	12	21	aphids, whiteflies	4A	Planthouse: 1 application. See label.
Agree WG (*Bacillus thuringiensis* subspecies *aizawai*)	0.5–2.0 lb	4	0	armyworms, hornworms, loopers, tomato fruitworm	11	Apply when larvae are small for best control. Can be used in greenhouse. OMRI-listed[2].
*Agri Mek 0.15EC (abamectin)	8–16 fl oz	12	7	broad mite, Colorado potato beetle, Liriomyza leafminers, spider mite, Thrips palmi, tomato pinworms, tomato russet mite	6	Do not make more than 2 sequential applications. Do not apply more than 48 fl oz per acre per season.
*Ambush 25W (permethrin)	3.2–12.8 oz	12	up to day of harvest	beet armyworm, cabbage looper, Colorado potato beetle, granulate cutworms, hornworms, southern armyworm, tomato fruitworm, tomato pinworm, vegetable leafminer	3	Do not use on cherry tomatoes. Do not apply more than 1.2 lb ai/acre per season (76.8 oz). Not recommended for control of vegetable leafminer in Florida.
*Asana XL (0.66EC) (esfenvalerate)	2.9–9.6 fl oz	12	1	beet armyworm (aids in control), cabbage looper, Colorado potato beetle, cutworms, flea beetles, grasshoppers, hornworms, potato aphid, southern armyworm, tomato fruitworm, tomato pinworm, whiteflies, yellowstriped armyworm	3	Not recommended for control of vegetable leafminer in Florida. Do not apply more than 0.5 lb ai per acre per season, or 10 applications at highest rate.
Assail 70WP (acetamiprid)	0.6–1.7 oz	12	7	aphids, Colorado potato beetle, thrips, whiteflies	4A	Do not apply to crop that has been already treated with imidacloprid or thiamethoxam at planting. Begin applications for whiteflies when first adults are noticed. Do not apply more than 4 times per season or apply more often than every 7 days.
Avaunt (indoxacarb)	2.5–3.5 oz	12	3	beet armyworm, hornworms, loopers, southern armyworm, tomato fruitworm, tomato pinworm, suppression of leafminers	22	Do not apply more than 14 ounces of product per acre per crop. Minimum spray interval is 5 days.
Aza-Direct (azadirachtin)	1–2 pts, up to 3.5 pts, if needed	4	0	aphids, beetles, caterpillars, leafhoppers, leafminers, mites, stink bugs, thrips, weevils, whiteflies	18B	Antifeedant, repellant, insect growth regulator. OMRI-listed[2].
Azatin XL (azadirachtin)	5–21 fl oz	4	0	aphids, beetles, caterpillars, leafhoppers, leafminers, thrips, weevils, whiteflies	18B	Antifeedant, repellant, insect growth regulator.
*Baythroid XL (beta-cyfluthrin)	1.6–2.8 fl oz	12	0	beet armyworm[(1)], cabbage looper, Colorado potato beetle, dipterous leafminers[(2)], European corn borer, flea beetles, hornworms, potato aphid, southern armyworm[(1)], stink bugs, tomato fruitworm, tomato pinworm, variegated cutworm , western flower thrips, whitefly adults[(2)]	3	[(1)]Ist and 2nd instars only [(2)]Suppression Do not apply more than 0.132 lb (Baythroid XL) ai per acre per season.
Beleaf 50 SG (flonicamid)	2.0–2.8 oz	12	0	aphids, plant bugs	9C	Do not apply more than 8.4 oz/acre per season. Begin applications before pests reach damaging levels.
Biobit HP (*Bacillus thuringiensis* subspecies *kurstaki*)	0.5–2.0 lb	4	0	caterpillars (will not control large armyworms)	11B2	Treat when larvae are young. Good coverage is essential. Can be used in the greenhouse. OMRI-listed[2].
BotaniGard 22 WP, ES (*Beauveria bassiana*)	WP: 0.5–2 lb/100 gal ES: 0.5–2 qts 100/gal	4	0	aphids, thrips, whiteflies	--	May be used in greenhouses. Contact dealer for recommendations if an adjuvant must be used. Not compatible in tank mix with fungicides.

Trade Name (Common Name)	Rate (product/acre)	REI (hours)	Days to Harvest	Insects	MOA Code[1]	Notes
*Brigade 2EC (bifenthrin)	2.1–5.2 fl oz	12	1	aphids, armyworms, corn earworm, cutworms, flea beetles, grasshoppers, mites, stink bug spp., tarnished plant bug, thrips, whiteflies	3	Make no more than 4 applications per season. Do not make applications less than 10 days apart.
CheckMate TPW, TPW-F (pheromone)	TPW: 200 dispenser TPW-F: 1.2–6.0 fl oz	0	0	tomato pinworm	—	For mating disruption See label.
Confirm 2F (tebufenozide)	6–16 fl oz	4	7	armyworms, black cutworm, hornworms, loopers	18A	Product is a slow acting IGR that will not kill larvae immediately. Do not apply more than 1.0 lb ai per acre per season.
Coragen (rynaxypyr)	3.5–7.5 fl oz	4	1	beet armyworm, Colorado potato beetle, fall armyworm, hornworms, leafminer larvae loopers, southern armyworm, tomato fruitworm, tomato pinworm	28	Can be applied by drip chemigation—See label. Do not use more than 15.4 fl oz product/acre per crop.
Courier 40SC (buprofezin)	9–13.6 fl oz	12	1	whitefly nymphs	16	See label for plantback restrictions. Apply when a threshold is reached of 5 nymphs per 10 leaflets from the middle of the plant. Product is a slow acting IGR that will not kill nymphs immediately. No more than 2 applications per season. Allow at least 28 days between applications.
Crymax WDG (*Bacillus thuringiensis* subspecies *kurstaki*)	0.5–2.0 lb	4	0	armyworms, loopers, tomato fruitworm, tomato hornworm, tomato pinworm	11B2	Use high rate for armyworms. Treat when larvae are young.
*Danitol 2.4 EC (fenpropathrin)	10.67 fl oz	24	3 days, or 7 if mixed with Monitor 4	beet armyworm, cabbage looper, fruitworms, potato aphid, silverleaf whitefly, stink bugs, thrips, tobacco hornworm, tomato pinworm, twospotted spider mites, yellowstriped armyworm	3	Use alone for control of fruitworms, stink bugs, tobacco hornworm, twospotted spider mites, and yellowstriped armyworms. Tank mix with Monitor 4 for all others, especially whitefly. Do not apply more than 0.8 lb ai per acre per season. Do not tank mix with copper.
Deliver (*Bacillus thuringiensis* subspecies *kurstaki*)	0.25–1.5 lb	4	0	armyworms, cutworms, loopers, tomato fruitworm, tomato pinworm	11B2	Use higher rates for armyworms. OMRI-listed[2].
*Diazinon AG500; 4E; *50 W (diazinon)	AG500, 4E: 14 qts 50W: 2–8 lb	48	preplant	cutworms, mole crickets, wireworms	1B	Incorporate into soil - see label.
Dimethoate 4 EC, 2.67 EC (dimethoate)	4EC: 0.5–1.0 pt 2.67: 0.75–1.5 pt	48	7	aphids, leafhoppers, leafminers	1B	Will not control organophosphate-resistant leafminers.
DiPel DF (*Bacillus thuringiensis* supspecies *kurstaki*)	0.5–2.0 lb	4	0	caterpillars	11B2	Treat when larvae are young. Good coverage is essential. OMRI-listed[2].
Entrust (spinosad)	0.5–2.5 oz	4	1	armyworms, Colorado potato beetle, flower thrips, hornworms, Liriomyza leafminers, loopers, other caterpillars, tomato fruitworm, tomato pinworm	5	Do not apply more than 9 oz per acre per crop. OMRI-listed[2].
Esteem Ant Bait (pyriproxyfen)	1.5–2.0 lb	12	1	red imported fire ant	7C	Apply when ants are actively foraging.
Extinguish ((S) methoprene)	1.0–1.5 lb	4	0	fire ants	7A	Slow acting IGR (insect growth regulator). Best applied early spring and fall where crop will be grown. Colonies will be reduced after three weeks and eliminated after 8 to 10 weeks. May be applied by ground equipment or aerially.
Fulfill (pymetrozine)	2.75 oz	12	0 - if 2 applications 14 - if 3 or 4 applications	green peach aphid, potato aphid, suppression of whiteflies	9B	Do not make more than four applications. (FL-040006) 24(c) label for growing transplants also (FL-03004).
Intrepid 2F (methoxyfenozide)	4–16 fl oz	4	1	beet armyworm, cabbage looper, fall armyworm, hornworms, southern armyworm, tomato fruitworm, true armyworm, yellowstriped armyworm	18A	Do not apply more than 64 fl oz acre per season. Product is a slow-acting IGR that will not kill larvae immediately.
Javelin WG (*Bacillus thuringiensis* subspecies *kurstaki*)	0.12–1.5 lb	4	0	most caterpillars, but not Spodoptera species (armyworms)	11B2	Treat when larvae are young. Thorough coverage is essential. OMRI-listed[2].
Knack IGR (pyriproxyfen)	8–10 fl oz	12	14 7 - SLN No FL-200002	immature whiteflies	7C	Apply when a threshold is reached of 5 nymphs per 10 leaflets from the middle of the plant. Product is a slow acting IGR that will not kill nymphs immediately. Make no more than two applications per season. Treat whole fields.
Kryocide (cryolite)	8–16 lb	12	14	armyworm, blister beetle, cabbage looper, Colorado potato beetle larvae, flea beetles, hornworms, tomato fruitworm, tomato pinworm	9A	Minimum of 7 days between applications. Do not apply more than 64 lbs per acre per season.
*Lannate LV, *SP (methomyl)	LV: 1.5–3.0 pt SP: 0.5–1.0 lb	48	1:	aphids, armyworm, beet armyworm, fall armyworm, hornworms, loopers, southern armyworm, tomato fruitworm, tomato pinworm, variegated cutworm	1A	Do not apply more than 21 pt LV/acre/crop (15 for tomatillos) or 7 lb SP/acre/crop (5 lb for tomatillos).
Lepinox WDG (*Bacillus thuringiensis* subspecies *kurstaki*)	1.0–2.0 lb	12	0	for most caterpillars, including beet armyworm (see label)	11B2	Treat when larvae are small. Thorough coverage is essential.
Malathion 5 Malathion 8 F (malathion)	1.0–2.5 .0 pt 1.5–2 pt	12	1	aphids, *Drosophila*, mites	1B	Can be used in greenhouse (8F).
*Monitor 4EC (methamidophos) [24(c) labels] FL-800046 FL-900003	1.5–2 pts	96	7	aphids, fruitworms, leafminers, tomato pinworm[(1)], whiteflies[(2)]	1B	[(1)]Suppression only [(2)]Use as tank mix with a pyrethroid for whitefly control. Do not apply more than 8 pts per acre per crop season, nor within 7 days of harvest.
M Pede 49% EC (Soap, insecticidal)	1–2% V/V	12	0	aphids, leafhoppers, mites, plant bugs, thrips, whiteflies	--	OMRI-listed2.
*Mustang Max *Mustang Max EC (zeta cypermethrin)	2.24–4.0 oz	12	1	beet armyworm, cabbage looper, Colorado potato beetle, cutworms, fall armyworm, flea beetles, grasshoppers, green and brown stink bugs, hornworms, leafminers, leafhoppers, Lygus bugs, plant bugs, southern armyworm, tobacco budworm, tomato fruitworm, tomato pinworm, true armyworm, yellowstriped armyworm. Aids in control of aphids, thrips and whiteflies.	3	Not recommended for vegetable leafminer in Florida. Do not make applications less than 7 days apart. Do not apply more than 0.15 lb ai per acre per season.

Trade Name (Common Name)	Rate (product/acre)	REI (hours)	Days to Harvest	Insects	MOA Code[1]	Notes
Neemix 4.5 (azadirachtin)	4–16 fl oz	12	0	aphids, armyworms, hornworms, psyllids, Colorado potato beetle, cutworms, leafminers, loopers, tomato fruitworm (corn earworm), tomato pinworm, whiteflies	18B	IGR, feeding repellant. OMRI-listed[2].
NoMate MEC TPW (pheromone)		0	0	tomato pinworm	—	See label.
Oberon 2SC (spiromesifen)	7.0–8.5 fl oz	12	7	broad mite, twospotted spider mite, whiteflies (eggs and nymphs)	23	Maximum amount per crop: 25.5 fl oz/acre. No more than 3 applications.
Platinum Platnum 75 SG (thiamethoxam)	5–11 fl oz 1.66–3.67 oz	12	30	aphids, Colorado potato beetles, flea beetles, leafhoppers, thrips, tomato pinworm, whiteflies	4A	Soil application. See label for rotational restrictions. Do not use with other growth insecticidesl
*Pounce 25 W (permethrin)	3.2–12.8 oz	12	0	beet armyworm, cabbage looper, Colorado potato beetle, dipterous leafminers, granulate cutworm, hornworms, southern armyworm, tomato fruitworm, tomato pinworm	3	Do not apply to cherry or grape tomatoes (fruit less than 1 inch in diameter). Do not apply more than 1.2 lb ai per acre per season.
*Proaxis Insecticide (gamma-cyhalothrin)	1.92–3.84 fl oz	24	5	aphids[(1)], beet armyworm[(2)], blister beetles, cabbage looper, Colorado potato beetle, cucumber beetles (adults), cutworms, hornworms, fall armyworm[(2)], flea beetles, grasshoppers, leafhoppers, plant bugs, southern armyworm[(2)], spider mites[(1)], stink bugs, thrips[(1)], tobacco budworm, tomato fruitworm, tomato pinworm, vegetable weevil (adult), whiteflies[(1)], yellowstriped armyworm[(2)]	3	[(1)]Suppression only. [(2)]First and second instars only. Do not apply more than 2.88 pints per acre per season.
*Proclaim (emamectin benzoate)	2.4–4.8 oz	12	7	beet armyworm, cabbage looper, fall armyworm, hornworms, southern armyworm, tobacco budworm, tomato fruitworm, tomato pinworm, yellowstriped armyworm	6	No more than 28.8 oz/acre per season.
Prokil Cryolite 96 (cryolite)	10–16 lb	12	14	blister beetle, cabbage looper, Colorado potato beetle larvae, flea beetles, hornworms	9A	Minimum of 7 days between applications. Do not apply more than 64 lbs per acre per season. Not for cherry tomatoes.
Provado 1.6F (imidacloprid)	3.8–6.2 fl oz	12	0	aphids, Colorado potato beetle, leafhoppers, whiteflies	4A	Do not apply to crop that has been already treated with imidacloprid or thiamethoxam at planting. Maximum per crop per season 19 fl oz per acre.
Pyrellin EC (pyrethrin + rotenone)	1–2 pt	12	12 hours	aphids, Colorado potato beetle, cucumber beetles, flea beetles, flea hoppers, leafhoppers, leafminers, loopers, mites, plant bugs, stink bugs, thrips, vegetable weevil, whiteflies	3, 21	
Radiant SC (spinetoram)	5–10 fl oz.	4	1	armyworms, Colorado potato beetle, flower thrips, hornworms, Liriomyza leafminers, loopers, Thrips palmi, tomato fruitworm, tomato pinworm	5	Maximum of 34 fl oz per acre per season.
Sevin 80S; XLR; 4F (carbaryl)	80S: 0.63–2.5 XLR; 4F: 0.5–2.0 A	12	3	Colorado potato beetle, cutworms, fall armyworm, flea beetles, lace bugs, leafhoppers, plant bugs, stink bugs[(1)], thrips[(1)], tomato fruitworm, tomato hornworm, tomato pinworm, sowbugs	1A	[(1)]suppression Do not apply more than seven times. Do not apply a total of more than 10 lb or 8 qt per acre per crop.
10% Sevin Granules (carbaryl)	20 lb	12	3	ants, centipedes, crickets, cutworms, earwigs, grasshoppers, millipedes, sowbugs, springrails	1A	Maximum of 4 applications, not more often than once every 7 days.
SpinTor 2SC (spinosad)	1.5–8.0 fl oz	4	1	armyworms, Colorado potato beetle, flower thrips, hornworms, Liriomyza leafminers, loopers, Thrips palmi, tomato fruitworm, tomato pinworm	5	Do not apply to seedlings grown for transplant within a greenhouse or shadehouse. Leafminer and thrips control may be improved by adding an adjuvant. Do not apply more than three times in any 21 day period. Do not apply more than 29 oz per acre per crop.
Sulfur (many brands)	See label	24	see label	tomato russet mite, twospotted spider mite	--	May burn fruit and foliage when temperature is high. Do not apply within 2 weeks of an oil spray or EC formulation.
*Telone C 35 (dichloropropene + chloropicrin) *Telone II (dichloropropene)	See label	5 days (See label)	preplant	garden centipedes (symphylans), wireworms	--	See supplemental label for restrictions in certain Florida counties.
*Thionex EC *Thionex 50W (endosulfan)	0.66–1.33 qt 1.0–2.9 lb	24	2	aphids, blister beetle, cabbage looper, Colorado potato beetle, flea beetles, hornworms, stink bugs, tomato fruitworm, tomato russet mite, whiteflies, yellowstriped armyworm	2	Do not exceed a maximum of 3.0 lb active ingredient per acre per year or apply more than 6 times. Can be used in greenhouse.
Trigard (cyromazine)	2.66 oz	12	0	Colorado potato beetle (suppression of), leafminers	17	No more than 6 applications per crop. Does not control CPB adults. Most effective against 1st & 2nd instar larvae.
Trilogy (extract of neem oil)	0.5–2.0% V/V	4	0	aphids, mites, suppression of thrips and whiteflies	18B	Apply morning or evening to reduce potential for leaf burn. Toxic to bees exposed to direct treatment. Do not exceed 2 gal/acre per application. OMRI-listed[2].
Ultra Fine Oil, JMS Stylet-Oil, and others (oil, insecticidal) Saf-T-Side	3–6 qts/100 gal water (JMS) 1–2 gal/100 gal	4	0	aphids, beetle larvae, leafhoppers, leafminers, mites, thrips, whiteflies, aphid-transmitted viruses (JMS)	--	Do not exceed four applications per season. Organic Stylet-Oil and Saf-T-Side are OMRI-listed[2].
Venom Insecticide (dinotefuran)	foliar: 1–4 oz soil: 5–6 oz	12	foliar: 1 soil: 21	Colorado potato beetle, flea beetles, leafhoppers, leafminers, thrips, whiteflies	4A	Use only one application method (soil or foliar). Limited to three applications per season. Do not use on grape or cherry tomatoes. Toxic to honeybees.
*Vydate L (oxamyl)	foliar: 2–4 pt	48	3	aphids, Colorado potato beetle, leafminers (except Liriomyza trifolii), whiteflies (suppression only)	1A	Do not apply more than 32 pts per acre per season.
*Warrior II (lambda cyhalothrin)	0.96–1.92 fl oz	24	5	aphids[(1)], beet armyworm[(2)], cabbage looper, Colorado potato beetle, cutworms, fall armyworm[(2)], flea beetles, grasshoppers, hornworms, leafhoppers, leafminers[(1)], plant bugs, southern armyworm[(2)], stink bugs, thrips[(3)], tomato fruitworm, tomato pinworm, whiteflies[(1)], yellowstriped armyworm[(2)]	3	[(1)]suppression only [(2)]for control of 1st and 2nd instars only. Do not apply more than 0.36 lb ai per acre per season. [(3)]Does not control western flower thrips.

Trade Name (Common Name)	Rate (product/acre)	REI (hours)	Days to Harvest	Insects	MOA Code[1]	Notes
Xentari DF (*Bacillus thuringiensis* subspecies *aizawai*)	0.5–2 lb	4	0	caterpillars	11B1	Treat when larvae are young. Thorough coverage is essential. May be used in the greenhouse. Can be used in organic production. OMRI-listed[2].

THE PESTICIDE INFORMATION PRESENTED IN THIS TABLE WAS CURRENT WITH FEDERAL AND STATE REGULATIONS AT THE TIME OF REVISION. THE USER IS RESPONSIBLE FOR DETERMINING THE INTENDED USE IS CONSISTENT WITH THE LABEL OF THE PRODUCT BEING USED. USE PESTICIDES SAFELY. READ AND FOLLOW LABEL INSTRUCTIONS.

[1]Mode of Action codes for vegetable pest insecticides from the Insecticide Resistance Action Committee (IRAC) Mode of Action Classification v. 6.1 August 2008.
1A. Acetylcholinesterase inhibitors, Carbamates (nerve action)
1B. Acetylcholinesterase inhibitors, Organophosphates (nerve action)
2A. GABA-gated chloride channel antagonists (nerve action)
3. Sodium channel modulators (nerve action)
4A. Nicotinic acetylcholine receptor agonists (nerve action)
5. Nicotinic acetylcholine receptor allosteric activators (nerve action)
6. Chloride channel activators (nerve and muscle action)
7A. Juvenile hormone mimics (growth regulation)
7C. Juvenile hormone mimics (growth regulation)
9B and 9C. Selective homopteran feeding blockers
10. Mite growth inhibitors (growth regulation)
11. Microbial disruptors of insect midgut membranes
12B. Inhibitors of mitochondrial ATP synthase (energy metabolism)
15. Inhibitors of chitin biosynthesis, type 0, lepidopteran (growth regulation)
16. Inhibitors of chitin biosynthesis, type 1, homopteran (growth regulation)
17. Molting disruptor, dipteran (growth regulation)
18. Ecdysone receptor agonists (growth regulation)
22. Voltage-dependent sodium channel blockers (nerve action)
23. Inhibitors of acetyl Co-A carboxylase (lipid synthesis, growth regulation)
28. Ryanodine receptor modulators (nerve and muscle action) un. Compounds of unknown or uncertain mode of action
[2] OMRI listed: Listed by the Organic Materials Review Institute for use in organic production.
* Restricted Use Only

NEMATICIDES REGISTERED

FOR USE ON FLORIDA TOMATO

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NEMATICIDES REGISTERED FOR USE ON FLORIDA TOMATO

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	ROW APPLICATION (6′ ROW SPACING - 36″ BED)[4]				
PRODUCT	BROADCAST (RATE)	RECOMMENDED CHISEL SPACING	CHISELS (PER ROW)	RATE/ACRE	RATE/1000 FT/CHISEL
FUMIGANT NEMATICIDES					
Methyl Bromide[1,3] 50-50	300-480 lb	12″	3	150–240 lb	6.8–11.0 lb
Chloropicrin EC[1]	300-500 lb	Drip applied		See label for use guidelines and additional considerations	
Chloropicrin[1]	300-500 lb	12″	3	150–250 lb	6.9–11.5 lb
PIC Chlor 60[1]	19.5–31.5 gal	12″	3	20–25 gal/250–300 lb	57–90 fl oz
Telone II[2]	9–18 gal	12″	3	4.5–9.0 gal	26–53 fl oz
Telone EC[2]	9–18 gal	Drip applied		See label for use guidelines and additional considerations	
Telone C-17[2]	10.8–17.1 gal	12″	3	5.4–8.5 gal	31.8–50.2 fl oz
Telone C-35[2]	13–20.5 gal	12″	3	6.5–13 gal	22–45.4 fl oz
Telone Inline[2]	13–20.5 gal	Drip applied		See label for use guidelines and additional considerations	
Metham Sodium	50–75 gal	5″	6	25–37.5 gal	56–111 fl oz
NON FUMIGANT NEMATICIDES					
Vydate L treat soil before or at planting with any other appropriate nematicide or a Vydate transplant water drench followed by Vydate foliar sprays at 7 14 day intervals through the season; do not apply within 7 days of harvest; refer to directions in appropriate "state labels", which must be in the hand of the user when applying pesticides under state registrations.					

[1] If treated area is tarped with impermeable film, dosage may be reduced by 40-50%.
[2] The manufacturer of Telone II, Telone EC, Telone C 17, Telone C-35, and Telone Inline has restricted use only on soils that have a relatively shallow hard pan or soil layer restrictive to downward water movement (such as a spodic horizon) within six feet of the ground surface and are capable of supporting seepage irrigation regardless of irrigation method employed. Crop use of Telone products do not apply to the Homestead, Dade county production regions of south Florida. Higher label application rates are possible for fields with cyst-forming nematodes. Consult manufacturers label for personal protective equipment and other use restrictions which might apply.
[3] As a grandfather clause, it is still possible to continue to use methyl bromide on any previous labeled crop as long as the methyl bromide used comes from existing supplies produced prior to January 1, 2005. A critical use exemption (CUE) for continuing use of methyl bromide for tomato, pepper, eggplant and strawberry has been awarded for calendar years 2005 through 2009. Specific, certified uses and labeling requirements for CUE acquired methyl bromide must be satisfied prior to grower purchase and use in these crops. Product formulations are subject to change and availability.
[4] Rate/acre estimated for row treatments to help determine the approximate amounts of chemical needed per acre of field. If rows are closer, more chemical will be needed per acre; if wider, less. Reduced rates are possible with use of gas impermeable mulches.

Rates are believed to be correct for products listed when applied to mineral soils. Higher rates may be required for muck (organic) soils. Growers have the final responsibility to guarantee that each product is used in a manner consistent with the label. The information was compiled by the author as of July 1, 2009 as a reference for the commercial Florida tomato grower. The mentioning of a chemical or proprietary product in this publication does not constitute a written recommendation or an endorsement for its use by the University of Florida, Institute of Food and Agricultural Sciences, and does not imply its approval to the exclusion of other products that may be suitable. Products mentioned in this publication are subject to changing Environmental Protection Agency (EPA) rules, regulations, and restrictions. Additional products may become available or approved for use.