ENY706

UF UNIVERSITY of FLORIDA
IFAS Extension

Tomato IPM in Florida[1]

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We present a historical narrative of tomato production in Florida that emphasizes the adoption and impact of Integrated Pest Management (IPM) practices and the future challenges facing tomato IPM research and technology transfer. In order to accomplish this task we have:

(1) gathered information (from publications and interviews) on all aspects of tomato production in Florida,

(2) addressed the impact and interaction of cultural and management practices with IPM,

(3) assessed the present status of the tomato industry and discussed the risks and barriers to further implementation of sustainable practices within an IPM systems approach, and

(4) identified critical research and extension needs as they relate to present and future pest complexes of tomatoes.

Tomato Production in Florida

Tomatoes (*Lycopersicon esculentum* Mill.) are herbaceous perennial plants in the family Solanaceae (Lawrence 1951) that are almost universally cultivated as annual crops (Jones et al. 1991, Benton Jones 1998). They are native to South America (Peru and Ecuador) and were first domesticated in Mexico. In the mid-16th century they were introduced into Europe and were subsequently re-introduced into America in the 18th century (Benton Jones 1998). Their importance as vegetables has occurred only in the last century. Originally tomatoes had an indeterminate plant habit, but determinate varieties have been bred with a bush-like form that is more easily harvested (Benton Jones 1998).

Tomato production in FL began in Alachua Co. in 1870 (Weber 1939, Crill et al. 1977). The first large tomato field (20 acres [8 ha]) was planted at Palmer, FL in 1872 (Weber 1939). The export industry was established in 1879 in the Palmetto-Manatee area when tomatoes were shipped to New York City (Crill et al. 1977). By 1891, tomatoes were being grown in the marl and muck soils of the Everglades by adding compost to this soil (Weber 1939). By 1893, Polk, Manatee, Brevard, Lake, Lee and Dade Co. were the most important tomato growing areas in the state (Weber 1939). Florida tomatoes quickly became popular with northern consumers primarily because of their low price. Increasing demands resulted in 6,675 acres

1. This document is ENY-706, one of a series of the Department of Entomology and Nematology, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: September 2001. Revised: March 2004. Please visit the EDIS Web site at http://edis.ifas.ufl.edu.

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(2,700 ha) grown in 1900, 16,000 ac (6,475 ha) in 1910, 21,000 ac (8,500 ha) in 1920, 29,000 ac (11,740 ha) in 1930, and 50,000 ac (20,240 ha) in 1970 (Weber 1939, Crill et al. 1977). The maximum acreage planted in FL was 66,000 acres (26,700 ha) in 1957 (Crill et al. 1977). Today tomatoes are the number one vegetable crop in the state with 46,100 acres in production in 2002-2003 (Smigiel 2003).

In the U.S., an average of 134,320 acres (54,360 ha) of fresh market tomatoes were planted per year between 1989-1993, with average yields of 26,450 pounds/acre, and a value of over $1.1 Billion. FL acreage (for the same period) accounted for 39.3% of the total (52,840 ac or 21,384 ha), yields were considerably higher than for U.S. averages (33,700 lb/ac), and crop value was $625 M or 55.6% of U.S. totals (Davis et al. 1998).

In the 2002-2003 season tomatoes were grown on 46,100 acres (18,440 ha), planted in 6 production areas scattered throughout the state with largest growing areas located in the southern half of the peninsula (NASS 2004). Yields for the 1996-97 season averaged 36,700 pounds/acre (90,650 lb/ha), which resulted in $462.5 M in on-farm revenue, accounting for 28.9% of the value of the vegetable industry in FL or more than double that of any other vegetable (FAS 1998). The value of the 1999-00 fresh market tomato crop totaled $418.3 million, down $45.9 million or ten percent from the 1998-99 value of $464.2 million. Acreage harvested at 43,200 acres decreased by only 200 acres from the 43,400 harvested in 1998-99 (FAS 2003).

In Florida tomatoes are commercially grown on soils that, in the native state, are considered infertile. In addition, soils are typically infested with soil-borne pathogens and pests including parasitic nematodes, fungi, bacteria, and weed seed. Lack of control of any one of these pests results in serious reductions in yield and quality of crops (Locascio et al. 1997a). At least 27 arthropods (Schuster et al. 1996), 29 diseases (J.P. Jones, pers. comm.) and 10-15 weeds (S. Olson, pers. comm.) are pests of tomatoes in FL (Appendix 1). Consequently, current management programs are sophisticated and require considerable knowledge and expertise to be successfully implemented.

Tomato management includes the use of broad-spectrum soil fumigants, polyethylene mulched beds, and adequate rates of fertilizer, irrigation and pesticides (Locascio 1987). In 1994, 15 million pounds of nitrogen, 9 million lb of phosphorous and 25.5 million lb of potash were applied as additives to 51,500 acres (20,842 ha) of tomatoes (FAS 1998). In 1998, 20,100 pounds of herbicides, 92,800 lb of insecticides, 1.05 M lb of fungicides and 6.84 M lb of fumigants were applied to 40,600 acres (16,431 ha) of tomatoes (NASS 1999). Average production costs per acre during 1997-98 were $11,558.57 ($28,549.67 per ha) or $0.33 per pound produced (Smith and Taylor 1999). Costs for chemical inputs (including fertilizer and lime, fumigants, fungicides, herbicides and insecticides) averaged $1,621.55 per acre ($4,005.23 per ha) or 14.03% of total production costs, with insecticides accounting for about 26.4% of that amount ($428.25 per acre [$1,057.78 per ha]) (Smith and Taylor 1999).

Florida's vegetable industry grew because of the demand for fresh produce in the U.S. especially during the winter months (Rose 1973). Florida climate is subtropical, with mild temperatures throughout the winter and with seasonal periods of high rainfall. As a consequence, cropping patterns are reversed from those in temperate regions (Pohronezny et al. 1986). Production is primarily as winter vegetables exported to northern states and Canadian provinces, with emphasis on supplying the fall-winter-spring market (Pohronezny et al. 1986, Schuster et al. 1996).

In preparation for planting, fields are plowed and disked to bury crop refuse and soil tested to determine lime and fertilizer requirements. Lime is used to adjust the soil pH (optimal range between 6.0-6.5) and is incorporated prior to bedding (Hochmuth 1997b). Almost 100% of the crop is grown on raised beds covered with polyethylene mulch (Schuster et al. 1996, Hochmuth 1997a). Height and width of the beds vary (Schuster et al. 1996), as does the type of irrigation used (which can be drip, seep, or overhead irrigation). Bedding is accomplished using a bed press, bedding disk or double-disk hiller, followed by a board to level the bed tops. Fertilizer is applied (in bands, through injection within the irrigation system or is broadcast into the fields prior to planting) and soil is fumigated prior to mulching (Hochmuth et al. 1998). If drip irrigation is used, irrigation tape is laid on the bed before mulching (S. Olson, pers. comm.). Several mulch types are used including black, white, white-on-black, gray, reflective or yellow oiled polyethylene mulches (Schuster et al. 1996, S. Olson, pers. comm.).

Close to 100% of the crop is staked and crop establishment is with transplants (Schuster et al. 1996). Crop windbreaks (sugarcane, rye, oats) are sometimes used to attenuate the effect of wind on transplants. Distance between tomato plants in beds is variable, but normally averages 18 inches (46 cm) within a row and 6 feet (1.83 m) between bed centers. This spacing yields a population of 4,840 plants/acre (12,000/ha) (Hochmuth and Vavrina 1997). Transplant prices vary between $224.00-336.00/acre ($553.00-830.00/ha) without accounting for labor and machinery used in field placement (Smith and Taylor 1999). Wooden or metal stakes (~4 ft) are used to keep plants upright and make fruit harvesting easier. Tying of plants to stakes begins about 3 wk after transplanting and is repeated 3-4 times/season (Aerts et al. 1999). Seventy to 90 days elapse between transplant and harvest and fruit is usually hand harvested at least twice in each field. After harvest plants are killed with herbicides or burned with propane burners. Stakes are mechanically removed from beds and disinfected. Plastic mulch is pulled-up and taken to the landfill or burned. In some parts of the state some mulched beds are sometimes used to grow a second crop (Aerts et al. 1999, S. Olson, pers. comm.).

There are generally 2 crops/year, although in some areas (i.e., Homestead) planting can be continuous from September to January with no discernible fall/spring dichotomy. In general planting dates for the fall and spring crop in south FL are August and January, in central FL fall tomatoes are planted in Aug.-Sept. and spring tomatoes in January and in north FL the dates are July-Aug. for fall and Feb.-Mar. for spring plantings (Schuster et al. 1996). Key publications for growers in FL are: The Tomato Production Guide for FL, edited by Hochmuth (1997a), which discusses all aspects of tomato growing; The FL Tomato Scouting Guide, written by Pernezny et al. (1996a), which assists field scouts and growers in identification of insects and diseases, provides seasonality charts for major diseases and pests as well as symptom descriptions, dichotomous keys and photographs; and chapter 41 (Tomato Production in FL by Olson and Simonne 2004) of the Vegetable Production Guide for FL (edited by Hochmuth and Maynard, 1998), which lists the newest and most popular tomato varieties, advises on fertilization and irrigation, lists the products registered for disease and insect management including application rates and restrictions, and provides up-to-date cost figures for tomato production.

In the last decade Florida's tomato acreage has dropped approximately 40% mainly due to the importation and sale of lower-priced tomatoes from foreign countries (Aerts et al. 1999). However, yields per acre have continued to increase (from 29,000 lb/ac in 1988-89 to 36,700 lb/ac in 1996-97) because of the adoption of improved growing practices and the use of high-yielding tomato varieties. Unfortunately, the elimination of methyl bromide as a soil fumigant by the year 2005 is expected to cause further drastic reductions in tomato production (69% reduction estimated by Spreen et al. 1995).

Implementation of Integrated Pest Management

Integrated pest management (IPM) is an approach to controlling pests which emphasizes minimizing crop loss by all means at the growers disposal including the use of resistant and tolerant varieties, cultural methods, biological controls, insect growth regulators and pheromones, other genetic methods (such as the use of sterile insects and transgenic plants) and judicious application of chemicals (Davis et al. 1998, Pernezny et al. 1996a). The ultimate goal of IPM is to insure production of abundant, high quality food using environmentally and economically sound methods (Davis et al. 1998). The formal concept of IPM is credited to Stern et al. (1959) who observed that prophylactic reliance on broad-spectrum pesticides was not a sustainable pest management tactic. Sound IPM programs should coordinate pest management activities with each other and with production methods in order to achieve economical and long-lasting solutions to pest problems; emphasis should be placed on anticipating and preventing problems whenever possible (Lewis et al. 1997, Mizell 1998). The components that are essential to any IPM program include accurate identification of pests, field monitoring, control action guidelines and effective methods of prevention and control, including the use of appropriate pesticides when needed.

In Florida, tomato IPM pilot programs were initiated in Dade Co. in 1976 (Pernezny et al. 1996a) and in Manatee and Hillsborough Co. in 1978 (Schuster et al. 1980) following heavy economic losses from a severe outbreak of leafminers (*Liriomyza spp.*) (Diptera: Agromizidae) in 1976-77. As many as 34 insecticide sprays were used in one 90 day season in a futile attempt to control the outbreak (Pohronezny et al. 1986). Interestingly, leafminers were (and are) considered a secondary pest of tomato (Schuster et al. 1996, Appendix 1). Control failures in 1976-77 were attributed to a buildup of pesticide resistance in leafminer populations and to high leafminer natural enemy mortality (Pohronezny et al. 1986). Additional factors such as rapid urbanization, which reduced available farmland and brought agriculture and residential communities into closer contact, and heavy losses from bacterial spot and late blight accelerated the implementation of tomato IPM in Dade Co. (Pohronezny et al. 1989, Pernezny et al. 1996a).

From their inception, tomato IPM programs have been interdisciplinary with components of horticulture, entomology, plant pathology and nematology (Pohronezny et al. 1986). Their most important feature has been the systematic, twice-per-week scouting of fields and the use of resultant biological data in farm management decisions. Extension and research scientists have worked cooperatively to investigate, validate and fine-tune information crucial to the implementation of tomato IPM (Pohronezny et al. 1986). Scouting procedures and action thresholds for tomato pests were proposed by Pohronezny and Waddill and modified by several authors (Pohronezny et al. 1986, Schuster et al. 1980, Pernezny et al. 1996a). The first tomato scouting guide was published by Pohronezny and colleagues in 1980. The most current scouting guide includes expanded dichotomous keys, color plates, seasonality charts and detailed bio-capsules for insects and diseases (Pernezny et al. 1996a). A recent review of tomato IPM in Florida was published by Schuster et al. (1996). However, with the ever-present threat posed by invasive pests and diseases, research endeavors in support of IPM implementation are ongoing.

Progress in adoption of IPM by FL tomato growers has been examined by several authors. Pohronezny et al. (1986) summarized information from 7 growing seasons in south FL, Pohronezny et al. (1989) evaluated the impact of IPM educational programs on selected vegetables through a grower survey (Dade, Collier, Manatee and Hillsborough Co.) conducted between 1984-1986, Bauske et al. (1998) collected data from growers in 7 southeastern states, including north Florida (Calhoun, Okaloosa, Gadsden, Jackson and Santa Rosa Co.), and Aerts et al. (1999) surveyed growers in southern Florida in 1997.

Tomato acreage participating in once-per-week scouting increased ten-fold in seven seasons, from 365 acres (147 ha) in 1976-77 to 4,700 acres (1902 ha) in 1982-83 (Pohronezny et al. 1986). After IPM demonstrated the benefits of conserving leafminer parasites, some growers reduced the use of broad-spectrum insecticides by 1/3 (Pohronezny et al. 1986). However, the authors cautioned that with the appearance of new classes of insecticides effective against key pests, some growers tended to return to routine spraying rather than continue practicing IPM. Forty-seven growers representing 69.2% (25,995 acres [10,520 ha]) of the total tomato acreage in FL responded to the survey by Pohronezny et al. (1989). They found that almost half (47%) of the acreage was routinely scouted and that growers realized an average savings of $121.00/acre ($299.00/ha) due to adoption of IPM. This economic benefit directly related to fewer pesticide applications per season. Despite the positive economic outcome, growers viewed early and accurate identification of pests as the major incentive for hiring scouts and thus adopting IPM (Pohronezny et al. 1989).

Bauske et al. (1998) reported that IPM adoption by tomato growers in northern FL was “medium or high" on 100% of the acreage, and concluded that northern FL had reached the national goal of having IPM adopted by 75% of the acreage before the (year 2000) deadline. The survey by Bauske et al. (1998) represented 54.4% of the tomato acreage in north FL, with an average farm size of 213 acres (86 ha). Aerts et al. (1999) reported that all southern FL tomato growers surveyed in 1997 performed some type of scouting for pests, while 81% performed "deliberate" scouting activities on a scheduled basis. Growers indicated that their participation in IPM had resulted in an increased use (up to 44%) of "soft" pesticides in the last 5 years. Schuster (pers. comm.) believes that IPM adoption by Florida tomato growers has stabilized at around 50% of the acreage with a resultant 82% reduction in overall pesticide use and that the savings realized by these growers are about 11% of their production costs. The figures reported by Pohronezny et al. in 1989 indicate similar results (47% of acreage under IPM, 80% reduction in pesticide and 10% savings). Davis et al. (1998) reported that IPM adoption in FL as an "unconscious component" of management was practiced on 100% of planted acres for diseases and weeds (use of resistant varieties, mulching, clean transplants), based on average responses by growers in a survey covering five years (1989-1993). In those same years, IPM was used as a "conscious component" of management on 45 and 60% of the acreage for diseases and weeds, respectively.

Growers, researchers and state IPM team members have identified similar problems and concerns affecting Florida tomato production (Appendix 1). Early blight, target spot, late blight, bacterial spot, bacterial speck and bacterial wilt are named as the main disease problems. Tomato yellow leaf curl virus and tomato mosaic virus, both vectored by silverleaf whitefly are increasingly important yield limiting viruses. Tomato spotted wilt virus (TSWV) vectored by thrips is identified as a problem in north Florida. Silverleaf whitefly, leafminers, tomato pinworm, thrips and caterpillars are viewed as important insect problems, and poor weather conditions, Government regulation and labor costs are identified as important production problems. Interestingly, only one grower surveyed by Bauske et al. (1998) suggested that the removal of methyl bromide should be an emerging concern for tomato growers.

Tomato Management Practices: Their Implementation, Impact, and Interactions.

Variety Selection - Host Plant Resistance

Variety selection is the most important management decision made by the grower. Yields, disease resistance, horticultural quality, adaptability and market acceptability should be used as criteria to select tomato varieties (Maynard 1997). The first tomato crops in FL were not seriously affected by disease (J.P. Jones, pers. comm.). However, by the turn of the century diseases became a limiting factor for tomato production. Growers reported the first *Fusarium* symptoms in tomatoes in 1899 (Crill et al. 1977). Before the discovery of resistant varieties, *Fusarium* wilt was the most destructive tomato disease (Watterson 1986).

The University of Florida tomato-breeding program, established in 1922, emphasized the development of high yielding, high quality, multiple disease resistant tomato varieties for use in FL and elsewhere. Among their key accomplishments were: (1) complete eradication of the causal pathogen of nail-head rust (*Alternaria tomato*); (2) development and release of 'Manalucie' in 1953, a variety that combined genetic resistance to eight different diseases while maintaining desirable horticultural characters; (3) development and release of 'Walter' in 1969, the first tomato variety resistant to race 2 of *Fusarium* wilt (discovered in FL in the 1960s). 'Walter' was also resistant to catface, graywall, tobacco mosaic virus and fruit cracking and produced large, firm and flavorful tomatoes; (4) release of 'Florida MH-1' in 1971, the first fresh market tomato suitable for machine harvest; and, (5) the release of 'Floramerica' in 1977, which was recognized as an All-America selection because of its widespread adaptation to diverse growing conditions and its multiple disease resistance (Crill et al. 1977).

One hundred percent of the FL tomato acreage is planted with varieties resistant to *Fusarium* and *Verticillium wilt*, gray leaf spot and early blight

(Davis et al. 1998). Large fruited varieties recommended for Florida include 'Agriset 761', 'Bonita', 'Merced', 'Olympic', 'Solar Set', 'Sunbeam' and 'Sunny'; 'Spectrum 882' for plum type varieties and 'Cherry Grande' for cherry tomatoes (Maynard 1997). Development of heat tolerant varieties ('Solar Set') has been extremely beneficial to the FL industry (S. Olson, pers. comm.). Fruit set in heat tolerant varieties occurs even at high temperatures which has allowed growers to plant a second crop in the fall in North Florida, while in South Florida heat tolerant varieties are requisite in the first planting of the year. Research to develop tomato varieties that are resistant to herbicides is underway (B. Stall, pers. comm.). Some varieties ('Sanibel') are moderately resistant to root-knot nematodes; however, development of varieties resistant to insects has been difficult. Normally, the most insect resistant accessions are closer to wild-type tomatoes, which do not possess desirable horticultural attributes. In the wake of the devastation caused by whitefly transmitted geminiviruses in 1992, University of Florida scientists have been working on development of virus-resistant tomato varieties. Unfortunately newer geminivirus variants have appeared that can infect these resistant plants. The latest research aims to endow plants with broad-scale resistance to the rapidly expanding family of gemini pathogens (J. Jones, pers. comm.).

Recent work by Thaler (1999) in California suggests that plant induced defenses in tomato can confer some resistance to damage by herbivores. However, caution must be used when using plant defense inducers, as there appears to be trade-offs in plant defenses against pathogens and herbivores (Thaler et al. 1999). Jasmonic acid application results in induction of proteinase inhibitors and polyphenol oxidase by tomato plants and in a decrease in preference, performance and abundance of many common herbivores including *Frankliniella occidentalis*, *Spodoptera exigua* and *Trichoplusia ni*, flea beetles and aphids. Induction of defenses did not decrease plant performance. Induced resistance in tomatoes may be an important tool for pest control (Thaler 1999). Actigard is being examined as a natural resistance inducer to manage transmission of tomato spotted wilt virus in North Florida (Momol, pers. comm.).

Weed Surveys

Surveys that identify the weed species present, their relative density and location can be used to select future control tactics. Although control tactics for weeds are mainly chemical (herbicides), weed surveys can be used to “target” treat for weeds thereby decreasing the total amount of herbicide used. Soil samples can also be used to collect and germinate weed seeds and test the soil for herbicide residues (Lange et al. 1986). Knowing which weed species can be expected is also useful in insect management. Some insect pests as well as their parasitoids use weeds as alternate hosts (Schuster et al. 1991, Stansly 1995, Stansly et al. 1997).

Fertilization - Proper Nutrition

In the last 100 years crop nutrition research has resulted in a 4-10 fold increase in tomato yields in FL (Locascio 1987). The objective is to provide proper levels of nutrients at each stage of plant development while minimizing the potential for leaching, which can cause profit loss and environmental problems (Jones et al. 1991) and facilitate arthropod pest (Bethke et al. 1987) or disease outbreaks (Jones et al. 1991). Soil samples are useful to determine fertilizer requirements in agricultural fields. Adjustment of the soil pH (to between 6.0-6.5) can be accomplished by adding lime. A higher pH will interfere with micronutrient availability (Ca, Mg) (Hochmuth et al. 1998). *Fusarium* wilt and gray mold (favored by low pH) and Verticillium wilt infection rates (favored by high pH) are reduced when soil pH is maintained near 6.5 (Jones et al. 1991). Numerous studies have attempted to determine optimal application rates for nitrogen and potassium (Locascio et al. 1997b). Optimal nutrition is important in preventing or causing certain disease problems (for example, Calcium levels and the incidence of blossom-end rot) (Jones et al. 1991). The recommended level of fertilization with N is 175 pounds per acre (Hochmuth and Hanlon 1995), but growers typically apply much more to their fields (~350 pounds/acre) (Everett 1976). Plant tissue analysis was initially used to assess N availability in the soil (Rhoads et al. 1995). Currently, cardy ion meters are used to determine N concentration in plant sap, which is a useful tool for managing N fertilization of tomatoes (Rhoads et al. 1995).

Bedding and Mulching

Raised beds permit the formation of more defined root zones in the tomato transplants and improve drainage control during high rainfall (Jones et al. 1991). In addition, the placement of polyethylene mulches is easier in bedded fields. Polyethylene mulches were first used in FL strawberry production in the 1950s. In the early 1970s tomato growers began using mulches in combination with broad-spectrum fumigants, which resulted in increased yields. In addition, movement of crops into new land every couple of years was minimized (Locascio 1987, Locascio et al. 1997a). By raising soil temperature, mulches increase yields both in terms of earliness and total yield/plant. They improve weed control, particularly annual weeds (Davis et al. 1998), conserve moisture and fertilizer in the beds and improve fruit quality (Hochmuth 1997b). Mulches minimize nutrient leaching during heavy rainstorms (Hochmuth 1997b), maintain bed integrity (Stansly and Schuster 1999) and prevent direct contact between fruit and soil thereby reducing fruit rot incidence (Jones et al. 1991). One hundred percent of FL tomatoes are grown on mulched beds (S. Olson, pers. comm.). It is generally believed that mulch helps retain the fumigants within the beds and, as such, enhances their killing action. Recent work in CA suggests that mulch is ineffective at keeping fumigants from escaping into the air (Raloff 1998).

Many colors of polyethylene mulch are used in tomato production. In the spring, black is recommended to increase soil temperature, while in the fall white or white-on-black polyethylene is used to keep temperatures low (S. Olson pers. comm.). Aluminum painted mulches can affect arthropod pests of tomato (Antignus et al. 1998). Aluminum mulch reduced the number of plants infected with an aphid-transmitted virus in south FL (Kring and Schuster 1992) and were reported to reduce immigration of thrips by 68% and the incidence of the virus they transmit (TSWV) by 64% in tomatoes in LA (Greenough and Black 1990). Similar results have been reported by Stavisky et al. (2001) in North FL. Stansly and Schuster (1999) found that reflective mulch reduced whitefly populations by 50% over those in black-mulched tomatoes in South FL. However, tomato yields were slightly lower in aluminum-mulched beds. The cost of reflective mulch is significantly higher ($600.00 vs. $200.00/acre [$1,480.00 vs. 494.00/ha]) (S. Olson, pers. comm.). The effect of reflective mulch on Lepidopteran pests of tomato has not been assessed (S. Olson, pers. comm.).

Irrigation

Drip irrigation is increasing in popularity in FL agriculture as water availability continues to decrease (S. Olson, pers. comm.). Currently, FL ranks second in drip/trickle irrigation usage in the U.S. (approximately 725,000 acres [293,000 ha] in all crops). Drip irrigation delivers water through small-diameter polyethylene tubing installed in each vegetable bed (Jones et al. 1991). It greatly improves water-use efficiency (cutting water use by 30-50%) and improves yields. A number of disease-control agents as well as fertilizers can be distributed with irrigation water, optimizing application to the root zone and maximizing their efficacy and utilization. Improper water management can contribute to prevalence of root-rot diseases in tomatoes (Allen Stevens 1986). Irrigation management to control (mainly bacterial) diseases is used in FL on about 25% of the acreage (Davis et al. 1998).

Water reuse in FL is becoming important as more areas of the state are designated as “water resource caution areas.” About 490 M gallons/day of reclaimed water was used in FL in 1998. Eighteen percent was employed in irrigation of agricultural lands. The nations largest desalination plant will begin operating in Hillsborough Co. by 2002. The plant will convert 25 M gallons of seawater to potable water/day and is expected to have a major impact on agriculture and urbanization. The plant will ease pressure from public use of agricultural water and will comply with guidelines that mandate reduction of water withdrawals from underground reservoirs in Pasco and Hillsborough Co. Nonetheless, water availability remains a critical concern for FL agriculture.

Soil Fumigation

The use of broad-spectrum soil fumigants has been an essential component of tomato production in FL, as they control a wide variety of tomato pests including soil pathogens, root-knot nematodes, weeds and some insects. Methyl bromide (MBr), by itself or in combination with chloropicrin are applied to ca. 93% of tomato acreage in FL (Aerts et al. 1999). A single application is injected into the soil two weeks before transplanting. Between 5.3-8.2 million pounds of fumigant active ingredient are used in FL each year (Aerts et al. 1999), accounting for 17% of MBr use in the United States (Anonymous 1993). The ban on MBr has been projected to reduce tomato production in FL by 69% (Spreen et al. 1995).

The U.S. Environmental Protection Agency (EPA) mandated the phase-out of MBr, as it has been associated with stratospheric ozone depletion. Under the EPAs Clean Air Act, its use, production and importation will be banned by the year 2001. Recent legislation passed with the Agriculture Appropriations Bill in FY 1999 delayed the ban of MBr until 2005, mainly because growers in the U.S. have few viable alternatives at this time. However, under the same legislation, developing countries including Mexico can continue to use MBr until 2015.

Alternative fumigants evaluated at different locations in FL by Locascio et al. (1997a) and others indicate that no single alternative provides the consistent broad-spectrum control provided by MBr. Data suggest that a mixture of different fumigants (i.e., 1,3-dichloropene and chloropicrin) plus a separate but complimentary herbicide treatment (pebulate) will be required to achieve satisfactory yields (Aerts et al. 1999). Unfortunately, some of the proposed alternatives are much more “toxic” than MBr and require that field personnel wear heavy protective gear during application, which is both impractical and expensive. In addition, field re-entry periods for some alternatives are much longer than for MBr (Gilreath, pers. comm.).

Soil solarization as an alternative to MBr has been investigated in FL with mixed results. Benzaldehyde, a peach aromatic extract, was identified by USDA-ARS as a potential alternative for controlling soil pathogens. Benzaldehyde was effective against *Fusarium oxysporum*, *Rhizoctonia solani*, *Pythium aphanidermatum* and *Sclerotinia minor*, and is not harmful to humans, animals or the environment. It significantly lowered soil pH, but the pH returned to normal levels within two weeks of application (Anonymous 1999a, Stanley Lowe 1999). Where double cropping is used, pest densities were higher when alternatives to MBr were used. These data suggest that double cropping may be not be feasible once MBr is phased out (Aerts et al. 1999). Essential oils (palmarosa, marjoram, thyme) are being studied in the laboratory as possible fumigants against bacterial wilt and other soilborne pathogens by researchers in North FL (Momol, pers. comm.).

Transplants

Nearly 100% of FL tomatoes are grown using staked transplants (Schuster et al. 1996). A detailed account of transplant production can be found in Jones et al. (1991). Transplants allow earlier planting times in the spring when seed germination would be low. They result in less disease problems in the field; provide more efficient use of hybrid seed; increase uniformity of stand maturity and increase predictability of harvest time. Their use has shortened the growing season allowing earlier harvest dates and has reduced the amount of water needed for irrigation. Transplant establishment is enhanced by adding small amounts of fertilizer in order to stimulate root development. Transplants are placed in the soil at least up to the cotyledonary node. Attention should be given to the source of the transplants. In FL, geminivirus infected fields have been traced back to SLWF infestations in some transplant production houses (Olson, pers. comm.).

Staking-Tying

These management practices involve increased material and labor costs but significantly improve overall production and fruit quality. They allow more control over canopy structure resulting in improved pesticide-spray coverage; they permit more air movement between plants reducing the time that foliage remains wet (from dew and rainfall) and thus lowering the potential for infection and spread of diseases that require high humidity (Jones et al. 1991). Staking also simplifies fruit harvesting and eases scouting activities.

Crop Rotation and Trap Crops

Crop rotation to control soil-borne diseases and nematodes was performed on 35% of FL tomato acreage between 1989-1993, and efficacy of this tactic was reported to be adequate (Davis et al. 1998). Crop rotation can also be helpful in weed control (Stall 1998). However, urbanization and its encroachment on agricultural lands will make it increasingly difficult to employ this tactic in tomato pest management. Trap crops are planted in close proximity to the crop that is wanting/needing to be protected. Trap crops are usually more attractive or palatable to pests and, as such, divert insect attack from the crop. Some investigations are currently underway on the use of trap crops in FL tomato production, but their application is not widespread.

Soil Solarization

In solarization, solar radiation is used to heat the soil beneath polyethylene mulch to temperatures that are detrimental to nematodes and other soilborne pests and diseases. Teams of researchers at several Universities (UC, UF) are examining solarization as an alternative to fumigation with MBr. In some experiments in CA the soil was reported to be nematode free after just 30 minutes of solarization during mid-summer (Anonymous 1999b). Research in FL has given mixed results (Gilreath, pers. comm.). Soil solar sterilization was examined by Overman (1985) and Overman and Jones (1986) as an off-season land management tool to control root-knot nematodes. Solarization was shown by Chellemi et al. (1997) to control nematodes, pathogenic fungi, and weeds in North FL although its effectiveness can vary from year to year. For solarization to work optimally soil needs to be wet (as high temperatures are evenly maintained in moist soil). Solarization in FL works best during the summer in preparation for fields that will be planted in the fall. At this time it is not seen as a dependable alternative to soil fumigation.

Harvesting and Crop Debris-Residue Destruction

Tomatoes are usually hand harvested at least twice-per-season and the first pick is the most economically important. The most active harvest period extends from November-June (Aerts et al. 1999) in FL. Fruit are harvested as mature green fruit, although there is a growing tendency towards harvesting pink fruit as “vine ripe” (Schuster et al. 1996). Destruction of crop debris in 50% of tomato acreage in 1993 was effective at controlling geminivirus transmission by SLWF. Seventy percent of FL acreage reported conducting destruction of crop residue to control multiple insect pests between 1989-1993, and weed destruction to remove alternate hosts for insects and diseases was reported in 75% of the acreage in that same period (Davis et al. 1998).

Fallowing Land

This is performed on 35% (18,494 acres [7484 ha]) of crop acreage between 1989-1993 in order to control the root-knot, sting and stubby-root nematodes in FL (Davis et al. 1998). The efficacy of this practice was considered to be adequate, but urban encroachment into agricultural lands will negatively impact the availability of this tactic.

Scouting

The most important feature of tomato IPM in FL is the systematic twice-per-week scouting of fields and the use of these data in making farm management decisions (Pohronezny et al. 1986). Scouting procedures and action thresholds were proposed in FL by Pohronezny et al. 1986, Schuster et al. 1980 and Pernezny et al. 1996a. Current scouting practices are outlined in Pernezny et al. (1996a) and Schuster et al. (1996). Modifications and improvements to the current procedures will have to be made as new pests enter Florida and as more information is available on presently occurring pests. For example, the action threshold for SLWF was lowered when the insects were identified as vectors of tomato yellow leaf curl virus (Schuster, pers. comm.).

It is interesting to note that the action taken based on scouting results can be very different depending on who performs the scouting (growers, pest consultants or paid scouts). Bauske et al. (1998), reports that scouting by pest consultants resulted in more applications of pesticide. The cost of scouting activities in FL tomato farms varies between $35.00-44.00 per acre ($86.50 and $108.70/ha) (Smith and Taylor 1999). According to Davis et al.

(1998) scouting for insects and diseases in FL was performed on 60% of the crop (31,704 acres [12830 ha]) between 1989-1993, however, Schuster (pers. comm.) believes that the figure is closer to 50%.

Pesticides - New Chemistries

Fresh tomato production and aggregate pesticide use in the U.S. is dominated by Florida and California. Implementation of IPM decision-making in both states has resulted in a more judicious use of pesticides. Having a wide selection of available products against key pests is important to IPM as it reduces the potential for resistance development against continually used pesticides. Since the adoption of IPM programs FL has experienced a reduction in the amount of pounds of active ingredient used for insect control (from an average of 8.9 to 3.5 pounds per acre between 1994-95 and 1996-97) as well as a shift towards more “reduced-risk” products in tomato farming. These newer chemistries are safer to workers and the environment and help conserve natural enemies. Unfortunately, overuse of these materials (i.e., imidacloprid against SLWF; spinosad against thrips: Trigard and Agrimek in rotation against *Liriomyza* spp. may result in the development of resistance in key pests, which could force growers to return to some of the more noxious products. It also must be kept in mind that in many cases only one “reduced-risk” alternative exists and every effort must be made to extend its useful life through judicious management within the context of IPM (J. Funderburk, pers. comm.).

Natural Enemies

Schuster et al. (1996) give an excellent description of the progress made in using natural enemies in tomato production in FL. Because a plethora of pests and plant diseases plague tomato production in the Southeast, stable biological controls cannot be sustained under the current production system. Nonetheless, some augmentative and inundative releases of natural enemies have had success against certain pests. Much work remains to be done, not only in conservation of natural enemies already present but in investigation of other promising agents. For example, the predatory thrips *Franklinothrips vespiformis* was found attacking larvae and adults of *Thrips palmi*, larvae of the SLWF *Bemisia argentifolii*, larvae of the serpentine leafminer *Liriomyza trifolii* and the two-spotted spider mite *Tetranychus urticae* in Okinawa, Japan. This species was reported from avocadoes in FL by Moznette in 1920 (Arakaki and Okajima 1998). This predatory thrip might be a good candidate for use in tomatoes. Joyce et al. (1999) report on a recently discovered Platygasterid parasitoid of SLWF. *Amitus bennetti* was first collected from *B. tabaci* in Puerto Rico. Studies indicate that this species has the highest intrinsic rate of increase ever recorded for parasitoids of *Bemisia*, which makes it a suitable candidate for evaluation as an agent in inundative release programs targeting *B. argentifolii* in agronomic systems (Joyce et al. 1999).

Production of Greenhouse Tomatoes

Researchers at the University of Florida are evaluating protected greenhouses for production of cluster tomatoes. This system would allow for effective competition with the cluster tomato imports from Holland (20% of current market) and other countries (Israel, Mexico). Greenhouse production would allow earlier planting, faster growth and potentially higher yields. Worldwide 300,000 ha of tomatoes were grown in greenhouses in 1998. However initial costs are very high; a 33.5 by 10.7 m greenhouse can cost $30,000.00 to build and about $14,000.00 per year to operate (energy, labor, supplies) (Blank 1999). A North FL tomato grower indicated that building a 1-acre greenhouse for hydroponic tomato production would cost about $ 40,000.00 dollars in 1999, but he expected to recover this investment in 3-4 years (P. Greany, pers. comm.).

Greenhouse tomatoes are grown in soil-less media (Perlite and Rockwool) and as such offer an alternative way of growing tomatoes in the face of MBr elimination (Blank 1999). Soil-less media eliminates problems caused by pests (like nematodes and weeds) and pathogens that are present in the soil. Nonetheless, several foliar diseases such as powdery mildew and early blight are more problematic inside greenhouses in Florida. In addition, the amount of water and nutrients that are provided to greenhouse plants is considerably lower than field applied amounts. The enclosed structure protects the crop from pests and those that do appear can be controlled more effectively using biological control, such as well-timed releases of natural enemies.

Present Status of the Tomato Industry in Florida

Florida is facing several challenges that will have direct bearing on the continued production of agricultural crops in the state. Since tomatoes are the number one vegetable crop in Florida, these challenges are particularly important to the future of the tomato industry.

- ***Competition from Foreign Markets***: The total tomato acreage in FL is getting smaller. In the last couple of years this reduction has been substantial (Aerts et al. 1999), and has been attributed to competition from the importation of inexpensive tomatoes, mainly from Mexico. The North American Free Trade Agreement (NAFTA), which was signed into law in the early 1990s, has eased restrictions on vegetable imports into the United States. Developing countries have much lower wages for farm workers, have large amounts of reasonably priced land in which to grow crops and have fewer restrictions in terms of registered pesticides and water usage. As such, crops like tomatoes can be produced for considerably less money per acre than in the U.S. (S. Olson, pers. comm.).

- ***Loss of Methyl Bromide***: The EPA mandated the phaseout of MBr for soil fumigation in the U.S. by the year 2005. To date, no suitable alternative offers the broad-spectrum control realized when fields are fumigated with MBr. Some predict that the loss of MBr will reduce tomato acreage in FL by up to 69%.

- ***Stringent Restrictions on Water Use***: Water reuse has become an integral part of water management in FL. In 1998 irrigation of agricultural lands used 18% of reclaimed water and this number is expected to go up. Reuse is required in designated “water resource caution areas,” defined as areas currently experiencing critical water supply problems and areas in which critical problems are projected to develop in the next 20 years. Almost 100% of the acreage destined for growing tomatoes is located within these caution areas in FL.

- ***Potential Importation of New Pests into Florida***: The story of insect pest management in FL is one of constant “change” in order to incorporate new technologies and adapt to new invading pests. Management systems should be based on scouting to provide information on pest populations (and their damage potential) and beneficial insects to help growers make wise management decisions.

- The reduced insecticide use that resulted from IPM implementation in tomatoes allowed for an increased role of naturally occurring natural enemies in managing pests, particularly leafminers. However, the introduction of silverleaf whitefly and western flower thrips into FL in the 1980s translated into increased application of broad-spectrum insecticides and temporarily reversed the trend towards reduced use of such chemicals. We can expect similar consequences when additional exotic pests are detected. As an example of what pests might be expected to invade FL we can cite *Tuta absoluta* (Lepidoptera: Gelechiidae), which is a serious and direct tomato pest in several countries in Latin America including Brazil (Leite et al. 1999).

- ***Food Quality and Protection Act (FQPA) of 1996***: The loss of available pesticides through the actions of this law will impact the tomato industry in FL. The FQPA has profoundly changed the way pesticide tolerances are determined. The cumulative effects of all pesticides with a common mode of action are now used to set tolerance levels as well as the aggregate risks of exposure. As such, re-entry periods into fields as well as other worker safety issues are affected by decisions made through FQPA. Even though FL has experienced a shift towards the use of reduced-risk pesticides, there is often only one reduce-risk product that is effective against particular pests and as such will tend to be severely overused. This situation might cause a premature development of resistance and will leave the growers with very limited or non-existent alternatives to combat pests.

- ***Urbanization and Encroachment on Agricultural Lands***: FL is experiencing tremendous real estate growth, especially in the southern part of the peninsula where most vegetables have been traditionally grown. The sale of agricultural land to real estate developers is occurring at an unprecedented rate. Some of the consequences of this urbanization include: 1) growers with less and less land available for agriculture, 2) increased conflict in crop management strategies (i.e., pesticide sprays) as urban properties are built closer to agricultural lands, and 3) conflict in the allocation of water resources between agricultural and urban properties.

- ***Changing demands by consumers***: Consumers are choosing to buy the more reasonably priced vine-ripe, cluster, hydroponically or glasshouse grown tomatoes when shopping at grocery stores. Normally, this translates into purchasing imported tomatoes, as productions costs are considerably lower in competing (importing) countries especially Latin America. Furthermore, consumers still demand blemish free tomatoes and larger numbers of consumers are requiring that their vegetables be grown without the use of pesticides. This trend will favor organically grown glasshouse tomatoes being imported from the Netherlands.

Critical Research and Extension Needs to Further Promote the Adoption and Adherence to IPM in Florida Tomato Production

- Continued work into viable and environmentally acceptable alternatives to methyl bromide is needed. Perhaps the focus should shift away from finding a “cure-all” (that will replace MBr) and be replaced by a search for individual solutions to particular problems that can integrate with one another (see below). Some examples of these tactics include, the use of bacteriophage antagonists against bacterial spot (J. Jones, pres. comm.), the use of essential oils against particular soilborne pathogens (T. Momol, pers. comm.), the development of varieties with higher resistance to root-knot nematodes (J. Gilreath, pers. comm.). All of these approaches are compatible with IPM. However, all require that growers have detailed knowledge of their particular pest problems. This information will only become available to the growers through systematic, constant and careful scouting of their fields.

- More focus on systems approach research. Almost all culture and management practices currently used in tomato production impact more than one pest, and sometimes the impact can be positive for one and negative for the other. Better interaction between different disciplines in the approach to tomato problem solving is critical to the success of IPM implementation into a system as complex as the tomato production in FL.

- Continued evaluation of reduced-risk pesticides and their efficacy against pests and natural enemies that are currently present.

- Continued work on factors contributing to the conservation and enhancement of natural enemies.

- Continued refinement of action thresholds for all pests. Addition of “potential invading pest” information into the current scouting guides for tomatoes; this will be beneficial in order to detect possible invasions in a timely manner.

- Continued careful training and evaluation of IPM scouts.

- Re-examination of greenhouses for production of fresh market tomatoes in selected areas of Florida. One of the major objections to the use of greenhouses in FL has been the very high costs. Now that consumer preferences are shifting and FL is facing the loss of MBr and increased restrictions in water use, greenhouse tomato production should be revisited by conducting cost-benefit analyses.

- Better interaction and enhanced communication between research and extension faculty and between faculty and commodity growers.

Growers need to be more involved in directing long-term research efforts by taking ownership of IPM programs. Active participation by growers will streamline implementation and enhances adherence to IPM programs while preventing “knee-jerk” reactions when unforeseen problems occur.

- Safeguarding against invasive species through collaboration with international entities. For example, collaborative research agreements with countries that might have potential invading pests would allow Florida to obtain necessary knowledge about these pests and might permit the implementation of programs (biocontrol) to reduce the pest in that country thereby indirectly reducing the risk of importation of that pest into the United States.

Concluding Remarks

The implementation of IPM programs for tomatoes in Florida is a “success story in progress.” Very significant advances have been made towards the adoption of IPM into a cropping system that is extremely sophisticated and is under constant threat by a plethora of already existing and of new invasive pests and pathogens. With the passing of NAFTA restrictions on importation of agricultural commodities has been relaxed and, as a consequence, the threat of introduction of additional pests has been heightened. The impending loss of Methyl Bromide and the actions of the Food Quality Protection Act are additional challenges that IPM implementation will have to face.

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APPENDIX 1

Problems Associated with Growing Tomatoes in Florida.

Weeds

Weeds cause yield loss and reduction in crop quality through direct competition for light, moisture and nutrients, by interfering with harvest, and by acting as alternate hosts for disease organisms, insects (and viruses they transmit), and nematodes (Lange et al 1986, Aerts et al. 1999). Early season competition is most critical and emphasis on control should be made at this time (Stall 1998). Currently, weed germination (in beds) is controlled by soil fumigation; however, weeds remain a season long problem in row middles (Hochmuth et al. 998, Aerts et al.1999). Understanding weed biology is essential for their effective managemen however, interest in this area waned after herbicides became important production tools (Lange et al. 1986). To plan a management program it is essential to know which weeds are present. Field surveys and survey cards are useful in this respect.

Yellow and purple nutsedge (*Cyperus esculentus* and *C. rotundus*), American black nightshade (*Solanum americanum*), and prostrate Eclipta (*Eclipta prostrata*) are the most important weeds in FL tomato production (Bewick et al. 1995, Locascio et al. 1997a, Davis et al. 1998). Other important species are listed in Davis et al. (1998). Nightshade was considered by south FL growers to be the most serious weed problem in 1984-86 (Pohronezny et al. 1989); it belongs to the same family as tomatoes and therefore its control by any means will also interfere with tomato growth. However, Davis et al. (1998) and others report that nutsedges are currently the most important weeds in the state. With the removal of methyl bromide as a soil fumigant, many anticipate that nutsedges will become a much more severe problem in tomato fields (Pernezny, pers. comm.).

Sanitation is an important tool to manage weeds, as crop seed, irrigation water, equipment and organic fertilizer (manure) may contain weed propagules. Good farm sanitation may prevent field re-infestation by tubers or seeds and certified clean transplants and filtered irrigation water also reduce contamination. Mechanical control includes activities such as plowing and disking, mowing, cultivation, hand pulling and hoeing. Williams (1974) and Williams and Warren (1975) showed that competition to tomatoes by purple nutsedge (which reduced yields by 53%) could be prevented by a single weeding 4 wk after transplantation. Cultivation is used on 100% of the acreage in FL (Davis et al. 1998). Polyethylene mulch may act as a physical barrier to weed growth; however, some weeds (i.e., purple nutsedge) can grow through the mulch (S. Locascio, pers. comm.).

Herbicides are used on 100% of the acreage in FL (Davis et al. 1998). Usually more than one product is used. Two application strategies: (1) herbicides that selectively kill weeds or (2) non-selective herbicides, where the crop is protected by adjusting timing and method of application are used in FL. Selective herbicides offer more flexibility, but excessive use has caused the development of resistance in some weeds (e.g., paraquat resistant nightshade). Soil type affects herbicide persistence, movement and relative activity. Herbicides are inactivated in soils by biological, chemical and physical means often working in conjunction. Inactivation often involves molecular degradation; binding with soil colloids also renders molecules inactive (like paraquat); others undergo volatilization (like pebulate). Ideally, herbicides should remain active throughout the season but should not persist to be harmful to the next crop. Of the herbicides registered for use in FL (Hochmuth et al. 1998), paraquat has temporary effects (1 month or less), metribuzin and pebulate provide early season control (1-3 months) and napropamide and trifluralin provide full season control (3-12 months) (Lange et al. 1986). Herbicide movement in the soil will depend on its chemical-physical properties, soil characteristics and the amount and source of water.

Leaching occurs with rainfall or sprinkle irrigation and furrow irrigation causes lateral movement. In sandy soils movement of herbicides may be considerable (Lange et al. 1986).

The herbicides registered for use in FL tomatoes are listed in Hochmuth et al. (1998). In terms of acres treated, paraquat and metribuzin are the most utilized herbicides in FL (NASS 1999). Herbicides are applied an average of once/season (NASS 1999) as pre-plant applications in row middles and field borders. As a consequence, by the time IPM scouts are in the field, all important decisions concerning weed control have been made. Nonetheless, observations by scouts will still be useful in planning for subsequent seasons or in double cropping situations (Pohronezny et al. 1989). Herbicides (e.g., diquat) are used to destroy tomato plants immediately following harvest (Davis et al. 1998). The importance of weed management has increased with the introduction of the silverleaf whitelfy (Aerts et al. 1999), as several weed species serve as alternate hosts for this serious pest.

Diseases

Over 200 diseases affect tomato plants worldwide (Watterson 1986, Jones et al. 1991). In FL, tomatoes are affected by nearly 30 disease causing fungi, bacteria and viruses; they also suffer from several physiological disorders (i.e., nutrient deficiencies, toxicities, damage from temperature extremes) that can cause serious loss (J.P. Jones, pers. comm.). The major tomato diseases in FL are listed by Davis et al. (1998) and others. Before the discovery of resistant varieties, *Fusarium* wilt (*Fusarium oxysporum var. lycopersici*) was perhaps the most destructive disease. Growers were constantly forced away from "wilt land" to newly cleared fields, and eventually entire areas of the eastern U.S. were lost to commercial tomato production (Watterson 1986). The fungus lives in the soil and can survive for years in soil not planted to tomatoes or even in fallow soil (Jones et al. 1982). Most tomato cultivars presently grown in FL are resistant to *Fusarium* races 1 and 2 (Hochmuth et al. 1998), although other races have been reported in FL (Stall 1961).

According to growers, bacterial spot (*Xanthomonas campestris pv. vesicatoria*) is the most widespread and destructive disease of tomatoes in FL (Pohronezny et al. 1989, Aerts et al. 1999). Where epidemics begin early (before flowering) losses in marketable fruit >50% have been reported (Pohronezny et al. 1990). Widespread resistance to streptomycin is documented (Pohronezny et al. 1989), and chemical control is often unsatisfactory. Despite repeated applications of copper and maneb or mancozeb (as often as 2-3 times/wk - J. Jones, pers.comm.), growers believe that bacterial spot is their most limiting disease problem. Non-chemical practices used to minimize damage include hypochlorite treatment of seed (if tomatoes are started from seed), avoidance of wet plants and destruction of summer volunteer plants (Pohronezny et al. 1989). Research on the use of a bacteriophage against bacterial spot is currently underway (J.B. Jones, pers. comm.). However, application of the bacteriophage to plants is somewhat difficult. For example, in order to avoid UV degradation the product needs to be applied at night. This, in turn, keeps tomato plants wet, which can facilitate the appearance of other diseases. The bacteriophage is also expensive to produce (S. Olson, pers. comm.). Infected transplants can be an important source of new infections (J. P. Jones, pers. comm.) and importation of other races of bacterial spot continually threatens tomato production.

Davis et al (1998) rank tomato diseases by impact on yield by state. In FL, viruses were identified as the most economically important disease problem, followed by target spot (*Corynespora cassiicola*, a fungus) and bacterial spot (see above). Pernezny et al. (1996b) reported losses of about 33% in large tomato fruit due to target spot in Florida. Viruses are discussed below with the arthropods responsible for their transmission. Pernezny (pers. comm.) believes that late blight (*Phytophtora infestans*) will cause more problems in the future due to constant threat of introduction of new and more aggressive pathogen strains into Florida. The impact of target spot in tomato production is underestimated due to the fact that its symptoms are easily confused with those of bacterial spot (Pernezny, pers. comm.).

An integrated management program for diseases involves host plant resistance (development and use of cultivars that prevent or impede the activity of a pathogen and exploit the genetically controlled differences in susceptibility to disease in *L. esculentum* and other species in the genus), exclusion (preventing the pathogen from coming into contact with the host), eradication (elimination of a pathogen after it has been established in an area), protection (use of cultural practices, manipulation of environments and planting times, regulation of moisture, adjustment of soil reaction and fertility) and protection (control of insect vectors and use of protective chemicals) (Jones et al. 1991). Tomato varieties resistant to one or more diseases are used on 86% of the fresh market acreage in the U.S.(Davis et al. 1998) and in 100% of the acreage in FL (Aerts et al. 1999). The best tomato varieties for FL are listed in Hochmuth (1997a). For a discussion on the University of Floridas tomato breeding program see below under Host Plant Resistance.

Diseases cannot be controlled by the “scout and spray” tactics used in IPM. Protective chemicals, applied on a calendar basis are required for adequate control. However, scouting may still have a substantial impact on decision making. For example, scouting may be used to evaluate the efficacy of spray programs and to adjust the choice of chemicals after laboratory confirmation of diagnoses made by scouts (Pohronezny et al. 1989). Researchers have developed new chemistries, such as methanokam, which exhibit some curative properties (Pernezny, pers. comm.) and can be used against late blight, *Pythium* diseases, early blight, gray leaf spot and target spot (Hochmuth et al. 1998).

Fungicides are used on 100% of the acreage in FL, with copper and mancozeb each used on 80% and chlorothalonil on 66% of the acres (Davis et al. 1998, NASS 1999). Copper is used against bacterial diseases (spot and speck) (Davis et al. 1998, NASS 1999). FAS (1998) indicates that the total amount of copper, fungicides and broad spectrum fumigants applied to tomatoes was higher in 1996 than in 1994. In almost all cases, it was the percentage of area receiving treatment that increased. Some bacterial pathogens are showing “tolerance” against copper in FL (Pernezny, pers. comm.).

Together with pathogen and host, it is the environment which determines whether a disease develops, and the rate and extent of such development. Temperature, moisture, light, pH, and nutrients all affect plant disease (Watterson 1986). Significant contributions towards understanding the role played by all these factors on disease development and severity have been made by University of Florida researchers. Risk forecasting of adverse weather is used more often in the eastern U.S. and can be an important tool in disease management (Davis et al. 1998).

Arthropods

Pests of tomato originated in 2 major ways. First, endemic pests of wild tomato were re-introduced to the crop when tomato was first cultivated and, secondly, local pests of other plant species adapted and shifted to feeding on tomato (Berlinger 1986). In addition, susceptibility to pests has no doubt increased inadvertently during plant domestication (Berlinger 1986). Twenty-seven species of arthropods are considered pests of tomato in FL (see Schuster et al. 1996). Davis et al. (1998) ranked FL tomato pests based on their economic importance for the period of 1989-1993. Whiteflies (*Bemisia* spp.) were the most important pest followed by leafminers (*Liriomyza trifolii*, *L.sativae*). Equal third place rankings were given to tomato pinworm (*Keiferia lycopersicella*), aphids (*Macrosiphum euphorbiae*, *Myzus persicae*) and armyworms (*Spodoptera eridania*, *S. exigua*, *S. ornithogalli*). Fourth place rankings were given to thrips (*Frankliniella occidentalis*, *F. fusca*, *F. bispinosa*, *F. tritici* and *Thrips tabaci*), loopers (*Trichoplusia ni*, *Pseudoplusia includens*), and stinkbugs (*Nezara viridula*, *Euchistus servus*), and fifth place was given to tomato fruitworm (*Helicoverpa zea*), leafhoppers (*Micrutalis malleifera*), and mole crickets (*Scapteriscus borellii*, *S. vicinus*). In a 1997 survey (Aerts et al. 1999), whiteflies and leafminers were named by growers at the most important tomato pests in south FL, followed by tomato pinworm, all caterpillar-type insects, thrips, aphids, stink bugs and mole crickets.

Mining by *L. trifolii*, the most abundant dipteran leafminer in tomatoes, results in plant desiccation and defoliation and increased susceptibility to pathogens (Schuster et al. 1996), and heavy mining can reduce photosynthesis (Aerts et al. 1999). A severe outbreak in Dade Co. in 1976-77 launched the first pilot IPM program for tomatoes in FL (see above) (Pohronezny et al. 1989). In late 1987 an outbreak in south FL of the silverleaf whitefly - SLWF - (*Bemisia argentifolii*) quickly spread to all major tomato growing areas. Phloem feeding by SLWF nymphs and adults reduces plant vigor and heavy infestations cause leaves to turn yellow and die. Honeydew produced by SLWF promotes development of black sooty mold which retards plant growth and reduces the market value of the fruit (Schuster et al. 1996). Toxins injected during fruit feeding cause irregular ripening of the fruit. SLWF are vectors of tomato mottle [TMoV] and tomato leaf curl [TLCV] geminiviruses which can result in total crop loss (Aerts et al. 1999). Virus transmission occurs even when SLWF infestations are low. Stansly (1995) examined seasonal abundance of SLWF in southwest FL and demonstrated that populations build-up in crops and migrate from crop to crop using weeds as intermediate hosts to support them over fallow periods. Parasitism of SLWF can reach 80% on weedy hosts (D. Schuster, pers. comm.).

The western flower thrips (*Frankliniella occidentalis*) and the virus they vector, tomato spotted wilt virus, (TSWV) are a serious problem for north FL growers (Kring and Schuster 1990), where the species was first detected in 1986 (Funderburk, pers. comm.). Other species of Thysanoptera also occur on tomato (*F. fusca*, *F. bispinosa*, *F. tritici* and *Thrips tabaci*). Tomato pinworm larvae (*Keiferia lycopersicella*) mine and roll the tomato foliage. Economic damage occurs when larvae attack the fruit and bore small pin-size holes under the calyx. Mating disruption as well as population monitoring with pheromone traps are available for this pest. In FL 20% of tomato acreage uses pheromone traps for pinworm monitoring (Davis et al. 1998).

Aphids (*Macrosiphum euphorbiae*, *Myzus persicae*) damage plants directly by feeding on plant sap or indirectly by vectoring plant viruses. Aphids can vector tobacco etch virus (TEV), potato virus Y (PVY) and tomato yellows virus (TYV) (Kring and Schuster 1990). The threecornered alfalfa hopper (*Spissistilus festinus*) has become a problem for north FL tomato growers. The insects fly into tomato fields and feed at the base of young plants girdling the stems. As a consequence the plants will “fall over” when it gets windy. They are a vagile species and, as such, are difficult to scout for (S. Olson, pers. comm.).

Insect management in tomatoes includes many non-chemical practices such as population monitoring through scouting, crop rotation, ditch-bank weed control, immediate crop residue destruction, use of certified pest-free transplants and the use of pheromone traps and oils (Davis et al. 1998). The 1997 survey by Aerts et al. (1999) determined that 81% of FL growers performed “deliberate” scouting activities on a scheduled basis. While not a direct control method, scouting can greatly reduce insecticide use and increase its efficiency by providing better timing and placement of applications (Davis et al. 1998). In response to scouting reports, recommendations for insecticide application are made on the basis of action rather than economic thresholds (Schuster et al. 1996). Ditchbank weed destruction (31.5% of acreage), crop residue destruction (27.5% of acreage) and isolation from suspect crops (9.8% of acreage) are practices (effective against several pests) that are only utilized in FL. Mating disruption (for tomato pinworm), pheromone traps (for monitoring tomato pinworm, tomato fruitworm and variegated cutworm), and oils (applied for whitefly and thrips control) as substitutes for conventional insecticides, are used in FL (Davis et al. 1998). Eighty nine percent of growers surveyed in 1997 indicated that their participation in IPM programs for tomatoes had resulted in an increase use of reduced risk pesticides over the last 5 years (Aerts et al. 1999).

Overall, 92,800 pounds of insecticide active ingredients were used on FL tomatoes in 1998 (NASS 1999). This included 10 products applied as either pre-plant, at planting, or as foliar treatments against a variety of insect problems. Bt products were applied on the highest number of acres (31,262 ac), followed by permethrin, esfenvalerate and abamectin (NASS 1999). In contrast, esfenvalerate is the insecticide most used on fresh market tomatoes in the U.S. (based on treated acres) followed by methomyl, methamidophos and endosulphan (Davis et al. 1998). This information suggests that FL tomato growers are shifting towards using reduced risk pesticides for insect control. Figures for pesticide use in 1994 list methamidophos (used on 84% of the acreage) as the insecticide most used in FL tomatoes (FAS 1998). However, by 1996 Bts replaced methamidophos as the most used product followed by abamectin (on 88 and 74% of the acreage, respectively) (FAS 1998).

The pesticides approved for use in FL tomatoes are listed in Hochmuth et al. (1998). In addition, Section 18 emergency exemptions have been recently granted for use of spinosad for management of thrips, and the insect growth regulators pyriproxyfen and buprofezin (which inhibits chitin biosynthesis), both for use against SLWF (Aerts et al. 1999). Confirm (Rohm and Haas Co.), which controls several Lepidoptera, has received EPA registration for use in fruiting vegetables like tomatoes (M. Aerts, pers. comm.). Currently, imidacloprid is the most widely used insecticide for SLWF management in FL tomatoes (Aerts et al. 1999). It is applied as a soil drench and can be used as a foliar spray. Almost complete reliance on imidacloprid has many believing that it is only a matter of time before SLWF develop resistance to this product (Schuster, pers. comm.). Abamectin, derived from a soil bacterium, is frequently used against leafminers, although imidacloprid is now being used against this pest. Control of thrips in tomato presents a special challenge, as accurate identification of the species present is difficult to make in the field. In addition, thrips are mostly found inside the closed tomato flower and as such insecticide treatments might not reach them. Finally, spinosad is only effective in the control of western flower thrips (*F. occidentalis*), and misidentification of the species could lead to over-utilization of this product. Before spinosad became available, thrips in north FL were controlled with fenpropathrin and methamidophos. University of Florida scientists have demonstrated that applying spinosad once per week is sufficient to control western flower thrips. Nonetheless, because of the threat of virus transmission, uneasy growers want to spray more frequently (twice per week). However, University of Florida scientists have been successful at implementing aluminum high UV-reflectance mulch plus once per week applications of spinosad for control of thrips on tomatoes in North Florida (J. Funderburk, pers. comm.)

The following are management strategies recommended by the University of Florida for controlling whiteflies. 1) Plant whitefly-free transplants; 2) delay planting new crops as long as possible; 3) do not plant new crops near or adjacent to infested weeds or crops (including tomato, cucurbits, cabbage and potato), abandoned fields awaiting destruction or areas with volunteer plants; 4) use UV-reflective (aluminum) plastic soil mulch; 5) control weeds on field edges if scouting indicates whiteflies are present and natural enemies are absent; 6) destroy old crops immediately after harvest and continue destruction of volunteer plants through the fallow period; and 7) avoid "you" pick operations unless effective control measures are continued (D. Schuster, pers. comm.).

Nematodes

Plant parasitic nematodes are small soil-borne roundworms that primarily attack the roots of plants. Nematodes are one of the major pests of tomatoes throughout the world, particularly in the subtropical and tropical regions (Anonymous 1983). Problems induced by nematodes occur as a result of root dysfunction, which directly affects utilization efficiency of water and nutrients by the plant (Gilreath, pers. comm.). Many genera and species are important tomato pests and in many cases a mixed community of species is present in the field. Root-knot nematodes are most damaging in sandy soils where injury to roots greatly reduces plant growth and yield. Monitoring involves soil sampling and checking for root galls, and principal control measures are the use of resistant varieties, crop rotation and treatment with soil nematicides (i.e., dichloropropene - Telone II).

It has been estimated that root-knot nematodes are responsible for about 29% yield loss of tomatoes in the tropics (Anonymous 1983). Nematodes may be present in fields over long periods of time or may be introduced via infested transplants, farm implements, by water (such as surface runoff) or by strong winds. Nematodes can interact with a number of other pathogens, they can predispose plants to infections, breakdown disease resistance and act as synergists in the development of disease or vector disease organisms themselves (Berlinger 1986). They can also predispose plants to infection with *Fusarium*, increasing symptoms and breaking down resistance in some tomato varieties (Gilreath, pers. comm.).

The root-knot nematode (*Meloidogyne incognita*) the peanut root-knot nematode (*M. arenaria*), the sting (*Belonolaimus longicaudatus*), the awl (*Dolichdorus* spp.), and the stubby-root (*Trichodorus* spp.) are the most important nematode pests of FL tomatoes (Locascio et al. 1997a). Infective stages invade roots where they feed and develop to adulthood. The next generation of juveniles hatching from egg masses on the surface of the nematode-induced gall infest other plants. The galls are easily detected when plants are uprooted. Above ground appearance of plants resemble the symptoms of nutrient deficiency such as leaf chlorosis, stunted growth, wilting, early senescence, and smaller and fewer fruit.

Florida uses fumigation with methyl bromide-chloropicrin on 98% of their harvested acres (Davis et al. 1998). In 1984-86 most growers did not view nematodes as a serious problem when surveyed. This probably reflected good control through the use of broad-spectrum soil fumigants (Pohronezny et al. 1989). Problems caused by nematodes will undoubtedly become more severe when methyl bromide use is discontinued.

Once present, elimination of nematodes is not possible. Application of soil fumigants or granular organophosphates and carbamate nematicides (carbofuran, aldicarb, oxamyl) can reduce nematode populations. The degree of control achieved will depend on the nematode species present and the particular growing conditions (soil type, moisture levels). Many cultural methods can be used to lower nematode populations (Anonymous 1983). Soil solar sterilization was examined by Overman (1985) and Overman and Jones (1986) as an off-season land management tool to control root-knot nematodes. Solarization was shown by Chellemi et al. (1997) to control nematodes, pathogenic fungi, and weeds in North FL although its effectiveness can vary from year to year. Crop rotation can be used to control nematodes. Few crops are completely resistant to attack but many are poor hosts and can reduce field populations sufficiently to give improved crop yields. Tomatoes should not be continually grown in the same field. A break of at least 1 year is recommended between planting tomatoes and other highly susceptible crops (like solanaceous crops, cucurbits and other vegetables). The species and race of nematodes present must be known in order to use crop rotation efficiently. Weeds (where nematodes reproduce) must also be controlled. Varieties of cereals (maize, sorghum), cruciferous crops (cabbage, cauliflower), watermelon, peanut, radish and other crops have been shown to reduce root-knot populations in fields. Plants such as sesame and *Tagetes* have nematicidal properties and have been used in crop rotation or by intercropping with susceptible plants (Anonymous 1983). Bare fallow fields are effective in reducing nematodes below threshold levels. Ploughing at 2-4 wk intervals exposes and thus kills nematode eggs and larvae. Tomatoes should be uprooted after harvest to kill nematodes present in the roots. Organic amendments (sewage sludge, manure, compost, plant bagasse) can significantly reduce nematode populations by acting as nematicides, by increasing the presence of beneficial organisms in the soil and by improving on fertilizer action. Adequate plant nutrition has been shown to help withstand nematode attack. Resistant varieties to one or more species of *Meloidogyne* nematodes are now available. Use of nematode resistant varieties depends on the species and race present and should be screened locally (Berlinger 1986).

Table 1. Acreage and fresh market production of toamtoes by areas in Florida for 1996-97.

Areas	**Planted** (acres)	**Harvested** (acres)	**Yield per Acre** (in 25lb cartons)	**Total Production** (per 1,000 cartons)
West, North, and N-Central	2,800	2,800	1,177	3,295
Palmetto-Ruskin	12,400	12,400	1,785	22,128
East Coast	4,100	4,100	1,848	7,575
Southwest	14,900	14,700	1,155	16,985
Dade	3,300	3,300	1,445	4,767
Total for State	37,500	37,300	1,468	54,750