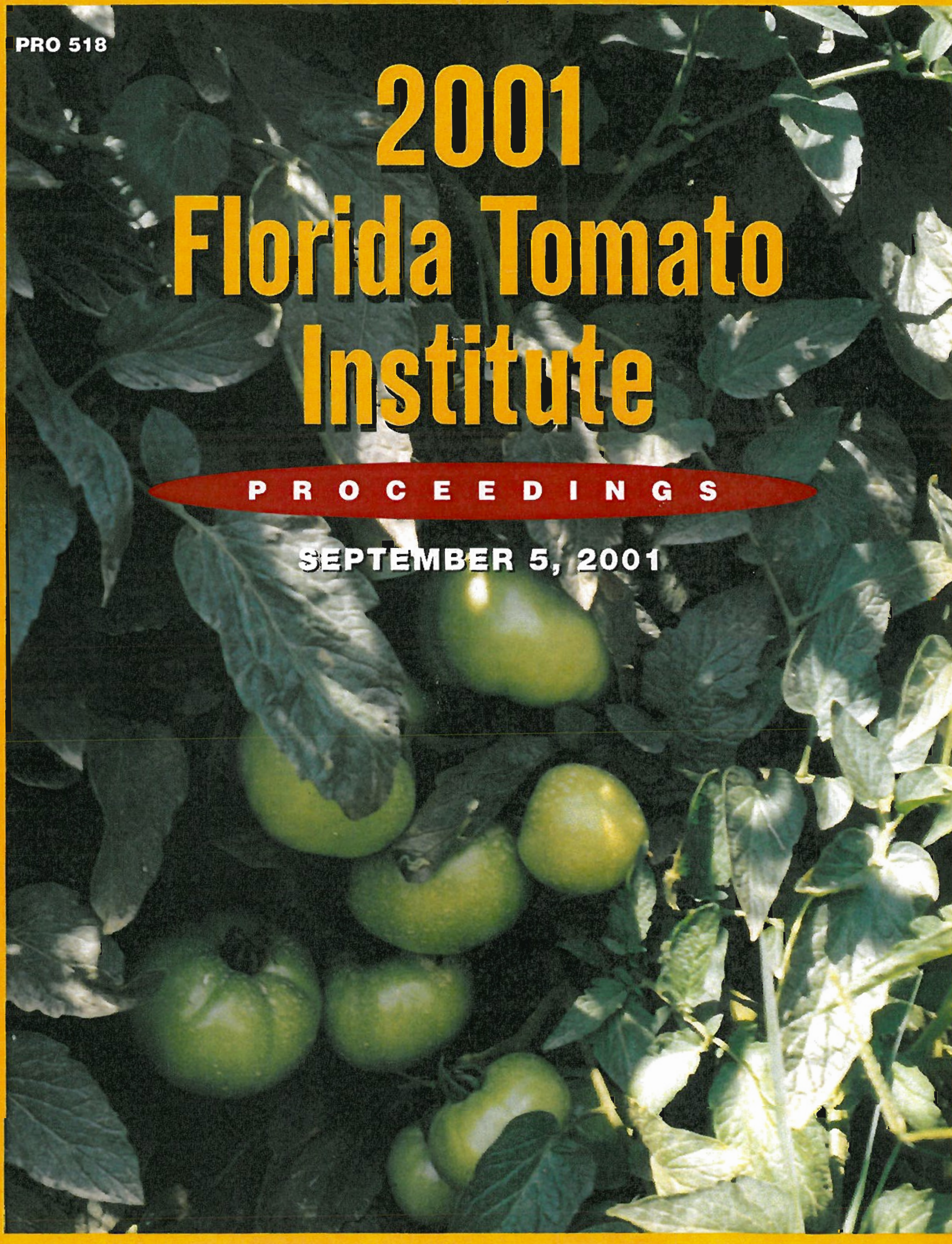
PRO 518

2001 Florida Tomato Institute

PROCEEDINGS

SEPTEMBER 5, 2001



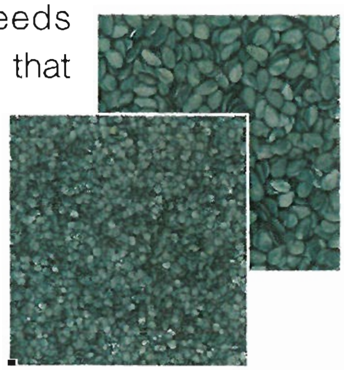
Citrus & Vegetable Magazine

University of Florida

Compiled by:
Phyllis Gilreath, Extension Agent, Manatee County, University of Florida and
C.S. Vavrina, Professor/Interim District Director, University of Florida, SWFREC, Immokalee

Excellence has a new look

Petoseed, Asgrow Vegetable Seeds and Royal Sluis products sold in North America will now be shipped in new Seminis Vegetable Seeds packaging. All Seminis products that receive film-coating will now be shipped with a new turquoise color. The transition to the new packaging and film-coating is expected to be completed by October 1.



Seminis Vegetable Seeds

ASGROW VEGETABLE SEEDS · PETOSEED · ROYAL SLUIS · Gi

Florida 47 R is well-adapted for mature green and vine ripe production in the eastern United States. The uniform green fruit is exceptionally firm, uniformly extra-large and smooth with a deep oblate shape. The tall, vigorous plant has excellent foliage and fruit cover and is resistant to V-1, F-1, F-2, ASC and St.

Florida 91 is a hot-set tomato for the eastern United States. Maturing in the main season, it has high yield potential and exhibits exceptionally firm and smooth fruit throughout the season. Fruit are mostly extra-large in size, uniform green with jointed pedicels. **Florida 91** features a strong, healthy vine; it is resistant to V-1, F-1, F-2, ASC and St.

2001 Florida Tomato Institute Program

Ritz Carlton Hotel • Naples, Florida • September 5, 2001

a.m. *Moderator: Mary Lamberts, Extension Agent, Tropical Vegetables, Dade County*
8:45 **Welcome & Introductory Remarks** - Charlie Vavrina, UF, SWFREC, Immokalee

8:55 **State of the Industry Address** - Reggie Brown, Manager, Florida Tomato Committee, Orlando

9:10 **Feasibility of Robotic Harvesting for Tomatoes** - Hagen Schempf, Carnegie Mellon University, Pittsburgh, PA, **pg. 2**

9:30 **Unlocking the Molecular Genetics of Tomato Flavor**- Harry Klee, Dickman Chair, UF, Horticultural Sciences Dept., Gainesville

9:50 **Policy and Trade Issues Critical to Florida Tomato Growers** - John VanSickle, UF, Food & Resource Economics Dept., Gainesville, **pg. 12**

10:10 **Monitoring Susceptibility of the Silverleaf Whitefly to Imidacloprid** - Dave Schuster, Sandra Thompson, UF, GCREC, Bradenton, **pg. 16**

10:30 **Engineered Resistance in Tomato to Geminiviruses** - Jane Polston, UF, GCREC, Bradenton, **pg. 19**

10:50 **The Potential of Recovered Tailwater as a Source of *Phytophthora capsici* and Other Vegetable Pathogens**- Bob McGovern, UF, CGREC, Bradenton; Pam Roberts, UF, SWFREC, Immokalee; T. E. Seijo, UF, GCREC, Bradenton; R. R. Urs, UF, SWFREC, Immokalee, E. A. Bolick, UF, SWFREC, Immokalee; and T. A. Davis, UF, SWFREC, Immokalee, **pg. 23**

11:10 **Packinghouse Sanitation: How Much is Enough?**- Steve Sargent, UF, Horticultural Sciences Dept., Gainesville; Jerry Bartz, UF, Plant Pathology Department, Gainesville; Tim Momol, UF, NFREC, Quincy; Michael Mahovic, UF, Horticultural Sciences Dept., Gainesville; Stephen Olson, UF, NFREC, Quincy; Phyllis Gilreath, UF, Florida Cooperative Extension Service, Palmetto, **pg. 26**

11:30 **Lunch**

p.m. *Moderator: Erin Rayfield, Extension Agent, Vegetables, Hillsborough County*
1:00 **New Product Updates**, Industry Representatives

1:50 **Methyl Bromide Alternatives: Long Term Trials, Application Techniques and Herbicides**- Jim Gilreath, UF, GCREC, Bradenton; Joe Noling, UF, CREC, Lake Alfred; Phyllis Gilreath, UF, Florida Cooperative Extension Service, Palmetto, **pg. 29**

2:10 **Methyl Bromide Rates, Reductions, Formulations and IPM Alternatives for Nematode Control**- Joe Noling, UF, CREC, Lake Alfred; Jim Gilreath, UF, GCREC, Bradenton, **pg. 40**

2:30 **Better Bed Wetting Through Science**- Joe Eger, Dow Agrosciences, Tampa; Jim Gilreath, UF, GCREC, Bradenton; Joe Noling, UF, CREC, Lake Alfred, **pg. 45**

2:50 **Results from Field Scale Demonstration/Validation Studies of Telone Products on the East Coast** - Dan Chellemi, USDA/ARS, Ft. Pierce; John Mirusso, Mirusso Fumigation & Equipment, Delray Beach; Jerry Nance, Dow Agrosciences, Winter Haven; Ken Shuler, UF, Florida Cooperative Extension Service, West Palm Beach, **pg. 51**

3:10 **Water Management for Tomato** - Eric Simonne, UF, Horticultural Sciences Dept., Gainesville, **pg. 59**

Control Guides:
Tomato Varieties for Florida - Donald N. Maynard, UF, CREC, Bradenton; and Stephen M. Olson, UF, NFREC, Quincy, **pg. 62**
Tomato Fertilizer Management - Eric H. Simonne, UF, Horticultural Sciences Dept. Gainesville; George J. Hochmuth, UF, NFREC, Quincy, **pg. 66**
Chemical Disease Management for Tomatoes - Tom Kucharek, UF, Plant Pathology Dept., Gainesville, **pg. 72**
Nematicides Registered for Use on Florida Tomato - Joe Noling, UF, CREC, Lake Alfred, **pg. 75**
Weed Control in Tomato - William M. Stall, UF, Horticultural Sciences Dept., Gainesville; James P. Gilreath, UF, GCREC, Bradenton, **pg. 76**
Selected Insecticides Approved for Use on Insects Attacking Tomatoes - Susan E. Webb, UF, Entomology Dept., Gainesville, **pg. 80**

Automated Tomato Harvesting

Hagen Schempf, Herman Herman and Anthony Stentz
National Robotics Engineering Consortium, Robotics Institute, Carnegie Mellon University

1.0 Tomato Harvesting - Background

The process of manual staked-tomato harvesting in Florida (100% of US winter tomatoes) is based on multiple 'pickings' per season (October thru June), following the growth and maturation process of the plant. Typically three pickings are done per season, with varying percentage-yields in each picking: 1st -50%, 2nd -30%, 3rd -20%.

Yields per acre are based on row-plantings and -spacings and plant-separation (typically 2 feet along the row), with stakes that are interconnected with synthetic twine. Productivity varies, but yields are typically of the order of 2,000 25-pound boxes per acre of tomato-fields. On average, each plant yields about 12 lbs. of tomatoes per season. Harvesting represents about 50% of the total cost, with $1,500.- to $2,000 per acre of labor-cost being typical. It was measured, that human pickers proceed at a rate of about 0.5 in/sec, or about 2.5 feet per minute (roughly one plant a minute!).

Manual picking is performed with migrant labor, who pick tomatoes in a zone of the plant (depending on the season), dropping them in a (typically) 5-gallon bucket and bringing them to a central location, where the bucket is emptied into an even larger container, and the picker is given a piece of paper; payment at the end of the day is based on the number of 'full' buckets each picker delivered[1]. Picking is done by sweeping the foliage aside and grabbing those tomatoes of a proper size (color is not the driving factor), twisting them off the vine, and making sure the stem is left on the vine or removed before putting the tomato in the bucket[2]. The pickers sit on the edge of the bucket and keep dropping the tomatoes between their legs into the bucket until it is full. Based on the productivity figures, it was determined that humans progress at a rate of about 1 foot/minute if dual-sided picking of a plant was done sequentially. Wastage (drop-of/fall-out) is typically in the range of 2% to 5%. The current picking method spends about 90 seconds filling the bucket[3] with tomatoes, followed by 30 to 45 seconds of walking and waiting back and forth to the truck, before filling of the next bucket occurs.

These numbers were all gathered during a field-trial trip to several tomato farms in mid- and western-Florida in November 2000, with collected data from on-site measurements and data provided by the Florida Tomato Committee and various growers we visited. A complete spreadsheet of the resulting data and extracted figures of merit by which to measure and compare manual picking effectiveness, are compiled in Figure 1-1 thru Figure 1-3. Notice that this data is important in assisting in the development of the performance and system requirements for an automated system.

1. some pickers 'fluff' the bucket to reduce the packing inside the bucket to increase the fullness with same number of tomatoes.
2. the stem should be removed as it would poke tomatoes and generate blemishes visible once ripened in the chambers, resulting in an inferior product
3. about 75 to 85 tomatoes fit into a 5-gallon pail, based on an average tomato-size/-weight figure

2.0 System Selection

Based on the data in Figure 1-1 thru Figure 1-3, the major points of which are highlighted in Table 1-1 below, it became possible to develop a set of overall technology-focus and automation-categories to allow us to refine the study further. This was necessary to allow the team to develop experimental prototypes and test them for intended use on a particular type and design for a potential automated staked-tomato harvester.

Table 1-1 : Major highlight points based on field-trip data and robotics expertise

Net price to pick a tomato: 0.56 cents
Average weight of tomatoes/plant: 12.53 lbs
Average number of tomatoes/plant: 33
Net picking speed on 1st pick (fastest): 0.532 inches/second
Net time spent/plant: ~ 45 seconds

Pluses: relatively low speed requirement, willingness to switch to jointless variety, tomato detection is possible
Minuses: inside-vine tomatoes will be very hard to pick; mechanical de-stemming unlikely.
UPSHOT: Tomato-harvesting is a mechanical and not a sensing nor software challenge.

The first question worth posing is the extent to which automation should be utilized. The possible solutions range from completely automating the process leaving a single operator supervising the operation, thru a simple automated towed (possibly instrumented) fruit-picker with humans transporting performing quality/de-stemming operations, to a simple bucket-conveyor to reduce wasted time based on a flow-analysis. A very simplified selection-matrix illustrates the degree to which labor-needs could be reduced based on these choices (see Table 1-2):

Based on these choices, we believed that only the simple conveyorized transport system (increased productivity with the same labor-force, or equivalent productivity with a 25% reduced labor-force), or an automated dual-sided 6-row picker would be feasible solutions in Florida.

3.0 System Concept Evaluation

Based on our field-trip and evaluation of the numerical data provided to us by growers, and a simple flow-analysis performed on-site, we developed two very simple concepts for mechanized and automated operations for staked-tomato harvesting.

Table 1-2: Automation-degree impact on labor requirements

Task	Benefit	Risk	Personnel Requirement
Automated Transport/Material Handling	25%	Low	Same as the current manual setup
Mechanized Picking Conveyor Transport & Manual Boxing	High (200+)	Medium	2-3 for picking 6 row
Automated Picking, Transport, and Boxing	High	High	1 for picking 6 rows

3.1 Concept Range

3.1.1 Mechanized Transportation

If the growers wanted a low-cost immediate solution to provide either a 25% productivity-increase or a 25% labor-force reduction capability, we would propose a conveyorized carrousel transport system to avoid the time spent walking to/from the collector-truck for each picker. A schematic top-view of the envisioned system is shown in Figure 1-4.

The system would be based on a simple overhead conveyor-chain with hooks. The ends of the horizontal conveyor are supported on chain-drive wheels that are slaved to the forward motion of the truck-towed conveyor arrangement. The configuration allows for picking three rows on eith ; side of a roadway, which would work for a 6-row planting between road-beds - note through that this could be modified to suit different layouts.

This system would allow each picker to hang and then retrieve their bucket (based on color or other marking) to fill with tomatoes, hang it on the chain and continue to pick. The existing paper-sheet payment system could be maintained, especially if the paper sheets are colored (same as the picker's bucket-color for instance).

3.1.2 Automated Harvesting Tool

The automated harvesting tool depicted diagrammatically in Figure 1-5, relies on dual-sided mechanical picking stations arranged on a frame with vertical and side-exiting horizontal conveyor, to automatically pick fruit in a pre-determined zone, and convey the tomatoes to an advancing truck. At the truck the tomatoes are manually fed and arranged in the standard boxes; the standard arrangement would call for one operator in the tractor pulling the implement, while two other operators (one driving; one packing) take care of packing the fruit. This scenario presumes that the fruit is stemless; if this is not the case, one or more packers would need to be added closer to the truck-end to help de-stem the tomatoes, and possibly assist in boxing them.

The artist-rendering in Figure 1-6, depicts the envisioned attachment to the tractor, powered through its PTO, working in a row-planted field of tomato plants (foliage omitted for clarity). It should be understood that different arrangements of this concept could be implemented, depending on the layout of the tomato-farm.

3.2 Critical Technologies

The proposed system concepts embody a critical element which needs to be explored further in terms of its feasibility. This element is clearly the mechanical tomato-picking device which in replicated and integrated form is pulled by the tractor. This part of the system combines both mechanical and sensory elements to allow for the removal of ripened fruit. This section depicts the design and functionality of both the sensory and picking elements in more detail.

The basic elements of the automated picking section are depicted diagrammatically in Figure 1-7. One can see that the tomato-stand atop the earth-berm, with tomatoes distributed within its branched foliage. The notion would be to utilize compressed-air blowers to move foliage away from the camera imager and mechanical picker. The camera would detect tomato-clusters within its image and tell the picking-mechanism when and where to pick within a particular zone. The tomatoes would drop onto a sloped ramp, from where a vertical conveyor would bring them up on either side to the height of a lateral conveyor, which in turn conveys them to the waiting boxing-truck.

The two main open technologies or subsystems that need to be evaluated are imaging the tomatoes (finding them and identifying them from amongst the foliage, despite occlusions from leaves and/or stems) and removing them from the plant. The remainder of this section focuses on the technical feasibility of both these subsystems based on experimental prototyping and processing of imagery gathered during field-trips.

3.2.1 Imaging

To minimize damage to the plant and to increase the picking efficiency, we are incorporating active sensors as part of the automated picker-system. These sensors, which consist of color video cameras, are used to detect and locate the tomatoes. This information is then used to guide the picking mechanism.

Although it is trivial for a human picker to detect and locate the tomatoes, the same task is harder for a machine. The following problems are just some of the challenges that we need to solve:

- **Color variation:** Tomatoes can be red, green or a mixture of both colors
- **Occlusion:** The tomatoes can be occluded by leaves, other tomatoes, and branches
- **Lighting variation:** The appearance of a tomato can be affected greatly by different lighting conditions.
- **Real-time processing:** The tomatoes need to be detected and located in real-time, which means that the processing hardware and software need to be very efficient and fast.

Fortunately, tomatoes also have some characteristics that make it easier to detect. These characteristics include a shiny and smooth surface and a well defined shape. Using these characteristics, we have come up with a prototype hardware and software system. Almost all the tomatoes are detected and located correctly, even when they are occluded by leaves and branches. The system is also fairly fast. It can detect the tomatoes in a fraction of a second.

From the development of the prototype system, we recognized the importance of controlling lighting. Natural lighting varies significantly depending on the weather and time of the day. These variations can degrade the performance of the vision system, so it is advisable that we put a canopy on top of the plant to shield it from sunlight and use artificial lighting to bathe the plant with constant illumination.

We believe that an enhanced version of the prototype system along with artificial lighting will be able to reliably detect most of the tomatoes.

3.2.2 Mechanical Fruit-Pickers

The concepts that were developed for the mechanical picking of tomatoes are depicted below in Figure 1-9. The tomato-cage solution is a revolving cage with tapered rails to trap individual tomatoes and then pull them off the vine. The system would work well on tomatoes outside of the string-support area, and would most likely require stemless tomatoes to minimize the need for de-stemming. The tomato-rake is a combination of guides and rotary fingered probes that would trap tomatoes between the fingers and be pulled off the vine as part of the rotation of the fingers on a vertical/horizontal drum-arrangement. This arrangement could be designed to be rigid and/or flexible, and be capable of reaching for fruit caught inside of the support-twine. The tomato-rail is similar to the cage in that it simply works on pulling overhanging fruit off the vine.

These concepts were all evaluated by a group of engineers at CMU, and only a subset of them were prototyped for testing on fake tomato-plants at CMU[1] , and then field-grown tomatoes in Florida.

1. synthetic ficus-plants with superglued vine-grown tomato clusters

4.0 Prototype Mechanical Picker Development

The prototypes for the mechanical tomato pickers are depicted in Figure 1-10. All three of them were tested at the CMU fake-tomato harvesting setup. The tomato-trident was a rotary set of rigid forks that was deployed into the plant and pulled to retrieve the fruit - its design kept twine from being caught; both rigid-frame and manual deployment was tested, and found to be promising and worthy of testing[1] . The tomato fingers were a spring-mounted version of the forked arrangement that would also not catch the support twine. This system was also deemed appropriate but not likely to be as successful as the rigid-fork trident arrangement. The tomato-guides were the set of rigid guides that we proved would work well only on overhanging fruit - tomatoes inside the plant and caught within vines and twine could not be picked. This prototype was thus brought to the test-site in Florida, but not deemed worthy of testing. A video of the system performance exists in digital form and is part of this final report in a digital presentation format.

1. notice that foliage response could not be really tested, as the plant was synthetic and thus very tough (both the leaves and the vines)

5.0 Field Trials

5.1 Setup

The setup involved bringing all the above prototypes to a farm in Florida, near the eastern edge of the central-Florida growing region. The two-person team from CMU spent the morning setting up the testing apparatuses and then proceeded to try them in sequence on several rows of a 30-foot section of a planted farm. The group set out to test the efficacy of three different implements for removing tomatoes from a one foot wide picking zone. The plants were approximately 2' high on a soil bed of 6-8 inch elevated above the ground. The tests were performed on the lowest 1' of the plants which had never been picked (i.e. this was first-pick). According to the farmers present during the testing, this was close to the ideal time to pick. The rows were an alternating pattern of 24" to 36" wide arrangements. In general all of the implements but one was intended to mount on an adjustable sliding frame.

- **Rotary Flexible Finger:** Four banks at 90 degrees from one another of 8" long foam covered springs. Each bank is comprised of five fingers ~2 inches apart. It operates in a rotary fashion. The Rotary Finger assembly was run through the plant picking zone with the axis of rotation vertically orientated. The unit was driven at medium speed (3-400 RPM).
- **Reverse Comb:** "Z" shaped arm with a series of three 2" diameter "U" shaped tines at the end of the arm.
- **Tapered Gate:** Four bar arrangement that is 6" at opening and 2" at exit portion.

5.2 Results

The rotary flexible finger implement removed all tomatoes of all sizes in the 12"(h) x 8"(w) pick zone which extended approximately 75% of the way into the plant profile. The device did not remove any fruit from the area near the center stalk. The relatively fast action and high friction of the fingers shredded most of the leaves in the area it covered but did not pull many branches off. Bruising of the fruit was negligible. The stakes and string did not get trapped. The Reverse Comb was tested in two modes, a circular action and a rectangular action. In the rotary mode the arms extended 12" from the axis of rotation and swept up through the plant from close to the ground surface at 60 RPM. In this mode, the implement removed all tomatoes of all sizes except those that were solitary under 1.5" within the swept area. It also trapped many secondary branches along with the fruit and broke them off. Because of the zig zag nature of some string arrangement this implement sometimes caught the strings. In the rectangular mode the implement was manually pushed horizontally in at the bottom of the plant and raised 8-10 inches vertically as close to the main stalk as possible. The tool was then pulled horizontally away from the plant level with the point of the top of the vertical stroke at ~3 seconds per cycle. Again, in this mode the implement removed all of the tomatoes except for the smallest that were not bunched with larger sizes. There was less branch breakage than in the rotary mode (~1/3rd). As part of this experimental run of about 33 feet on a one-sided plant for a 1-foot high picking-zone, from a total of 27 tomatoes, 19 tomatoes were removed (leaving 8 on the vine), with 50% of them still having vines/stems attached. It was also observed that this implement was able to remove fruit but not regularly able to differentiate size (minor modifications could be made to avoid capturing the string). While able to dig deeper into the plant than the other instruments the tines would also grab main branches in the process.

The tapered gate has four "C" shaped bars running horizontally in the direction of travel with a 6" opening in front tapering to 2". The 6" opening allows fruit and branches to enter and traps the larger tomatoes as it tapers down. This device did operate as planned on isolated fruit that were orientated ideally. The horizontal bars that extend into the plant would sometimes push branches out of the way of the mouth preventing them from being captured. It was able to allow branches and smaller solitary tomatoes to exit without damage but would pick entire clusters if they entered the device. The rounded leading edge would sometimes bump roughly against the stakes and vertical branches. While this implement did not break as may branches and leaves, it did rub the skin off the main stalks and would occasionally capture a branch along with a fruit. This tool was unable to reach any of the fruit that was clustered near the center especially those that were bounded by outboard branches[1] .

1. A sharper angle on the leading edge may prevent bumping into the sturdier portions of the row. As with the Reverse Comb tool a teflon type coating may reduce the capture of branches and the damage due to rubbing.

6.0 Conclusions & Recommendations

While none of the tests were close to a solution they did prove the ability to pick. They were not able to precisely differentiate by size and the breakage damage was described as slightly worse than that of normal picking. Stem and leaf bruising was worse than incurred during normal picking. The leaves and branches left behind exhibited excessive bruising, which implies a potential site of bacterial infection and thus highly undesirable. The remaining stems on half the fruit were also undesirable and would require either another de-stemming machine or operators performing this task. The farmers present at the testing, and based on the video shot during the experiments, the damage to the plant and the tomatoes left behind on the vine was deemed unacceptable. It seems at this point that simple low-cost technical mechanical picking is not feasible unless stemless tomatoes are grown and the twining method is changed to avoid bunching; furthermore, plant-damage needs to be reduced based on different picking approaches and use of materials. The project was thus halted and upon conferring with several people the following recommendations were generated:

- Consider the use of a simple conveyorized bucket-chain arrangement to increase productivity or tolerance to reduced labor-pools by up to 25%
- It is unlikely that fully de-stemmable mechanically-picked tomatoes can be harvested stemless varieties would help mechanical harvesting greatly
- Fingered pickers that are capable of accessing areas within the twine-area are the recommended method •A different form of twining should be explored to avoid the bunching of the vines and thus the trapping of tomatoes if at all possible
- More low-cost experimental work is necessary to see if a

lower plant-damage mechanical picking method/system can be developed

- Another method might be to grow a tomato-type that has a single harvest, but can be planted several times per season - akin to those used on the west coast, allowing the use of existing (destructive) harvesting mechanisms
- Consider as a last resort, the development of a more sophisticated and costlier sensor-guided tomato-picking system. We caution against it not because it is infeasible, but because of its cost, complexity, need for maintenance and potential lack of sufficient ruggedness, irrespective of who develops and builds it

Acknowledgements

The authors would like to thank the Florida Tomato Committee for supporting this work.

CRITERIA	VALUE	UNITS	COMMENTS
Number of tomato plants per acre	3990	plants/acre	Based on 5-foot (4350) to 6-foot (3630) row-spacing
Spacing between adjacent tomato plants	2	feet	
Linear feet of tomato-beds per acre	7980	tomato-feet/acre	Based on 5-foot(8700) to 6-foot (7260) row-spacing
Yield of tomato-farm measured in number of 25 lbs. Boxes per acre	2,000	25lb-box/acre	Over 3 pickings
Number of tomatoes picked in first picking	50%	%	About 1,000 25-lbs-boxes per acre
Number of tomatoes picked in second picking	30%	%	About 600 25-lbs-boxes per acre
Number of tomatoes picked in third picking	20%	%	About 300 25-lbs-boxes per acre
Total manual labor cost of three pickings: Harvesting cost per acre	$2,000	$/acre	Labor cost ONLY - $1,500 to $1,800 is typical
Remaining Costs in the field: Plant, Stake, Tie, Prune, Clean	$800	$/acre	Range is $1,500 to $1,800 per acre
Time-window during which tomato is dry and pickable	8	hrs	Typically 10 AM to 4 PM Could be later - until dew sets in!!
Tomato Size Designations - XL: 5 x 6	5 x 6		Min Size: 2" + 27/32"
Tomato Size Designations - L: 6 x 6	6 x 6		
Tomato Size Designations - M: 6 x 7	6 x 7		Min Size: 2" + 9/32"
TOMATO COUNCIL NUMBERS			
Wintercrop Value in FL	$400M	$	Tomato Sales from Nov. thru June - Gross Sales
% of total tomatoes sold in the US per year that are produced in FL	65%	%	Range from 60% to 65%
% of tomatoes on shelves in winter in the US grown by FL	100%	%	
% of tomatoes on shelves in summer in the US grown by FL	0%	%	
Weight-range on a 25-lb box	25-27	lbs	
Sales price on a 25-lbs box of FL winter tomatoes	$8	$/box	Range from $6.89 (1999) to $14.- (2000), typical $9.11
Number of tomato-acres in all of FL	35,000	acres	
Volume of boxes sold	52M	25-lb-boxes	Range is from 47M to 58M
Number of growers that have 80% to 90% of the FL market	20	ea.	
Number of growers that have 10% to 20% of the FL tomato market	40 - 50	ea.	

Figure 1-1 : Manual staked-tomato harvesting data collected during Florida field-trip - Dec.00

MANUAL PRODUCTIVITY & COST FIGURES - GROWERS			
Average worker productivity in a 7 to 8-hr day	4,000	lbs/8-hr-day	Range is 3,500 to 4,500 lbs/8-hr-day
Average crew productivity : lbs per day with 80 to 100 laborers	500,000	lbs/day/crew	
Average yield of an acre	50,000	lbs/acre	Range is 40,000 to 50,000 lbs/acre over 3 pickings
Price paid per bucket to a picker	45	cents	
Number of buckets per ~1,000 lbs bin	33	buckets	
Number of buckets picked per worker per day	150	buckets	Range is from 100 to 200 buckets/person/day
Average weight per bucket loaded	30	lbs	
Aveage price paid to a worker	~$10	$/hr.	
Number of bins per acre (calculated?)	30	bins per acre	Range is 15 to 45
Total cull-out for 3 pickings	25	%	About 10% to 15% PER picking
Number of acres 150 pickers can do in 2 days	40	acres	
Breakeven cost per 25-lb box	$7 to $8	$/25-lbs-box	$7 (fall harvest) for spring and $8 (spring harvest)
Harvesting Costs per box	85	cents/25-lbs-box	ALREADY CULLED THOUGH!!!
Packing Costs per box	4	$/25-lbs-box	ONLY CULLED TOMATOES!!!!
MANUAL PRODUCTIVITY FIGURES - MEASURED			
Number of minutes to fill a bucket	2	min	
Number of tomatoes per bucket	80	ea.	Range from 75 to 90
Number of seconds to fill a bucket	90	sec	
Numbre of seconds walking to/from truck	30	sec	
Numbre of seconds waiting for bucket-dumping at truck	15	sec	
Number of tomatoes dropped per bucket loading, lifting and dumping	3	ea.	Ranges from 2 to 5
OTHER			
Width of roads at ends of beds	30	feet	
Free space in the ditch between rows of tomatoes	2	feet	
Number of roads in-between roads ALONG beds	3 to 6	ea.	

Figure 1-2 : Manual staked-tomato harvesting data collected during Florida field-trip - Dec.00 - cont.

CALCULATED	VALUE	UNITS	COMMENTS
Net price to pick a tomato	0.56	cents/tomato	(cents-paid/bucket)/(#tomatoes/bucket)
Average total weight of tomatoes per plant	12.53	lbs/plant	Yield in lbs per acre / # plants per acre
Average weight of a tomato	0.38	lbs/tomato	(lbs/bucket)/(tomatoes/bucket)
Average number of tomatoes per plant	33	tomatoes/plant	Divide the above 2 numbers
Average number of tomatoes picked per worker per day	10667	# tomatoes/day/worker	((lbs/worker/day)/(lbs/bucket))*(#tomatoes/bucket)
Number of tomatoes picked per worker per day	12000	# tomatoes/day/worker	(#buckets/day/worker)*(tomatoes/bucket)
Number of plants picked per worker per day	359	# plants/day/worker	Divide above to get # plants/ day/worker
Total number of tomato-bed-feet travelled by picker in a day	718.2	bed-feet/day/worker	Above times spacing between plants
Net average picking-speed in a bed	0.30	inches/sec	Above/(8hrs*60min/hr*60sec/min)
Net picking speed on 1st pick (will be fastest)	0.532	inches/sec	*((lbs/day/worker)/(hrs/day))/((lbs/plant)*%1stpick))*(12in/ft)/(60min/hr*60sec/min)
Number of seconds spent per worker picking a 2-foot spaced plant (1st pick)	45.11	sec/plant	((feet-spacing/plant)*(12in/sec))/(worker-speed-in-inches/sec)
Number of seconds per worker spent picking a tomato (1st pick)	2.7	sec/tomato	Above/((#tomatoes/plant)*(%1stpick))

Figure 1-3 : Derived performance and cost figures from the gathered field-trip data in Florida - Dec00

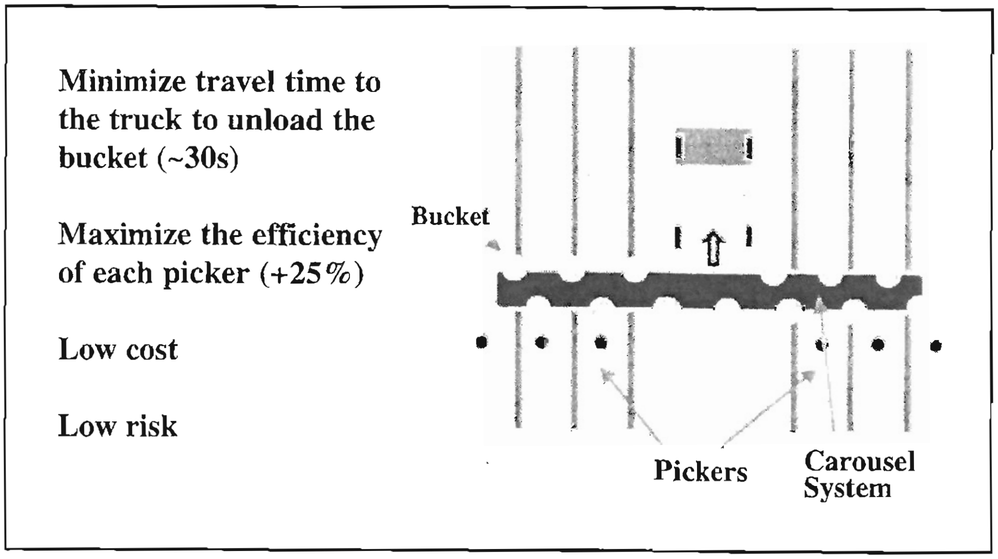


Figure 1-4: Mechanized picking-bucket transport system

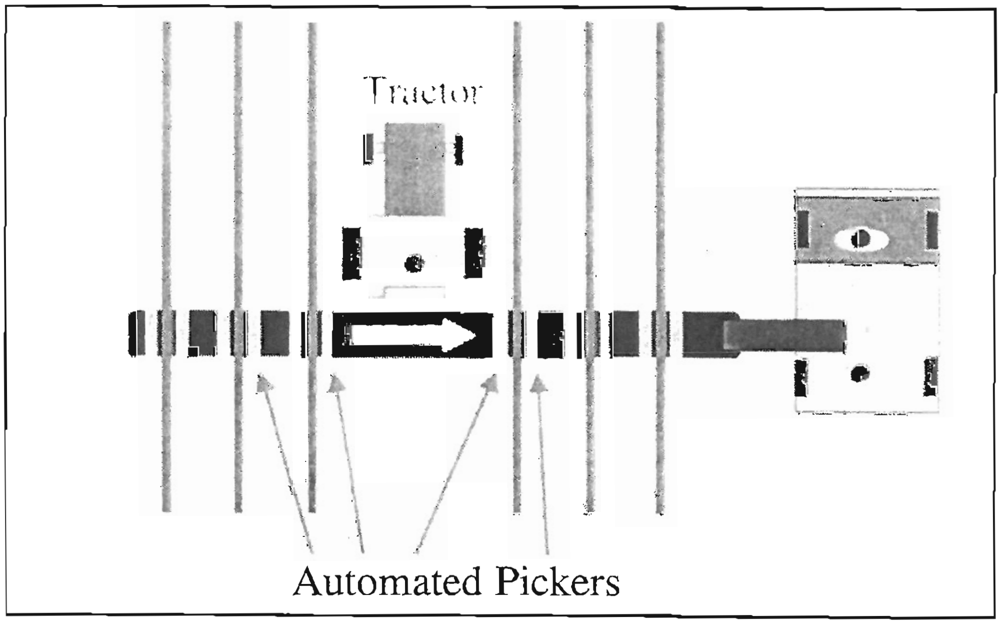


Figure 1-5: System diagram of automated, dual-sided row-picker

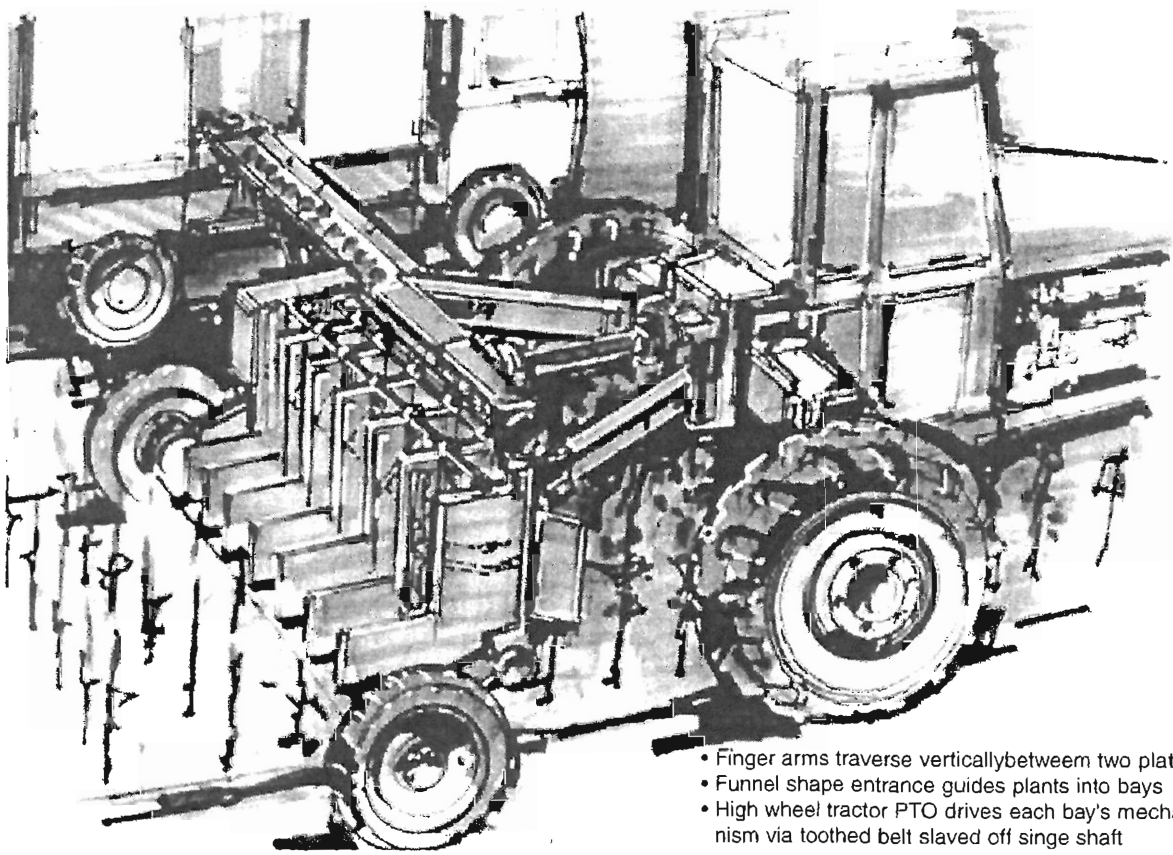


Figure 1-6: Artist-rendering of automated staked-tomato picker system

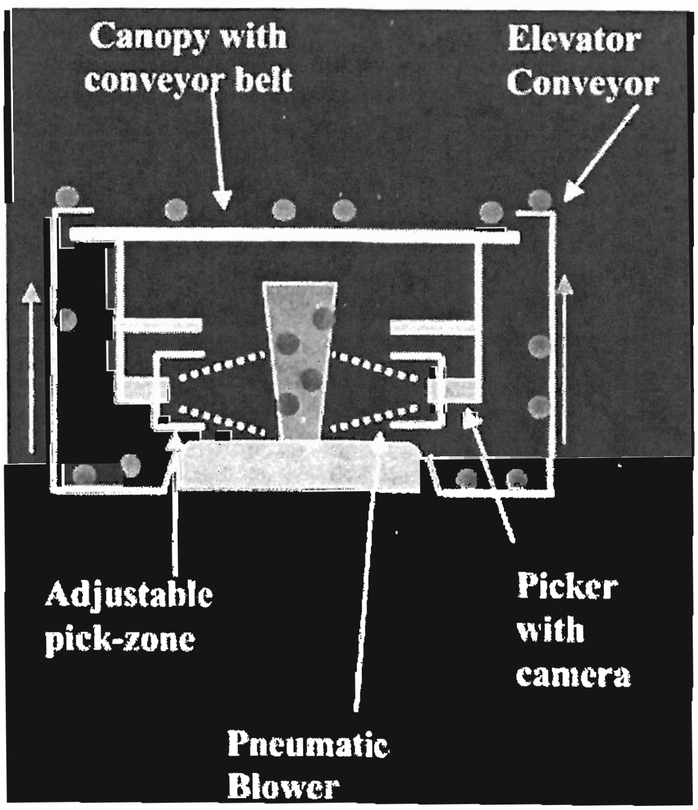
•Two, six-rowed two-sided pick-trailer behind high-boy tractor with PTO

•Use camera to locate tomato-clusters & turn picker on/off

•Pick the tomato using 'raking' mechanism

•Track tomato-picking effectiveness using the camera

•Transport (elevate & convey) tomatoes to the boxing-truck



Tomato-Cage

Tomato-Rake

Tomato-Rail

Others

Figure 1-9 : Mechanical tomato-picking design concepts

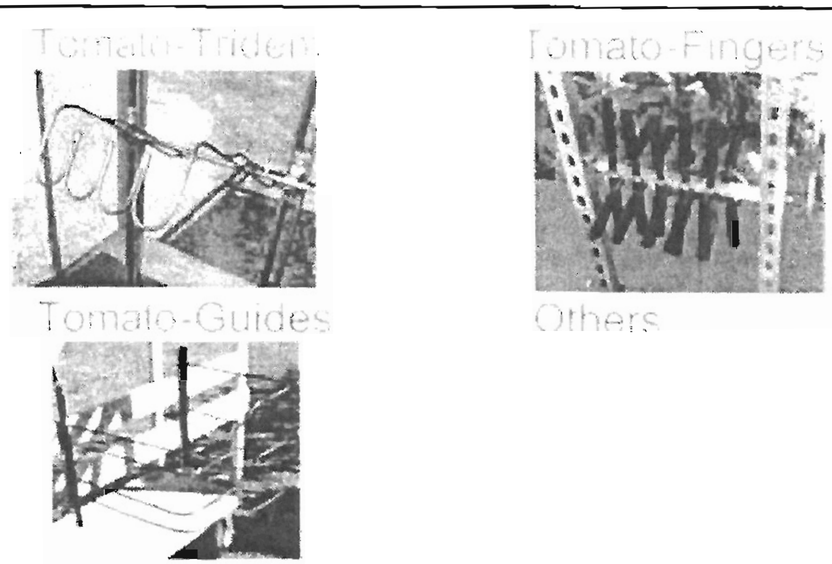


Figure 1-10 : Prototype mechanical tomato picking systems

Policy and Trade Issues Critical to Florida Tomato Growers

John J. VanSickle

The fresh tomato market has undergone a rocky ride over the last several years due to several factors that have influenced supply and demand. The decade of the 1980s and through 1992 were good years in this industry. The industry experienced growth in demand and managed competition so that most years were good with the exception of weather events that cut production in some areas. The 1992 season was exceptional for U.S. producers, especially in Florida, because of poor weather conditions in Mexico. The market remained good until December, 1994, when the large devaluation in the peso and the implementation of the North American Free Trade Agreement began a series of trade disputes that left the industry in a state of disarray. U.S. growers filed an antidumping case with the U.S. International Trade Commission in 1996 that resulted in a suspension agreement that placed an effective floor on the price of tomatoes imported from Mexico. U.S. producers responded with marketing programs that placed a floor on the price at which they would sell most of their production. The 1997 season was again a strong season for producers of field grown fresh tomatoes. Both U.S. and Mexican producers experienced their best year since 1992.

Since the 1997 season, field grown producers in Mexico and the U.S. have had to deal with increased competition from several countries. Holland, Spain and Israel increased their presence in the U.S. market with hothouse tomatoes. Imports from the European Union increased from $13.6 million in 1993 to a high of $81.1 million in 1998 and then back to $59.1 million in 2000. Canada emerged as a significant source of tomatoes for U.S. consumers, increasing from $6.3 million of tomatoes sold in the U.S. in 1993 to $160.9 million of tomatoes in 2000. U.S. growers of hothouse tomatoes filed an antidumping petition in calendar year 2000 with the U.S. International Trade Commission against Canadian producers, alleging the Canadian hothouse producers were selling tomatoes below fair market value and causing material injury to the U.S. greenhouse tomato industry. The Canadian hothouse industry responded by petitioning their government in 2001 for relief from what they called the marketing of U.S. tomatoes in Canada at prices below fair market value.

Imports of tomatoes in the U.S. reached a high of $757.9 million in 1998 with Mexico, Canada and the European Union all setting records in that year for shipments of tomatoes into the U.S. market. Since 1998, field grown tomato producers have suffered significant losses. Mexico has seen its share of the U.S. market decline with imports from Mexico declining from $567 million in 1998 to $411.8 million in the year 2000. Florida acreage has declined from a high of 62,500 acres in the 1988/89 season to 35,900 acres in the most recent season. These declines occurred while imports from Canada set new records. Exports of field grown tomatoes to Canada have remained almost flat over the decade of the 1990s, averaging $105 million.

The increase in trade disputes is indicative of the increase in global competition that has occurred within the fresh tomato market. Consumption of fresh tomatoes has increased significantly, especially over the last 5 years, and with that increase in demand has come an increase in suppliers who want to satisfy that demand. Globalization of markets through trade agreements increases the level of competition and tension between countries in competitive products. Because fresh vegetables are labor intensive crops, competition increases and disputes are brought by industries injured by that competition. The cost of taking an antidumping case forward to defend an industry against imports that enter unfairly is prohibitive to some producer groups. The cost of defending against a case filed by foreign producers in their home market may be equally as prohibitive. The U.S. tomato industry has been fortunate in that it has been able to organize producers to present their case in these venues. That cooperation could be significant in keeping markets fair, but may also be important to keeping the industry competitive through cooperation in technology development.

The outlook for the coming season will depend on the outcome of the trade disputes with Canada. Canada is a significant market for U.S. producers, with $121.2 million of tomatoes sold into the Canadian market in calendar year 2000. Imports into the U.S. from Canada are at record levels at $160.9 million in 2000 and prices in the U.S. have been depressed. A continuation of existing trends would indicate that field tomato growers will continue to suffer without a positive resolution in the trade disputes or some form of cooperation in the market. The development of new technologies that make field grown tomatoes more competitive could also be important to long term sustainability. Without any of these developments, the field grown tomato industry will suffer and policy makers will be looking for tools to help the industry transition without larger losses of capital. This industry is truly at a crossroads and the routes taken by producers, packers and policy makers will be important to long term survival.

The policy and trade issues critical to Florida tomato growers include the Farm Bill that will be passed within the next 6 months, the Free Trade Area of the Americas (FTAA) that is scheduled to be implemented in 2005, and the next round of WTO negotiations that are scheduled to begin in the near future. All of these policy issues are important to Florida tomato growers and could have profound impacts on the future of the industry in Florida.

Farm Bill Legislation

The U.S. Congress is in the midst of writing the new Farm Bill that will shape the policies that support the agricultural sector in the U.S. over the next 6 years. The Federal Agriculture Improvement and Reform (FAIR) Act of1996 ended deficiency payments for program crops and provided fixed production flexibility contract payments. The intent of the 1996 FAIR Act was to get government out of agriculture and to make agriculture more market oriented. The result has been an increase in the level of involvement of the government in agriculture with direct government payments to farmers exceeding $23 billion in 2000. Direct government payments increased from $7.3 billion in 1996, amounting to 13 percent of all net farm income, to $23.3 billion in 2000, accounting for 51 percent of U.S. net farm income.

The fresh vegetable industry has not participated in previous farm programs that make direct government payments to farmers. The industry is not seeking those kinds of support out of the next farm bill, but it does appear to be taking a more aggressive strategy in the developing provisions more friendly to the industry in the next farm bill. Several groups have testified before the Congressional Committees to give their views on what the next farm bill should do for the fruit and vegetable industry. Positions promoted by the fruit and vegetable sector include the following:

- Support for policies that sustain the financial stability and viability of agriculture and maintains flexibility for producers. The industry recommends that current planting restrictions for fruits and vegetables on federally subsidized lands be maintained.

- Support for policy based on the "market basket" approach, and would be opposed to any policy that distorts the market place.

- Adopts the goal for policy which increases demand, utilization and consumption of agricultural products.

- Promotes a "fair share" of government outlays for the fruit and vegetable industry in programs promoting: conservation incentives; loan mechanisms; nutrition; international market access and food aid; pest and diseases prevention initiatives; marketing and fair trading priorities; risk management tools; infrastructure investments; research priorities; food safety initiatives and other initiatives.

- Promotes funding assistance and credit to preserve a commitment to support conservation initiatives to guarantee a safe, healthy and sustainable environment within produce production areas.

- Promotes agricultural policies and related domestic and international nutrition assistance programs that support incentives and key strategies that help Americans reach national health goals and ultimately reduce health care costs.

- Promotes policies that counter inequities caused by subsidies, tariffs and domestic supports as measured against U.S. tariff structure and trade policy. Supports aggressive policy measures that would strengthen U.S. negotiating positions under the WTO.

- Supports aggressive actions and funding to eradicate and protect the domestic market from the increasing threat of exotic pests and diseases entering the U.S. through international commercial shipments of products as well as import of contraband by vacationing travelers and commercial smugglers.

- Supports utilization of the PACA law and encourages USDA to administer the law in a fair and timely manner.

- Supports a coordinated federal research agenda to further promote produce consumption and competitive prominence in both the domestic and international marketplaces.

- Supports the use and development of marketing orders, promotion programs, and research programs to help influence consumption and facilitate increased marketing opportunities.

- Promotes a thorough review of the implications of consolidation of retailers and suppliers and the impact on fruit and vegetable growers and shippers.

- Supports improvements and innovations for the advancement of risk management tools that do not distort the fresh fruit and vegetable market.

The fruit and vegetable industry promotes the notion of supporting agriculture without distorting the marketplace. A significant concern in the 1996 FAIR Act was the possibility of flexible acres being diverted into fruit and vegetable production. A restriction against that possibility was written into the 1996 FAIR Act and the industry is asking for that provision to be included in new farm legislation.

The primary objective of the fruit and vegetable industry is to receive a proportionate share of federal outlays from the farm bill. The fruit and vegetable industry accounts for over $28 billion in farm gate revenue, almost 15 percent of all farm gate revenues from agriculture and 30 percent of all crop revenues. A proportionate share of federal outlays for fruits and vegetables would decrease the amount available for traditional farm program crops significantly. The fresh fruit and vegetable industry outlined $3.58 billion in budgetary outlays for industry related programs. This still dwarfs the $23.3 billion in direct government payments made to traditional farm program crops.

Free Trade Area of the Americas

The countries of the western hemisphere are embarking on the development of a trade agreement covering all the nations of the western hemisphere with the exception of Cuba. Negotiations for the Free Trade Area of the Americas (FTAA), which began four years ago, has a target date of 2005 for implementation of the agreement. The United States has long been a proponent of global markets and has worked diligently through the years in removing trade barriers throughout the world so that U.S. and other producers could have access to markets and become more efficient in producing and marketing those goods where they have a comparative advantage. The development of the World Trade Organization was a large step forward in leveling the playing field for agricultural producers, but concerns remain over the uneven application of environmental and labor regulations across countries.

The agricultural sector of Florida knows first-hand the importance of competing in global markets. Global markets have provided added opportunities to many of our growers and expanded the market for many of the products they produce. The citrus industry benefited from expanded exports of fresh and processed products, but the fresh fruit and vegetable sectors have experienced significant stress from the influx of imports from Mexico following the implementation of NAFTA in 1994. The fresh tomato industry experienced serious declines in market share and price as Mexican producers increased their presence in the U.S. market in 1995 and 1996. Only after an investigation by the U.S. Department of Commerce verified that fresh tomatoes were being unfairly sold in our markets below a fair market price (i.e., dumping) did Mexican producers sign a suspension agreement with the U.S. government, assuring they would not sell fresh tomatoes below a fair market price. The U.S. industry cooperated with this agreement by limiting its own sales of fresh tomatoes when prices were depressed. The suspension agreement eliminated the disastrous low market prices, but did not stymie competition in the marketplace. This result would not have been achieved, however, without the protections insured by dispute resolution procedures allowed within the disciplines of the WTO.

Part of the cause for the increase in imports of fresh products from Mexico was the devaluation in the peso that occurred between December 1994 and March 1995. Following a change in Administrations within the Mexican government, the peso was devalued nearly 50 percent from 6.7 pesos to the U.S. dollar to 3.4 pesos. This devaluation resulted in declines in domestic demand within Mexico and in export products being shipped to the U.S. at prices well below cost of production.

Our experiences with NAFTA point to some very important lessons as we embark on an agreement that could encompass all of the western hemisphere. Producers in the tropical and subtropical climates of the southern U.S. suffered following the implementation of NAFTA because of the direct competition that existed with Mexico even before implementation of NAFTA. Grain and livestock producers faced greater competition with Canada. An agreement that brings in all of the countries of the western hemisphere provides a threat to even more producers. As southern hemispheric producers are given freer access to U.S. and global markets without assurances of fair trade practices, a much larger part of our agricultural sector will be at risk. The fresh fruit and vegetable industries and the sugar industry will need to cope with greater competition in the marketplace. Brazil has become a world leader in the production and export of many agricultural crops including citrus, sugar, and oilseeds. Grain production has also increased in South America. Many of these industries evolved following assistance from their governments to develop land and processing facilities for these crops. In addition, U.S. producers incur much larger regulatory costs associated with the environment, labor practices, and food safety, putting them at a disadvantage in competition with other producers in the FTAA. It will be imperative in this environment of increased competition that measures are allowed to assist import-sensitive crops that compete against industries that benefit from these advantages.

Other issues important to the agricultural industry and U.S. consumers include disciplines for proper implementation of Sanitary and Phytosanitary (SPS) restrictions. There are numerous risks that increased trade brings to food safety (e.g., the recent discovery of *salmonella* found on cantaloupes from Mexico) and food security (e.g., Foot and Mouth Disease that can threaten an entire industry). States like Florida are at much greater risk because of the increased flow of goods and people that pass through them. Although the business sectors of these states benefit financially from the increased flow of goods and people, the agricultural sectors are at a much larger risk to invasive pests and diseases. Discipline will be critical to ensuring the safety and security of our food. Discipline on SPS will also be critical to ensuring that SPS restrictions do not serve as a mechanism used primarily for restricting trade. The guidelines of the WTO must be followed to ensure restrictions are science-based, but appropriate dispute resolution procedures must be developed to ensure parties injured by inappropriate use of SPS measures are compensated fairly for lost markets. The beef hormone case in Europe is one example of an industry that lost markets from unjustified SPS restrictions, yet the dispute resolution procedures of the WTO did little to compensate U.S. beef producers when the U.S. retaliated against products not related to those produced by the U.S. cattle industry.

As we move to freer markets with fewer tariff and non-tariff barriers, currencies will become even more important in impacting trade between nations. The EU recognized this issue and chose to develop a common currency for trade across nations, following the model of the U.S. Federal Reserve Banking system. Changes in currency value can have much larger impacts on trade flows than other tariff and non-tariff barriers. The trade dispute with Mexico on fresh tomatoes and bell peppers was caused, in part, by the large devaluation in the peso. The impact on U.S. producers from the surge in imports from Mexico was great enough to cause U.S. producers to seek relief through U.S. trade laws. Mechanisms to facilitate adjustments in currency value without injury to global competitors could go far in ensuring that markets are driven by resource advantages instead of macroeconomic policy. It would also avoid the costly remedies for which producers must file through trade remedy laws when injury is caused by surges in imports.

These issues also point to the need to maintain reasonable trade remedy laws. The Escape Clause provisions allowed by the WTO were placed into the U.S. Code (Section 201 of the Trade Act of 1974). This law allows an industry to seek relief from surges in imports that cause serious injury to a domestic industry. Section 202(d) of the Act allows growers of perishable agricultural products to seek provisional relief pending the completion of a full 180-day investigation by the U.S. International Trade Commission and the 60-day Presidential review period. U.S. growers of fresh tomatoes sought relief under these provisions in 1995, only to be denied. Tomato and bell pepper growers sought relief under Section 201 in 1996, again only to be denied. Dissenting Commissioner Lynn Bragg wrote in her opinion in the 1996 Section 201 petition for fresh tomatoes and bell peppers that "In my view, by making a negative determination in these investigations, the [ITC] has set a standard for obtaining relief under Section 201 that is virtually impossible to satisfy." These trade laws are critical to ensuring the future of many industries within the U.S., especially in light of the fact that many producers in the western hemisphere will be entering the global market, with high aspirations and little experience. These trade laws need to remain in place and must be enforceable to ensure a reasonable adjustment to increased trade within a FTAA.

It is also critical that countries within the FTAA be allowed to support their industries as they move forward in imposing stricter environment and labor practice standards. No country can be forced to adopt environmental or labor standards without consent, but those who adopt stricter standards should not be penalized for becoming better stewards of their resources. Regulatory offsets would allow countries to subsidize production practices that increase costs, without increases in quality or yield. Allowing a system of regulatory offsets would require discipline to ensure they do not become veils for production-related subsidies. The U.S. has been a leader in protecting the environment and workers. Regulatory offsets would allow the U.S. to continue on that path and other countries to follow without penalties to their producers.

Trade is important to all of the producers in the western hemisphere. Producers in all of these countries have resources that may be impacted by the changes that will occur when FTAA is implemented. Trade can become an engine of growth for all countries that participate. It is critical, however, that fair trade practices be ensured so that adjustments that follow the implementation of a FTAA are caused by resource advantages and the ingenuity of the people who control those resources.

World Trade Organization

The World Trade Organization (WTO) evolved from the Uruguay Round of GATT negotiations (GATT 1994) as the means to enforce trade rules adopted by parties to the agreement. GATT originated in 1947 with 23 nations and has evolved into a membership of 135 countries with several others asking for entry. An effort was made to launch the next round of negotiations at the Ministerial meetings in November 1999. That effort failed when labor, environmental and other groups disrupted the meetings and cried foul for being excluded. No official launching of the negotiations has occurred, but negotiators continue to meet and discuss the key points that will have to be agreed to in the next agreement.

One of the key issues that will need to be addressed when the negotiations do begin is the types and amounts of domestic support that can be given to agriculture in the member countries. The WTO currently classifies domestic support in boxes based on the impact a policy may have on markets. Blue Box policies include those policies that give direct payments to producers based on production under production-limiting programs. The farm program prior to the FAIR Act contained provisions for paying farmers to idle land, which would have qualified as a Blue Box program. The U.S. currently has no Blue Box programs, but the European Union uses these programs extensively. Green Box programs provide domestic support to producers that have no, or minimal, effect on trade. Included in the Green Box are the production flexibility payments made to U.S. producers of farm program crops, food stamp programs, research and development, and natural disaster programs.

The Amber Box of the WTO includes support that is linked to production and distorts trade. The WTO quantified the level of support given by member countries in the Amber Box and required a 20 percent reduction from the baseline of 1986-88 period by 2000. Programs falling within the Amber Box include price support loans, loan deficiency payments, livestock and crop loss payments intended to shore up income, and the peanut, dairy and sugar programs. The U.S. was given a WTO ceiling of $19.1 billion in aggregate measured support for 2000 and provided $18.6 billion in Amber Box support. The U.S. is perilously close to exceeding its agreed target for Amber Box support. The new farm bill will be critical to allowing the U.S. to meet its targets and all farm groups who have testified before the Congressional Committees on the Farm Bill have been asked to comment on how their proposals impact the ability of the U.S. to meet its Amber Box targets in the WTO.

The Bush Administration has not articulated its goals for the next round of negotiations for the WTO. The previous Administration sought to eliminate agricultural export subsidies and lower tariff rates on imported goods. The Bush Administration is likely to push these goals forward. The E.U. provides the greatest threat to U.S. trade interests under current guidelines because of the large subsidies they provide to agricultural producers. A key issue promoted by E.U. interests is the need to recognize multifunctionality. E.U. negotiators want to expand the support they can give agricultural producers based on externalities provided by agriculture. These externalities could range from measurable environmental benefits to benefits that are more difficult to quantify like open green space. This is seen as a means of moving support currently included in the Amber Box, which is limited in the WTO, to the Green Box, which is not limited in the amount of support that can be provided. Other countries have promoted the concept of limiting all support given to agriculture - Blue Box, Green Box and Amber Box. This position is particularly supported by developing countries who do not have the budget to support agriculture like the U.S. and E.U.

Summary

The tomato industry truly is at a crossroads for determining its long term sustainability. The next Farm Bill, FTAA and the WTO could all have decided impacts on the fresh tomato industry in Florida. The fresh vegetable industry has not played a significant role in previous farm bills, but could see increased visibility in the next farm bill, especially in the conservation programs that are funded under authorization of the farm bill. FTAA and WTO are policy issues that could also have profound impacts on Florida tomato producers. Competition in the market place has increased over the last decade and could intensify if these trade agreements do not contain fair trade provisions. This industry must be protected from unfair trade practices and be placed on a level playing field with their competitors. Decisions made by policy makers on these issues will be important to long term survival in the tomato industry.

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Monitoring Susceptibility of the Silverleaf Whitefly to Imidacloprid

David J. Schuster and Sandra Thompson

Abstract

Imidacloprid is applied at transplanting to nearly 100% of the tomato acreage in Florida for control of the silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, and the geminiviruses it transmits, primarily tomato yellow leaf curl virus (TYLCV). A cut leaf petiole (CLP) method using cotton seedlings was used to develop the level of susceptibility of whitefly adults from a laboratory colony to imidacloprid. The CLP method was easy and quick and was used to estimate the susceptibility of whitefly populations from three imidacloprid-treated tomato fields in the spring of 2000 and nine in the spring of 2001 using adults reared from field-collected nymphs. Standard probit analyses was used to calculate the slopes and intercepts of the linear equations describing the log dose response and to estimate the LC_{50} values (the concentration estimated to kill 50% of the population) for the laboratory colony and each field population. LC_{50} values of field populations ranged from about 2 to 15 times that of the highly susceptible laboratory colony. Values on the high side of the range were found at two sites, suggesting that growers need to follow a resistance management program for imidacloprid to help assure the continued effectiveness of this important whitefly management tool.

Introduction

The silverleaf whitefly (SLWF), *Bemisia argentifolii* Bellows & Perring, has been the key insect pest of tomato in Florida since 1988 (Schuster et al. 1996a). The insect causes losses by inducing the irregular ripening (IRR) disorder of tomato fruit and by transmitting the geminiviruses tomato mottle virus (ToMoV) and tomato yellow leaf curl (TYLCV) (Schuster et al. 1996b). To avoid the losses due to ToMoV and TYLCV, nearly 100% of the tomato transplant and field growers are applying imidacloprid (Admire 2F® [flowable], 21.4% of imidacloprid, Bayer Corp., Kansas City, MO), primarily as a drench. Some growers are relying on drench applications of imidacloprid at transplanting for near season-long control. This heavy reliance upon a single insecticide for SLWF management may lead to resistance to imidacloprid. Resistance to imidacloprid already has been detected in a greenhouse tomato production area of Spain (Cahill et al. 1996, Elbert and Nauen 2000).

Information regarding the susceptibility of the SLWF in Florida to imidacloprid is needed. The purpose of the present investigation was to develop a laboratory method for assessing imidacloprid susceptibility and to begin assessing and monitoring the susceptibility of field populations.

Materials and Methods

A cut leaf petiole (CLP) method was developed from modifications of methods reported previously (Cahill et al. 1996, Williams et al. 1996, Prabhaker et al. 1997). Cotton seedlings grown whitefly-free in vermiculite in the greenhouse were used at the two true leaf stage. The petioles of leaves of the cotton plants were cut and placed individually in vials containing solutions of different concentrations of imidacloprid. After 24 hrs, 10 SLWF adults were confined on each leaf with a clip cage for another 24 hrs after which the resulting mortality was determined. Mortality was defined as any adult not capable of standing, walking or flying. The SLWF adults used had been reared on tomato in the laboratory for about 12 years without re-introduction of whiteflies from the field.

SLWF populations from three imidacloprid-treated tomato fields in the spring of 2000 and nine fields in the spring of 2001 were compared with the laboratory colony for susceptibility to imidacloprid using the CLP method. Bioassays were conducted using adults reared from foliage infested with nymphs that had been collected from tomato fields that had been treated with imidacloprid at transplanting. Standard probit analyses was used to calculate the slopes and intercepts of the linear equations describing the log dose response and to estimate the LC_{50} values (the concentration estimated to kill 50% of the population) for the laboratory colony and each field population (SAS Institute 1989). Decreasing slope values are indicative of increasing heterogeneity which could indicate the potential for increased selection for resistance.

Results

The LC_{50} values of whiteflies collected from the fields near Rye and near Myakka City in 2000 were two to three times the LC_{50} value of the tomato laboratory colony while the LC_{50} value for the population from GCREC was six times that of the laboratory colony (Table 1). Such variability is not unexpected when comparing field-collected insects with susceptible, laboratory-reared insects. Slope values for the field populations were one third to one half of the laboratory colony, suggesting that the potential for selection for reduced susceptibility existed.

In 2001 the LC_{50} values of field populations generally were greater than those of field populations in 2000, ranging from 2.6 to 14.6 times that of the highly susceptible laboratory colony. At the Immokalee1 site, the LC_{50} value of whiteflies collected from a field sampled in May was nearly twice that of another field at the same site sampled in April. Furthermore, the slope value from the May collection was lower than that of the April collection and was about half that of the laboratory colony. An elevated LC_{50} value and lower slope also was observed at the Ft. Hammer site.

Discussion

Whitefly management programs that growers currently are using are generally very effective, as evidenced by the overall low whitefly populations and the resulting difficulty in obtaining whitefly samples large enough to evaluate for susceptibility to imidacloprid. Of the 13 tomato fields sampled in 2000 and 2001, most had whitefly populations that had LC_{50} values that would be expected when comparing field-collected insects with laboratory-reared insects. The laboratory colony used as a susceptible standard in this study had been in continuous culture since the late 1980's without the introduction of whiteflies collected from the field and, therefore, would be anticipated to be particularly susceptible to insecticides. Nevertheless, two of the fields sampled had whitefly populations that had LC_{50} values that were sufficiently higher than the laboratory colony to draw attention. Because monitoring for susceptibility to imidacloprid has only been conducted for two years, it is not known whether these two fields represent the higher points in the natural susceptibility range, a trend toward increasing tolerance or whether such events have occurred in the past and that observed increased tolerance will disappear or decrease between cropping seasons. Only continued and expanded monitoring can provide the answer. Certainly, elevated LC_{50} values should encourage growers to more strictly adhere to resistance management recommendations. Failure to do so could lead to increasing levels of tolerance of the silverleaf whitefly to imidacloprid and the eventual loss of this important tool in whitefly management. It should be noted that none of the fields sampled, including the two with higher LC_{50} values, had populations of whiteflies that were out of control.

A new insecticide, thiamethoxam (Syngenta Crop Protection, Inc.), has recently received approval from EPA for whitefly control on tomato and other crops. The insecticide is formulated and marketed as Platinum® for soil applications and as Actara® for foliar applications. The use patterns of these formulations will be the same as those for the Admire and Provado® formulations of imidacloprid, respectively, although application rates will differ. Because imidacloprid and thiamethoxam are both in the nicotinoid class of insecticides, there is the potential for the development of cross-resistance, as has been documented in southern Spain (Elbert and Nauen 2000). That is, whiteflies resistant to imidacloprid were resistant to thiamethoxam. This has important ramifications for managing resistance.

Imidacloprid Resistance Management Recommendations

- Reduce overall whitefly populations by strictly adhering to cultural practices including:
  - Plant whitefly-free transplants
  - Delay planting new crops as long as possible and destroy old crops immediately after harvest to create or lengthen a tomato-free period
  - Do not plant new crops near or adjacent to infested weeds or crops, abandoned fields awaiting destruction or areas with volunteer plants
  - Use UV-reflective (aluminum) plastic soil mulch
  - Control weeds on field edges if scouting indicates whiteflies are present and natural enemies are absent
  - Manage weeds within crops to minimize interference with spraying
  - Avoid u-pick or pin-hooking operations unless effective control measures are continued
  - Do not use a nicotinoid like imidacloprid on transplants or apply only once 7-10 days before transplanting; use other products in other chemical classes, including pymetrozine (Fulfill®), before this time
  - Apply a nicotinoid like imidacloprid (16 ozs/acre for imidacloprid) at transplanting and use products of other chemical classes (such as the insect growth regulators Knack® or Applaud®) as the control with the nicotinoid diminishes
  - Never follow an application (soil or foliar) of a nicotinoid with another application (soil or foliar) of the same or different nicotinoid on the same crop or in the same field within the same season (i.e. do not treat a double crop with a nicotinoid if the main crop had been treated previously)
  - Save applications of nicotinoids for crops threatened by whitefly-transmitted plant viruses or whitefly-inflicted disorders (i.e. tomato, beans or squash) and consider the use of chemicals of other classes for whitefly control on other crops

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Table 1. Relative susceptibility of silverleaf whitefly adults to imidacloprid in the laboratory using a cut leaf petiole method. Adults were reared from nymph-infested foliage collected from tomato fields treated with imidacloprid at transplanting.

County/Site	Date	n[1]	Slope	LC_{50}[2]	RR_{50}[3]
Manatee/GCREC[4], Laboratory	March 2000	750	2.32	0.10	----
Manatee/GCREC, Field	June 2000	350	0.77	0.60	6.0
Manatee/Rye	June 2000	500	1.06	0.28	2.8
Manatee/Myakka City	June 2000	700	1.07	0.23	2.3
Hendry/Devil's Garden	April 2001	320	1.02	0.31	3.1
Collier/Immokalee1, Field 1	April 2001	350	1.67	0.80	8 0
Collier/Immokalee1, Field 2	May, 2001	240	1.19	1.46	14.6
Collier/Immokalee2	May, 2001	70	2.35	0.51	5.1
Manatee/Duette1	May, 2001	70	1.37	1.06	10.6
Manatee/Duette1	June, 2001	400	1.03	0.80	8.0
Hillsborough/Ruskin	June, 2001	400	1.26	0.46	4.6
Manatee/Ft. Hammer	June, 2001	400	1.12	1.31	13.1
Manatee/GCREC, Field	June, 2001	400	1.15	0.26	2.6
Hillsborough/Riverview	July, 2001	400	0.95	0.45	4.5

[1]Total number of adults tested excluding the control.
[2]Estimated dose (μg/ml) to kill 50% of the insects.
[3]Ratio of the LC_{50} of the indicated population to the LC_{50} of the laboratory colony.
[4]Gulf Coast Research & Education Center, Bradenton, FL.

Engineered Resistance in Tomato to Geminiviruses

Jane E. Polston and Ernest Hiebert

Abstract:

Geminiviruses are a becoming a major problem for production of tomatoes throughout the tropics and subtropics. The use of resistant cultivars is an important and economically desirable component of a virus management program. A few tolerant cultivars are available for Florida growers, but new and superior sources of resistance are in development. Two different sources of resistance genes are being employed – genes from wild species of *Lycopersicon* (conventional resistance) and genes from the geminiviruses (genetically engineered resistance). Engineered resistance is an attractive method which can 1) improve the resistance of tomatoes against TYLCV, 2) provide resistance to other geminiviruses, 3) avoid the linkage of resistance with undesirable low fruit quality, and 4) rapidly produce resistance cultivars with a broad base of horticultural traits. Our work in developing resistance to tomato mottle virus (ToMoV) and tomato yellow leaf curl virus (TYLCV) has demonstrated that one of the geminivirus genes (*Rep*) can produce very high levels of resistance, the highest ever found. Our latest results with engineered resistance to TYLCV in tomato are presented.

Genetically Engineered Resistance

The goal of genetic engineering is to introduce desirable trait, such as virus resistance, into a host's chromosomes, select for the desired trait, and obtain a breeding line that can pass the trait on to succeeding generations. Conventional breeding has the same goal, the main differences are the techniques that are used to get the trait into the plant and the choice of genes. Genetic engineering using techniques developed in the laboratory to introduce the trait followed by standard selection and crossing of plants to fix the trait; conventional breeding sometimes uses tissue culturing techniques to introduce the trait from plants of related species but usually uses the technique of crossing one plant with another.

New Sources of Resistance Genes Genetic engineering can use genes obtained from many sources, and can broaden the scope of what plants and plant breeders can do. Genes for resistance can be obtained from the same plant species, closely related plant species, unrelated plant species or from the pathogen itself. Conventional breeding is restricted to genes from the same species of the plant, or closely related species. Genetic engineering introduces only the desired trait, while genes obtained from related species through crossing always introduce unwanted genes that must be selected against for several generations. Because of this last difference, genetic engineering is often much faster than conventional breeding. Genetic engineering can produce plants with traits that are due to a single gene, while conventional breeding must sometimes rely on the use of multiple genes to obtain the same trait. However, though genetic engineering is superior in many ways, it can only modify those plant traits that are controlled by multiple genes (fruit size, fruit flavor, etc...). Those genes are best obtained by conventional approaches. Once the desired trait is obtained both genetic engineering and conventional approaches rely on standards techniques for selection and crossing to obtain breeding lines that can be used to make hybrids.

For traits like geminivirus resistance, genetic engineering can produce a breeding line suitable for use in hybrids much faster than conventional breeding. This is because the resistance obtained by genetic engineering is due to one gene, such as one obtained from a virus, whereas conventional breeding has had to rely on multiple genes for resistance. In addition, genetic engineering introduces only the desired trait obtained from the virus and no others, whereas conventional approach obtained the resistance trait from wild species of *Lycopersicon* and many undesirable traits at the same time. Geminivirus resistant breeding lines can be developed with 3 to 5 years, whereas conventional breeding requires approximately 8 to 10 years.

At this time, the greatest disadvantage to genetic engineering is the perception by some that it is an undesirable approach to producing superior cultivars. Much misinformation has been circulated about this technology. Perhaps as with many new technologies, such as the light bulb, the car, and electricity, fear of this technology will pass as the predicted ill effects are not experienced.

Success with Engineered Virus Resistance in Other Crops

Genetic engineering has provided genes for virus resistance in several crops where no conventionally derived resistance was known, or where the current resistance was inadequate. Genetic engineering created the squash cultivars with resistance to four viruses in the same plant ('Freedom' by Asgrow). This is in a host where no resistance to these viruses had existed previously. Genetic engineering created the first resistance to papaya ringspot virus in papaya. This virus is the major constraint to papaya production in many parts of the world. The cultivar "Rainbow' is now in production in Hawaii., and has had a tremendous impact on papaya production there. Resistance to tomato spotted wilt virus has been developed by genetic engineering and is being placed in several crops where no resistance existed previously.

Importance of Obtaining High Levels of Resistance to Geminiviruses in Florida

Current Situation. Geminiviruses, transmitted by the whitefly, pose a serious threat to the Florida tomato industry. Two geminiviruses have been found in Florida thus far, tomato mottle virus (ToMoV) and tomato yellow leaf curl virus (TYLCV). **ToMoV** reduces yields by causing a reduction in fruit size and TYLCV reduces yields by significantly reducing fruit number. Tomato geminiviruses are managed primarily through the use of insecticides and cultural practices. The systemic insecticide, Admire, has been a critical component of geminivirus management. Losses caused by ToMoV, though moderately high in the early 1990's, have been minimized by the use of Admire since its first use in 1994. **TYLCV** causes severe symptoms in tomato, including severe reductions in leaflet size, upward cupping of leaflets, marginal chlorosis, severe stunting of the plant, and, most importantly, severe reductions in fruit number (Polston *et al.*, 1999b). TYLCV has a broad host range and infects plants in more than 12 families. TYLCV is known to infect a number of wild plant species and is established in most of Florida. An examination of the spread and incidences of TYLCV in tomato fields from 1998 to 2000 indicates that TYLCV is slowly increasing in incidence each year, so yield losses are expected to increase. In the last 2 years, TYLCV has appeared in three other states (Georgia, Louisiana, and Mississippi) where it has caused significant losses to tomato crops.

Future Geminiviruses In 1985, Florida had no geminiviruses in tomato. In 1990 there was one, ToMoV, which caused serious economic hardships for several years. In 1997 a second virus, TYLCV, appeared. Our investigations and those of other researchers have shown that at least 20 geminiviruses are known to infect tomatoes in the New World (Polston and Anderson, 1997). Therefore, it is highly probable that other geminiviruses will appear in Florida in the future. One likely candidate is potato yellow mosaic virus (PYMV), a virus with symptoms similar to those of ToMoV but which can infect potatoes and peppers as well as tomatoes. Due to this broader cultivated host range, PYMV is likely to occur in higher than expected incidences in tomato especially those planted near or after potato and pepper crops. PYMV is widely distributed in the Caribbean and South America.

Whitefly-transmitted geminiviruses are currently expanding in number and geographic distribution in the Western Hemisphere. The number of characterized viruses has increased from three to over 20 in the last 15 years, and these viruses are causing significant problems in tomato production in the southern U.S., the Caribbean and much of Central and South America. Individual geminiviruses are expanding their known geographic range, due in large part to the movement of infected plant material and viruliferous whiteflies. These geminiviruses are reducing tomato yields in many countries, and total crop losses are not uncommon (Polston and Anderson, 1997).

The spread of ToMoV and TYLCV within and between tomato fields and concomitant losses, have been mitigated by the use of imidacloprid and other management tactics employed. However, history tells us that the whitefly will probably become resistant to imidacloprid in the future, at which point this very important tool will be less effective. Resistance to Admire has already been reported in Arizona and Spain (Cahill et al., 1996, Williams et al 1996, 1997).

The Role of Resistance in Geminivirus Management

TYLCV and other geminiviruses are very difficult to economically manage in fresh market tomatoes. At this time, geminiviruses are managed in Florida primarily through the use of a single class of insecticides, the neonicotinoids (imidacloprid and more recently thiamethoxam) (Polston and Schuster, 2000). Resistance to imidacloprid has already been reported from other countries (Cahill *et al.*, 1996) and it may be only a matter of time before it becomes less useful in Florida. In addition, growers use an array of contact insecticides and insect growth regulators, contract with IPM scouts for information and recommendations, rogue TYLCV-infected plants from fields, and use reflective mulches (Polston *et al.*, 1999b). In spite of all these often expensive management practices, incidences of TYLCV-infected tomato plants continue to increase each year (Polston *et al.*, 1999b, Polston and Schuster, 2000).

The least expensive and most practical control of whitefly-transmitted geminiviruses is the use of resistant cultivars. Geminivirus-resistant tomato cultivars would greatly reduce the use of insecticides for whitefly control, and therefore would reduce production costs and chemical contamination of the environment. Our research on the characterization and biology of geminiviruses in the Western Hemisphere has convinced us that the development and use of strategies for broad-spectrum resistance will be essential to the success of geminivirus-resistant cultivars, and, once available, will become the cornerstone for management programs. There are many geminiviruses known to infect tomato, and in most production areas multiple geminiviruses occur in the same fields and even in the same plants. In most cases, resistances to single geminiviruses will not be sufficient to justify the costs of development. **Broad-spectrum resistance** is needed, however, sources of broad-spectrum resistance and strategies for their use in breeding lines must be developed.

In addition to broad-spectrum resistance, cultivars are needed that do not allow the virus to replicate. Plants with **immunity** to TYLCV prevent virus replication, show no virus symptoms, and produce a good yield, while **tolerant** cultivars allow the virus to replicate, may or may not show virus symptoms, and in spite of the presence of the virus are able to produce a good yield. Though tolerant cultivars may no show symptoms, the virus is still present, and whiteflies that feed on these plants can acquire and transmit virus (M. Lapidot, unpublished). Immune cultivars do not have any TYLCV for whiteflies to acquire and transmit. The two TYLCV-resistant tomato cultivars which became available in 2000 and have been evaluated by growers this past year are tolerant to TYLCV (Gilreath *et al.* 2000). These cultivars produce a yield in the presence of TYLCV, but still support the replication of TYLCV and have been shown to act as sources of TYLCV for susceptible crops (Gilreath *et al.* 2000). The use of immune cultivars would prevent the spread of TYLCV, and would not serve as sources of virus for susceptible tomato cultivars or other susceptible crops (beans, tobacco, and others), and for this reason immunity is preferable to tolerance.

Success With Resistance Derived From Wild Relatives Of Tomato

Conventional breeding of resistant tomato lines has been carried out against TYLCV in Israel during the last two decades, and against ToMoV and TYLCV in the United States for the last 10 years using genes derived from wild species of *Lycopersicon* (Pilowski and Cohen, 1990; Rom, *et al.*, 1993; Scott *et al.*, 1995, Zamir *et al.*, 1994). These resistant lines are often unsatisfactory due to a linkage with small fruit size and lower than desired levels of resistance. Tolerant commercial cultivars can collapse under early or severe infection pressure and require protection during early growth stages. In addition, tolerant plants still support virus replication and can act as sources of virus for susceptible crops. Most of the resistant cultivars tested thus far have resistance to only a single geminivirus.

Success With Genetically Engineered Resistance To Other Geminiviruses A number of strategies for genetically engineered resistance to geminiviruses have been investigated in different host plants, though most studies have been conducted in experimental plants species like tobacco. Four of the seven genes present in geminiviruses, *Rep*, *coat protein*, *movement protein*, and *AC4* genes have been shown to provide resistance. However, few of these genes have been put into crop plants. In most cases this is because the resistance was associated with an unmarketable phenotype, provided an unacceptable level of tolerance, or was evaluated in a non-crop plant by molecular biologists and funding to move the gene into a crop plant was not available. Our results with the *Rep* genes of ToMoV and TYLCV in tomato are the most advanced in terms of the quality of resistance and the horticultural usefulness of the plants.

Geminivirus Rep Resistance In 1996, resistance was developed to tomato yellow leaf curl Sardinia virus (TYLCSV, a unique virus, not closely related to TYLCV) in *Nicotiana benthamiana* plants using a shortened version of the TYLCV-Sar *Rep* gene (Noris et al. (1996). However, the resistance was overcome with time. Brunetti *et al.* (1997) transformed tomatoes with the same modified gene and found that high levels of the truncated Rep protein were required for resistance, that all resistance plants had very curled leaves, and that the resistance was narrow-spectrum. This resistance was not marketable due to altered horticultural characteristics (stunting and leaf curling) associated with the resistance. Studies with whole and shortened *Rep* genes from the African cassava mosaic virus (ACMV) were shown to reduce ACMV replication in *Nicotiana tabacum* protoplasts (Hong and Stanley (1996). This resistance was never tested in whole plants. A mutated ToMoV *Rep* gene was put into tomato plants and was shown to interfere with ToMoV replication (Stout et al.,1997). Plants were tested in the field, and plants with the gene were tolerant to ToMoV, however, studies were not continued to put this resistance into a suitable tomato cultivar.

ToMoV *Rep* Resistance In 1993, we generated resistance to ToMoV in both tobacco and tomato using the ToMoV Rep (replicase-associated protein) gene (Abouzid, et al. 1996, Polston et al. 1996). The ToMoV *Rep* gene was put into the tomato inbreds, Fla.7324 and Fla.7613, the parents of the hybrid Fla. 7578 (from J. W. Scott). The *Rep* gene provided stable resistance and has been successfully passed through five generations of tomato. Plants have been identified where no evidence of replication could be found suggesting this gene may confer immunity to ToMoV, while in other plants we have found very high levels of tolerance. Plants with high levels of resistance have been shown to carry single copies of the *Rep* gene.

Resistance and horticultural qualities were evaluated in the field in the fall 1997, spring 1998, and fall 1998 seasons (Polston et al., 1997). Yields of transformed plants were found to be equivalent to the untransformed parents in the absence of ToMoV and greatly superior in the presence of ToMoV. Fla.7578 containing the ToMoV *Rep* gene performed better than either parent in the presence of ToMoV. Fla.7324 is one of the parents of >Equinox=. Since horticulturally superior inbred lines are being transformed, effective genetically engineered resistances could be commercialized relatively quickly. This work is one of the most advanced and successful studies on the use of genetic engineering to develop resistance to geminiviruses in tomato, and has made exceptional progress in the development of genetically-engineered resistance to Western Hemisphere bipartite geminiviruses.

TYLCV *Rep* Resistance

In 1998 and 1999, we put eight different versions of TYLCV *Rep* gene in tomato backgrounds, Fla. 7613 and Fla. 7324, and began to screen the plants containing each of the modified genes for their ability to provide resistance to TYLCV. The evaluation of the T_1 generation began in 2000 and ended in 2001. We evaluated 15 progeny from each of 108 T_0 generation plants. Resistant plants were selected and their progeny was also evaluated. Plants were tested in the T_1 generation in the greenhouse, selected for resistance, and their progeny (the T_2 generation) were tested in the field in Fall 2000, selected, and the T_3 generation was tested in the field in Spring 2001. The highly stringent screening method we used (inoculation of each seedling with 10-20 viruliferous whiteflies) was very effective and resulted in a transmission rate of 95-100% in susceptible plants. We selected for resistant plants that did not express virus symptoms and in which we could not detect TYLCV by either PCR or nucleic acid spot hybridization.

Of the eight constructs evaluated to date, we found that one of the constructs (TYLCV 2/5 *Rep*) consisting of an approximately 2/5 portion of the TYLCV *Rep* gene, gave excellent resistance to TYLCV. We found high incidences of resistant plants in the progeny of many of the T_0 generation plants. These as well as the results with their T_2 and T_3 generation progeny are shown in Table 1. The percent of resistant plants increased from generation to generation, although, as expected, plants were still segregating for resistance in the T_3 generation. The horticultural characteristics of all non-inoculated transformed plants were normal in both greenhouse and field trials (Figure 1).

Resistant plants look horticulturally like non-transformed plants, show no symptoms of infection, and no virus could be detected by laboratory techniques in inoculated plants. Resistance was successfully carried through 3 generations of tomato. Grafting studies in the greenhouse further indicated that TYLCV was not present in resistant plants. On the basis of three different assays, the 2/5 TYLCV *Rep* gene appears to confer immunity to TYLCV in tomato.

In order to increase the diversity of the horticultural backgrounds, we put the 2/5 TYLCV *Rep* gene into 2 more breeding lines from (J. W. Scott): Fla. 7777 and Fla 7722. We have obtained 23 T_0 generation plants of Fla. 7777 and 12 T_0 generation plants of Fla. 7722. We will be selecting these plants for resistance, for their future use as parents of TYLCV-resistant hybrids. And in order to simply the process of developing TYLCV-resistant tomato cultivars, we are currently selecting resistant plants from all four horticultural backgrounds that have single copies of the 2/5 *Rep* gene.

Conclusion

Resistance that is broad-spectrum and that can be described as immunity or near immunity against whitefly-transmitted geminiviruses is needed in tomato cultivars for production in Florida. These are high expectations that have not yet been achieved by using sources of resistance from wild relatives of tomato. The use of genetic engineering offers alternative sources of resistance that are both relatively fast to develop and responsive to changes in the geminivirus population. Recent work at Bradenton, using the *Rep* gene from 2 different geminiviruses has shown that engineering this gene from geminiviruses into tomato can give high levels of resistance to these viruses within a few years. And in the case of ToMoV, engineered plants were shown to have excellent yields in the presence or absence of ToMoV. These genes can easily be combined with each other and with *Rep* genes from other geminiviruses, and with genes from other problematic viruses (such as tomato spotted wilt virus) to give broad-spectrum resistance.

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Table 1. Summary of the evaluation of thr e generations of tomatoes transformed with 2/5 *Rep* gene of TYLCV for resistance to TYLCV.

T_0 Gener. Plant	Greenhouse – T_1 Generation	Field: Fall 2000 – T_2 Generation		Field: Spring 2001- T_3 Generation		
	% Resistance [1]	Plant Id. No.	% Resistance	Plant Id. No.	Total No. Plants	% Resistance
2	30%	2-9	63%	2-9-26	35	69%
				2-9-46	43	70%
21	91%	21-8	69%	21-8-22	44	80%
				21-8-43	44	86%
23	20%	23-2	27%	23-2-8	42	60%
				23-5-26	31	84%
25	20%	25-4	57%	25-4-44	27	56%
				25-11-22	43	42%
				25-15-35	43	49%
37	73%	37-13	52%	37-13-1	38	87%
Fla.7613 (no Rep gene)	5%	Fla. 7613	0%	Fla. 7613	40	0%

[1] Resistance based on visual assessment, dot spot hybridization and PCR results taken at the end of the season during harvest. % Resistance = the percent of plants that tested resistant to TYLCV after inoculation in the greenhouse.

Figure 1. Fla. 7613 plants (T_2 generation) containing the 2/5 TYLCV Rep gene in the foreground, Fla. 7613 without the resistance gene in the background (photo taken May 7, 2001)

Evaluation of the Potential of Recovered Tail-Water to Disseminate *Phytophthora capsici* and Other Vegetable Pathogens

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Summary

During 2000-2001, surveys were conducted of water from run-off ditches at commercial tomato, pepper, and cucurbit production sites in Manatee and Collier counties, and from retention ponds at the Gulf Coast and Southwest Florida Research and Education Centers to determine the potential of such water to spread *Phytophthora*, *Pythium*, and *Xanthomonas* species. In addition, the survival of zoospores of *P. capsici* in these retention ponds was examined. *Pythium* spp. were consistently detected from all sites, while *Phytophthora* spp. were less consistently detected. Thus far, *Xanthomonas* spp. have been confirmed from three sites in Collier county. Our data indicates the inadvisability of using such unprocessed water for irrigation of vegetable crops.

Background

The increasing need for water conservation has required examination of strategies to limit use of this resource by both commercial and private sectors. Some commercial vegetable growers have adapted their production systems for partial or whole scale utilization of drip irrigation. In certain instances sub-irrigation through water table management (seep irrigation) may be used to supplement drip irrigation during the growing season, and is commonly used to insure adequate soil moisture prior to bed formation. Collection of precipitation and irrigation runoff from vegetable farms (tail water recovery) and storage in retention ponds for future use may provide an option for further water conservation. The potential of this recycled water to harbor plant pathogens of vegetable crops in Florida is not known. The dissemination of plant pathogens in recycled water especially such "water molds" as Phytophthora and *Pythium* species has been well documented in greenhouse systems, and to some extent in citrus (4, 7, 10). Recently, severe outbreaks of Phytophthora blight caused by *Phytophthora capsici* have resulted in major losses in all major vegetable crops in west central and southwest Florida (5). Losses of up to 31%, 36%, and 100% were observed in plantings of tomato, pepper, and summer squash, respectively. Damping-off and root rot caused by *Pythium* species are perennial problems for all field-grown crops in the state. In addition, outbreaks of an unusual foliar blight of tomato transplant caused by *Pythium myriotylum* were observed in Southwest and West Central Florida during 1997-1998 (Roberts *et al*, 1999).

Bacterial leaf spot caused by *Xanthomonas campestris* pv. *vesicatoria* consistently causes significant foliar and fruit damage in tomato and pepper foliage in Florida's central and southern vegetable production regions (2). Although it has been established that *X. campestris* pv. *begoniae* and *X. phaseoli*, pathogens of begonias and beans, respectively, can be disseminated in irrigation water (1, 9), little data exists on the potential for *X. campestris* pv. *vesicatoria* to spread in a similar fashion.

The use of recovered tail water on strawberries has been researched in Florida (8), but this study did not include a plant disease component. Furthermore, an investigation of the potential of run-off water from field-grown vegetables to disseminate plant pathogens has not previously been conducted in the state. Our objective with this research was to determine the potential of tail water recovered from vegetable fields to serve as a mode of dissemination of *Phytophthora*, *Pythium*, and *Xanthomonas* species.

Experimental Methods

Water Sampling. Precipitation and irrigation run-off ditches were surveyed during 2000-20001 at active commercial vegetable production sites in Manatee and Collier counties that previously experienced problems with Phytophthora blight caused by *P. capsici*. Retention ponds at the Gulf Coast Research and Education Center (GCREC) and Southwest Florida Research and Education Center (SWFREC) were also examined during the same vegetable production periods. Weekly or biweekly, one-liter water samples from selected sites were subdivided and vacuum filtered, and the filters were placed on *Phytophthora*- and *Pythium*-selective media. Representative *Phytophthora* and *Pythium* isolates were preserved for speciation and pathogenicity screening using tomato and pepper. Generic confirmation used enzyme linked immunosorbent assays (ELISA) and a specific DNA probe assay. Speciation was based on the morphology of spores.

Additional one-liter water samples were collected from certain sites for detection of plant pathogenic *Xanthomonas* species. Bacterial assays utilized two vacuum filtrations, culturing on a semi-selective medium, and a polymerase chain reaction (PCR) assay using primers that are specific to the *hrp* gene region of plant pathogenic *Xanthomonas* species (3). Confirmation of the ability of recovered *Xanthomonas* isolates to cause disease is pending.

Survey Sites. In Manatee county, during the Fall 2000 and Spring 2001 seasons, run-off ditches adjacent to individual commercial watermelon and cucumber fields were sampled for the presence of *Phytophthora* and *Pythium* species. A commercial tomato production site in Manatee county was also surveyed for the presence of these two pathogens as well as *Xanthomonas* species in 2000. The retention pond at GCREC was sampled for all three pathogens during the 2000-2001 vegetable seasons. In Collier county, run-off ditches adjacent to a tomato field at SWFREC and a commercial pepper production site were sampled for the presence of *Phytophthora*, *Pythium*, and *Xanthomonas* species during 2000. Two pepper sites were surveyed in 2001. The retention pond at the Southwest Florida REC were surveyed for all three pathogen groups during the 2000-2001 vegetable season. (Phytophthora blight in cucurbits caused by *P. capsici* has occurred at GCREC and SWFREC over the past several years).

Survival of *P. capsici* in Retention Ponds. A separate study was conducted during February through April 2000 to evaluate the ability of zoospores of *P. capsici* to survive in retention ponds at GCREC and SWFREC. (Zoospores are motile spores produced by *Phytophthora*, *Pythium*, and related genera). A standardized number of zoospores were placed in plastic containers filled with non-treated pond water and suspended about 12 in. below the pond surface. The containers were capped with a membrane that allowed for movement of bacteria and gas exchange but prevented loss of the zoospores. Zoospore survival was assessed at 3-11 day intervals by serial dilution and/or vacuum filtration using a *Phytophthora*-selective medium.

Results And Conclusions

Water Surveys. Outbreaks of Phytophthora blight caused by *P. capsici* are totally dependent on saturated soil conditions and the presence of abundant surface moisture. Such conditions were common during the 1997-1998 vegetable seasons due to the prevalent "*El niño*" weather pattern. On the other hand, precipitation throughout Florida was significantly below normal for both the Fall 2000 and Spring 2001 seasons. As a result, natural outbreaks of Phytophthora blight did not occur during the sampling periods.

Nonetheless, *Phytophthora* species were detected intermittently at low levels in water samples from all commercial sites and the GCREC retention pond in both seasons, but not from the SWFREC retention pond (Tables 1 and 2). *Phytophthora* species tentatively identified from Manatee county include *P. cinnamomi*, and *P. nicotianae* (= *P. parasitica*). High levels of *Pythium* species were detected at each sampling period from all sites during each season. Preliminary identification of *Pythium* species from vegetable sites in Manatee county includes *P. aphanidermatum*, *P. catenulatum*, *P. irregulare*, *P. myritoylum*, and *P. splendens*. *Xanthomonas* isolates positive by PCR were recovered from a runoff ditch adjacent tomatoes at SWFREC during 2000, and from a commercial pepper site and the SWFREC retention pond during Spring 2001. Water samples collected from Manatee county for detection of *Xanthomonas* sp. are being processed.

Phytophthora nicotianae is an important pathogen of many crops including ornamentals, citrus, and vegetables, and can cause such diseases as Phytophthora blight of vinca (*Catharanthus roseus*), foot rot and gummosis of citrus, and root rot and "buckeye" fruit rot of tomato. *Phytophthora cinnamomi* is primarily a pathogen of ornamental and fruit crops. All tentatively identified *Pythium* species except *P. catenulatum* can cause root rot in a broad range of cultivated crops including tomato. It is interesting to note that *P. myriotylum*, which was a commonly recovered species, can also cause a foliar blight of tomato transplants. Outbreaks of Pythium blight of tomato were recently detected in West Central and Southwest Florida (6). Further characterization of *Phytophthora*, *Pythium*, and *Xanthomonas* isolates recovered from run-off ditches and retention ponds is underway.

Survival of *P. capsici* zoospores. Bottles were assayed for the presence of viable zoospores of *P. capsici* periodically for 45 days at GCREC and 49 days at SWFREC using dilution plating and vacuum filtration. Although zoospore survival rapidly decreased within 2-3 weeks at both sites, low levels of the pathogen could be detected up to 45 and 49 days at GCREC and SWFREC, respectively (Figure 1).

Our data on the recovery of *Pythium*, *Phytophthora*, and *Xanthomonas* from run-off ditches and retention ponds indicates the inadvisability of using such unprocessed water for irrigation of vegetable crops. Survival of zoospores of *P. capsici* in retention ponds appears to be lengthy enough to enable its dissemination during periods conducive to pathogen buildup such as those that may occur during severe outbreaks. We are currently conducting additional research on the survival and dissemination of *P. capsici*.

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Acknowledgements

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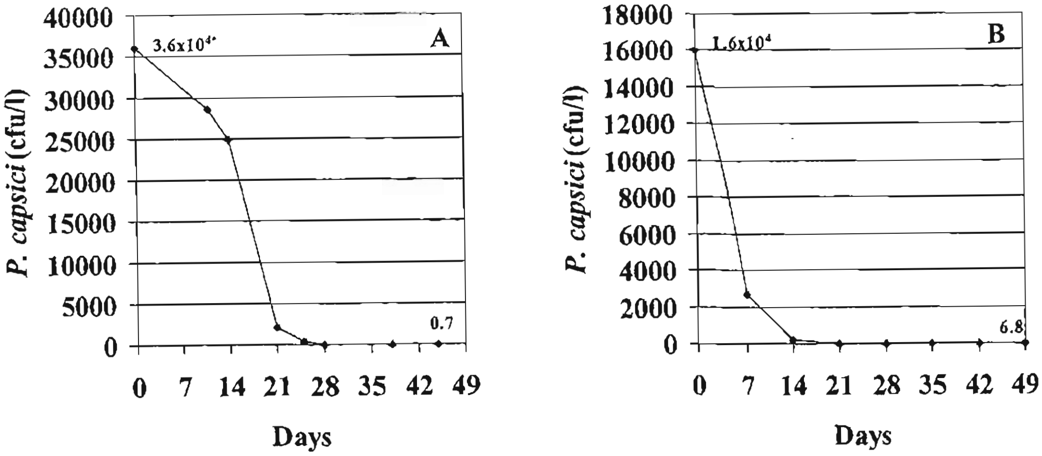

Figure 1. Survival of zoospores of *Phytophthora capsici* during February through April 2000 in retention ponds at the Gulf Coast Research and Education Center, Bradenton, FL (A), and at the Southwest Florida Research and Education Center, Immokalee, FL (B). *Numbers next to data points indicate the population level of *P. capsici*.

Table 1. Detection of *Phytophthora*, *Pythium*, and *Xanthomonas* species in run-off ditches and retention ponds at vegetable production sites in Fall 2000.

County	Site[1]	*Phytophthora* spp.	*Pythium* spp.	*Xanthomonas* spp.
Manatee	Watermelon	+[2]	++	N.S.
	Cucumber	+	++	N.S.
	Tomato	+	++	?
	GCREC - Pond	+	++	?
Collier	Tomato	+	++	+
	Pepper	+	++	-
	SWFREC - Pond	-	++	-

[1]Water samples were collected weekly or biweekly during the growing season from run-off ditches adjacent to commercial vegetable production fields and from retention ponds at the Gulf Coast and Southwest Florida Research and Education Centers.
[2]+, ++, and – indicate that the target genera were detected intermittently, at every sampling, or not detected, respectively. N.S. indicates that the target genus was not sampled, while a "?" indicates that detection has not been confirmed.

Table 2. Detection of *Phytophthora*, *Pythium*, and *Xanthomonas* species in run-off ditches and retention ponds at vegetable production sites in Spring 2001.

County	Site[1]	*Phytophthora* spp.	*Pythium* spp.	*Xanthomonas* spp.
Manatee	Watermelon	+[2]	++	N.S.
	Cucumber	+	++	N.S.
	GCREC - Pond	+	++	?
Collier	Pepper - 1	+	++	+
	Pepper - 2	+	++	-
	SWFREC - Pond	-	++	+

[1]Water samples were collected weekly or biweekly during the growing season from run-off ditches adjacent to commercial vegetable production fields and from retention ponds at the Gulf Coast and Southwest Florida Research and Education Centers.
[2]+, ++, and – indicate that the target genera were detected intermittently, at every sampling, or not detected, respectively. N.S. indicates that the target genus was not sampled, while a "?" indicates that detection has not been confirmed.

Packinghouse Sanitation: How Much is Enough?

Steven A. Sargent, Jerry A. Bartz, M. Tim Momol, Michael Mahovic, Stephen M. Olson and Phyllis R. Gilreath

Several new and on-going experiments were conducted during this past year to provide a better understanding of tomato packinghouse sanitation. These experiments involved collaboration between grower/packer/shippers, county extension faculty, and extension specialists and researchers located throughout the state.

1. On-site Visits
Numerous visits were made to tomato production areas from Quincy to Homestead during Fall 2000 and Winter/Spring 2001 seasons to determine sanitation practices during handling and packing. Dump tank conditions were monitored (free chlorine concentration; pH; temperature; oxygen-reduction potential (ORP); residence times in tank; procedures followed by packinghouse personnel). Extensive analyses were made at regular intervals in packinghouses in the Palmetto/Ruskin and Quincy areas during the Fall 2000 and Spring 2001 seasons. In addition to measurement of dump tank conditions, other analyses included: water samples taken from the dump tanks, various fruit contact surfaces on the packing lines were swabbed, and tomatoes were sampled before and after packing.

At the Postharvest Laboratory in Gainesville or the North Florida Research & Education Center-Quincy, microbes were plated out from these samples using specialized media to identify potential pathogens or tomatoes were wound-inoculated with samples of wash water to find if pathogens were present. During these visits, packinghouse managers were updated on water sanitation procedures and their equipment was validated with our readings. Many of the packer/shippers were monitoring dump tank conditions, either manually or via automated sanitation systems.

For several years we have recommended that packers install automated sanitation equipment to enable continuous monitoring and control of dump tank conditions. Several automated systems are available that are specifically designed for the challenging conditions encountered in tomato dump tanks. These systems often measure ORP and pH, and correlate these values to parts per million of free (active) chlorine; chlorine and an acidizer are added to the on demand.

Our monitoring studies revealed that many of the automated systems were performing within UF/IFAS guidelines (see references below) to ensure that postharvest decay pathogens were being effectively sanitized. However, at the times of our visits, several systems were not meeting minimal requirements, providing a false confidence in the reliability of the equipment. The reasons for these systems not performing correctly ranged from poor system design, to fouled sensors, to inaccurate sampling of the tank water, to failure to properly start-up the system (such as forgetting to turn on acid or chlorine feed pumps).

These problems highlight the need for each packinghouse to monitor the performance of the automated system at all times during packing operations as part of the overall Best Management Practices established by the company. An effective dump-tank monitoring program should include:

- a written start-up procedure to ensure that the sanitation system is functioning properly prior to the start of packing,
- manually sampling dump-tank water to determine free chlorine concentration, pH, and temperature **each 30 to 60 minutes** during packing,
- maintaining a record of these readings for future reference,
- comparing these readings with those of the automated equipment,
- having an action plan with corrective procedures in the event the system is found to be working outside of acceptable levels.

2. Incidence of Decay Pathogens from Tomato Samples
Packing season and production area affected the populations of pathogens identified from the packinghouse samples.

Palmetto/Ruskin area. In Fall 2000 and Spring 2001, no significant tomato pathogens were identified from the surfaces of tomatoes sampled before and after packing, nor from the swabs of packing line components. The severe drought conditions were most likely responsible for these unusually low populations of pathogens in this production area.

Quincy area. In contrast to tomatoes from the Palmetto/Ruskin area, significant incidences of sour rot and soft rot decays developed in red-ripe tomatoes inoculated with the rinse water in both seasons. Rainfall amounts, though below normal levels, were higher than those during the seasons in the Palmetto/Ruskin area. Soft rot decays were prevalent in Fall 2000 and ranged from 41.5% on October 17 to 16.2% on October 27 (Table 1). No decays were observed in samples harvested after October 30. Washing decreased incidence of decay only for the first sample (Oct. 17); however, all other samples had similar incidences of decay before and after packing. The only incidence of sour rot (*Geotrichum* spp.) developed from tomatoes packed after a 24-hour delay(October 19/20). This demonstrates the importance of packing tomatoes as soon after harvest as possible. In Spring 2001, sour rot and soft rot decays developed on all samples (Table 1). With minor exceptions, washed tomatoes had significantly less decay pathogens than unwashed tomatoes.

3. Mechanical Injuries and Decay

Dump tanks have been used for many years to minimize mechanical injury to tomatoes during the transfer from field bins or gondolas to the packing line. It has been reported that immersion in heated dump tanks caused ripening tomatoes ("pinks") to be more susceptible to bruising than green-harvested tomatoes. To test this, 'Florida 47' tomatoes were sampled the day of harvest (November 2000) at five ripeness stages: green, breaker (<10% red color), turning (10 to 30%), pink (30 to 60%) and light red (60 to 90%). The same day the samples were returned to the laboratory and held overnight at 55°F (12.5°C)/85% relative humidity. The following day, tomatoes at each ripeness stage (n=5) were submerged for 1, 2, 3 or 4 minutes in 104°F (40°C) water to simulate immersion time in a dump tank. Five tomatoes were not immersed as a control. Immediately upon removal from the water bath, firmness was nondestructively measured on the equator of each tomato (two readings/fruit) using an Instron Universal Testing Instrument (convex-tip probe 0.4 inches (11 mm) in diameter and the force was recorded when the probe reached 1 mm deformation.

Results showed that tomato firmness remained constant despite up to 4 minutes in heated water. Between ripeness stages (green to light-red) firmness did decrease significantly, from 2.2 to 1.1 lb-f (10.2 to 4.9 Newtons), respectively. These results indicate that ripening tomatoes are more susceptible to bruising due to softening that occurs during normal ripening, and not due to temporary heating of the skin during dump-tank handling. Minimizing injuries (cuts, abrasions, punctures) during harvest and handling will further reduce the potential for development of decays during handling and shipping.

During Fall 2000, several packer/shippers reported observing white fungal growth at stem ends of tomatoes in the ripening room. Upon further discussion, we learned that this fungal growth appeared on lots of tomatoes that required from 6 to 8 days to reach breaker stage. This delay in ripening indicates that the tomatoes were being harvested at immature-green stage. The ripening times necessary for these tomatoes to reach breaker stage facilitated the growth of secondary fungi due to longer than normal storage time at elevated temperature and relative humidity. We previously reported (Proceedings 1998 Florida Tomato Institute) that mature-green harvested tomatoes should reach breaker stage within 3 days of gassing for maximum flavor, and that tomatoes should be discarded if breaker stage isn't reached after 5 days of gassing.

Summary

Although populations of pathogenic microbes on tomatoes fluctuate during growing season, dump tank sanitation must be constantly maintained during packing, since it is not yet possible to predict when increased populations might be introduced into the water. All surfaces that contact the tomatoes during harvest and handling should be sanitized on a regular basis to minimize the potential for decay.

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Additional Information

For additional information about tomato sanitation, please read: Handling, Cooling and Sanitation Techniques for Maintaining Postharvest Quality. Chapter 17. Vegetable Production Guide for Florida (Revised 2000). Publ. SP-170. University of Florida/*Citrus & Vegetable Magazine*.

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Table 1. Incidence of postharvest decays from tomatoes (green stage) sampled before and after packing. Tomatoes were washed in sterile tap water and this rinse water was used to inoculate wounded tomatoes (at red-ripe stage) to determine populations of bacteria and fungi. (5 punctures/fruit X 12 fruits/sample = 60 observations/sample location). Quincy area.

Season	Sample Date	Variety	Sample Location	Sour Rot Incidence (%)	Soft Rot Incidence (%)
Fall 2000	17 Oct	A*	Field Bin	0	41.5
	17 Oct	A	Packed Carton	0	1.5
	19 Oct	A	Field Bin (pre-ship)	0	33.0
	19 Oct	A	Field Bin (post-ship)	0	38.0
	20 Oct	A	Packed Carton (Post-ship)	16.5	27.7
	24 Oct	A	Field Bin	0	11.5
	24 Oct	A	Packed Carton	0	29.7
	27 Oct	A	Field Bin	0	16.2
	27 Oct	A	Packed Carton	0	18.2
	30 Oct	A	Field Bin	0	0
	30 Oct	A	Packed Carton	0	0
	02 Nov	A	Field Bin	0	0
	02 Nov	A	Packed Carton	0	0
Spring 2001	19 Jun	B	Field Bin	1.5	33.0
	19 Jun	B	Packed Carton	6.5	12.7
	22 Jun	B	Field Bin	8.2	24.7
	22 Jun	B	Packed Carton	0	19.7
	26 Jun	B	Field Bin	0	39.7
	26 Jun	B	Packed Carton	0	1.5
	29 Jun	C	Field Bin	3.0	11.2
	29 Jun	C	Packed Carton**	0	3.0
	03 Jul	C	Field Bin	31.5**	21.2
	03 Jul	C	Packed Carton**	16.2	9.7
	06 Jul	C	Field Bin	0	14.7
	06 Jul	C	Packed Carton**	3.0	1.5

*A='FL 91'; B='SunPride'; C=BHN 444.
** Field samples. Dump tank simulated by surface treatment with 2% sodium hypochlorite for 2 minutes.

Methyl Bromide Alternatives: Long Term Trials, Application Techniques and Herbicides

Jim Gilreath, Joe Noling and Phyllis Gilreath

Numerous studies have been conducted since 1993 when we first learned that we might lose methyl bromide as a soil fumigant. Results of these studies have been published here and in other publications. Over the ensuing eight years we have learned a lot about the alternatives to methyl bromide, both labeled and experimental, some of which those of us with a history of soil fumigant research extending more than 20 years into the past already knew from previous experience. Although it may have seemed sometimes as if we were re-inventing the wheel, much of the historical information was not recorded, but rather resided in the memories of a select few. Knowing how memories improve with time, we often found ourselves re-discovering what we already knew but had forgotten. Retracing our footsteps over previously tread research also was important because any time you change one thing in a system, it can have an effect on others and our production system has changed drastically since many of the older fumigants were introduced. Simple things like forming a more compact bed can greatly influence fumigant movement in the soil and efficacy and our beds are certainly vastly different from what they were 30 years ago.

So what have we learned or re-learned since 1993? We know that Vapam is not always as effective as we would like it to be and that its efficacy often is inconsistent. Telone products (Telone II, Telone C-17, and Telone C-35) are the most likely replacements for methyl bromide when one considers the currently registered fumigants. Nothing is a drop in replacement for methyl bromide. All of the alternatives are much more demanding in their management and use and are less forgiving of lack of attention to details during application or soil moisture conditions at time of application. Most importantly, we have learned that none of the currently labeled fumigant alternatives consistently provide the level of nutsedge control required by growers, thus necessitating the integration of herbicides into the fumigant program. Therein lies one of the problems with alternatives; we have only one herbicide which will provide nutsedge control and its use requires the utmost attention to details in order to maximize efficacy.

The research and grower demonstrations which have been conducted since 1993 have been supported by grants from the Florida Tomato Committee, the Florida Fruit and Vegetable Association, the United States Department of Agriculture / Agricultural Research Service and the United States Environmental Protection Agency and we are very grateful for their support because without this support, the information in this article would not be possible. There are 4 areas we wish to touch upon in this article; areas which we feel are the most important for growers today. We want to share with you the results of the long term alternatives study being conducted at the Gulf Coast Research and Education Center in Bradenton, information gleaned from studies comparing broadcast applications of Telone C-35 to in bed applications, some information on the timing of Tillam application in relation to Telone C-35, and summary information related to grower weed control trials with Tillam, Devrinol, and Treflan/Trilin, alone or as tank mixes, when combined with broadcast application of Telone C-35.

Long Term Methyl Bromide Alternatives Study

This study compares the current chemical replacement for methyl bromide, Telone C-17 (35 gal/acre) applied in the bed plus Tillam herbicide (4 lb.a.i./acre) and Devrinol (included only in 2000 at 2 lb.a.i./acre) applied broadcast prior to bed formation, and the best nonchemical alternative, soil solarization for 8 weeks with Devrinol herbicide (included in 2000 at 2 lb.a.i./acre) in the bed, to methyl bromide (67/33 @ 350 lb/acre). We are beginning our fourth year of this study. The study was designed to answer many questions but the most important probably was what happens over time when we continually use these alternatives and the effect of previous methyl bromide use is diminished. Over the first three years of fumigation for fall tomato followed by spring double cropping, millet cover crop or fallow practices we have seen large fluctuations in nutsedge and nematode populations but a more stable incidence level of Fusarium wilt, race 3, which has averaged about 95% in the nontreated controls since the second year of this study. We observed reductions in the populations of nematodes this past year as a result of moisture stress in the crop. The prolonged drought made it difficult to maintain good soil moisture in the bed. Weed populations were less affected by the drought because weeds are more efficient scavengers of moisture in the bed.

Tomato plant vigor early in the season during the third fall crop season was not affected that much by treatment, other than the reduction in vigor where no fumigant or alternative was used, but by midseason plant vigor was greatly reduced with solarization, and plants in the nontreated controls were almost dead due to the ravages of intense nematode, nutsedge and Fusarium wilt pressure (Table 1). The least amount of root gall formation was observed on plants which grew in soil treated with Telone C-17. The most occurred with soil solarization.

Weed control was a mixed bag (Table 2). Both alternative treatments controlled nutsedge and pigweed as well as methyl bromide, statistically speaking, although from a numerical perspective the Telone C-17 treatment did not appear that good. Soil solarization had an advantage in that the nutsedge was allowed to emerge through the mulch then was burned off with Gramoxone Extra prior to transplanting tomatoes. The soil heating promoted more of the tubers to germinate early so that the Gramoxone weakened them and few non-germinated tubers remained to replace them. Also, it is believed that Devrinol aided nutsedge control, even though it is not normally considered particularly effective against nutsedge. Pigweed has been observed to be a weed problem with Tillam on some farms, but it was not in this study. Results of grower herbicide trials help explain this and will be discussed later in this paper. Crabgrass continues to be a problem with solarization, even after including Devrinol this past fall in order to give solarization some help with weed control. One explanation for this may be the degradation of Devrinol over time and the heating of the soil due to the opacity of the clear mulch after painting prior to transplanting tomatoes. Remember that Devrinol was already in the soil for 2 months prior to planting, thus we were nearing the end of its effective life in the soil before we even began the crop. The grass which did appear did not do so until about midseason, after what would normally be considered the life expectancy of residual activity from Devrinol. Telone C-17 + Tillam + Devrinol was applied later in the summer, closer to planting, and thus was able to maintain weed control farther into the crop season.

Did we have nematodes? You bet! Unfortunately, the population levels were not as great as they had been the year before. There were few rootknot nematodes in the soil around the tomato roots where no fumigant was used because there were few live roots to support them as most of the plants had been killed by Fusarium wilt (Table 3). The most rootknot nematodes were found associated with roots grown in soil solarization plots. Both alternatives reduced the populations of stunt and sting nematodes, but no treatment impacted stubby root nematodes. We saw little effect of the spring cropping practice on the pest levels or crop response in fall tomatoes, with the exception of populations of nematodes (Table 4). Spring millet reduced the number of stubby root nematodes recovered from soil around tomato roots in the following fall compared to double cropped cucumbers or allowing the land to lay fallow. There appeared to be more rootknot nematodes in the fall following spring double cropping, but this was not a statistically significant difference.

The most important thing in tomato production is what you put in the bucket and how it grades out. Fruit were harvested and sorted into cull and marketable categories by hand, then were size graded using a portable mechanical grader. The sorting criteria were based on what two growers indicated would be allowed during fall 2000 so as to assure our criteria reflected not only the USDA grade standards, but also the local interpretation of those standards. Telone C-17 + Tillam + Devrinol produced as many tomatoes as methyl bromide in each of the three size categories and total marketable (Table 5). Production was reduced with soil solarization + Devrinol compared to methyl bromide or Telone C-17, with solarization falling between no fumigation and methyl bromide.

Double cropping is an important part of tomato production for many growers as it provides certain economies to the farming operation. Growers have questioned the future of double cropping in the absence of methyl bromide. This long term study also addresses that issue.

Cucumber was grown as a double crop the following spring for each of the 3 years of this study. Cucumber plant vigor, vine length (as a measure of growth) and yield were reduced with solarization and in the nontreated control, compared to methyl bromide (Table 6). Telone C-17 + herbicide performed as well as methyl bromide for these parameters. Weed control during the double crop was not different among the alternative treatments with both Telone C-17 + Tillam + Devrinol and solarization + Devrinol performing as well as methyl bromide for all weed species, except crabgrass where, once again, there was more crabgrass with solarization than with anything else (Table 7). There was a resurgence of rootknot nematodes with all treatments, but the levels were lower than in the fall for soil solarization, presumably due to lack of sufficient host plant material. There was no difference in rootknot nematode populations among the treatments, but methyl bromide and the two alternatives reduced the numbers of ring, cyst, and sting nematodes present in the soil around the cucumber roots.

The implications of the results of this project are that Telone C-17 or Telone C-35 combined with the appropriate herbicide can be as effective as methyl bromide against soilborne pests and can maintain that level of control in the absence of methyl bromide. However, the application of herbicide partners will require greater attention to detail and selection of proper application procedures and equipment. Nematode control with Telone products can be as good as with methyl bromide. Telone C-17 can control Fusarium wilt as well as methyl bromide / chloropicrin mixtures when it is applied in the bed using the same equipment as methyl bromide.

Broadcast vs. In Bed Telone C-35 Study

The study reported on above utilized Telone C-17 applied in the bed, just as we apply methyl bromide, but the PPE requirements for Telone application make in bed applications difficult at best. The greatest problem with the PPE issue, aside from the fact that you will not have anyone show up for work if required to work in a full face respirator, rubber gloves and boots, and a spray suit, is the issue of worker health with regards to body temperature management and avoidance of heat induced illnesses. Recognizing the seriousness of this issue, we began studies several years ago comparing efficacy of broadcast and in bed applications of Telone C-35. These studies consisted of large replicated plots (1 acre or larger) on commercial farms and results appeared favorable leading us to believe that we could apply Telone broadcast and obtain results as good as what we saw with in bed applications. However, there was one thing which continued to nag us and that was that we never seemed to have a lot of disease pressure in our grower trials. We knew that Telone would be effective against nematodes when applied broadcast because they move up and down in the soil profile seeking a hospitable environment and the Yetter coulter equipment, which we had determined to be the best application equipment for broadcast, places the fumigant 12 inches deep so that the nematodes are more effectively controlled. The superiority of the Yetter coulter rig was clearly demonstrated in Manatee County this past spring where Telone C-35 provided better rootknot nematode control than methyl bromide due to this mobility of nematodes and deeper placement of Telone. What we were concerned about was the disease portion of the soilborne pest picture. Disease spores do not move around in the soil like nematodes and they can be resistant to adverse environmental conditions, thus surviving throughout the soil profile, including in the upper 2 inches where we believe that chloropicrin loss will occur rapidly under most field conditions, especially when the soil is hot and the surface dries. A broadcast application of chloropicrin under these conditions might not remain in the top few inches at sufficient concentration long enough to be effective.

To better test this idea, we established a study in small plots at the Gulf Coast Research and Education Center where we have a more uniform disease population and better experimental control. We evaluated Telone C-35 in the bed, versus Telone C-35 broadcast with and without additional chloropicrin applied to the bed. We also included Telone II broadcast followed by chloropicrin in the bed. All of these treatments were compared to methyl bromide (67/33) and a nontreated control. All of the Telone treated plots were treated with a tank mix of Tillam + Devrinol for weed control by broadcast spraying the mixture and incorporating it immediately with a field cultivator.

Results in a fall 2000 study suggested there was no problem with broadcast application of Telone C-35 and that application of chloropicrin to the bed was not necessary. This was following application under hot but very moist to wet conditions and to a field site with no rootknot nematodes and only a small amount of soilborne disease as evidenced by the incidence levels in the field. The study was repeated the following spring, applying the treatments to the exact same spots to see the effects of repeated use of the same treatments. Things were different this time. The soil was cool, but it dried on the surface soon after application and the study was conducted during the prolonged drought of this past winter and spring. Tomato plant vigor was similar with all fumigant treatments and there was no significant difference in nutsedge control among any of the treatments, suggesting a lot of variation in the population across the two lands or blocks used for this study (Table 8). The incidence of Fusarium wilt was only about 20% in this study, but as many as 45% of the plants were infected with *Sclerotium rolfsi*, the casual agent of Southern blight, and by the end of harvest season as many as 76% of the nontreated plants were dead due to various causes (Table 9). All treatments which included chloropicrin application into the bed reduced the incidence of Southern blight and plant mortality as well as methyl bromide, but the broadcast application of Telone C-35 not followed by additional chloropicrin to the bed, resulted in increased disease incidence and increased mortality, suggesting that chloropicrin loss was a significant factor during the spring with broadcast application of Telone C-35. Nematode control generally was good with all Telone treatments, lending additional credibility to the theory that broadcast applications of Telone would perform well, but not covering chloropicrin with a tarp soon after application is likely to reduce efficacy (Table 10). Tomato fruit production followed the same trend as Southern blight control: broadcast application of Telone C-35 without chloropicrin applied to the bed resulted in reduced fruit production (Table 11).

Results of this study appear to support the contentions that excellent nematode control can be obtained with broadcast applications of Telone, but to obtain consistent soilborne disease control chloropicrin needs to be applied to the bed and covered. This conclusion is further supported by results of the next study in this paper.

Tillam Application Timing Relative to Telone C-35 Application

Growers have asked repeatedly when is the preferred time to apply Tillam, before broadcast application of Telone C-35 or after application but before bed formation. Little information is available on that and we have previously based our opinions on observations made over 8 years of small plot research and large plot grower trials. Our philosophy was that it was best to apply the Tillam first, but we did not have strong scientific basis for it, so we conducted an experiment this past spring to examine just that question. We applied Tillam (4 lb.a.i./acre) broadcast and incorporated it with a field cultivator 21, 14, and 0 days before Telone application and 7 days after broadcast Telone application. We also further complicated this experiment by comparing these timings with broadcast application of Telone C-35 with the results of the same timings with in bed application of Telone C-35.

We found that there was no significant pattern to the incidence of Southern blight or tomato plant mortality due to time of Tillam application, but there was more Southern blight and mortality where we applied the Telone C-35 broadcast as compared to in bed application (Tables 12 and 13). Tomato fruit production was not affected by the time of Tillam application, but fewer 6x7 size fruit were produced where Telone C-35 was broadcast applied, probably as a result of disease pressure (Tables 14 and 15).

These results are similar to those in the previous study where we were looking at the effect of chloropicrin placement, suggesting that application of chloropicrin is best made to the bed in situations similar to those described herein.

Weed Control Studies

As previously mentioned, weed control will be the greatest challenge facing growers in the post methyl bromide era. Effective weed control relies upon effective herbicides and herbicide application skills. These skills usually are obtained over time through experience a d educational opportunities. Unfortunately, growers do not have that much time left to gain this experience. Successful postemergence weed control in row middles is nothing like broadcast preemergence control. Broadcast application of a herbicide prior to bed formation introduces the opportunity for crop injury. The herbicide rate must be correct, there should be no streaking or excessive overlap of spray, and the incorporation must be done properly. Proper incorporation is where many people get into trouble. Just dragging a disk across the field will not get it. You have to choose your implement based on soil moisture conditions and required depth of incorporation. For example, when soil moisture is good and the tilth is proper, an s-tine harrow with crumbler bars is far better than a disk, but if it is too wet or even too dry, a disk is a better choice. With a disk, you need to consider the amount of set you provide. Too much set or gang angle and you bury the material excessively, too little and the mixing is poor. Whatever implement you choose, make sure you incorporate to the depth from which you will be pulling soil to form your bed. It is better to go too deep than too shallow as a shallow incorporation allows untreated soil to be mixed into the bed and poor weed control will follow.

During fall 2000 and spring 2001, approximately 12 large plot grower trials were conducted to evaluate the performance of Tillam (4 lb.a.i. or 2/3 gallon /acre), Devrinol (2 lb.a.i. or 4 lb product /acre), and Treflan (Trilin) (0.75 lb a.i. or 1.5 pints /acre), alone or in combination, depending upon the anticipated weed spectrum. In all trials, Telone C-35 was applied broadcast. In the spring, there was some additional chloropicrin applied to the beds. In most trials the herbicide was incorporated with an s-tine harrow or field cultivator. In remaining trials, a finishing disk was used as the incorporation tool. These trials were replicated and the individual plots ranged in size from 1 acre upward.

We found that, in most cases, Tillam provided good nutsedge control when used with broadcast application of Telone C-35. In the one case where control was poor, it was as good as or better than what we saw with methyl bromide and nontreated check strips were easy to detect because you could not see your feet when standing in them. We found that tank mixing Devrinol with Tillam improved the weed control spectrum and there was some suggestion that our nutsedge control might be a bit better with the tank mix, but we never were able to prove it beyond doubt. Tank mixing Treflan or Trilin with Tillam also broadened our weed control spectrum and allowed us to control some weeds we were not able to control with Tillam alone and strengthened the control of those we were controlling, but only marginally. Treflan (Trilin) was especially effective against crabgrass and provided improved pigweed control in at least one location. Interestingly, Tillam controls some pigweed species, but not others (Table 16). Treflan improved upon that and only cost us approximately an extra $5 per acre. Devrinol (alone) was the best looking treatment in at least two trials where there was little to no nutsedge. It provided good weed control, and the crop looked very uniform and healthy. Yields appeared to not be affected by Devrinol. In none of these trials did we see any indication that a particular herbicide or herbicide combination was causing an increase in soilborne diseases nor did we see much in the way of tomato yield differences, except where nutsedge was not controlled by a particular treatment. Soil samples were collected from many of the trial sites and we saw no impact of herbicide treatment on nematode control other than those cases where there was poor control and the resultant weeds served as hosts as well as the tomato plants. In those few cases, improved nematode control was associated with improved weed control.

Nutsedge remains the biggest concern and we hope to have at least one additional herbicide for its control in the not too distant future. While some herbicide labels have replant or plant back restrictions, we have seen no evidence of crop injury where cucumbers have been grown as a double crop following application of these herbicides with Telone C-35 the previous season. This will be a major concern for any new herbicides in tomato since double cropping is such an important practice in Florida.

Summary

During the past 8 years, we have appeared to move slowly at times, but reliable recommendations require prudence and thorough research to properly address the issues. We have come a long way from not knowing what we would do to feeling confidant that we have an alternative to methyl bromide. Telone C-35 may not be the silver bullet that methyl bromide is, but it will allow us to stay in production and give us time for more research for other options or refinement of it as an alternative.

What have we learned over the past 8 years? We know that Telone combined with chloropicrin currently is our best alternative to methyl bromide, but it requires the addition of a herbicide. Broadcast application of Telone provides effective nematode control and in many cases it also is effective against soilborne diseases; however, for best soilborne disease control, we feel that at least some chloropicrin needs to be applied to the bed and covered with plastic mulch. If we could ever get the PPE requirements reduced, in bed applications might be preferred, but broadcast application of Telone controls nematodes in all of the field soil and is a very fast way to cover ground. Additionally, it allows for the deeper placement of Telone than our conventional in bed applicators and this deep placement can be a real plus during prolonged dry or cold weather as we experienced this spring. The time of application of Tillam does not seem to be that important, but work is continuing on this. What herbicide you use is dependent upon the weeds you anticipate dealing with in a given field. In the future, we will have to pay closer attention to field history so that we use the best herbicide for the situation and do not waste money by using a herbicide which is either ineffective or not needed. Weed control will be a challenge and will require growers to increase their level of management. Greater detail to procedures and timing will be necessary to assure good weed control. Perhaps the most important thing we are learning is that there is life after methyl bromide; the control we see with Telone + chloropicrin + herbicide can be repeated and will stand the test of time. The concerns many had that after a few years of no methyl bromide the control obtained with Telone C-17 or C-35 would begin to decline has not occurred and does not appear likely.

Growers need to start thinking in terms of how good it has been to have methyl bromide and not how bad it is that we are losing it. To those who say they can not produce without methyl bromide, I would have to ask "what did you do before you had methyl bromide?". Few of us like change, but this is a time of change in our industry and change we must, if we are to survive. It is a time for growers to re-learn old skills of herbicide application and soilborne pest management. It also is a time for scientists to press forward in the search for alternatives and better define the operating parameters of those we currently have so that Florida growers can remain competitive no matter how uneven the playing field.

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Table 1. Effect of methyl bromide alternative on vigor of tomato plants and the extent of gall formation on tomato roots as a result of infestation with rootknot nematodes in the long term cropping system study. Year 3. Fall 2000.

Alternative	Plant vigor (%)		Root Galling Index
	Early season	Midseason	(0 to 10 scale)
Nontreated	56 b[z]	16 c	4.4 a
Methyl bromide (67/33)	79 a	80 a	1.9 b
Telone C-17 + Tillam + Devrinol	79 a	79 a	0.4 c
Solarization (8 wks.) + Devrinol	79 a	52 b	5.0 a

[z] Treatment means within columns followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's new multiple range test.

Table 2. Effect of methyl bromide alternative on weed control in tomato in the long term cropping system study. Year 3. Fall 2000.

Alternative	Number of weeds per 70 ft of row					
	Midseason			Late season		
	Nutsedge	Pigweed	Crabgrass	Nutsedge	Pigweed	Crabgrass
Nontreated	585 a[z]	22 a	3 ab	620 a	18 a	4 a
Methyl bromide (67/33)	6 b	1 b	1 b	29 b	0 b	0 b
Telone C-17 + Tillam + Devrinol	77 b	1 b	1 b	114 b	0 b	1 b
Solarization (8 wks.) + Devrinol	37 b	1 b	7 a	52 b	1 b	7 a

[z] Treatment means within columns followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's new multiple range test.

Table 3. Effect of methyl bromide alternative on nematodes in the rhizosphere of tomato plants in the long term cropping system study. Year 3. Fall 2000.

Alternative	Number of nematodes per 100 cc of soil								
	Rootknot	Stunt	Stubby	Ring	Cyst	Sting	Lance	Awl	Total
Nontreated	43 b[z]	37 a	24 a	7 a	2 a	43 a	9 a	1 a	166 b
Methyl bromide (67/33)	4 b	1 b	40 a	0 b	0 b	1 b	0 b	1 a	46 b
Telone C-17 + Tillam + Devrinol	4 b	4 b	38 a	0 b	0 b	1 b	0 b	0 a	46 b
Solarization (8 wks.) + Devrinol	481 a	12 b	24 a	1 a	0 b	6 b	1 b	0 a	524 a

[z] Treatment means within columns followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's new multiple range test.

Table 4. Effect of spring cropping practice on nematodes in the rhizosphere of tomato plants in the long term cropping system study. Year 3. Fall 2000.

Cropping Practice	Number of nematodes per 100 cc of soil								
	Rootknot	Stunt	Stubby	Ring	Cyst	Sting	Lance	Awl	Total
Double cropped cucumber	234 a[z]	11 a	37 a	3 a	1 a	11 a	0 a	1 a	298 a
Millet	88 a	15 a	22 b	2 a	1 a	14 a	1 a	0 a	142 a
Fallow	78 a	14 a	35 a	1 a	0 a	13 a	6 a	1 a	148 a

[z] Treatment means within columns followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's new multiple range test.

Table 5. Effect of methyl bromide alternative on seasonal total yield of fresh market tomatoes in the long term cropping system study. Year 3. Fall 2000.

Alternative	Weight (kg) of fruit per 10 plants (20 ft of row) per plot				
	5x6	6x6	6x7	Marketable	Cull
Nontreated	4.3 c[z]	1.5 c	4.4 b	10.2 c	3.7 b
Methyl bromide (67/33)	27.4 a	7.7 a	14.1 a	49.2 a	6.5 a
Telone C-17 + Tillam + Devrinol	25.2 a	7.6 a	13.1 a	45.8 a	6.1 a
Solarization (8 wks.) + Devrinol	13.6 b	4.1 b	7.6 b	25.4 b	7.5 a

[z] Treatment means within columns followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's new multiple range test.

Table 6. Effect of fall fumigant treatments on vigor, height and fruit production of spring double-cropped, trellised cucumber plants in the third year of the long term cropping system study. 10 April 2001.

Fall Treatment	Rate per acre	Vigor (%)	Height (cm)	Lbs. of fruit per 20 ft of row
Nontreated	0	30 b[z]	70.7 a	36 b
Methyl bromide (67/33)	350 lbs.	85 a	81.0 a	153 a
Telone C-17 Tillam Devrinol	35 gal 4 lb.a.i. 2 lb.a.i.	74 a	76.2 a	122 a
Solarization Devrinol	8 wks. 2 lbs.a.i.	40 b	42.0 b	69 b

[z] Treatment means followed by the same letter are not significantly different at the 5% level as determined by Duncan's new multiple range test.
Height is an average of 10 plants per plot from the center row of each plot.

Table 7. Effect of fall fumigant treatments on weed control and nematode populations in the rhizosphere of spring double-cropped cucumber plants in the third year of the long term cropping system study. 21 May 2001.

Fall	Rate	Number of weeds per 70 ft of row			Number of nematodes per 100 cc of soil					
Treatment	per acre	Nutsedge	Grass	Pigweed	Rootknot	Stunt	Stubby	Ring	Cyst	Sting
Nontreated	0	1501 a[z]	2 b	51 a	40 a	32 a	38 a	117 a	62 a	56 a
Methyl bromide (67/33)	350 lbs.	59 b	1 b	0 b	59 a	1 b	46 a	0 b	0 b	1 b
Telone C-17 Tillam Devrinol	35 gal 4 lb.a.i. 2 lb.a.i.	489 b	2 b	0 b	82 a	14 ab	41 a	0 b	0 b	3 b
Solarization Devrinol	8 wks. 2 lbs.a.i.	112 b	28 a	2 b	156 a	11 ab	39 a	7 b	7 b	19 b

[z] Treatment means followed by the same letter are not significantly different at the 5% level as determined by Duncan's new multiple range test.

Table 8. Effect of in-bed and broadcast applications of Telone C-35, alone or in combination with additional in-bed application of chloropicrin, on vigor and mortality of tomato plants and nutsedge control. Spring 2001.

Treatment	Rate Per acre	method of application	Plant vigor (%) 23 April	1 June	Number of nutsedge plants per plot
Nontreated	0	n/a	30 b[z]	21 b	220 a
Methyl bromide 67/33	350 lbs	in bed	91 a	76 a	2 a
Telone C-35 Tillam + Devrinol	35 gal 4 lbs.ai 2 lbs.ai	in bed ppi	91 a	79 a	1 a
Telone C-35 Tillam + Devrinol	26 gal 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	85 a	76 a	316 a
Telone C-35 Tillam + Devrinol	26 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	87 a	82 a	13 a
Chloropicrin	137 lb. In bed a week later (9.8 gal)(equivalent to C-35 at 35 gpa rate of pic)				
Telone II Tilllam + Devrinol	18 gal 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	90 a	85 a	11 a
Chloropicrin	137 lbs (9.8 gal)	in bed a week later			

[z] Duncan's multiple range test, 5% level of significance.

Table 9. Incidence of Southern blight, Fusarium wilt (race 3) of tomato, and plant mortality with in-bed and broadcast applications Telone C-35, alone or in combination with additional in-bed application of chloropicrin. 29 June 2001.

Treatment	Rate Per acre	method of application	Percentage of plants per plot: Southern blight	F. wilt	Dead
Nontreated	0	n/a	45 a[z]	21 a	76 a
Methyl bromide 67/33	350 lbs	in bed	19 b	11 a	22 c
Telone C-35 Tillam + Devrinol	35 gal 4 lbs.ai 2 lbs.ai	in bed ppi	13 b	11 a	18 c
Telone C-35 Tillam + Devrinol	26 gal 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	44 a	15 a	49 b
Telone C-35 Tillam + Devrinol	26 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	19 b	11 a	21 c
Chloropicrin	137 lb. (9.8 gal)(equivalent to C-35 at 35 gpa rate of pic)	In bed a week later			
Telone II Tilllam + Devrinol	18 gal 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	19 b	5 a	24 c
Chloropicrin	137 lbs (9.8 gal)	in bed a week later			

[z] Duncan's multiple range test, 5% level of significance.

Table 10. Nematode control with in-bed and broadcast applications of Telone C-35, alone or in combination with additional in-bed application of chloropicrin, 25 May 2001. Spring 2001.

Treatment	Rate Per acre	method of application	Number of nematodes per 100 cc of soil: RKN	Stunt	Stubby-root	Ring	Cyst	Sting	Awl	Total
Nontreated	0	n/a	0 a[z]	28 a	141 a	8 a	5 a	24 a	9 a	216 a
Methyl bromide 67/33	350 lbs	in bed	0 a	0 b	149 a	0 a	0 a	0 b	2 a	151 a
Telone C-35 Tillam + Devrinol	35 gal 4 lbs.ai 2 lbs.ai	in bed ppi	0 a	0 b	175 a	0 a	0 a	0 b	2 a	177 a
Telone C-35 Tillam + Devrinol	26 gal 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	0 a	20 ab	174 a	0 a	2 a	0 b	0 a	195 a
Telone C-35 Tillam + Devrinol Chloropicrin	26 4 lbs.ai 2 lbs.ai 137 lb. (9.8 gal)(equivalent to C-35 at 35 gpa rate of pic)	broadcast (Yetter) ppi In bed a week later	2 a	0 b	102 a	0 a	0 a	0 b	1 a	104 a
Telone II Tilllam + Devrinol	18 gal 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	0 a	7 ab	156 a	0 a	0 a	0 b	1 a	164 a
Chloropicrin	137 lbs (9.8 gal)	in bed a week later								

[z] Duncan's multiple range test, 5% level of significance.

Table 11. Effect of in-bed and broadcast applications of Telone C-35, alone or in combination with additional in-bed application of chloropicrin, on seasonal total tomato production. Spring 2001.

Treatment	Rate	method of	Weight (kg) of fruit per 10 plants (20 ft)				
	Per acre	application	5x6	6x6	6x7	Marketable	Cull
Nontreated	0	n/a	2.2 b[z]	0.9 c	1.6 c	4.6 c	2.2 b
Methyl bromide 67/33	350 lbs	in bed	23.4 a	8.4 a	13.4 ab	45.3 a	9.0 a
Telone C-35 Tillam + Devrinol	35 gal 4 lbs.ai 2 lbs.ai	in bed ppi	18.0 a	8.5 a	14.9 a	41.3 ab	8.4 a
Telone C-35 Tillam + Devrinol	26 gal 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	17.2 a	4.8 b	10.8 b	32.8 b	8.8 a
Telone C-35 Tillam + Devrinol	26 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	20.8 a	8.2 a	15.1 a	44.1 a	9.6 a
Chloropicrin	137 lb. In bed a week later (9.8 gal)(equivalent to C-35 at 35 gpa rate of pic)						
Telone II Tilllam + Devrinol	18 gal 4 lbs.ai 2 lbs.ai	broadcast (Yetter) ppi	22.4 a	8.2 a	13.8ab	44.4 a	8.1 a
Chloropicrin	137 lbs (9.8 gal)	in bed a week later					

[z] Duncan's multiple range test, 5% level of significance.

Table 12. Effect of Tillam application timing in relation to application of Telone C-35 on incidence of Southern blight and tomato plant mortality. 29 June 2001.

Tillam rate	Days before Telone	Percentage of plants affected	
(lb.a.i./A)	application	Southern blight	Dead
0	21	5 a[z]	12 a
4	21	7 a	13 a
4	14	6 a	10 a
4	0	11 a	14 a
4	7 after	4 a	9 a
0	n/a	12 a	16 a

[z] Treatment means followed by the same letter are not significantly different at the 5% level as determined by Duncan's new multiple range test.

There was no interaction between herbicide application timing and method of Telone C-35 application.

Table 13. Effect of Telone application method in relation to application of Tillam on incidence of Southern blight and tomato plant mortality. 29 June 2001.

Telone Application Method	Percentage of plants affected: Southern blight	Dead
Broadcast	13 a[z]	18 a
In bed	2 b	6 b

[z] Treatment means followed by the same letter are not significantly different at the 5% level as determined by Duncan's new multiple range test.

Table 14. Effect of Tillam application timing in relation to application of Telone C-35 on the seasonal total yield of fresh market tomatoes. Spring 2001.

Tillam rate (lb.a.i./A)	Days before Telone application	Weight (kg) of fruit per 10 plants (20 ft) per plot: 5 x 6	6 x 6	6 x 7	Marketable	Cull
0	21	43.4 a[z]	8.7 a	12 7 a	64.8 a	9 2 a
4	21	42.1 a	8.9 a	13.2 a	64.1 a	9.1 a
4	14	40.3 a	8.8 a	11.4 a	60.4 a	7.7 a
4	0	42.4 a	9.1 a	12.9 a	64.4 a	10.2 a
4	7 after	39.4 a	8.1 a	12.9 a	60.5 a	9.0 a
0	n/a	38.8 a	8.0 a	10.7 a	57.4 a	8 6 a

[z] Treatment means followed by the same letter are not significantly different at the 5% level as determined by Duncan's new multiple range test.
There was no interaction between herbicide application timing and method of Telone C-35 application.

Table 15. Effect of Telone application method in relation to application of Tillam on the seasonal total yield of fresh market tomatoes. Spring 2001.

Telone Application Method	Weight (kg) of fruit per 10 plants (20 ft) per plot: 5 x 6	6 x 6	6 x 7	Marketable	Cull
Broadcast	41.4 a[z]	8.3 a	11.5 b	61.2 a	8 4 a
In Bed	40.8 a	8.9 a	13.2 a	62.9 a	9.5 a

[z] Treatment means followed by the same letter are not significantly different at the 5% level as determined by Duncan's new multiple range test.

Table 16. Efficacy of selected herbicides for some common weeds of tomato fields.

Weed species	Devrinol	Tillam	Treflan / Trilin	Dual
nutsedges	no	yes	no	yellow
crabgrass	yes	yes	yes	yes
goosegrass	yes	yes	?	yes
pigweed	yes	yes, some species	yes	yes
eclipta	no	no	no	no
smartweed	no	no	no	no
purslane	yes	yes	yes	partial
lambsquarters	yes	yes	yes	no
carpetweed	yes	no	yes	yes
ragweed	yes, at 2 lb.a.i.	no	no	no
millet	?	yes	?	partial
nightshade	no	Hairy - partial	no	Eastern black, Hairy - partial

? Indicates the label does not specify this species and the authors have no data to support the contention that the indicated herbicide provides control.

Methyl Bromide Rates, Reductions And Formulations, and IPM Alternatives For Nematode Control In Tomato

J. W. Noling and J. P. Gilreath

This past January, methyl bromide production and importation was reduced an additional 25% as a result of the EPA regulatory implementation of the U.S. Clean Air Act and provisions of the Montreal Protocol Agreement. This additional reduction, implemented January 1, 2001, means that now methyl bromide manufacturers can produce only 50% of the levels produced in 1991. Once again, methyl bromide prices have increased in response to reduced supply, and likely will continue to do so. Not only has availability been reduced, but market competition among the different end users is intensifying and redefining how remaining methyl bromide supplies are allocated. For example, the sale of methyl bromide for use as a structural fumigant is currently priced at as much as $4.00 per pound, in contrast to the price of $2.60 per pound for 67/33 which growers currently pay. Clearly there is a profit incentive to allocate more methyl bromide sales towards its use as a structural fumigant rather than for agricultural soil fumigant uses.

Each year, field research continues to explore new products, application technologies, and treatment regimes to serve as alternatives to soil fumigant uses of methyl bromide. In this paper we will try to address some of the current research on alternative management tactics which can have an impact on nematode control in the post methyl bromide era.

Methyl Bromide / Chloropicrin Formulation And Application Rate

Previous research has demonstrated that methyl bromide (Mbr) is the component with principal nematicidal activity and chloropicrin (Pic) is only weakly nematicidal. Given the changes which have occurred in cost, availability and formulation of methyl bromide, field microplot experiments were conducted to evaluate differences in pest control efficacy and tomato yield response to reduced application rates of three formulations of methyl bromide and chloropicrin. During spring 2001, two experiments were conducted to evaluate three formulations of methyl bromide and chloropicrin and three application rates. The different formulations included 1) 98% methyl bromide and 2% chloropicrin; 2) 75% methyl bromide / 25% chloropicrin, and 3) 50% methyl bromide / 50% chloropicrin. Application rates of 50, 75, and 100% of the maximum broadcast equivalent were evaluated within each formulation. All formulations and application rates were evaluated for control of the southern root-knot nematode (*Meloidogyne incognita*) and yellow nutsedge (*Cyperus esculentus*), and resultant impacts on 'Florida 47' tomato plant growth, development, and yield . In general, the results of these microplot trials (Figures 1 and 2) clearly showed :

- All formulations and application rates of methyl bromide and chloropicrin provided significant control of nematode and nutsedge compared to the untreated control.
- Incremental loss of nematode and nutsedge control with reduced methyl bromide and chloropicrin rate.
- Compared to a formulation of 98% methyl bromide and 2% chloropicrin, nematode and nutsedge control decreased with increased chloropicrin content of the methyl bromide formulation.

These results appear to validate field observations of increased severity and incidence of weed and nematode problems associated with the change in methyl bromide formulation from 98/2 to 67/33, and with reduced rates of methyl bromide field application. It also suggests a further erosion of nematode and weed control if chloropicrin content of methyl bromide formulations is increased further from the current 67/33 formulation (ie., 50/50).

Virtually Impermeable Plastic Mulches

During the past two years, field studies were conducted to evaluate and validate the feasibility of using virtually impermeable plastic mulch films (VIF) to reduce methyl bromide field application rates without serious loss of crop yield or pest control efficacy. Large scale grower field demonstration trials were conducted in west central (Parrish & Plant City, FL) and south Florida (Immokalee) to compare possible methyl bromide and chloropicrin (67/33) rate reductions of 25 to 50% compared with a full grower standard rate using the standard low density polyethylene plastic mulch. In addition, a field microplot experiment was conducted on the use of the VIF plastic mulch to evaluate the extent to which field application rates can be reduced without compromise of nematode control or tomato yield. Differences in plant growth, including comparisons of plant size, height, vigor, consistency, mortality, and nematode and disease incidence and severity, were evaluated in all trials. In general, the results of the grower field demonstration trials indicated:

- No significant loss of pest control efficacy or crop yield (tomato, pepper, cantaloupe, or strawberry) when applications rates of methyl bromide were reduced as much as 50% **when** reduced rates were accompanied by the use of a VIF mulch.
- Some problems were incurred during the plastic laying operation, in that tractor speeds needed to be reduced as low as 3 mph to properly install the plastic.

Alternative Fumigant Evaluations

During fall 2000 and spring 2001, single preplant applications of Propargyl bromide (40-120 lb/A), Telone II (12 gal/A), Telone C17 (17 gal/A), Telone C35(26 gal/A), Propylene oxide (50,75 gal/A), Vapam (75 gal/A), and Basamid (400 lb/A) were evaluated for control of the southern root-knot nematode (*Meloidogyne incognita*) and yellow nutsedge (*Cyperus esculentus*), and resultant impacts on tomato plant growth, development, and yield in field microplots. Three biorational or new systemic acquired resistance compounds (SAR) also were evaluated and compared for nematode and nutsedge control. Biorational treatments included Armorex (30 gal/A) and repeated foliar applications of Messenger and Rezist. In general, all fumigant treatments significantly reduced root gall severity caused by *M. incognita* (Figures 3 and 4); however, no fumigant treatment completely eliminated final harvest root galling , and treatment responses in tomato yield were generally a direct reflection of nematicidal efficacy and root gall severity. Use of Vapam and Basamid reduced root gall severity to only an intermediate level compared to the untreated control and most other fumigant treatments . Little or no reduction in root gall severity was achieved with Messenger, Resist, or Armorex. Of all the treatments, only Telone II, Messenger, and Resist failed to provide significant control of yellow nutsedge compared to the untreated control.

Post Harvest Crop Destruction

One of the foundation principals of an integrated nematode management strategy is to ensure early destruction of the tomato crop immediately after final harvest. The major objective is to remove the plant food source which maintains nematode reproduction and soil population growth. Any delay in crop termination can increase soil populations of nematodes, particularly in the span of a few weeks after final harvest if the plant and its roots are not killed immediately. In general, the more nematodes left in the soil after a crop, the more which will survive to infect roots of the following crop, and the more difficult it will be to achieve satisfactory nematode control with a preplant fumigant. Clearly, the opportunity to enhance nematode control with soil fumigation and minimize losses in crop yield due to nematodes is dependent upon the adoption of early crop destruction after final harvest.

Currently, tomato fields are sprayed with paraquat in a 'top - down' approach to kill the foliage after harvesting is completed in the spring or fall (Figure 5). While foliage is killed, roots are initially unaffected by the paraquat treatment, and nematode reproduction continues until nutrient reserves within roots are exhausted and roots die. New field research efforts are evaluating a 'bottom - up' approach in which water soluble fumigants are chemigationally applied via drip irrigation to simultaneously and immediately: 1) kill the roots; 2) stop nematode reproduction; 3) reduce soil population levels of nematodes; and 4) kill the foliage, as in the paraquat treatment. Previous research has demonstrated the feasibility of the approach with drip applied metham sodium (Vapam), and more recently with metham sodium or Telone EC. Results of field trials performed during Spring 2001 clearly demonstrated the ability to kill foliage via destruction of roots. Soil populations of nematodes also were substantially reduced in the 'bottom-up' approach. However, the efficiency in reducing nematode populations in soil was directly related to the volume of water supplied and the resultant distribution of the fumigant within the bed. To maximize the efficiency of the 'bottom - up' approach will require additional on-farm chemigation research to determine the most appropriate drip emitter spacing and injection period to maximize bed coverage within the plant row.

Crop Rescue

During the past year, numerous tomato fields were identified in which root-knot nematode became a serious problem within the established crop. Infested fields displayed classic symptoms of stunted plant growth and chlorotic foliage. In most cases, the problem appeared to be related to droughty conditions at the time of soil fumigation. Other factors such as reduced methyl bromide application rate and possible formulation effects (ie., 67/33) cannot be excluded as possible contributing causes for the nematode problematic fields.

Once the discovery is made that nematodes have colonized tomato roots and stunted plant growth, the question is whether it is possible to effectively reduce nematode population levels and restore tomato yield potential. At present the only post plant nematicide which can be used to help resolve an established nematode problem is Vydate (Oxamyl). Vydate is not considered a true nematicide, but rather a nematostat. Nematostats, rather than kill nematodes, induce a narcotic effect which paralyzes the nematode and prevents it from feeding, movement, mating, and other normal activities. The narcotic effect is only as persistent as adequate Vydate concentrations are maintained within soil and roots. Following nematode application, irrigation and rainfall can dilute and leach toxic concentration from the nematode environment, thereby restoring its ability to conduct normal bodily functions. As a result, repeated Vydate applications to soil are required to maintain toxic (narcotic) concentrations. Field observations of crop rescue attempts with Vydate injections via the irrigation system have usually demonstrated some improvement to plant growth and vigor, but not necessarily yield. Many factors simultaneously interact to influence the extent to which plants respond to Vydate treatment. Not all factors are well understood at this time.

In general, use of Vydate as a postplant, crop rescue treatment for nematodes should consider the following:

- Foliar applications of an upwardly mobile systemic, such as Vydate, have not proven to be effective for nematode control or for improved plant growth response. Vydate treatment should not be considered unless made via the drip irrigation system.
- Fields with previous history of nematode problems should be closely monitored after transplanting. The sooner a nematode problem is identified in the field and the sooner Vydate treatments are initiated, the greater the response in tomato plant growth and yield will be. Clearly the nematode problem and impact to tomato yield will intensify over time if nothing is done, particularly if the plant undergoes periods of moisture stress.
- Regardless of the time of discovery in the field, roots which are heavily galled are not likely to respond satisfactorily (stage a dramatic comeback) to Vydate treatment.
- The inability to uniformly distribute Vydate along the entire plant row via the irrigation system in itself sets a limit to the degree of possible plant improvement.
- After Vydate application, the effect of daily irrigation (ie., two or more times per day) on Vydate soil and root concentrations and tomato yield response is not known. However, given the possible dilution and leaching effect of daily irrigation cycles, repeated weekly applications throughout the remainder of the growing season are likely to be superior to 1 or 2 early season applications made immediately after discovery of the nematode problem in the field.

General Conclusions

Nothing has changed with regard to the phase-out schedule for methyl bromide (January 1, 2005) and it is not at all apparent at this point whether any political or regulatory changes will occur in the near future to alter the current schedule. As such, the University of Florida continues to conduct a comprehensive field research program to identify and evaluate potential alternatives to methyl bromide for nematode management. Results from field trials conducted during the previous year have demonstrated a number of new alternative fumigants with excellent nematicidal activity. However, these new fumigant products are currently not federally registered for grower use, nor are they likely to be until after the phaseout, if at all. It also is reasonably clear that even with methyl bromide soil fumigation, nematode problems can develop in an established crop after its use. Methyl bromide is not perfect, and problems with nematodes are expected to increase as a result of increased chloropicrin content of the formulation.

The alternative fumigants which are currently registered for use are not perfect either, and the overall success that a grower will achieve with an alternative will depend upon the degree to which growers have learn how touse them. Given the continuing reduced supply, availability, and cost of methyl bromide, growers are again strongly encouraged to begin the evaluation of alternatives to methyl bromide. Last year we recommended that as much as 10% of current farm acreage be committed to the evaluation of a methyl bromide alternative tactic. This year, we would highly recommend as much as 25% of current acreage be committed to such evaluations. It is clear from previous work that some combination of alternative treatments will be required to achieve similar pest control efficacy and tomato yield as that of methyl bromide. The list below represents particular treatments which have demonstrated potential and are currently being grower evaluated around the state. In the short term, those treatments involving the use of gas impermeable plastics are included simply as a means for growers to distribute what methyl bromide they can acquire to adequately treat their existing acreage without fear of significant loss or to have to completely rely on alternative tactics at this time.

Possible Alternative Treatments to be evaluated with methyl bromide standard:

TELONE PRODUCTS + Herbicide(s)

1. Telone C35 Broadcast (26 gal/a) + Herbicide(s) (Tillam, Devrinol, and/or Treflan)
2. Telone C35 in-row (35 gal/a) + Herbicide(s)
3. Telone C35 Broadcast (reduced rate) + Herbicide(s) + Methyl Bromide /Chloropicrin in-row (reduced rate)
4. Telone II broadcast (12-18 gal/a) + Chloropicrin in-row (100-150 lb/a)
5. Telone C35 Broadcast (20 gal/a) + Herbicide(s) + Chloropicrin in-row(50-100 lb/a)
6. Telone II broadcast (12-18 gal/a) + Metham Sodium-in bed (37-75 gal/a)

GAS IMPERMEABLE PLASTIC MULCH (VIF):

7. 25% Reduced in-row Methyl Bromide/ Chloropicrin application Rate with VIF
8. Telone C35 in-row (18-26 gal/a) + VIF

J.W. Noling, University of Florida, IFAS, Citrus Research & Education Center, Lake Alfred, FL; J.P. Gilreath, University of Florida, IFAS, Gulf Coast Research & Education Center, Bradenton, FL

Figure 1. Final harvest root gall severity caused by Meloidogyne incognita following soil application of three formulations (98/2, 75/25, 50/50) and three rates of methyl bromide chloropicrin during Spring 2001, Lake Alfred, FL

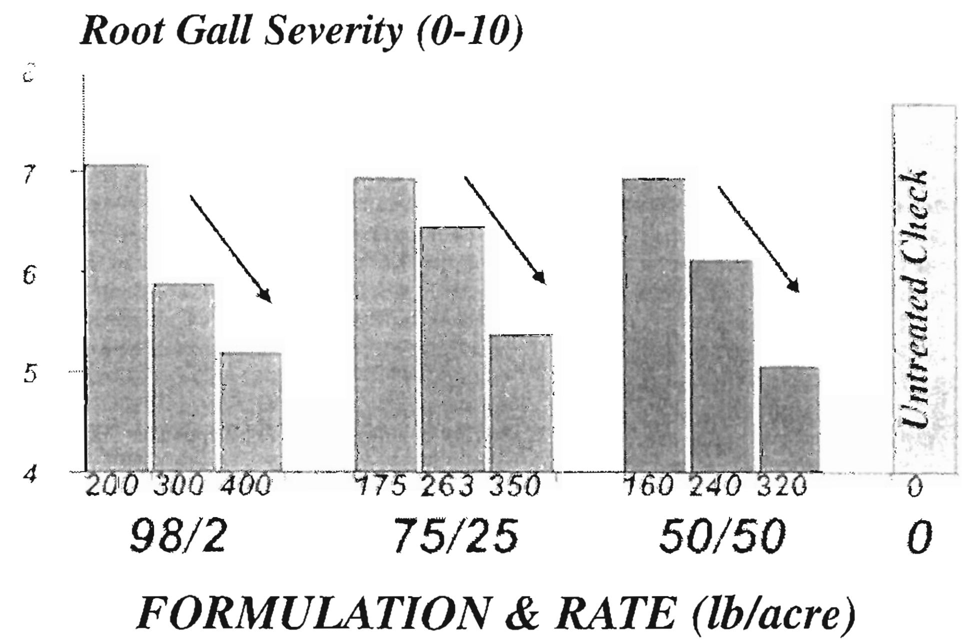
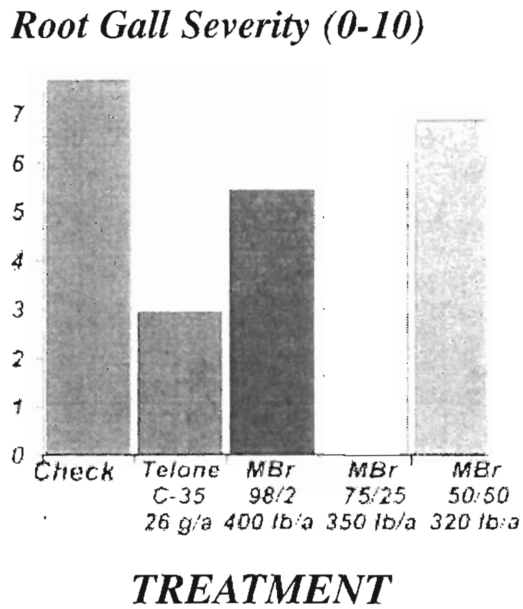


Figure 2. Final harvest root gall severity and numbers of germinating yellow nutsedge nutlets following application of various soil fumigants, Spring 2001, Lake Alfred, FL



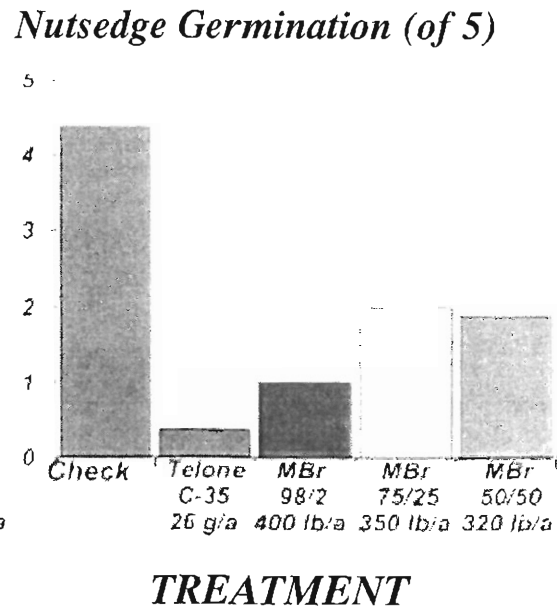


Figure 3. Final harvest root gall severity caused by Meloigogyne incognita following soil application of various fumigant and nonfumigant nematicides, Fall 2001, Lake Alfred, FL

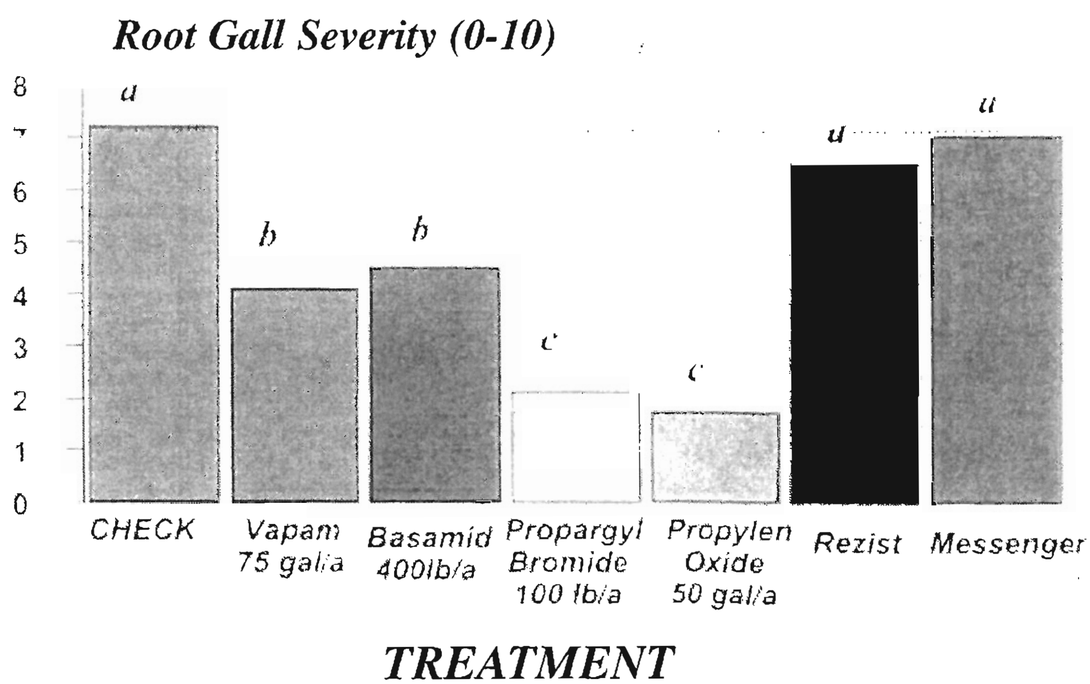


Figure 4. Final harvest root gall severity caused by Meloidogyne incognita following soil application of various fumigant and nonfumigant nematicides. Spring 2001, Lake Alfred, FL

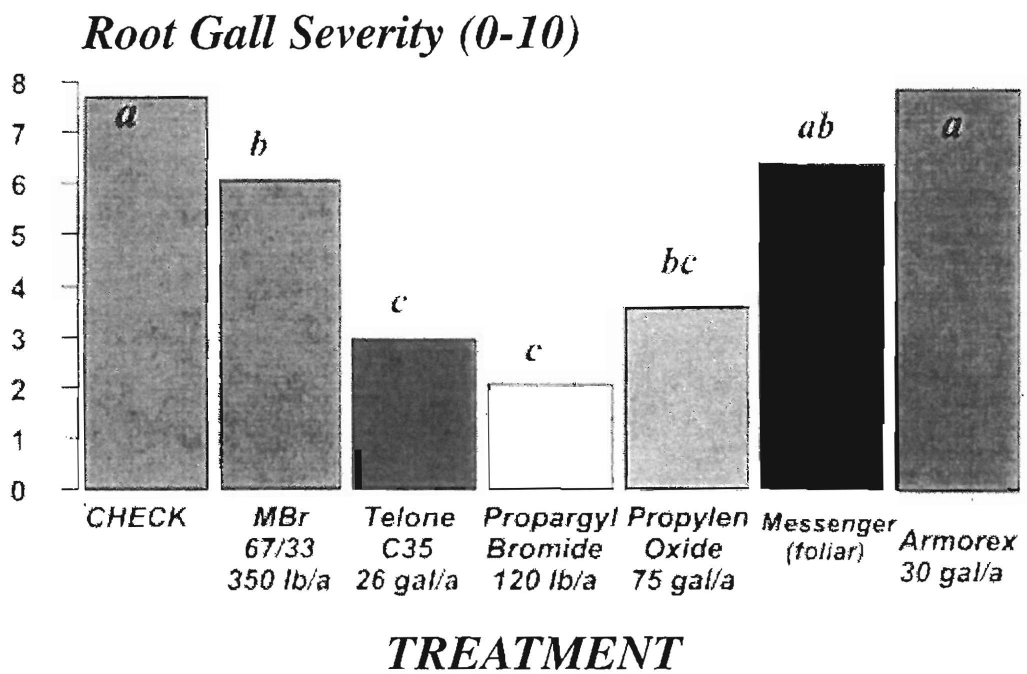
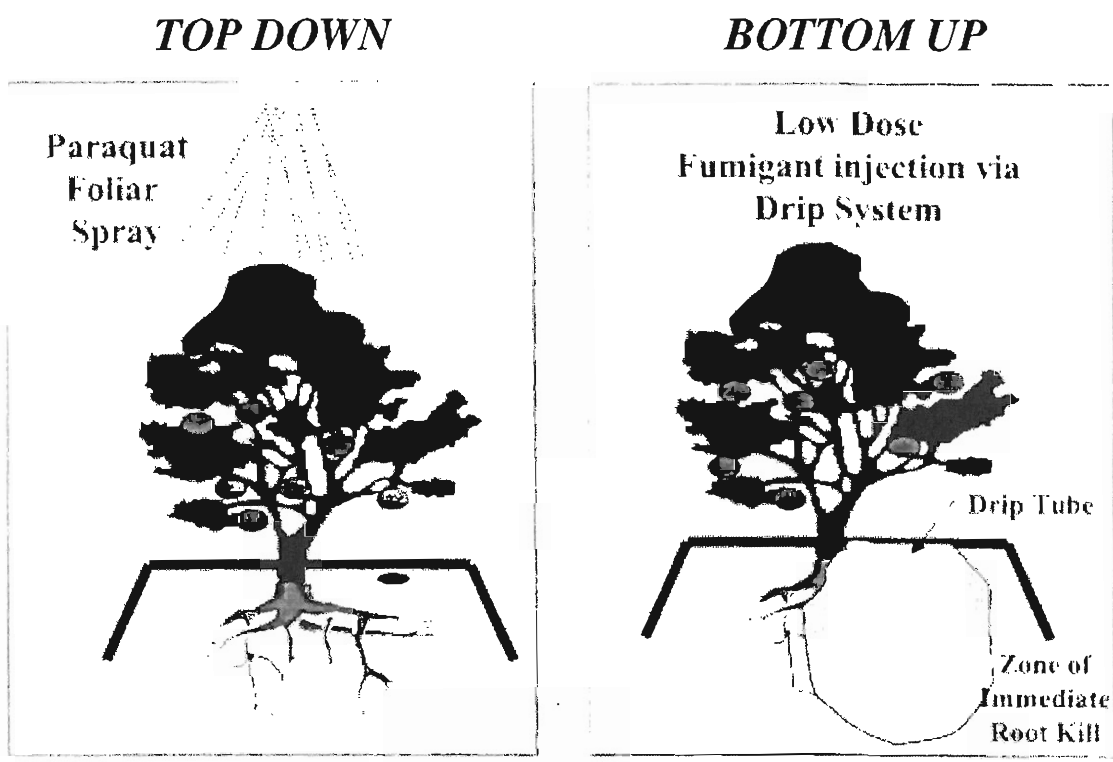


Figure 5.

APPROACHES TO EARLY CROP DESTRUCTION



Better Bed Wetting Through Science

J. E. Eger, Jr., J. P. Gilreath and J. W. Noling

Summary

Trials were conducted at the Gulf Coast Research and Education Center of the University of Florida in Bradenton, FL to determine the distribution of drip irrigation water applied through one and two drip tubes over a range of run times. These studies were conducted to determine optimum parameters for application of soil fumigants through drip systems. Wetting patterns from various treatments were determined using a blue marking dye. A single drip tube did not wet over 45% of the soil volume in raised beds even at run times of up to 12 hrs, suggesting that two drip tubes will be necessary to obtain thorough bed wetting in Florida soils. Two drip tubes, operated for 10 hrs resulted in about 85% wetting of the total soil volume in the bed. Adequate application of soil fumigants will require the use of two drip tubes and relatively long run times to maximize the distribution of soil fumigants under most Florida conditions.

Introduction

The impending loss of methyl bromide for soil fumigation in Florida's tomato crops has led to the evaluation of numerous new and old products for control of soil diseases, nematodes and weeds. In Florida, 1, 3-dichloropropene + chloropicrin provided soilborne pest control and crop yields equivalent to those of methyl bromide + chloropicrin when applied in a conventional shank injection (Eger, 2000, Gilreath et al., 2000, Noling and Gilreath, 1998). Efficacy of emulsified 1, 3-dichloropropene and chloropicrin products through drip irrigation systems was excellent in the western United States (Trout and Ajwa, 1999, 2000). However, in the sandy soils of Florida, drip application of these and other materials was ineffective for control of soilborne pests (Dickson and Locascio 1995, unpublished report, Olson, 1995, unpublished report). The lack of performance in Florida soils with a high percentage of sand (>95%), coupled with excellent performance in heavier western soils, suggested that drip application in sandy soils may not provide adequate distribution of soil fumigants in sandy soils.

Csinos et al. (2001) determined that a blue dye added to drip irrigation water was effective for determining the distribution pattern of drip applied water. Other methods (Clark et al., 1993, Omary and Ligon, 1992, Vellidis et al., 1990) have been used to determine water movement patterns, but these methods are cumbersome, expensive or require disruption of the soil prior to application. The use of a dye provides a quick, inexpensive and readily visible method for evaluating patterns of drip water distribution without disturbing the beds prior to application.

The objectives of the studies reported here were to validate the use of dye to determine drip water distribution patterns. We also wanted to evaluate the distribution of drip irrigation water in sandy soils when applied through one or two drip tubes at various run times.

Materials and Methods

Trials were conducted at the Gulf Coast Research and Education Center of the University of Florida in Bradenton, FL. Soil type was EauGallie Fine Sand. Test fields were disked periodically to eliminate plant residue and prepared for bedding in accordance with normal grower practices. Prior to bedding, fields were seep irrigated to provide moist soil needed for adequate bed formation. Beds were formed using standard bed presses and covered with clear plastic mulch. Drip tubing was laid on top of the bed under the plastic mulch in a shallow trench. Single drip tubes were placed slightly off center. Where two drip tubes were used, they were spaced 12 in apart on the center of the bed.

Irrigation water was pumped from a 55 gal tank directly into a 1 inch OD polypropylene tube. This tube was divided into a series of lateral lines connected to each plot. Valves located at the head of each plot were opened or closed to allow application of a specific treatment to the desired plots. Drip tubes were attached directly to the valves. Drip tubing used was T-Tape® with an emitter spacing of 12 in and delivering 0.45 gal/min/100 ft at 8 psi. Pressure at the pump was maintained at 10 psi. Distribution of drip irrigation water was evaluated using a blue marking dye (Signal®). The dye was mixed in the 55 gal tank at the rate of 1 quart per tank and was introduced into every other tank.

The effect of run time on drip water distribution was evaluated in four trials. Run times in the initial trial (October, 2000) were 0.5, 1, 2, 3, and 4 hr. One and two drip tubes per bed were evaluated. The second trial was conducted in December, 2000 with a single drip tube and run times of 2, 4, 6, 8, 10 and 12 hr. A third trial was conducted in January, 2001 using a single drip tube and run times of 4, 6, and 8 hrs. In April, 2001, a fourth trial was conducted using two drip tubes per bed and run times of 4, 6, 7, 8, and 10 hr. Bed width was 28 in at the top and 32 in at the bottom in the first three trials, 32 in top and 36 in bottom in the fourth trial. Plots in all trials were prewetted by running the drip system for 5 hrs the evening before test initiation.

Width, depth and area of soil covered by the drip water was evaluated by digging trenches across the beds or by digging out the lateral ½ of a section of the bed along the drip tubing. After digging rough trenches, the bed face was prepared for measurement by shaving off thin layers of soil until a flat surface was exposed at the desired location in the bed. For trials with single drip tubes, measurements were made across the bed at points on the emitters and equidistant between emitters. In the December and January single tube trials, additional measurements were made along the bed directly below the drip tubing. Trials with two drip tubes were evaluated by digging a trench across the bed and preparing a flat surface similar to the process for single tubes. No effort was made to offset emitters on the two tubes as this would not be a practical grower practice. Observations in the October trial were made at three random locations in the bed. Observations in the April trial were made at a point on one of the emitters, then the bed face was shaved back in 2 in increments for a total of four faces at each location in the bed. Measurements were taken at two locations in each replicate.

To measure the distribution of drip water, a 3 ft x 3 ft sheet of clear ¼ in plexiglass was scored at 1 in intervals in both directions to create a grid. The grid was held against the bed face to be measured. Maximum width of the blue dye pattern, depth of the pattern from the top of the bed and area covered by the blue dye were recorded for each surface. Area was estimated by counting all grid squares in which half or more of the square was blue.

The October trial was not replicated. The other trials were set up in a randomized complete block design with four replicates. Plot size was 25 ft of bed. Data were analyzed using analysis of variance. Means of comparative treatments were separated with Tukey's Studentized Range Test ($P = 0.10$). The analytical software was Statgraphics Plus®, Manugistics, Inc., Rockville, MD). Depth of soil in beds was assumed to be 16 in in the October, 2000 – January, 2001 trials. Using a 16 in depth and accounting for slope of the bed, the surface area for a bed was determined to be 478 in^2. The depth to spodosol was somewhat higher in the April, 2001 trial and depth from the top to the spodosol was measured in each plot and used to determine bed surface area. Volume of bed wetted by drip irrigation in single tube trials was determined by taking an average of area wetted on and between emitters. Volume of bed wetted by two tubes was simply the mean for the treatment. Percent of bed volume wetted by drip water was computed using 478 in^2 in the first three trials and the actual bed volume in the fourth trial.

Results and Discussion

Single Tube Trials

Width, depth and area wetted by drip irrigation water in single tube trials are given in Tables 1-3. In the October, 2000 trial, run times were relatively short, ranging from 0.5 to 4 hrs. Drip patterns on the emitter were wider than deep and increased in a linear manner as run time increased. Drip patterns between emitters were also somewhat wider than deep, but were not as consistent as patterns on emitters. As with patterns on the emitters, increases in width, depth and area were generally linear when measured between emitters. The maximum percent of total bed volume wetted by drip irrigation water in this trial was only about 20% at 4 hrs (Fig. 1).

Run times were considerably longer in the December, 2000 trial (Table 2). Results at 2 and 4 hrs were similar to those in the October, 2000 trial. Despite run times of up to 12 hrs, increases over time in width, depth and area of wetting on or between emitters remained linear, suggesting that distribution of drip water would continue to increase at run times longer than 12 hrs. Because emitters were spaced 12 in apart, the maximum pattern width possible along the drip tube was 12 in. Drip patterns reached this width in all plots between 8 and 10 hrs. Depth along the drip tube was similar to that on emitters and continued to increase with increased run times. When percent of total bed volume wetted was computed, none of the run times resulted in even 50% coverage (Fig. 1).

Drip irrigation in the third trial (January, 2001) was run for 2, 4, and 6 hrs to confirm results seen in the December, 2000 trial. Results on the emitters and along the drip tube were very similar to those in the earlier trial (Table 3). Distribution of drip water between emitters was somewhat less than in the earlier trial. The percent of total bed volume wetted in this trial was very similar to that in the December trial (Fig. 1).

Two Tube Trials

Width, depth and area wetted by drip irrigation water applied through two drip tubes are given in Tables 4 and 5. Run times ranged from 0.5 to 4 hrs in the October trial and from 4 to 10 hrs in the April trial. The width of the wetting pattern was the distance from the outer edge of the pattern from one drip tube to the outer edge of the pattern from the other drip tube and did not take into account gaps in distribution between the two patterns. As expected, the widths of drip irrigation patterns with two tubes were considerably larger than those from a single drip tube. All measures of water distribution increased in a relatively linear manner as run times increased in the October trial. Width of the drip irrigation patterns approached the maximum bed width after about 7 hrs run time in the April trial. Depth of drip water also approached the maximum depth of beds at about 7 hrs. Despite similar width and depth of wetting patterns at 8 and 10 hrs in the April trial, the area wetted after 10 hrs was significantly greater than that after 8 hrs. This suggests that the additional drip water was filling in gaps between or within patterns although the overall width and depth were not increasing.

The percent of total bed volume wetted at various run times in the October, 2000 and April, 2001 trials is given in Fig. 1. Although the two trials had only a single run time in common, combined data from the two trials suggests a relatively linear response. Increases in percent of bed volume wetted over time were relatively consistent in the October, 2000 trial but were somewhat erratic in the April, 2001 trial. The percent of bed volume wetted with two drip tubes was about double that with a single tube as we would expect. Maximum wetted volume was about 85% after 10 hrs with two tubes.

Based on the three single tube trials, the distribution of water from single drip tube was very consistent across trials and increased in a linear manner in each trial. The fact that no run time resulted in more than about 45% wetting of the total bed volume suggests that single drip tubes will not provide thorough coverage of the soil volume needed for adequate soil fumigation. Run times of greater than 12 hrs should improve distribution of drip water, but may be impractical for injecting soil fumigants which should be monitored during injection. As a result, two drip tubes appear to be necessary to obtain the degree of coverage needed to apply soil fumigants.

Earlier studies with soil fumigants applied through drip irrigation systems (Dickson and Locascio 1995, unpublished report, Olson, 1995, unpublished report) involved run times of about 2 hrs. Although longer than the run times recommended for adequate irrigation (Clark et al., 1993), our studies demonstrated that these short run times were not adequate for injection of soil fumigants. A lack of efficacy in the above trials supports this conclusion. Adequate application of soil fumigants will require the use of two drip tubes and relatively long run times to maximize the distribution of soil fumigants under most Florida conditions. Our studies only evaluated the distribution of drip irrigation water. Future studies are needed to evaluate the efficacy of soil fumigants applied through drip systems using two drip tubes and optimum run times, and to determine the degree of bed wetting necessary to provide adequate fumigation.

Finally, our studies were conducted on one soil type at one location. Differences in soil type, depth of soil layers restrictive to water movement, bed width, etc. will undoubtedly impact drip water distribution. Prior to the application of soil fumigants through drip irrigation systems, growers and researchers should determine optimum run times for their situation. The use of a dye to determine wetting patterns is simple and quick and should be considered.

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Table 1. Effect of run time on distribution across beds of drip water applied through a single drip tube, Bradenton, FL, October, 2000.

Run Time (hrs)	On Emitters			Between Emitters		
	Width (in)	Depth (in)	Area (in^2)	Width (in)	Depth (in)	Area (in^2)
0.5	8.0	5.5	31	0.0	0.0	0
1.0	9.7	6.5	45	5.7	5.5	17
2.0	11.5	8.8	74	2.7	2.3	8
3.0	13.5	10.0	108	5.0	5.7	29
4.0	14.2	11.3	120	10.8	10.0	71

Table 2. Effect of run time on distribution of drip water applied through a single drip tube, Bradenton, FL, December, 2000. Means followed by the same letter in the same column are not significantly different according to Tukey's Studentized Range Test (P = 0.10).

	On Emitters			Between Emitters			Along Drip Tube		
Run Time (hrs)	Width (in)	Depth (in)	Area (in^2)	Width (in)	Depth (in)	Area (in^2)	Width (in)	Depth (in)	Area (in^2)
2	10.6 f	7.7 e	66 e	3.2 d	3.3 d	9 e	10.3 c	7.5 e	68 e
4	12.8 e	9.6 d	103 d	6.9 c	7.4 c	47 d	11.3 b	9.4 d	93 d
6	14.5 d	11.3 c	138 c	11.5 b	9.9 b	101 c	11.8 a	10.9 c	115 c
8	16.3 c	12.5 b	175 b	12.6 b	11.1 ab	118 c	11.8 a	12.1 b	131 b
10	18.3 b	13.2 b	196 b	15.8 a	12.0 ab	156 b	12.0 a	12.4 b	137 ab
12	20.3 a	15.1 a	236 a	17.6 a	13.3 a	199 a	12.0 a	13.8 a	150 a

Table 3. Effect of run time on distribution of drip water applied through a single drip tube, Bradenton, FL, January, 2001. Means followed by the same letter in the same column are not significantly different according to Tukey's Studentized Range Test (P = 0.10).

	On Emitters			Between Emitters			Along Drip Tube		
Run Time (hrs)	Width (cm)	Depth (cm)	Area (cm^2)	Width (cm)	Depth (cm)	Area (cm^2)	Width (cm)	Depth (cm)	Area (cm^2)
2	10.9 c	7.9 c	73 c	1.8 b	2.6 b	6 a	10.1 b	7.8 c	66 c
4	13.7 b	9.9 b	113 b	7.8 a	6.6 a	41 a	10.9 a	9.7 b	94 b
6	15.3 a	11.6 a	149 a	9.5 a	8.5 a	62 a	11.4 a	11.1 a	112 a

Table 4. Effect of run time on distribution across beds of drip water applied through two drip tubes, Bradenton, FL, October, 2000.

Run Time (hrs)	Width (cm)	Depth (cm)	Area (cm^2)
0.5	10.8	4.8	37
1	13.5	6.7	64
2	17.2	8.3	107
3	23.0	9.7	157
4	23.3	10.7	189

Table 5. Effect of run time on distribution of drip water applied through two drip tubes, Bradenton, FL, April, 2001. Means followed by the same letter in the same column are not significantly different according to Tukey's Studentized Range Test ($P = 0.10$).

Run Time (hrs)	Width (in)	Depth (in)	Area (in^2)
4	24.9 a	17.6 b	250 c
6	26.0 a	19.0 ab	298 c
7	30.0 a	20.3 a	487 b
8	29.5 a	20.4 a	472 b
10	29.7 a	20.7 a	573 a

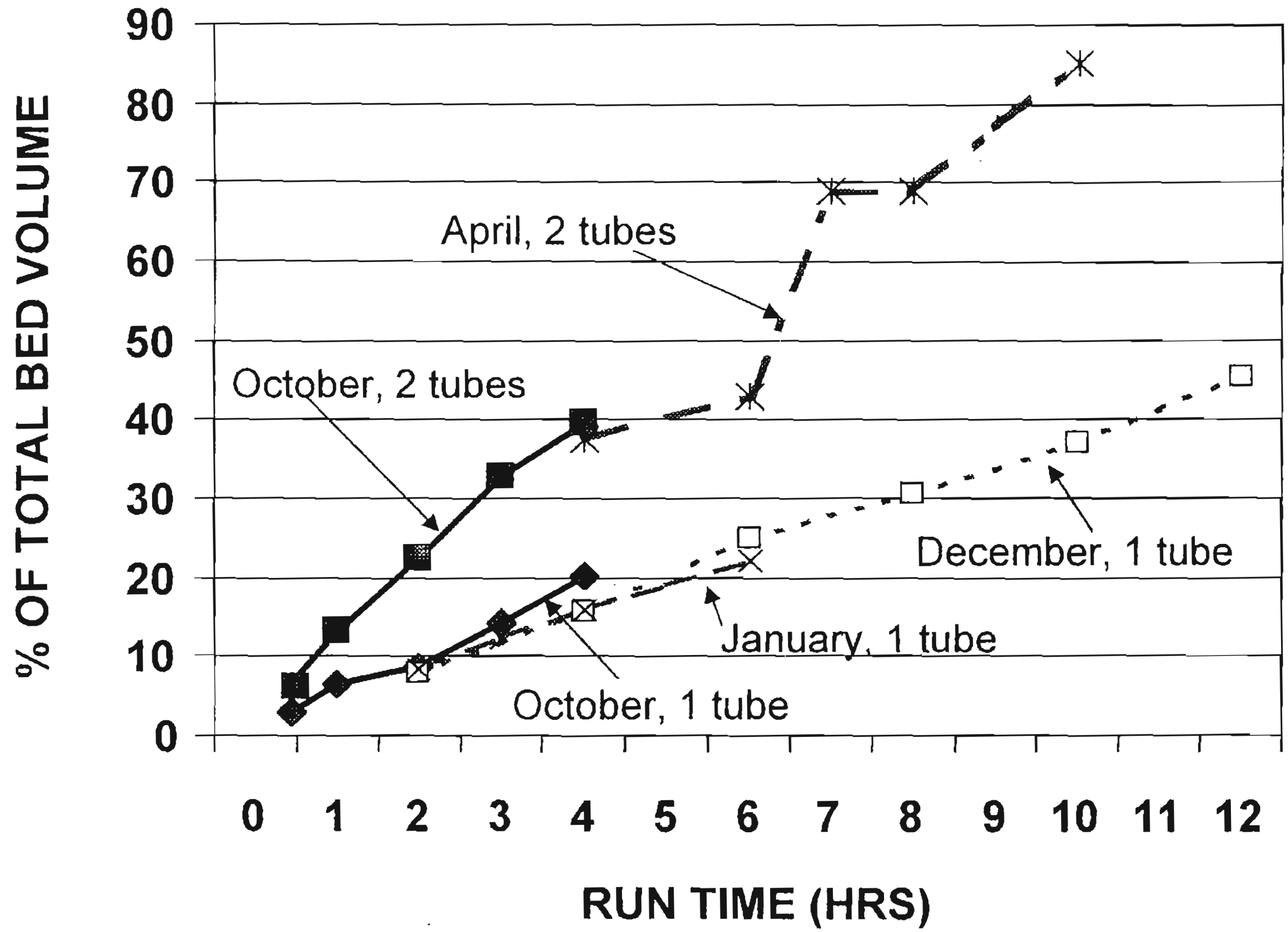

Figure 1. Percent of total bed volume wetted by drip irrigation water applied through one or two drip tubes in five trials at Bradenton, FL. Depth of bed was assumed to be 16 inches in all trials except the April trial where depth to spodosol was measured in all plots and used as the bed depth.

Results From Field Scale Demonstrations/Validation Studies of Telone® Products on the Florida East Coast

Dan O. Chellemi, John Mirusso, Jerry Nance and Ken Shuler

Summary

Field scale demonstration/validation studies of Telone (1,3-dichloropropene) products for use as alternatives to fumigation with methyl bromide were conducted in nine trials along the southeast coast of Florida during the spring and fall production seasons of 2000 (Table 1). Various rates and formulations of Telone were tested along with herbicides and chloropicrin in commercial tomato or pepper production fields. Field trials ranged in size from 2 to 13.6 acres. Telone was broadcast applied using a deep placement coulter system (Yetter 30" Avenger, Yetter Manufacturing Co.). In two trials a second (double) crop of cucumber was planted directly into the beds after completion of the first crop. Disease incidence and weed populations were highest during the fall season. In fields with a history of Fusarium wilt and Fusarium crown rot and high populations of nightshade species, the chemical alternatives did not provide the same level of pest control as methyl bromide. Levels of pest control similar to methyl bromide were achieved on fall plantings of pepper when Telone was combined with herbicides and an application of chloropicrin at bedding. Levels of pest control similar to methyl bromide were observed for chemical alternatives during the spring season. The results indicate that broadcast applications of Telone products using a deep coulter placement system can provide levels of pest control similar to methyl bromide when used with an effective herbicide program. For the fall production it is recommended that an additional application of chloropicrin be made during bedding. Some factors found to impact pest control included selection, calibration, and timing of herbicide applications, proper soil moisture, and tillage operations. In fields with a history of severe pest pressure, additional pest control tactics or strategies may have to be employed to achieve levels of pest control similar to fumigation with methyl bromide.

Introductions

In January, 2001 production of methyl bromide in the United States was reduced to 50% of the 1998 levels and the price has escalated. With the next reduction set to take place in January 1, 2003, growers must begin evaluating alternatives under their own production scenario's. Large scale field evaluations are necessary because they identify technical problems not evident in small scale research plots, indicate the potential for new or re-emerging soilborne pests under the range of environmental and cultural practices experienced by growers, generate information on costs incurred at the farm level, and provide growers with the experience to evaluate alternatives (Chellemi et al., 1997).

Applications of 1,3-dichloropropene plus chloropicrin (Telone C17 and Telone C35), when combined with the herbicide pebulate (Tillam), have resulted in tomato yields similar to those achieved with methyl bromide (Gilreath et al., 1997; Locascio et al., 1997). However, Telone label requirements require the use of personal protective equipment (PPE) by workers present in the field during application. Thus, Telone can not be applied via shank injection during bedding, which is the recommended procedure for methyl bromide application in Florida vegetable production. Recent research has focused on the broadcast application of Telone at least five days in advance of bedding using straight shank, forward swept, or para-chisels arranged in staggered rows (Noling and Gilreath, 2000). Deep disking prior to fumigation is recommended to achieve deep placement and uniform diffusion of the fumigant through soil (Noling and Gilreath, 2000). Using this approach, average yield loss in two large scale field trials were 21.8% when compared to adjacent methyl bromide treated plots (Noling and Gilreath, 2000).

Recently, a 30 inch deep placement coulter system (Avenger, Yetter Manufacturing Co., Colchester, IL) was modified to permit injection of Telone into undisturbed soil (John Mirusso, Mirusso Fumigation and Equipment, Delray Beach, FL). The equipment uses technology developed in conservation tillage programs to place the fumigant at 12 inch depths and seal the soil above without creating channels or chisel traces for the fumigant to escape. The intact crust layer at the soil surface serves as an additional barrier to hold the fumigant in. Eliminating deep disking prior to fumigation cuts costs, saves time, and expands the application window.

The objective of this study is to evaluate the performance of chemical-based alternatives to methyl bromide using the deep placement coulter system to apply Telone products. All trials were conducted in conjunction with commercial tomato and pepper growers on the southeast coast of Florida.

Field Trials

Trial 1. The site had a history of production problems due to intense weed pressure from nightshade species and epidemics of Fusarium wilt and Fusarium crown rot. Chemicals were applied in September. Telone was applied after the ground was laser leveled. Herbicides and chloropicrin were applied at bedding. Soil moisture conditions during chemical applications were extremely high.

The combined incidence of disease (Fusarium wilt and Fusarium crown rot) was high and ranged from 44% in an alternative treatment to 17% in the methyl bromide treatment (Table 2). The incidence of Fusarium wilt was similar in all treatments including the methyl bromide application. Application of chloropicrin, either in a formulation with Telone or separately at bedding reduced the incidence of Fusarium crown rot. However, none of the chemical alternatives were as effective as methyl bromide. Weed pressure from nightshade species was severe. Only methyl bromide provided acceptable control of nightshade. Some phytotoxicity in the form of plant stunting was observed in treatments were Tillam was included.

Trial 2. Chemicals were applied in September in a location near site 1 with a similar history of soilborne pests. Telone was applied after the ground was laser leveled. Herbicides and chloropicrin were applied at bedding. Again the soil moisture conditions were extremely high during chemical applications.

The combined incidence of disease (Fusarium wilt and Fusarium crown rot) ranged from 56% in a Telone II treatment to 18% in the methyl bromide treatment (Table 3). As in Trial 1, the incidence of Fusarium wilt was similar in all treatments including the methyl bromide application. Control of Fusarium crown rot at levels similar to methyl bromide was achieved in only one of the treatments with Telone C17 and chloropicrin. Plant injury from Tillam was observed and the incidence of disease was highest in those treatments. Weed pressure from nightshade species was severe. Only methyl bromide provided acceptable control of nightshade.

Trial 3. The trial was conducted in a field with a history of Fusarium diseases and nightshade species. Chemicals applications were made in November and the crop was planted in late December. Pest levels remained low throughout the cooler winter months and all treatments performed similar to methyl bromide (Table 4).

Trial 4. The trial was conducted on pepper in a field with a history of Phytophthora blight and nightshade species. Chemical were applied in November and the crop was planted in late December. Disease and weed populations remained low throughout the trial and all treatments performed similar to methyl bromide (Table 4).

Trial 5. This trial was conducted on pepper at a site where disease pressure was less intense. Chemical applications were made in September. No differences in pest incidence was observed between the methyl bromide treatment and the chemical alternative (Table 4).

Trial 6. This trial on pepper was conducted during the fall in a field with a known history of Phytophthora blight. Chemical applications were made in July. Ten inches of rainfall were recorded between the Telone application and bedding operations. After the final pepper harvest, the crop was mowed and cucumber planted into the beds. All treatments including methyl bromide provided equal levels of pest control in both the first and second crop (Table 5).

Trial 7. This trial on pepper was conducted during the fall in a field with a known history of Phytophthora blight. Chemical applications were made in August. After the final pepper harvest, the crop was mowed and cucumber planted into the beds. The incidence of damping off due to the fungi *Pythium aphanidermatum* and *Pythium myriotylum* was reduced from 17% to less than 1% when an additional application of chloropicrin was made prior to bedding (Table 6). The incidence of Phytophthora blight remained low in the pepper and cucumber crops. No root galling was observed in the pepper crop. Equivalent levels of moderate root galling were observed in all fumigant treatments at the end of the cucumber crop. Marketable yield of pepper in the Telone treated areas was 10% below the yield in the methyl bromide treated area. Marketable yield of cucumber was 24% higher in the Telone treated area than in the methyl bromide treated area. Yield data for cucumber was obtained from grower pack-out data and the difference between the two Telone treatments was not determined.

Trial 8. Chemical applications were made in February for a spring crop of tomato. Telone was applied after laser leveling. Herbicides were applied at bedding. Disease incidence and weed populations were low in both the Telone and methyl bromide treatments. Some stunting of the plants was observed in Telone treatment, presumably due to uneven incorporation of the herbicide Tillam.

Trial 9. This trial was conducted on pepper at a site where disease pressure was less intense. Chemical applications were made in February for a spring crop. No differences in disease or weed control were observed except when the soil was disked 24 hours after application of Telone. Disking increased Phytophthora blight from 1% to 17% (Table 7). Weed control was also made less effective from the disking operation.

Discussion

Tillam applications were made immediately prior to bedding in trials 1,2 and 8 and some herbicide injury was observed. In trial 3, Tillam was applied prior to fumigation. Adequate incorporation of Tillam is critical in achieving control without injuring the plants (Noling and Gilreath, 2000). Double disk incorporation is the preferred method and this was not done in trials 1,2, and 8. The high moisture levels in the fields during application of materials in trials 1 and 2 may also contributed to the poor incorporation of herbicides. There was an association between poor incorporation of Tillam and increased levels of disease in trial 2.

Improved control of damping off was observed when an additional application of chloropicrin during bedding was included. This additional procedure is recommended for fall season when conditions are most favorable for damping off and Pythium root rot. When soil was disked 24 hours after Telone application (Trial 9), pest control was seriously impacted highlighting the importance of obtaining a good seal for the fumigant. Growers should strive for conditions that optimize retention of the fumigant in the soil after application. This includes use of the deep placement coulter system for injecting the fumigant followed by sealing of the soil with a roller or other implement.

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Table 1. Demonstration/validation trials conducted in 2000/2001.

Site	County	Crop	Acres Treated	Application Date	Double Crop
1	Palm Beach	tomato	10.2	September	No
2	Palm Beach	tomato	13.6	September	No
3	Palm Beach	tomato	8.0	November	No
4	Palm Beach	pepper	11.8	November	No
5	Palm Beach	pepper	12.0	September	No
6	Palm Beach	pepper	4.0	July	Yes
7	Palm Beach	pepper	2.8	August	Yes
8	St. Lucie	tomato	2.0	February	No
9	St. Lucie	pepper	10.0	February	No
		total	74.4		

Table 2. Final rating of pest incidence at Site 1 (fall planting)

Treatment	Chemical (rate)	Disease incidence: Fusarium crown rot	Disease incidence: Fusarium wilt	Weed density in the bed
1	Telone II (15 gal) Tillam (2 lbs) Devrinol (2 lbs) Treflan (0.3 lbs)	35%	9%	1 every 2 ft
2	Telone II (15 gal) chloropicrin (100 lbs) Tillam (2 lbs) Devrinol (2 lbs) Treflan (0.3 lbs)	23%	11%	1 every 1.0 ft
3	Telone C17 (18 gal) Tillam (2 lbs) Devrinol (2 lbs) Treflan (0.3 lbs	18%	11%	1 every 1.6 ft
4	Telone C17 (18 gal) chloropicrin (100 lbs) Tillam (2 lbs) Devrinol (2 lbs) Treflan (0.3 lbs)	18%	9%	1 every 1.4 ft
5	methyl bromide/ chloropicrin 67:33 (400 lbs)	7%	10%	<1 per 50 ft

Chemical rates are broadcast rates per acre. Herbicide rates expressed as active ingredient (a.i.). Herbicides were applied immediately before bedding and incorporated with a field cultivator. Chloropicrin was shank injected into the bed. Tomato cultivar was Sanibel. Disease ratings taken 128 days after transplanting. Weed ratings taken at 114 days after transplanting. Weed populations were dominated by nightshade.

Table 3. Final rating of pest incidence at Site 2 (fall planting)

Treatment	Chemical	Disease incidence: Fusarium crown rot	Disease incidence: Fusarium wilt	Weed density in the bed
1	Telone C17, chloropicrin, Tillam, Treflan	38%	18%	1 every 8 in
2	Telone II, Tillam, Treflan	36%	11%	1 every 1.3 ft
3	Telone C17, Tillam, Treflan	22%	12%	1 every 1.2 ft
4	Telone C17, Devrinol, Treflan	20%	10%	1 every 5.5 ft
5	Telone II, chloropicrin, Tillam, Treflan	16%	13%	1 every 8 in
6	Telone II, Devrinol, Treflan	14%	11%	1 every 2.6 ft
7	Telone II, chloropicrin, Devrinol, Treflan	14%	8%	1 every 7 ft
8	Telone C17, chloropicrin, Devrinol, Treflan	8%	8%	1 every 7 ft
9	methyl bromide/ chloropicrin 67:33	4%	14%	<1 per 50 ft

Chemical rates are the same as used for Site 1. Herbicides were applied immediately before bedding and were incorporated with a field cultivator. Chloropicrin was shank injected into the bed. Tomato cultivar was Florida 47. Disease ratings and weed ratings taken 115 days after transplanting. Weed populations were principally nightshade species.

Table 4. Final rating of pest incidence at Sites 3,4, and 5

Treatment	Chemical (Rate)	Combined incidence of soil borne diseases	Weed density in the bed
		Site 3 (tomato, spring planting)	
1	Telone C17 (20 gal), Tillam (3 lbs), Treflan (0.5 lbs), Devrinol (2 lbs)	1%	<1 per 50 ft
2	Telone C17 (20 gal) Tillam (3 lbs) Treflan (0.5 lbs)	1%	1 per 23 ft
3	Telone C17 (20 gal) Treflan (0.5 lbs) Devrinol (2 lbs)	2%	1 per 36 ft
4	methyl bromide/ chloropicrin 67:33 (400 lbs)	3%	1 per 50 ft
		Site 4 (pepper, spring planting)	
1	Telone C17 (20 gal) Devrinol (2 lbs) Treflan (0.5 lbs)	<1%	<1 per 50 ft
2	methyl bromide/ chloropicrin 67:33 (400 lbs/A)	0	<1 per 50 ft
		Site 5 (pepper, fall planting)	
1	Telone C35 (20 gal) chloropicrin (100 lbs) Devrinol (2 lbs) Treflan (0.5 lbs)	<1%	<1 per 50 ft
2	methyl bromide/ chloropicrin (67:33) (400 lbs)	<1%	<1 per 50 ft

Chemical rates are broadcast rates per acre. Herbicide rates expressed as active ingredient (a.i.). Herbicides were applied prior to the Telone application and incorporated into the soil with a field cultivator. Tomato cultivar was Florida 47. Pepper cultivar was Yorktown. Disease ratings and weed ratings taken 110 days after transplanting.

Table 5. Final rating of pest incidence at Site 6

Treatment	Chemical (Rate)	Combined incidence of soil borne diseases	Weed density in the bed
	1st crop (pepper, fall planting)		
1	Telone C35 (20 gal), Chloropicrin (100 lbs) Treflan (0.62 lbs), Devrinol (2 lbs)	<1%	<1 per 50 ft
2	Telone C35 (26 gal) Chloropicrin (100 lbs) Treflan (0.62 lbs) Devrinol (2 lbs)	<1%	<1 per 50 ft
3	methyl bromide/ chloropicrin 67:33 400 lbs	<1%	<1 per 50 ft
	2nd crop (cucumber, spring planting)		
1	same as above	<1%	<1 per 50 ft
2	same as above	<1%	<1 per 50 ft
3	same as above	<1%	<1 per 50 ft

Chemical rates are broadcast rates per acre. Herbicide rates expressed as active ingredient (a.i.). Herbicides applied after Telone applications and several days before beds were formed and the plastic mulch applied. Pepper cultivar was Brigader. Cucumber cultivar was Dasher. Disease ratings and weed ratings taken 105 days after transplanting for pepper and 38 days after seeding for cucumber.

Table 6. Final rating of pest incidence at Site 7

Treatment	Chemical (Rate)	Pythium (damping off)	Phytophthora crown rot	root gall rating	Weed density in the bed	Marketable yield (boxes/acre)
		1st crop (pepper, fall planting)				
1	Telone C35 (26 gal), Treflan (0.5 lbs), Devrinol (2 lbs)	15%	4%	0%	1 per 3 ft	1544
2	Telone C35 (26 gal) Chloropicrin (200 lbs) Treflan (0.5 lbs) Devrinol (2 lbs)	6%	4%	0%	1 per 33 ft	1568
3	methyl bromide/ chloropicrin 67:33 400 lbs	4%	2%	0%	1 per 40 ft	1745
		2nd crop (cucumber, spring planting)				
1		0%	0%	18%	1 per 33 ft	430
2		0%	0%	12%	<1 per 50 ft	430
3		0%	0%	16%	<1 per 50 ft	326

Chemical rates are broadcast rates per acre. Herbicide rates expressed as active ingredient (a.i.). Herbicides applied after Telone applications and several days before beds were formed and the plastic mulch applied. Pepper cultivar was Brigader. Cucumber cultivar was Dasher. Ratings for Pythium made 20 days after transplant for pepper and 37 days after transplanting for cucumber. Weed ratings taken 105 days after transplanting for pepper and 37 days after seeding for cucumber. Yield data for pepper was obtained from small plots. Yield data for cucumber was obtained from grower pack-out data and was combined for both Telone treatments.

Table 7. Final rating of pest incidence at Sites 8, and 9

Treatment	Chemical (Rate)	Combined incidence of soil borne diseases	Weed density in the bed
		Site 8 (tomato, spring planting)	
1	Telone C35 (26 gal), Treflan (0.5 lbs), Tillam (3 lbs) Devrinol (2 lbs)	<1%	<1 per 50 ft
2	methyl bromide/ chloropicrin 67:33 (400 lbs)	<1%	1 per 50 ft
		Site 9 (pepper, spring planting)	
1	Telone C35 (26 gal) Devrinol (2 lbs) Treflan (0.5 lbs)	<1%	<1 per 50 ft
2	Telone C35 (26 gal) Devrinol (2 lbs) Treflan (0.5 lbs) *field was disked 24 hrs after Telone application	<17%	<1 per 3 ft
3	methyl bromide/ chloropicrin (67:33) (400 lbs)	<1%	<1 per 50 ft

Chemical rates are broadcast rates per acre. Herbicide rates expressed as active ingredient (a.i.). Herbicides applied after Telone application and before beds were formed and the plastic mulch applied. Tomato cultivar was Florida 47. Pepper cultivar was Alladin. Disease ratings and weed ratings taken at 115 and 84 days after transplanting for tomato and pepper, respectively.

Water Management For Tomato

Eric Simonne

Approximately 43,400 acres of tomatoes were harvested in Florida during the 1999-2000 growing season. The value of the fresh-market tomato crop that year was estimated at slightly above $418 million (Florida Agricultural Statistics, Vegetable Summary). The main areas of production are Gadsden county (Quincy), Manatee County (Palmetto-Ruskin), Hendry county (southeast cost), Palm Beach county (southwest coast), and Dade county (Homestead). Production systems include bare ground with overhead irrigation, polyethylene mulch and seepage irrigation, and polyethylene mulch and drip irrigation (plasticulture). The popularity of staked tomatoes grown with plasticulture has increased in recent years. Although it is not recommended, some tomatoes are still grown with polyethylene mulch and overhead irrigation.

Water and nutrient management are two important aspects of tomato production in all these 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 in Florida. Recommendations in this article should be considered together with those presented in the 'Fertilizer and nutrient management for tomato', also included in this publication.

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, with corresponding levels of water managements (Table 1). The recommended method to schedule irrigation for tomato is to use together a measurement of soil water status and the tomato crop water requirement method that takes into account plant stage of growth (water management level 5 in Table 1).

Soil water status and soil water tension 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, 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.

Several tools are available to measure SWT in the field: tensiometers, granular matrix sensor (GMS), and time domain reflectometry (TDR). 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, thereby affecting the level 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.

SWT can also be measured with GMS. They are made of two concentric metal conductors that are embedded in a sand-like matrix (hence the term granular). The electrical conductivity between the two metal parts depends on the moisture content of the granular matrix. A slow dissolving calcium sulfate pellet is included in the unit, so that changes in soluble salts in the soil solution do not affect the reading. As the GMS is buried into the soil, moisture content inside th GMS becomes in equilibrium with that of the soil. GMS cost approximately $35 each, and require a $260 reader. GMS can be used for approximately 5 to 8 years. While some theroretically valid concerns have been made regarding the accuracy of the GMS readings, they have proven to be useful field devices to schedule irrigation. An on-farm testing project of GMS is currently underway in North Florida with several vegetable crops. Therefore, GMS should be used for tomato production on a trial basis only.

Times domain reflectometry (TDR) is not a new method for measuring soil moisture. However, the recent availability of inexpensive equipment ($1,200 to $1,500/unit) has increased the potential of this method to become practical. TDR actually determines percent soil moisture. A soil water release curve has to be used to convert soil moisture in to SWT. The advantage of TDR is that probes need not be buried permanently, and readings are available within seconds. This means that, unlike the tensiometer and the GMS, TDR can be used as a hand-tool. As the potential use of TDR as an on-farm tool for scheduling irrigation for vegetables is currently under evaluation, it should be used on an experimental basis only.

With any of these three methods, it is necessary to monitor SWT at two soil depths. A shallow 6-in depth is useful at the beginning of the season when tomato roots are near that depth. A deeper 12-in 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 irrigation applied. When the 6-in SWT increases (from 4-8 cb to 10-15cb) while SWT at 12-in remains within 4-8, the upper part of the soil is drying, and it is time to irrigate. If the 6-in 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-in depth remaining with the 4-8 range, but the 12-in 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-in 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

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 2) 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 3). 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 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 irrigation requirement (IR)

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 60-80% for overhead irrigation, 20-70% for seepage irrigation, and 90-95% for drip irrigation. Applied water that is not available to the plant may have been lost from the crop root zone through evaporation or wind drifts of spray droplets, leaks in the pipe system, surface runoff, subsurface runoff, or deep percolation within the irrigated area. Tomato IR are determined by dividing the desired amount of water to provide to the plant (ETc), by Ea as a decimal fraction (Eq. [2]).

Eq. [2] Irrigation requirement = Crop water requirement / Application efficiency
IR = ETc/Ea

Units for measuring irrigation water

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

Acre-inches are still used for drip irrigation, despite that 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 exact amount of water to apply. In addition, drip tape flow rates are reported in gallons/hour/emitter or in gallons/hour/100ft 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 0.30gallons/hour/emitter and emitters are spaced 1 foot apart.

1. In the 2-acre field, there are 14,520 feet of bed (2 x 45,560/6). 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 ½ hours to apply 75 gallons. The total volume applied will be 8,168 gallons/2-acre (75 x 108.9).

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Table 1. Levels of water management and corresponding irrigation scheduling method for tomato

Water Mgt. Level	Irrigation scheduling method
0	Guessing (irrigate whenever)
1	Using the 'feel and see' method
2	Using systematic irrigation (example: 3/4 in. every 4th day)
3	Using a soil water tension measuring tool to start irrigation
4	Using a soil water tension measuring tool to schedule irrigation and apply amounts based on a budgeting procedure
5[z]	Adjusting irrigation to plant water use, and using a dynamic water balance based on a budgeting procedure and plant stage of growth, together with using a soil water tension measuring tool

[z] recommended method

Table 2. Crop coefficient estimates (Kc) for tomato[z].

Tomato Growth Stage	Bare Ground, Overhead Irrigated	Plasticulture
1	0.20 to 0.40	0.30
2	0.20 to 0.40	0.40
3	1.15	0.90
4	1.15	0.90
5	1.00	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)

Table 3. Historical Penman-method reference ET (ETo) for four Florida locations (in gallons per acre per day)

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, i.e., sprinkler or seepage irrigation with 100% efficiency

Tomato Varieties For Florida

Donald N. Maynard and Stephen M. Olson

Variety selection, often made several months before planting, is 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 and race 2; 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.
- **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.

'Florida 47' was grown on about 40% of the acreage in Florida in the 2000-2001 season - an increase from the approximately 36% of the acreage the previous season. 'Florida 47' was grown on about 48% of the acreage in southwest Florida, 40% in west central Florida, 32% of the east coast acreage and was the predominate spring variety in north Florida.

'Sanibel' had about 12% of the state's acreage. It was the predominant variety in Miami-Dade County with almost 60% of the acreage.

All BHN varieties are lumped together and comprise about 10% of the state's acreage, mostly in north Florida and southwest Florida.

'Florida 91' acreage increased to about 10% from 7% the previous year. West central Florida was the principal production site.

Other varieties with some acreage in the 2000-2001 season were the long-time popular 'Agriset 761' (5%), 'Solimar' (5%), 'Solar Set (3%) and 'Sunpride' (2%). Many other varieties and advanced experimental hybrids were grown on less than 1% of the state's acreage.

Tomato Variety Trial Results

Summary results listing the five highest yielding and the five largest fruited varieties from trials conducted at the University of Florida's Gulf Coast Research and Education Center, Bradenton; Indian River Research and Education Center, Fort Pierce and North Florida Research and Education Center, Quincy for the Spring 2000 season are shown in Table 1. High total yields and large fruit size were produced by PS 150535 at Bradenton; Agriset 761, Solimar, Sunbeam, and Florida 47 at Fort Pierce; Sanibel at Homestead; and BHN 444 and PS 150535 at Quincy. Florida 7885, Agriset 761, and Solimar produced high yields at three of the four locations. Large fruit size was produced by Florida 47 at all locations and by Agriset 761 at three of the four locations. The same entries were not included at all locations.

Summary of results listing the five highest yielding and five largest fruited entries from trials at the University of Florida's Indian River Research and Education Center, Ft. Pierce; and the North Florida Research and Education Center, Quincy for the fall 2000 season are shown in Table 2. High total yields and large fruit size were produced by Florida 91, Florida 47, and Fla. 7945 at Fort Pierce and by Florida 91 at Quincy. Florida 91 and Fla. 7945 produced high yields at both locations and Florida 91 produced large fruit at both locations. Not all entries were included at both locations.

Tomato Varieties For Commercial Production

The varieties listed have performed well in University of Florida trials conducted in various locations in recent years.

Large Fruited Varieties

Agriset 761. Midseason, determinate, jointed hybrid. Fruit are deep globe and green shouldered. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), Alternaria stem canker, gray leaf spot. (Agrisales).

BHN-444. Early-midseason maturity. Fruit are globe shape but tend to slightly elongate, and green shouldered. Not for fall planting. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), gray leaf spot, and Tomato Spotted Wilt Virus. **For Trial.** (BHN).

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

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 and 2), Alternaria stem canker, and gray leaf spot. (Seminis/Asgrow).

Floralina. A midseason, determinate, jointed hybrid. Uniform, green shoulder, flattened, globe- shaped fruit. Recommended for production on land infested with Fusarium wilt, Race 3. Resistant: Fusarium wilt (race 1, 2, and 3), Verticillium wilt (race 1), gray leaf spot. (Seminis/Petoseed).

PS 150535. Midseason, determinate, jointed hybrid. Fruit are oblate and uniform-green shouldered. Recommended for situations where tomato yellow leaf curl virus is expected to be a problem. Resistant: TYLCV, Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), Alternaria stem canker, gray leaf spot. (Seminis/Petoseed).

Solar Set. An early, green-shouldered, jointed hybrid. Determinate. Fruit set under high temperatures (92°F day/72°night) is superior to most other commercial varieties. Resistant: Fusarium wilt (race 1 and 2), Verticillium wilt (race 1), Alternaria stem canker, and gray leaf spot. (Seminis /Asgrow).

Sanibel. A late-midseason, jointless, determinate hybrid. Deep oblate shape fruit with a green shoulder. Tolerant/resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), Alternaria stem canker, root-knot nematode, and gray leaf spot. (Seminis/Petoseed).

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/Asgrow).

Sunbeam. Early midseason, deep-globe shaped uniform green fruit are produced on determinate vines. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and race 2), gray leaf spot, Alternaria stem canker. (Seminis/Asgrow).

Plum Type Varieties

Marina. Medium to large vined determinate hybrid. Rectangular, blocky, fruit may be harvested mature green or red. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), Alternaria stem canker, root-knot nematodes, gray leaf spot, and bacterial speck. (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).

Spectrum 882. Blocky, uniform-green shoulder fruit are produced on medium-large determinate plants. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), root-knot nematode, bacterial speck (race 0), Alternaria stem canker, and gray leaf spot. (Seminis/Petoseed).

Supra. Determinate hybrid rectangular, blocky, shaped fruit with uniform green shoulder. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1 and 2), root-knot nematodes, and bacterial speck. (Syngenta).

Veronica. Tall determinate hybrid. Smooth plum type fruit are uniform ripening. Good performance in all production seasons. Resistant: Verticillium wilt. (Sakata).

Cherry Type Varieties

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). For trial. (Syngenta).

Cherry Grande. Large, globe-shaped, cherry-type fruit are produced on medium-size determinate plants. Resistant: Verticillium wilt (race 1), Fusarium wilt (race 1), Alternaria stem blight, and gray leaf spot. (Seminis/Petoseed).

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Reference

Maynard, D. N. and S. M. Olson (eds.). 2001. Vegetable variety trial results in Florida for 2000. Fla. Agr. Expt. Sta. Circ. S-396.

Tomato variety evaluations were conducted in 2000 by the following University of Florida faculty:

H. H. Bryan, Tropical Research & Education Center, Homestead

D. N. Maynard., Gulf Coast Research & Education Center, Bradenton.

S. M. Olson., North Florida Research & Education Center, Quincy

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Table 1. Summary of University of Florida tomato variety trial results. Spring 2000.

Location	Variety	Total Yield (ctn/acre)	Variety	Average Fruit Weight (oz)
Bradenton	Fla. 7885	3247	Agriset 761	7.8
	HA-3017	3185	PS 150535	7.8
	Agriset 761	3072	Florida 91	7.8
	PS 150535	2941	Florida 47	7.4
	Solimar	2883[1]	Sanibel	7.4[2]
Fort Pierce	Agriset 761	1859	Florida 47	6.6
	Solimar	1703	Agriset 761	6.5
	Sunbeam	1645	Sunbeam	6.3
	Florida 47	1542	Solimar	6.1
	Fla. 7885	1513[3]	Sanibel	6.1[4]
Homestead	Sanibel	2159	Sanibel	6.1
	Agriset 761	2306	Fla. 7816	5.8
	Fla. 7885	2270	Florida 47	5.6
	Solimar	2225	Equinox	5.6
	Sunbeam	2169[5]	Solar Set	5.5[6]
Quincy	BHN 466	2356	BHN 444	8.5
	BHN 444	2262	Sunbeam	8.4
	PS 150535	2180	PS 150535	8.3
	Solar Set	2104	Agriset 761	8.3
	BHN 446	2100[7]	Florida 47	8.1

[1] 12 other entries had yields similar to Solimar.
[2] 10 other entries had fruit weight similar to Sanibel.
[3] 3 other entries had yields similar to Fla. 7885.
[4] 3 other entries had fruit weight similar to Sanibel.
[5] 5 other entries had yields similar to Sunbeam.
[6] 6 other entries had fruit weight similar to Solar Set.
[7] 8 other entries had yields similar to BHN 446.
[8] 13 other entries had fruit weight similar to Florida 47.

Seed Sources:

Agrisales: Agriset 761, Equinox.
Asgrow: Florida 47, Florida 91, Solar Set, Solimar, Sunbeam.
BHN: BHN 444, BHN 446, BHN 466.
Petoseed: PS 150535, Sanibel.
University of Florida: Fla. 7816, Fla. 7885.

Table 2. Summary of University of Florida tomato variety trial results. Fall 2000.

Location	Variety	Total Yield (ctn/acre)	Variety	Average Fruit Weight (oz)
Fort Pierce	Florida 91	1933	Florida 91	6.6
	Florida 47	1931	Florida 47	6.2
	Agriset 761	1862	Sunbeam	6.1
	Fla. 7945	1799	Sanibel	6.0
	Solar Set	1740[1]	Fla. 7945	5.9[2]
Quincy	Fla. 7945	1905	ASR 1440598	6.8
	BHN 555	1873	Florida 91	6.7
	BHN 537	1843	Solar Set	6.4
	Florida 91	1790	Fla. 7816	6.3
	BHN 120	1710[3]	Rock Star	6.3
			Fair Lady	6.3
			ASR 1405037	6.3[4]

[1] 5 other entries had yields similar to Solar Set.

[2] 5 other entries had fruit weight similar to Fla. 7945.

[3] 13 other entries had yields similar to BHN 120.

[4] 14 other entries had fruit weight similar to ASR 1405037.

Seed Sources:

Agrisales: Agriset 761.
Asgrow: ASR 1405037, ASR 1440598, Florida 47, Florida 91, Solar Set, Sunbeam.
BHN: BHN 120, BHN 537, BHN 555.
Petoseed: Rock Star, Sanibel.
United Genetics: Fair Lady
University of Florida: Fla. 7816, Fla. 7945.

Fertilizer And Nutrient Management For Tomato

E.H. Simonne and G.J. Hochmuth

Fertilizer and nutrient management are an essential component 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 guessing out of fertilization

Prior to each cropping season, soil tests should be conducted to determine fertilizer needs and eventual pH adjustments. Obtain an IFAS soil sample kit from the local agricultural Extension agent for this purpose. Commercial soil testing laboratories also are available, however, be sure the commercial lab uses methodologies calibrated for, and extractants suitable to 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 the routine calibrated soil test 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-P_2O_5-K_2O) 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 produced on 6-ft centers. Under these conditions, there are 7,260 linear feet of tomato row in an acre. When different row spacings are used or when a significant number of drive rows are left unplanted, it is necessary to adjust fertilizer application accordingly.

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 1-acre tomato field planted on 7-ft centers with one drive row every six rows, there are only 5,333 lbf (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 tomatoes is between 6.0 and 6.5. This is the range for which the availability of the essential nutrients is highest. Fusarium wilt problems are reduced by liming within this range, but it is not advisable to raise the pH higher than 6.5 because of reduced micronutrient availability. In areas where soil pH is basic, micronutrient deficiencies may be corrected by foliar sprays.

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

Changes in soil pH may take several weeks to occur when carbonate-based liming materials are used (hi-cal 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 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/or oxide ('O') part of CaCO3 and 'CaO', respectively, that raise pH. Through several chemical reactions that occur in the soil, carbonates and/or oxides release OH- ions that combine with H+ to produce water. As large amounts of H+ react, the pH raises. 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 At certain times, growers have problems with blossom-end-rot, especially on the first one or two fruit clusters. Blossom-end rot (BER) is basically 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 in the plant occurs with the water stream. Thus, Ca moves preferentially to the leaves. As an enlarging 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. High fertilizer increases the salt content and osmotic potential in the soil reducing the ability of roots to obtain water.

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 formally 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 virgin, acidic sandy soils, or sandy soils where a proven need exists, a general guide for fertilization is the addition of micronutrients (in pounds per acre) 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. More information on micronutrient use is available from the suggested literature list.

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. For more information on foliar micronutrient fertilization of tomatoes, consult the Commercial Vegetable Fertilization Guide, Circular 225E.

Fertilizer Application

Full-Bed Mulch with Seep 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 "starter" fertilizer or "in-bed" mix. This should comprise only 10 to 20 percent of the total nitrogen and potassium seasonal requirements and all of the needed phosphorus and micronutrients. Starter fertilizer 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 a "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. Application of remaining fertilizer. The remaining 80 to 90 percent of the nitrogen and potassium is placed in narrow bands 9 to 10 inches to each side of the plant row in furrows. The 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.

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.

There is equipment that will do most of the operations in steps 4 and 5 above in one pass over the field. More information on fertilization of mulched crops is available.

Water management with the seep irrigation system is critical to successful crops. Use water-table monitoring devices and/or tensiometers in the root zone to help provide an adequate water table but no higher than required for optimum moisture. Do not fluctuate the water table since this can lead to increased leaching losses of plant nutrients (see the water management for tomato production article for more information).

Mulched Culture with Overhead Irrigation For the sandy soils, maximum production has been attained by broadcasting 100 percent of the fertilizer in a swath 3 to 4 feet wide and incorporating prior to bedding and mulching. Be sure fertilizer is placed deep enough to be in moist soil. Where soluble salt injury has been a problem, a combination of broadcast and banding should be used. Incorporate 30 percent to 40 percent of the nitrogen and potassium and 100 percent of the phosphorus and micronutrients into the bed by rototilling. The remaining nitrogen and potassium is applied in bands 6 to 8 inches to the sides of the transplant and 2 to 4 inches deep to place it in contact with moist soil. Perforation of the plastic is needed on coarse sands where lateral movement of water through the soil is negligible. Due to a low water and nutrient efficiency, this production method should be avoided and replaced with drip irrigation.

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, prior to mulching. Apply the remaining nitrogen and potassium through the drip system in increments as the crop develops.

Successful crops have resulted where the total amounts of N and K_2O 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 K_2O to ensure young transplants are established quickly. In most situations, some preplant N and K fertilizers are needed.

Suggested schedules for nutrient injections are presented in Table 2. These schedules have been successful in both research and commercial situations, but might need slight modifications based on potassium soil-test indices and grower experience.

Additional nutrients can be supplied through drip irrigation if deficiencies occur during the growing season.

Sources of N-P_2O_5-K_2O

About 30 to 50 percent of the total applied nitrogen 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 fertilizers incorporated in the bed. Nitrogen from natural organics and most controlled-release materials should be considered ammoniacal nitrogen when calculating the total amount of ammoniacal nitrogen applied.

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 tomatoes. 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 K_2O are applied, then there should be no concern for the K source or its associated salt index.

Sap test and tissue analyses

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.

Analysis of tomato leaves for mineral nutrient content can help guide a fertilizer management program during the growing season or assist in diagnosis of a suspected nutrient deficiency. Tissue nutrient norms are presented in Table 3. Growers with drip irrigation can obtain faster analyses for N or K by using a plant sap quick test. Several kits have been calibrated for Florida tomatoes. Interpretation of these kits is provided in Table 4. More information is available on plant analysis.

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.

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 requires management levels of 3 or above (Table 5).

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Table 1. Fertility recommendations for mulched tomatoes on irrigated soils testing very low in phosphorus and potassium.

		Nutrient requirements	Supplemental Applications[1]	
Soil	Number of expected harvests	lbs/A[2] $N-P_2O_5-K_2O$	lbs/A $N-P_2O_5-K_2O$	Number of Applications
Mineral	2-3	200-150-225	30-0-20	0-2

[1]Sidedressing to replenish nitrogen and potassium can be accomplished by the use of a liquid fertilizer injection wheel.
[2]Approximately 7200 linear bed feet of crop per acre (43,560 square feet).

Table 2. Schedules for N and K_2O injection for mulched tomato on soils testing low in K.

Crop development		Injection (lb/A/day)[z]	
stage	weeks	N	K_2O
1	2	1.5	1.5
2	2	2.0	2.0
3	7	2.5	3.0
4	1	2.0	2.0
5	1	1.5	1.5

[z] Total nutrients applied are 200 lb N and 225 lb K_2O per acre (7260 linear bed feet). These injection programs assume no N or K preplant. If 20% of N and K are applied preplant in the bed, then first two week's of injection can be reduced.

Table 3. Deficient, adequate, and excessive nutrient concentrations for tomatoes [most-recently-matured (MRM) leaf (blade plus petiole)].

				N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
				%						ppm					
Tomato	MRM[z] 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	10	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	0.2 0.6
			High	>3.0	0.4	2.5	2.0	0.5	0.6	100	100	40	40	10	0.6

[z]MRM=Most recently matured leaf.

Table 4. Suggested nitrate-N and K concentrations in fresh petiole sap for tomatoes.

	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 5. Progressive levels of nutrient management for tomato production

Nutrient Mgt. Level	Description
0	Guessing
1	Soil testing and still guessing
2	Soil testing and implementing 'a' recommendation
3	Soil testing, understanding IFAS recommendations, and correctly implementing them
4	Soil testing, understanding IFAS recommendations, correctly implementing them, and monitoring crop nutritional status
5	Soil testing, understanding IFAS recommendations, correctly implementing them, monitoring crop nutritional status, and practice year-round nutrient management and/or following BMPs

Chemical Disease Management for Tomatoes

Tom Kucharek
University of Florida, Plant Pathology Department

Chemical	Maximum Rate/Acre/		Minimum Days to Harvest	Pertinent Diseases	Select Remarks
	Application	Crop			
**For best possible chemical control of bacterial spot, a copper fungicide must be tank-mixed with a maneb or mancozeb fungicide.					
Ridomil Gold EC	2 pts/trtd acre	12 pts/trtd acre		Pythium diseases	See label for use at and after planting.
Kocide 101, Blue Shield or Champion WP's	4 lbs		1	Bacterial spot	
Kocide LF, Blue Shield 3L or Champion FL's	5⅓ pts		1	Bacterial spot	
Champ 4.6 FL	2⅔ pts		1	Bacterial spot	
Basicop or Basic Copper 53	4 lbs		1	Bacterial spot	
KOP 300 FL	½ gal		12 hr	Bacterial spot	
Basic Copper Sulfate 98 WP	4 lbs			Bacterial spot	Reenter when spray is dried
Oxycop WP	6 lbs		1	Bacterial spot	
Microsperse C.O.C. 53WP	4 lbs		2	Bacterial spot	
Champ 4.6 FL	2 2/3 pts		1	Bacterial spot	
ManKocide 61.1 DF	5.3 lbs	112 lbs	5	Bacterial spot Bacterial speck Late & early blights Grey leaf spot	
Manex 4F	2.4 qts	16.8 qts	5	Early and late blight, Gray leaf spot, Bacterial spot[1]	Field and Greenhouse use
Kocide 2000 53.8 DF	3 lbs		1	Bacterial spot	
Maneb 80 WP	3 lbs	21 lbs	5	Same as Manex FL	Field and Greenhouse use
Manex II or Dithane F45 FL's	2.4 pts	16.8 qts	5	Same as Manex FL	
Dithane, Penncozeb or Manzate 75 DF's	3 lbs	21 lbs	5	Same as Manex 4 FL	
Bravo 720 or Echo 720	3 pts		2	Early and late blight, Gray leaf spot, Target spot	Use higher rates at fruit set and lower rates before fruit set.

Chemical Disease Management for Tomatoes

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Chemical	Maximum Rate/Acre/		Minimum Days to Harvest	Pertinent Diseases	Select Remarks
	Application	Crop			
Maneb 75DF	3 lbs	22.4 lbs	5	Same as Manex FL	
Echo 90 DF	2.3 lbs		2	Early and late blight, Gray leaf spot, Target spot	Use higher rates at fruit set and lower rates before fruit set.
Bravo 500, Echo 500, or GK Chloro Gold FL's	4 pts		2	Early and late blight, Gray leaf spot, Target spot	Use higher rates at fruit set and lower rates before fruit set.
Ridomil Gold Bravo 81W	3 lbs		14	Early and late blight, Gray leaf spot, Target spot	Limit is 4 appl/crop
Ridomil Gold 76.4 MZ WP[2]	2.5 lbs	7.5 lbs	5	Late blight	Limit is 3 appl/crop
Benlate 50WP	1 lb		1	Leaf mold, Botrytis, Sclerotinia	Manufacturing has ceased
JMS Stylet Oil	3 qts		NTL	Potato Virus Y, Tobacco Etch Virus	See label for specific info on appl. technique (e.g. use of 400 psi spray pressure)
Ridomil Gold Copper 70W	2.5 lbs[3]		14	Late blight	Limit is 3 appl/crop.
Sulfur			1	Powdery mildew	
Kocide 4.5 LF	2 ⅔ pts		1	Bacterial spot	
Dithane M45 or Manzate 80 WP's	1 ½ lbs	21 lbs	5	Same as Manex 4F	
Aliette 80 WDG	5 lbs	20 lbs	14	Phytophthora root rot	Using potassium carbonate or Diammonium phosphate, the spray of Aliette should be raised to a pH of 6.0 or above when applied prior to or after copper fungicides.
Bravo Ultrex 82.5 WDG	2.75 lbs		2	Early and Late blights, Gray leafspot, Target spot, Botrytis, Rhizoctonia fruit rot	Use higher rates at fruit set.
Bravo Weather Stik	3 pts		2	Same as Bravo Ultrex	Use higher rates at fruit set

Chemical Disease Management for Tomatoes

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Chemical	Maximum Rate/Acre/ Application	Maximum Rate/Acre/ Crop	Minimum Days to Harvest	Pertinent Diseases	Select Remarks
Quadris 2.08 FL	6.2 fl oz	37.2 fl oz	0	Early blight, late blight, sclerotinia	Use Quadris in strict alteration with other types of fungicide. Limit is 6 appl.
Botran 75W	1 lb	4 lbs	10	Botrytis	Greenhouse tomato only. Limit is 4 applications. Seedlings or newly set transplants may be injured.
Exotherm Termil	1 can/1000 sq. ft.		2	Botrytis, Leaf mold, Late & Early blights, Gray leafspot	Greenhouse use only. Allow can to remain overnight and then ventilate. Do not use when greenhouse temperature is above 75F.
Nova 40 W	4 ozs	1.25 lbs	0	Powdery mildew	Note that a 30 day plant back restriction exists
Actigard 50 WG	1/3 to 3/4 oz[4]	4 ozs	14	Bacterial spot Bacterial speck	*Do not use highest labelled rate in early sprays to avoid a delayed onset of harvest. Begin with 1/3 oz and progressively increase the rate as instructed on the laabel. Limit is 6 appl./crop/season. Do not exceed a concentration of 3/4 oz/100 gal of spray mix. Begin spray program before occurrence of disease.*

[1]When tank mixed with a copper fungicide.
[2]Do not exceed limits of mancozeb active ingredient as indicated for Dithane, Penncozeb, Manex or Manzate
[3]Maximum crop is 3.0 lbs a.i. of metalaxyl from Ridomil/copper, Ridomil MZ 58 and Ridomil Bravo 81W.
[4]Label indicates 1/3, 1/2 & 3/4 oz for 30-50, 60-70, and 70-100 gpa of water.

NEMATICIDES REGISTERED FOR USE ON FLORIDA TOMATO

		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[3]					
67-33	225-375 lb	12"	3	112-187 lbs	5.1 - 8.6 lb
Chloropicrin[1]	300-500 lb	12"	3	150-250 lbs	6.9 - 11.5 lb
Telone II[2]	9-18 gal	12"	3	4.5-9.0 gal	26 - 53 fl oz
Telone C17	10.8-17.1 gal	12"	3	5.4-8.5 gal	31.8-50.2 fl oz
Telone C35	13-26 gal	12"	3	6.5-13 gal	22-45.4 fl oz
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, dosage may be reduced by 33%.
2. The manufacturer of Telone II, Telone C-17, and Telone C-35 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. Consult manufacturers label for other use restrictions which might apply.
3. Use of methyl bromide for agricultural soil fumigation is scheduled for phaseout Jan 1, 2005.
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.

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 17, 2001 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.

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Weed Control in Tomato

William M. Stall and James P. Gilreath

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 may 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 all of the 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 it from drifting onto the tomato crop.

Field ditches as well as canals are a special consideration 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 as tomatoes are very sensitive to this herbicide. Particular caution should be exercised if Arsenal is used on seepage irrigated farms as 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 buildup 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 control problem confronting the tomato industry today is control of 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 are 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 is usually necessary.

With post-directed contact herbicides, several studies have shown that gallonage 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 then 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 Dessication

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. Both diquat and paraquat are now labeled for postharvest dessication of tomato vines. The labels differ slightly. follow the label directions.

The importance of rapid vine destruction can not 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.

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Table 1. Chemical weed controls: tomatoes.

Herbicide	Labeled Crops	Time of Application to Crop	Rate (lbs. AI./Acre)	
			Mineral	Muck
Clethodem (Select 2 EC)	Tomatoes	Postemergence	0.9-.125	---
Remarks: Postemergence control of actively growing annual grasses. Apply at 6-8 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. 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 of replanting non-registered crops within 8 months.				
Diquat (Reglone)	Tomato Vine Burndown	After final harvest	0.375	---
Remarks: Special Local Needs (24c) label for use for burndown of tomato vines after final harvest. Applications of 1.5 pts. material per acre in 60 to 120 gals. of water is labelled. Add 16 to 32 ozs. of Valent X-77 spreader per 100 gals. of spray mix. Thorough coverage of vines is required to insure maximum burndown.				
Diquat dibromide (Reglone)	Tomato	Pretransplant Postemergence directed-shielded in row middles	0.5	---
Remarks: Diquat can be applied as a post-directed application to row middles either prior to transplanting or as a post-directed hooded spray application to row middles when transplants are well established. Apply 1 qt of Diquat in 20-50 gallons of water per treated acre when weeds are 2-4 inches in height. Do not exceed 25 psi spray pressure. A maximum of 2 applications can be made during the growing season. Add 2 pts non-ionic surfactant per 100 gals spray mix. Diquat will be inactivated if muddy or dirty water is used in spray mix. A 30 day PHI is in effect. Label is a special local needs label for Florida only.				
MCDS (Enquik)	Tomatoes	Postemergence directed/shielded in row middle	5 - 8 gals.	---
Remarks: Controls many emerged broadleaf weeds. Weak on grasses. Apply 5 to 8 gallons of Enquik in 20 to 50 gallons of total spray volume per treated acre. A non-ionic surfactant should be added at 1 to 2 pints per 100 gallons. Enquik is severely corrosive to nylon. Non-nylon plastic and 316-L stainless steel are recommended for application equipment. Read the precautionary statements before use. Follow all restrictions on the label.				
Metribuzin (Sencor DF) (Sencor 4)	Tomatoes	Postemergence Posttransplanting after establishment	0.25 - 0.5	---

Herbicide	Labeled Crops	Time of Application to Crop	Rate (lbs. AI./Acre)	
			Mineral	Muck
Pebulate (Tillam 6E)	Tomato	Pretransplant Incorporated Directed	4 6	--- ---
Remarks: Do not use on seeded tomatoes. Has supplemental labeling for use in transplanted tomatoes grown under polyethylene mulch and in combination with Telone C-17 or C-35. Transplants may be set by hand if chemical resistant gloves are worn. Consult label for incorporation methods recommended. May be applied post transplanting as a directed spray to clean cultivated soil. There is a 8 day PHI. Product is volatile and not persistent in soil. Susceptible weeds germinating late in the season may not be controlled.				
Pelargonic Acid (Scythe)	Fruiting Vegetable (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.				
Sethoxydim (Poast)	Tomatoes	Postemergence	0.188 - 0.28	---
Remarks: Controls actively growing grass weeds. A total of 4½ 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 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 (1½ pts.) to perennial grasses emerging from rhizomes etc. Consult label for grass species and growth stage for best control.				
Trifluralin (Treflan HFP) (Treflan TR-10) (Trilin) (Trilin 10G) (Trifluralin 480) (Trifluralin 4EC) (Trifluralin HF)	Tomatoes (except Dade County)	Pretransplant incorporated	0.5	---
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 of planting non-registered crops within 5 months. Do not apply after transplanting.				
Trifluralin (Treflan HFP) (Treflan TR-10) (Trilin) (Trilin 10G) (Trifluralin 480) (Trifluralin 4EC) (Trifluralin HF)	Direct-Seeded tomatoes (except Dade County)	Post directed	0.5	---
Remarks: For direct-seeded tomatoes, apply at blocking or thinning as a directed spray to the soil between the rows and incorporate.				

Table 1. Chemical weed controls: tomatoes.

Herbicide	Labeled Crops	Time of Application to Crop	Rate (lbs. AI./Acre) Mineral	Muck
Remarks: Controls small emerged weeds after transplants are established 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.				
Napropamid (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.				
Napropamid (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.				
Paraquat (Gramoxone Extra) (Boa)	Tomatoes	Premergence; Pretransplant	0.62 - 0.94	---
Remarks: Controls emerged weeds. Use a non-ionic spreader and thoroughly wet weed foliage.				
Paraquat (Gramoxone Extra) (Boa)	Tomatoes	Post directed spray in row middle	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 Extra) (Boa)	Tomato	Postharvest dessication	0.62-0.93 0.46-0.62	
Remarks: Broadcast spry over the top of plants after last harvest. Label for Boa states use of 1.5-2.0 pts while Gramoxone label is from 2-3 pts. Use a nonionic 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.				

Selected insecticides approved for use on insects attacking tomatoes.

Chemical Name	REI (hours)	Days to Harvest	Insects	Notes
Admire 2 (imidacloprid)	12	21	aphids, Colorado potato beetle, flea beetles, thrips, whiteflies	
***Agrimek 0.15EC** (abamectin)	12	7	Colorado potato beetle, Liriomyza leafminers, spider mite, tomato pinworms, tomato russet mite	Do not make more than 2 sequential applications.
***Ambush 2EC, 25W** (permethrin)	12	Up to day of harvest	beet armyworm, cabbage looper, Colorado potato beetle, granulate cutworms, hornworms, southern armyworm, tomato fruitworm, tomato pinworm, vegetable leafminer	Do not apply more than 1.2 lb active ingredient per acre per season.
***Asana XL 0.66EC** (esfenvalerate)	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	Not recommended for control of vegetable leafminer in Florida.
Avaunt (indoxacarb)	12	3	beet armyworm, hornworms, loopers, southern armyworm, tomato fruitworm, tomato pinworm	Do not apply more than 14 ounces of product per acre per crop. Minimum spray interval is 5 days.
Azatin XL (azadirachtin)	4	0	aphids (suppression), armyworms, beetles, caterpillars, cutworms, leafhoppers, leafminers, loopers, thrips, whiteflies	Use with oil for leafminers.
BT (Bacillus thuringiensis)	4	See label	armyworms, cabbage looper, corn earworm, cutworms, hornworms, loopers, tomato fruitworm	
***Baythroid 2** (cyfluthrin)	12	0	beet armyworm (1), cabbage looper, Colorado potato beetle, dipterouus leafminers, European corn borer, flea beetles, hornworms, potato aphid, southern armyworm (1), stink bugs, tomato fruitworm, tomato pinworm, variegated cutworm, western flower thrips, whitefly (2)	(1) Ist and 2nd instars only (2) suppression
Confirm 2F (tebufenozide)	4	7	armyworms, black cutworm, hornworms, loopers	
***Danitol 2.4 EC** (fenpropathrin) □	24	3 days, or 7 if mixed with Monitor 4	beet armyworm, cabbage looper, fruitworms, potato aphid, silverleaf whitefly, stink bugs, thrips, tomato pinworm, twospotted spider mites, yellowstriped armyworm	Use alone for control of fruitworms, stink bugs, twospotted spider mites, and yellowstriped armyworms. Tank-mix with Monitor 4 for all others.
Dimethoate 4 EC, 2.67 EC (dimethoate)	48	7	aphids, leafhoppers, leafminers	
***D.z.n.; AG-500, 4 EC** (diazinon)	24	1	**foliar application:** aphids, beet armyworm, banded cucumber beetle, *Drosophila*, fall armyworm, dipterous leafminers, southern armyworm **soil application at planting:** cutworms, mole crickets, wireworms	Will not control organophosphate-resistant leafminers.
Fulfill (pymetrozine)	12	14	green peach aphid, potato aphid, suppression of whiteflies	Do not apply by air.

Chemical Name	REI (hours)	Days to Harvest	Insects	Notes
***Guthion 2L (EC); Solupak** (azinphosmethyl)	48 hours for mowing, irrigating, scouting. 4 days for all other activities.	up to 4 days before harvest if 3 pts or less; 14 for > 3 pts	aphids, banded cucumber beetle, Colorado potato beetle, Drosophila, European corn borer, flea beetles, grasshoppers, hornworms, leafhoppers, leafminers, stink bugs, thrips, tomato fruitworm, tomato pinworm, whiteflies, yellowstriped armyworm	Allow at least 7 days between applications.
Kelthane MF (dicofol)	12	2	Mites	Do not apply more than twice a year.
Knack IGR (pyriproxyfen)	12	14	immature whiteflies	Apply when first nymphs appear.
Kryocide 96 WP; Prokil Cryolite 96 (cryolite)	12	14	blister beetle, cabbage looper, Colorado potato beetle larvae, flea beetles, hornworms, tomato fruitworm, tomato pinworm	Minimum of 7 days between applications.
***Lannate LV, SP** (methomyl)	48	1	aphids, armyworms, beet armyworm, fall armyworm, hornworms, loopers, southern armyworm, tomato fruitworm, tomato pinworm, variegated cutworm	
Malathion 5 EC, 57 EC, 8 EC (malathion)	12	3 (5EC) 1 (57EC, 8EC)	aphids, *Drosophila*, mites	
***Monitor 4EC** (methamidophos)	48	7	tomato pinworm (1), thrips (North Florida only), whiteflies (2)	(1) Suppression of pinworms (2) Use as tank mix with a pyrethroid for whitefly control. 24(C) SLN labels
M-Pede 49% EC (Soap, insecticidal)	12	0	aphids, leafhoppers, mites, plant bugs, thrips, whiteflies	
Neemix .25 (azadirachtin) **Neemix 4.5**	4 12	0 0	aphids, armyworms, hornworms, psyllids, Colorado potato beetle, cutworms, leafminers, loopers, thrips, tomato fruitworm (corn earworm), tomato pinworm, whiteflies	
NoMate MEC (pheromone)			tomato pinworm	
***Pounce 3.2 EC** (permethrin)	12	0	beet armyworm, cabbage looper, Colorado potato beetle, dipterous leafminers, granulate cutworm, hornworms, southern armyworm, tomato fruitworm, tomato pinworm	Do not apply to cherry or grape tomatoes (fruit less than 1 inch in diameter).
Provado 1.6E (imidacloprid)	12	0 - foliar	aphids, Colorado potato beetle, whiteflies	Do not apply to crop that has been treated with Admire.
Pyrellin EC (pyrethrin + rotenone)	12	12 hours	aphids, Colorado potato beetle, cucumber beetles, European corn borer, flea beetles, flea hoppers, leafhoppers, leafminers, loopers, mites, plant bugs, stink bugs, thrips, vegetable weevil, whiteflies	
Py-Rin 60-6 EC (pyrethrin + piperonyl butoxide)	12	0	aphids, armyworms, cabbage looper, Colorado potato beetle, corn earworm, crickets, cucumber beetles, *Drosophila*, flea beetles, leafhoppers, psyllids, thrips, whiteflies	

Chemical Name	REI (hours)	Days to Harvest	Insects	Notes
Sevin 80S (WP); XLR; 4F (carbaryl)	12	3	Colorado potato beetle, cutworms, European corn borer, fall armyworm, flea beetles, lace bugs, leafhoppers, plant bugs, stink bugs**, thrips**, tomato fruitworm, tomato hornworm, tomato pinworm, sowbugs	**suppression
Sevin 5 Bait (carbaryl)	12	3	ants, crickets, cutworms, grasshoppers, sowbugs	
SpinTor 2SC (spinosad)	4	1	armyworms, Colorado potato beetle, European corn borer, flower thrips, hornworms, *Liriomyza* leafminers, loopers, *Thrips palmi*, tomato fruitworm, tomato pinworm	Do not apply to seedlings grown for transplant within a greehouse or shadehouse.
Sulfur	24	See label	tomato russet mite	
SunSpray Ultrafine (Horticultural Spray Oil)	4	0	aphids, beetle larvae, leafhoppers, leafminers, mites, thrips, whiteflies	
***Telone II; Telone C17** (dichloropropene)	5 days (See label)	Preplant	garden centipedes (symphylans), wireworms	See supplemental label for restrictions in certain Florida counties.
Thiodan 3EC, Phaser (endosulfan)	24	2	aphids, blister beetle, cabbage looper, Colorado potato beetle, flea beetles, hornworms, stink bugs, tomato fruitworm, tomato russet mite, whiteflies, yellowstriped armyworm	Do not exceed a maximum of 3.0 lb active ingredient per acre per year or apply more than 6 times.
Trigard (cyromazine)	12	0	Colorado potato beetle (suppression of), leafminers	No more than 6 applications per crop.
***Vydate L 2EC** (oxamyl)	48	3	aphids, Colorado potato beetle, leafminers (except *Liriomyza trifolii*), whiteflies**	**suppression
***Warrior T** (lambda-cyhalothrin)	24	5	aphids (2), beet armyworm (1), cabbage looper, Colorado potato beetle, cutworms, European corn borer, fall armyworm (1), flea beetles, grasshoppers, hornworms, leafhoppers, leafminers (2), plant bugs, southern armyworm (1), stink bugs, tomato fruitworm, tomato pinworm, whiteflies (2), yellowstriped armyworm (1)	Do not use on cherry or grape tomatoes. (1) for control 1st and 2nd instars only. (2) suppression only
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.				
*** Restricted Use Only**				

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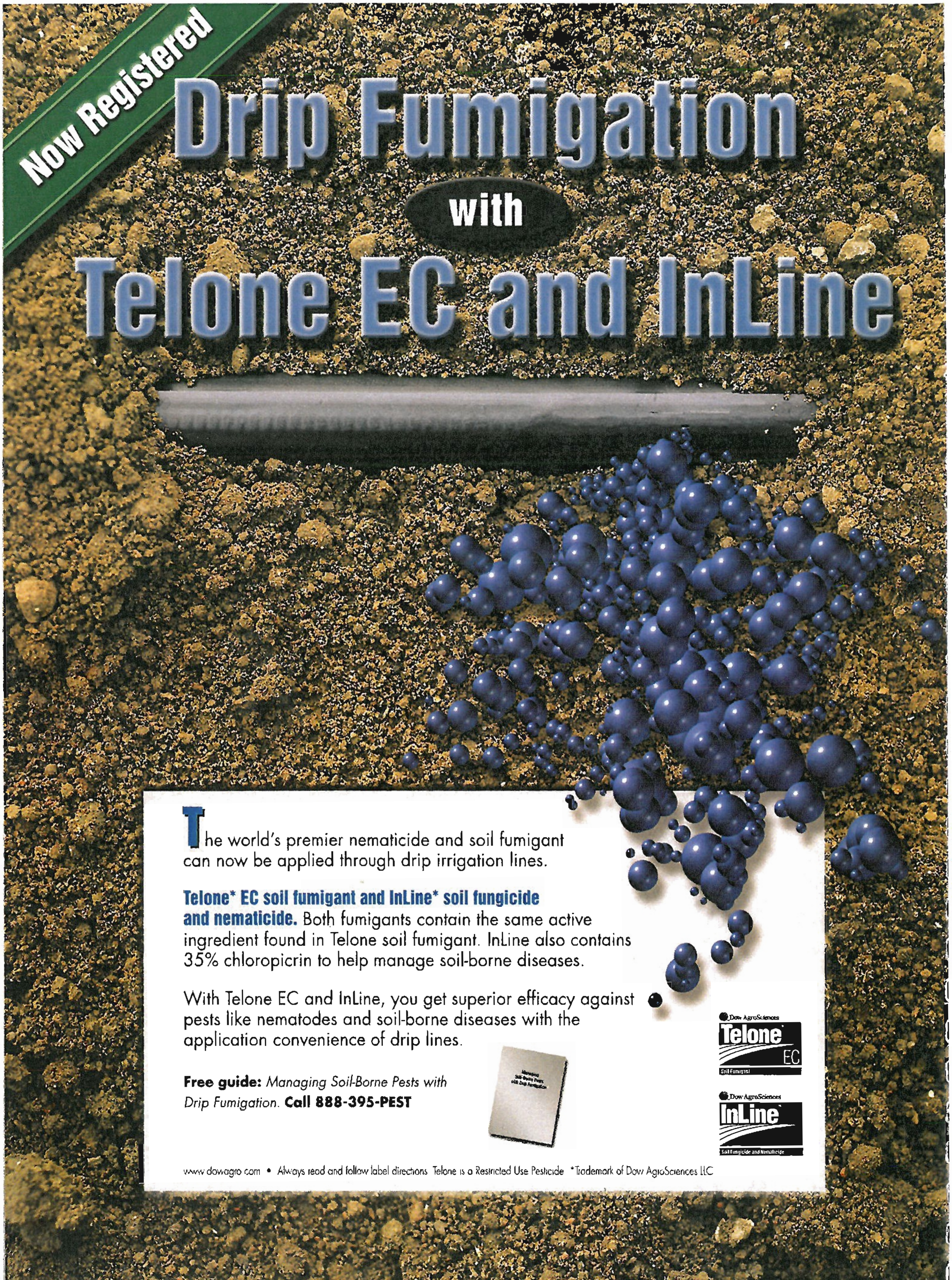
NOTES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