Impact of Microirrigation on Florida Horticulture

G. J. Hochmuth[1], S. J. Locascio[1], T.E. Crocker[1], C.D. Stanley[2], G.A. Clark[2], and L.R Parsons[3]

Additional index words. citrus production, irrigation, ornamentals, small fruits, vegetable production, water conservation

Summary. The Florida horticulture industry (vegetables, ornamentals, citrus, and deciduous fruit), valued at $4.5 billion, has widely adopted microirrigation techniques to use water and fertilizer more efficiently. A broad array of microirrigation systems is available, and benefits of microirrigation go beyond water conservation. The potential for more-efficient agricultural chemical (pesticides and fertilizer) application is especially important in today's environmentally conscious society. Microirrigation is a tool providing growers with the power to better manage costly inputs, minimize environmental impact, and still produce high-quality products at a profit.

The Florida horticulture industry is valued at about $4.5 billion at the farm-gate level. Vegetables, ornamentals, citrus, and deciduous fruits make up most of the horticulture industry in Florida. Horticulture commodities are costly to produce and irrigation accounts for up to 10% of the costs of inputs. Water quantity and quality are important issues in Florida for both the general public and for agriculture. Pressure is being placed on growers to conserve water, yet still remain productive. Florida growers also are being encour-

[1]Horticultural Sciences Department, IFAS, University of Florida, Gainesville, FL 32611-0690.

[2]Gu1f Coast Research and Education Center, IFAS, University of Florida, Bradenton, FL 34203-9324.

[3]Citrus Research and Education Center, IFAS, Lake Alfred, FL 33850-2299.

Florida Agricultural Experiment Station Journal Series no. R02907.

aged to improve management of pesticides and fertilizers so that environmental impact is minimized (Hochmuth, 1989; Hornsby, 1989). Pressure placed on the agricultural industry has led to the development of production technologies that enable growers to address concerns over water quantity and quality. One technology that has had a large impact in Florida has been microirrigation. We present here the development and impact of microirrigation on the major horticulture commodities in Florida.

Microirrigation. The term microirrigation used in this paper refers to the application of small volumes of water to the root zone of a crop through various low-flow-rate emitters. Depending on the crop, microirrigation systems include:

Drip or trickle irrigation where water is applied at low pressure from emitters in a tube (usually polyethylene) placed on the soil surface or just below the soil surface near the plant. Drip irrigation is used mostly for crops such as vegetables or field-grown ornamentals growing in rows in soil.

Microsprayers and microsprinklers refer to various systems that apply water from low-flow sprayer emitters usually inserted in the end of a polyethylene water supply tube attached to a stake or riser above the ground from a buried water supply line. Water is sprayed from the emitter in various application patterns, as determined by crop cultural, irrigation, or frost-protection requirements. Microsprayers and microsprinklers are used in both field application (citrus, deciduous fruits, and pecans) and in pot culture of ornamentals.

*Spaghetti tubes are usually polyethylene tubes with a small inner channel diameter to convey water from a larger-diameter supply lateral to a plant. Spaghetti tubes can be attached to a stake or weighted at the end for positioning near the plant to be irrigated.

Vegetable. During the late fall to spring, Florida is the main producer ofvegetables in the United States. The on-farm value of vegetables in the 1990-91 season exceeded $1.6 billion from 156,200 ha, placing the average crop value at about $10,000/ha (Freie and Young, 1992). Tomato, the most important crop, with a total value of $577 million, was grown on 20,500 ha. High-value crops such as tomato, pepper, eggplant, and strawberry are grown with polyethylene mulch, soil fumigation, irrigation, and other intensive production practices.

Polyethylene mulch, first used on strawberries in Florida in 1958 (Locascio and Thompson, 1960; Thompson, 1959), has been responsible for increasing irrigation efficiency because the mulch reduces evaporation of water from the soil. By 1970, polyethylene mulch was used commonly on tomato, bell pepper, eggplant, and strawberry. At present, ≈40,500 ha (25%) of vegetables in Florida are grown with polyethylene mulch. Other advantages of mulch include a reduction in nutrient leaching, an increase in soil temperature, and better weed control; it also is used as a barrier for soil fumigation.

Most vegetables grown in Florida must be irrigated to supplement irregular rainfall to avoid water stress, and to produce economic yields. At present, the most extensively used methods of irrigation are sprinkler and subirrigation systems. It is estimated that about 38 to 50 cm ha^{-1} or 115 to 150 cm ha^{-1} of water are applied for a typical tomato crop with the two systems, respectively (Locascio et al., 1989). In 1972, Myers and Locascio found that soil moisture could be maintained at a higher level in polyethylene-mulched strawberries with half as much water when applied by drip irrigation compared with sprinkler irrigation. In 1974, Locascio and Myers reported that, in a dry year, tomato yields tripled with irrigation, and that yields similar to those produced with sprinkler irrigation could be produced with ≈50% as much water from drip irrigation. Similar savings in water applications favored drip irrigation over subirrigation for tomatoes (Clark et al., 1991).

As water shortages increased in a number of areas in Florida, and the cost of energy for pumping increased, grower interest in drip irrigation increased sharply. At present, about 8000 to 10,000 ha of high-value vegetables that are grown with polyethylene mulch, including strawberry (1600 ha), tomato (4700 ha), pepper (800 ha), watermelon (800 ha), and cucumber (400 ha), are drip-irrigated.

Some advantages of drip irrigation compared with sprinkler irrigation include the following:

- Potential for reduction in irrigation requirements of about 50%.
- Smaller pumps sometimes can be used because crop water needs generally are applied on a daily basis by drip as compared to weekly applications. For example, 19,000-48,000 liters/day are used by drip as compared with 250,000 liters/h [generally, a minimum of 2.5 cm ha^{-1} (250,000 liters) is supplied weekly] applied with one overhead sprinkler application.
- Plant nutrients and certain pesticides can be applied efficiently under polyethylene mulch by drip irrigation.
- Crop and row middles remain drier, resulting in improved insect and disease control, reduced weed growth, and better field conditions for harvesting.
- Higher yields with some crops compared to other irrigation systems.
- Initial cost for a small farm may be less due to smaller well, pump, and pipe requirements.
- Smaller beds can be used with drip irrigation compared to subirrigation (Clark and Maynard, 1992), reducing the needs for polyethylene, fumigants, and power to till soil and form beds.

Some of the disadvantages of drip irrigation include:

- The system is much more complicated to set up and operate properly. Large fields might require large pipes to meet flow requirements for large zones.
- Water filtration and chemical amendments are necessary to prevent clogging of emitters with sand, algae, bacteria, and chemical precipitates.
- Leaching of nutrients occurs when the system is operated for excessively long periods and the water applied exceeds the water-holding capacity of the soil.
- Limited lateral distribution of water in sandy soils.
- Lack of effectiveness for frost protection.
- Potential for crop injury from soil blowing from dry row middles.
- Increased labor for maintenance and management.

Improper use of irrigation recommendations has resulted in reduced crop yields with a number of drip irrigation installations. In many grower installations, the discharge rate from the drip tubing is very low, ≈0.8 liter/h per emitter. In addition, all the fertilizer is often applied before planting.

With this low discharge rate and the poor horizontal water conductivity in sandy soils, only a small soil area is irrigated. The soil-wetting pattern may extend only 12 to 15 cm on each side of the emitter in an inverted cone pattern. In an attempt to increase water distribution, the grower may continue to run the system, often 24 h/day, without effectively wetting a larger area of the soil. Soluble nutrients are moved with the wetting front. If nutrents are not added with the irrigation water, nutrient shortages often occur (Locascio et al., 1989). Due to nutrient deficiencies and poor water distribution, crop yields can be reduced. Precise management of water and nutrients is essential with drip irrigation. To produce maximum yields of high-quality vegetables, water and nutrients must be applied at adequate levels.

The water quantity applied by drip irrigation can be scheduled efficiently by use of a factor ofevaporation from a U.S. Weather Service Class A pan (Epan) at the production site, or the use of tensiometers placed in the plant bed (Smajstrla and Locascio, 1990). Typical Epan values vary from about 3 to 6 mm/day. Based on Epan, average daily water requirements for most drip-irrigatedvegetables on most soils are about 0.5 to 1.0 Epan (Locascio et al., 1992). The use of tensiometers to help schedule water application can reduce early crop water applications (Smajstrla and Locascio, 1990). For tomatoes, irrigation needs may range from 0.2 Epan early in the season to 0.75 Epan near the first harvest (Clark et al., 1991). For a 0.75 Epan, water quantities would vary from about 2.2 to 4 mm/day; this water can be appliedin one to three applications per day (Locascio et al., 1989). With tensiometer scheduling, water is applied to maintain the soil water tension below a specific level. On coarse-textured soils, soil tension should be maintained below 10 to 15 kPa at 10 to 15 cm below the drip emitters. On soils with higher water-holding capacities, soil tensions can be 20 to 30 kPa or more in the root zone without resulting in plant water stress. When the soil water tension reaches the specified value, water can be applied in an amount about equal to 0.5 to 0.75 Epan (Smajstrla and Locascio, 1990).

Nutrient requirements for most drip-irrigated vegetables are similar to those for subirrigated or sprinkler-irrigated vegetables. Soluble nutrients are leached readily by improperly operated drip irrigation systems, particularly on coarse-textured soils. Therefore, N and K applications generally must be split to produce maximum yields. Less-soluble nutrients, such as P and micronutrients, can be applied preplant with 20% to 40% of the N and K. The remaining N and K can be injected into the drip lines throughout the growth period of the crop. The weekly amount can be applied in one weekly or seven daily applications (Locascio and Smajstrla, 1989). On heavier soils, yields with split N and K application may be similar to yields when all the fertilizer is applied preplant (Locascio et al., 1989).

Initial or fixed expenses for drip irrigation systems are higher than for subirrigation or sprinkler systems, but less than for a subsurface tile irrigation system (Prevatt et al., 1981; 1984; 1992). Annual operating costs also are higher for drip irrigation systems compared to subirrigation systems because of increased maintenance and management costs (Prevatt et al., 1992). Pumping costs, however, are lower for drip irrigation than for subirrigation. Thus, drip irrigation will have the greatest economic benefits for high-value vegetables grown when water costs are high and the quantity of available water is limited.

Ornamentals. Farm receipts for ornamental floriculture crops (foliage, potted plants, greenery, cut flowers, and bedding plants) were valued at $523 million in 1991 (Florida Agricultural Statistics Service, 1992). Ornamental shrubs, trees, and sod added another $475 million. The combination of high production costs and high-value crops virtually requires that adequate irrigation systems be used. However, traditional irrigation systems do not always apply water efficiently. In recent years, issues concerning the irrigation of ornamental crops and waste of water resources have received greater attention from producers, causing them to consider improving irrigation system efficiency. Additional incentives include regulatory limitations on water supplies available for irrigation and the impact of excessive irrigation on the movement of applied nutrients and pesticides from the production area into the environment. Improved irrigation management and increased control over other cultural practices are factors that producers must consider when changing an irrigation system (Harbaugh et al., 1986; 1988; Stanley et al., 1982; 1992).

Perhaps the widest range of irrigation system options for agriculture is available for production of ornamental crops. These options include subirrigation, overhead irrigation, hand-watering, and many types of microirrigation. The nature of microirrigation and its ability to address water quantity limitations and to manage agrichemical movement make it an attractive alternative to more conventional irrigation systems.

Microirrigation systems for ornamental production include line-source lateral drip tubes, microsprayers, microsprinklers, spaghetti tubes, capillary mats, and numerous other emitter devices and systems. In general, these systems have localized application characteristics operating with low pressure requirements. Volume of water applied is controlled by the duration of operation as well as the emitter characteristics. These systems apply water to localized zones and allow precise and controlled irrigation applications. With proper management, low-volume applications can be achieved precisely. Poor management can result in excessive water applications, reducing system efficiency.

Field systems used with polyeth ylene-mulched beds have one or more lateral drip tubes in each bed. The tubes are placed under the plastic mulch either on the soil surface or at shallow depths below the surface (Harbaugh et al., 1982; Stanley et al., 1983). Because upward capillary movement of water is very limited in sandy soils, installation depths of only 2 to 8 cm are recommended for these soils.

Emitter or orifice spacing can vary from 10 cm to a meter or more. Because lateral movement of water in sandy soils is limited, emitter spacings should be close enough to provide uniform distribution of water or any additive applied through the irrigation system. Typical emitter spacings range from 22 to 56 cm on sandy soils. Greater emitter spacings can be used on heavier soils, which provide greater lateral movement of water. For more information on this type of system, see Clark et al. (1988a).

Several microirrigation systems are available for use with container-grown plants (Clark et al., 1988b). These systems include microsprayers, spaghetti tubes, and line-source drip tubes used with a capillary mat. Required operating pressures range from 35 to 200 kPa, depending on emitter type and other system design factors.

Microsprayers apply water as small streams or sprays and are used extensively in potted plant production (Clark et al., 1988b). Use in field-planted woody ornamental production systems also is common. These systems may be designed to apply water to the foliage if crop cooling or foliar chemigation is desired. However, if chemical precipitation on foliage is a problem, these systems should be designed to avoid wetting the foliage. Emitter discharge rates can vary from 20 to 200 liter/h with diameters of coverage ranging from 1 to 7 m. This allows precise water control in relatively small areas. Microsprayer systems also are sometimes used for crop cooling or frost and freeze protection. These applications generally are limited to low-height crops with foliage in or near the spray from the emitters.

Spaghetti-tube systems also are used with container-grown ornamental crops (Clark et al., 1988b). Spaghetti-tube emitters apply water as small streams or drips directly to the soil in the individual containers. The inside diameter of spaghetti tubing is small (0.09 to 0.18 cm), thus providing a restricted flow path for water control. The spaghetti tubing is cut to the desired length and then one end of the tubing is weighted or attached to a small stake and placed in the container to be irrigated. The other end is inserted into the lateral, which conveys water from the pump or water supply system. Spaghetti-tube systems are designed to deliver water and chemicals directly to the pot media when operating at pressures dependent on emitter requirements. This eliminates irrigation of nonproduction areas and increases application efficiency. Because water movement in container media is controlled by both gravitational and capillary action; damp, uniformly mixed, and well-graded potting media is needed. Use of these systems may require initial sprinkler- or hand-watering to dampen potting media.

A capillary mat system is one that applies water to a fabric mat with line-source microirrigation tubing (Harbaugh et al., 1984; Harbaugh and Stanley, 1985). The mat then distributes the water to the pots, and irrigation is accomplished by upward capillary movement of water through the peat- based potting media. As with the spaghetti-tube systems, damp potting media is necessary to establish capillarity. Therefore, sprinkler watering may be initially necessary for this procedure. Chemigation should not be used with capillary mat systems. These systems do not apply water directly to the plants or pots; therefore, control of chemical application rates and amounts is not possible. The use of controlled-release fertilizers placed in the soil in the pots is recommended to supply plant nutritional requirements.

Because water is applied so precisely, microirrigation systems can be managed for optimal water conservation. As with the sprinkler and spray systems, water should be limited to amounts that will remain within the active root zone of the crop. In addition to poor water conservation, overapplications of water can leach beneficial nutrients from the root zone (Harbaugh et al., 1982; Stanley and Harbaugh, 1983; 1989). The benefits of microirrigation systems to the ornamental industry go beyond the well-known ability to conserve water. Because environmental issues are foremost in the mind of the public, the ability to more precisely control the amounts of agrichemicals applied and to minimize the potential for movement away from the production area is very important due to the intensive culture ofornamental crops. Microirrigation systems allow application of water and nutrients under the foliage, reducing disease and lime precipitates from the water, thus allowing more control of plant quality. Sometimes, less physical labor is required for drip irrigation system operation, freeing up labor for other production duties (unless fertilizer injection and system maintenance is done manually).

Citrus. Although citrus is produced commercially in only five states (Florida, California, Texas, Arizona, and Louisiana), it [*Citrus sinensis* (L.) Osb., *C. paradisi* Macf., and *Citrus* spp.] is one of the most-important fruit crops in the United States. For the past decade, U.S. production of oranges and grapefruit alone was greater than the total U.S. production of apples, peaches, pears, nectarines, cherries, prunes, plums, apricots, avocados, strawberries, pineapple, olives, cranberries, figs, kiwi fruit, papaya, and dates combined (Florida Agricultural Statistics Service, 1992; U.S. Dept. of Agriculture, 1992). The on-tree value of the 1991-92 Florida citrus crop was $1.2 billion (Florida Agricultural Statistics Service, 1992). Between 1976 and 1990, severe freezes in Florida, California, and Texas reduced U.S. citrus bearing land area by nearly 25%- to 360,340 ha. Total bearing and nonbearing area in Florida had recovered by 1992 to 237,000 and 83,200 ha, respectively. Despite risks, citrus is still a profitable crop and is being replanted in some freeze- and hurricane-damaged areas.

Florida scientists and growers have experimented with various citrus growing practices over the years. Experiments often have focused on irrigation as one way to increase fruit production. A number of methods have been used to irrigate citrus. Early systems included traditional flood, seepage (subirrigation), or furrow irrigation. These were followed by systems using movable pipe, stationary or traveling guns, and overtree sprinklers. Economics and water-conserving trends moved the industry toward low-pressure, low-flow-rate systems. The earlier microirrigation systems consisted of drippers, usually spaced 1 m apart. Dripper output ranged from 1.9 to 7.6 liters/h with 3.8 liters/h being the most common. As an evolution from dripper systems, microsprinklers, which were introduced into Florida from South Africa in the early 1970s, commonly delivered 20 to 100 liters/h. Problems with emitter plugging from sand, calcium carbonate deposits, algae, or slime organisms were common in the early days of microirrigation. These problems have been reduced significantly by better filtration, improved emitter design, line flushing, and injection of chlorine or other preventative chemicals. While high-pressure and high-flow-rate sprinkler irrigation systems still are used commonly, microirrigation use has increased greatly during the 1980s due to better freeze protection and lower installation costs compared to sprinklers.

Microirrigation is important because it has become the most common form of irrigation in several major citrus-producing areas. With decreasing water availability and increasing energy costs, microirrigation more often is being installed to conserve water. These systems can reduce water loss by wetting only the area under or near the tree canopy. Hence, primarily the zone of greatest root density is irrigated by the microirrigation system. In Texas, with young grapefruit trees, Swietlik (1992) showed water savings of more than 90% with drip irrigation compared to flood irrigation, with no differences in tree growth, yield, or fruit size. More roots were found at a deeper soil depth with the drip treatments than with the flood treatments.

While microirrigation systems deliver less water per unit of area, they are not necessarily low-volume systems. Compared to an overtree sprinkler system that is divided into relatively small zones, a microirrigation system operating over an entire large block at one time may move a greater flow rate of water and require larger-diameter mainlines. To conserve water, proper management is a key in operating these systems. As with vegetable systems, microirrigation systems for citrus that are run for long periods of time can cause noticeable water loss through deep percolation (Koo, 1985). Percolation losses of 20% to 30% also were noted with drip systems in Israel (Bielorai, 1977). To reduce percolation losses, schedules have been developed for Florida citrus that increase frequency and decrease the length of the irrigation period (Parsons, 1989).

Depending on soil type and texture, individual drip emitters wet a soil column 0.6 to 1.5 m in diameter (Koo and Tucker, 1974). Microsprinklers cover more area and usually wet a pattern 3 to 5 m in diameter. A number of studies in Florida (Koo, 1978, 1985; Koo and Smajstrla, 1984; Smajstrla and Koo, 1984) have shown that amount of soil surface area covered by irrigation has a major effect on fruit production. More fruit production was obtained when greater ground area was covered. Compared to nonirrigated trees, yield was increased 44% by drip irrigation and 65% by microsprinklers (Smajstrla and Koo, 1984).

In Florida, greater yield in relation to increased soil area covered is probably due to higher rainfall and better root distribution. Peninsular Florida commonly receives 1200 to 1500 mm of rainfall annually, and this encourages a shallow, spreading root system. In mature groves, roots can be found below the entire soil surface. Hence, during dry periods, trees with extensive horizontal spread take up more water when irrigation coverage is greater. Zekri and Parsons (1988) found higher leafwater potential and leaf stomatal conductance values (less water stress) with overhead sprinkler systems that covered 100% of the soil surface. Greater leaf water stress was found in the drip-irrigated trees, while responses with microsprinklers were generally intermediate. Leaf, fruit, and tree canopy growth followed similar trends, with greatest growth occurring with overhead sprinklers and least growth with the drip treatments or no irrigation (Zekri and Parsons, 1989).

In more-arid climates, higher yields have not always resulted from greater coverage. In Arizona, greater growth and yield was found in young Valencia trees with drip and basin irrigation than with sprinkler irrigation (Rodney et al., 1977). The drip-irrigated trees received only 11% as much water as the flood-irrigated trees. In Israel, irrigation frequency affected number of fruit per tree, but Bielorai (1977) found no difference in grapefruit yield or fruit quality with wetting rates ranging from 30% to 70% of the soil root-zone volume. In Australia, microsprinkler-irrigated trees with partial (60% to 75%) ground coverage produced 12% greater yield than trees with full ground-sprinkler coverage (Grieve, 1989). In arid climates, where root distribution generally is restricted to the soil volume wetted, increased area of coverage may not be so critical beyond a certain point.

An additional advantage of microirrigation is the ability of the system to distribute injected chemicals to the trees. Fertigation, the injection of fertilizer into irrigation systems, now is practiced commonly, particularly on young trees. Irrigation design is of key importance to achieve uniform distribution to all trees. In areas of abundant rainfall, high root concentrations may not be restricted to areas under the emitters, particularly if granular fertilizer is broadcast widely. Under these conditions, broad ground-surface-area coverage is essential. Koo (1980) showed that leaf N concentration of fertigated trees increased with increased ground coverage, and hypothesized that 60% to 70% of the root zone should be covered with irrigation water.

Another major advantage of microsprinkler irrigation is frost and freeze protection. One of the primary reasons that microsprinkler installations increased dramatically during the 1980s was that there were five major freezes in Florida in that decade. Because overtree sprinklers caused damage in a windy 1962 Florida freeze, there was debate about the cold-protection effectiveness of microsprinklers in the early 1980s. Work in Florida has shown that microsprinklers can, indeed, be effective in major freezes (Oswalt and Parsons, 1981; Parsons et al., 1981, 1982) and are less expensive to install in new groves than solid-set sprinklers. Even when the risk of evaporative cooling was high in low-humidity, windy freezes, microsprinklers provided some protection (Parsons et al., 1985, 1991; Parsons and Wheaton, 1987). Drip irrigation provided virtually no freeze protection. Between 1979 and 1992, citrus groves with microirrigation in Florida increased by ≈500%, to more than 146,000 ha. This was due primarily to the installation of microsprinkler irrigation, the method now used most commonly for citrus frost protection in Florida.

Deciduous fruits. The use of microirrigation in the deciduous fruit industry in Florida is quite small, but is used for pecans, blueberries, and grapes. Microirrigation is used on these deciduous fruits for many reasons, but probably most important are the relatively low cost of the system and the reduced water use compared to overhead or flood-type systems.

Pecan [***Carya illinoiensis*** (Wangenh.) C. Koch], the oldest of these deciduous crops, has been grown since the late 18th century. In 1991, the total crop value of pecans from 6100 ha was $3.3 million (Florida Agricultural Statistics Service, 1991).

Early pecan orchards traditionally were not irrigated, but it was determined that yields could be increased by irrigation. The first microirrigation systems used were the bi-wall and drip-type systems, which supplied a limited amount of water to a small soil area. These systems are very efficient for establishment of young orchards. Emitters are placed next to the young trees or a small length of tubing is used to transport water to the base of the tree. Emitters are added as demand for water increases. Both above-ground (microsprinklers and microsprayers) and below-ground (drip) emitter systems now are used in Florida. Below-ground systems have an advantage of not interfering with machine-harvesting and mowing. The above-ground microsprayer types, however, give better distribution of water for large mature trees. The latter system does require more maintenance and repair.

Commercial blueberry production in Florida began with a few rabbiteye blueberry (*Vaccinium ashei* Reade) pick-your-own farms in northern Florida in the 1960s. The first commercial shipment of fresh blueberries was made in 1983 with southern highbush blueberries *(V. corym-bosom* L. hybrids), which ripened earlier than other cultivars and commanded higher prices. The area of Florida blueberries in 1989 was 580 ha of rabbiteye and 272 ha of highbush; in 1992, the crop was valued at $5.5 million (P. Sheehan, personal communication).

Microirrigation on blueberries has not been accepted as widely as with some other crops because overhead sprinklers commonly are used on blueberries for frost protection. As with pecan, the bi-wall and drip-type systems were the first microirrigation systems used. These systems had major problems with limited lateral water distribution. Also, in Florida, the well water used for irrigation is alkaline in reaction and, after one season of drip irrigation, the pH around the plant in the drip-wetted zone can be too high for optimum blueberry plant growth. Microsprayers with a head angle of 40° in each direction are used currently for most new blueberry plantings in Florida. Water is applied over a larger area than with the drip system, and microsprayers provide a better distribution of water for this shallow-rooted crop.

Two types of grapes are grown in Florida. The first type, muscadine (*Vitis rotundifolia* Michx.), is well-adapted to Florida conditions and requires minimum amounts of insect- and disease-control measures. Growth of the second type, the bunch grape *(Vitis* hybrid), was made possible by the development of Pierce s-disease-resistant cultivars suitable for Florida s severe growing conditions. The typical hot and wet environmental conditions of Florida prior to harvest make the production of a high-quality wine grape very difficult. In 1989 (Florida Agricultural Statistics Service, 1990), there were 235 ha of commercial grapes in Florida, with production valued at $821,000.

Irrigation of grapes in Florida is essential for establishment ofplantings and to sustain fruit production. About 84% (Florida Agricultural Statistics Service, 1990) of the acreage is irrigated-52% by drip and 34% by a microsprayer vineyard assembly system. The latter assembly system is attached to the water supply line that is attached about 60 cm above the ground to the trellis post. This places the irrigation distribution system off the ground and reduces the amount of maintenance due to equipment damage and allows for mechanical weed control under the trellis.

In the deciduous fruit industry in Florida, it is estimated that there will be an increased use of microirrigation because of the low cost of the systems, better fruit production, and better fruit quality compared to the use of no irrigation. Possible regulations regarding the availability of water are encouraging growers to become more efficient in their use of water.

Summary. During the past 2 decades, microirrigation of horticultural crops in Florida has increased greatly. Microirrigation has provided opportunities for small growers to irrigate crops with reduced start-up and operation costs compared to older, traditionalirrigation systems. Microirrigation has provided all growers the capability of reducing water costs in a state where increasing demands are placed on water supplies due to a rapidly increasing population. The need for efficiencies in water application is increasing along with the requirements for minimizing pollution from agricultural chemicals. These production constraints means that microirrigation will remain an important production tool for horticultural crops in Florida into future decades. Although this paper mostly deals with Florida conditions, it is likely some of the principles can be adapted to other horticultural areas in the country. Adaptation would be particularly easy for areas with similar warm, humid environmental conditions and sandy soils.

Literature Cited

Bieolorai, H. 1977. The effect of drip and sprinkler irrigation on grapefruit yield, water use and soil salinity. Proc. Intl. Soc. Citricult. 1:99-103.

Clark, G.A., C.D. Stanley, and A.G. Smajstrla. 1988a. Micro-irrigation on mulched bed systems: Components, system capacities, and management. Fla. Coop. Ext. Bul. 245.

Clark, *G.A., B.K. Harbaugh, and C.D.* Stanley. *1988b.* Irrigation of container and field grown ornamentals: Systems and management guidelines. Fla. Coop. Ext. Bul. 808.

Clark, G.A., C.D. Stanley, D. N. Maynard, G.J. Hochmutb, E.A. Hanlon, and D.Z. Haman. 1991. Water and fertilizer management of microirrigated fresh market tomatoes. Trans. Amer. Soc. Agr. Eng. 34:429-435.

Clark, G.A. and D. N. Maynard. 1992. Vegetable production on various bed widths using drip irrigation. Applied Eng. Agr. 8:28-32.

Cracker, T.E. and L. Willis. 1989. Survey of southern highbush and rabbiteye blueberries in Florida. Proc. Fla. State Hort. Soc. 102:204-206.

Freie, R.L. and N.V. Young Jr. 1992. Florida agricultural statistics. vegetable summary 1990-1991. Florida Agr. Stat. Serv., Orlando.

Florida Agricultural Statistics Service. 1990. Florida vineyard and winery report. Florida Agr. Stat. Serv., Orlando.

Florida Agricultural Statistic Service. 1991. Field crops summary. Florida Agr. Stat. Serv., Orlando.

Florida Agricultural Statistics Service. 1992. Cash receipts, 1991. Florida Agr. Stat. Serv., Orlando.

Grieve, A.M. 1989. Water use efficiency, nutrient uptake and productivity of micro-irrigated citrus. Austral. J. Expt. Agr. 29:111-118.

Harbaugh, B.K., C.D. Stanley, and J.F. Price. 1982. Trickle irrigation rates and chrysanthemum cut-flower production. HortScience 17:598-599.

Harbaugh, B.K., R. W. Henley, and C.D. Stanley. 1984. Capillary mat irrigation for bedding plants. Univ. Of Florida Bradenton GCREC Res. Rpt. BRA1984-12.

Harbaugh B.K. and C.D. Stanley. 1985. Guidelines for the choice and use of capillary mat, spaghetti tube, and trickle irrigation systems for floricultural crops. Univ. of Florida Bradenton GCRFC Res. Rpt. BRA1985-18.

Harbaugh, B.K., C.D. Stanley, and J.F. Price. 1986. Interactive effects of trickle irrigation rates with cultivars and culture on chrysanthemum cut flower production. HortScience 21:94-95.

Harbaugh B.K., C.D. Stanley, *J.F. Price,* and *J.B. Jones.* 1988. Irrigation and fertilizer management of cut chrysanthemums. HortScience 24:150.

Hochmuth, G. 1989. Managing nitrogen and water for protection of groundwater quality, p. 21-33. In: G.J. Hochmuth (ed.). Nitrogen management in vegetable production for groundwater and health protection. Florida Coop. Ext. Spec. Ser. SS-VEC-940.

Hochmuth, G.J. 1992. Concepts and practices for improving nitrogen management forvegetables. HortTechnology2(1):121-125.

Hornsby, A. 1989. Nitrogen in health and the environment, p. 3-l 1. In: G. J. Hochmuth (ed.). Nitrogen management in vegetable production for groundwater and healthprotection. Florida Coop. Ext. Spec. Ser. SS-OVFC-940.

Koo, R.C.J. 1978. Response of densely planted Hamlin orange on two rootstocks to low volume irrigation. Proc. Fla. State Hort. Soc. 91:10.

Koo, R.C.J 1980. Results of citrus fertigation studies. Proc. Fla. State Hort. Soc. 93:33-36.

Koo, R.C.J. 1985. Response of Marsh grapefruit trees to drip, under tree spray and sprinkler irrigation. Proc. Fla. State Hort. Soc. 98:29-32.

Koo, R.C.J. and A.G. Smajstrla. 1984. Effects of trickle irrigation and fertigation on fruit production and juice quality of Valencia orange. Proc. Fla. State Hort. Soc. 97:8-10.

Koo, R. C. J., and D.PH. Tucker. 1974. Soil moisture distribution in citrus groves under drip irrigation. Proc. Fla. State Hort. Soc. 87:61-65.

Locascio, S.J. and B.D. Thompson. 1960. Strawberry yield and the soil nutrient levels as affected by fertilizer rate, type of mulch and time of application. Proc. Fla. State Hort. Soc. 73:172-179.

Locascio, S.J. and J.M. Myers. 1974. Tomato response to plug mix, mulch and irrigation method. Proc. Fla. State Hort. Soc. 87:126-130.

Locascio, S.J. and A.G. Smajstrla. 1989. Drip irrigated tomato as affected by water quantity and N and K application timing. Proc. Fla. State Hort. Soc. 102:307-309.

Locascio, S.J., S.M. Olson, and F.M. Rhoads. 1989. Water quantity and time of N and K application for trickle-irrigated tomatoes. J. Amer. Soc. Hort. Sci. 114(2):265-268.

Locascio, S.J., G.A. Clark, A.A. Csizinszky, C.D. Stanley, S.M. Olson, F. Rhoads, A.G. Smajtrla, G. Vellidis, R.J. Edling, H.Y. Hanna, M.R. Goyal, S. Crossman, and A.A. Navarro. 1992. Water and nutrient requirements for drip-irrigated vegetables in humid regions. Florida Agr. Exp. Sta. USDA Southern Coop. Series Bul. 363.

Myers, J.M. and S.J. Locascio. 1972. Efficiency of irrigation methods for strawberries. Proc. Fla. State Hort. Soc. 85:114-117.

Oswalt, T.W. and L.R. Parsons. 1981. Observations on microsprinkler use for cold protection during 1981 freeze. Proc. Fla. State Hort. Soc. 94:52-54.

Parsons, L. 1989. Management of microirrigation systems for Florida citrus. Fla. Coop. Ext. Fruit Crops Fact Sheet FC-81.

Parsons, L.R., B.S. Combs, and D.P.H. Tucker. 1985. Citrus freeze protection with microsprinkler irrigation during an advective freeze. HortScience 20:1078-1080.

Parsons, L.R. and T.A. Wheaton. 1987. Microsprinkler irrigation for freeze protection: Evaporative cooling and extent of protection in an advective freeze. J. Amer. Soc. Hort. Sci. 112:897-902.

Parsons, L.R., T.A. Wheaton, D.P.H. Tucker, and J. D. Whitney. 1982. Low volume microsprinkler irrigation for citrus cold protection. Proc. Fla. State Hort. Soc. 95:20-23.

Parsons, L.R., T.A. Wheaton, and J.D. Whitney. 1981. Low volume microsprinkler undertree irrigation for frost protection of young citrus trees. Proc. Fla. State Hort. Soc. 94:55-59.

Parsons, L.R., T.A. Wheaton, N.D. Faryna, and J.L. Jackson. 1991. Elevated microsprinklers improve protection of citrus trees in an advective freeze. HortScience 26:1149-1151.

Prevatt, J.W., C.D. Stanley, and A.A. Csizinszky. 1981. An economic evaluation of three irrigation systems for tomato production. Proc. Fla. State Hort. Soc. 94:166-168.

Prevatt, J. W., C. D. Stanley, and S. P. Kovach. 1984. An economic comparison of vegetable irrigation systems. Proc. Fla. State Hort. Soc. 97:213-215.

Prevatt, J.W., G.A. Clark, and C.D. Stanley. 1992. A comparative cost analysis of vegetable irrigation systems. HortTechnology 2(1):91-94.

Rodney, D.R., R.L. Roth, and B.R. Gardner. 1977. Citrus response to irrigation methods. Proc. Intl. Soc. Citricult 1:106-110.

Smajstrla, A.G. and R.C.J. Koo. 1984. Effects of trickle irrigation methods and amounts of water applied on citrus yields. Proc. Fla. State Hort. Soc. 97:3-7.

Smajstrla, A.G. and S.J. Locascio. 1990. Irrigation scheduling of drip-irrigated tomato using tensiometers and pan evaporation. Proc. Fla. State Hort. Soc. 103:88-91.

Stanley, C.D., J.W. Prevatt, S.P. Kovach, and B.K. Harbaugh. 1982. An economic analysis of two irrigation systems for field production of cut-flower chrysanthemums. Soil and Crop Sci. Soc. Fla. Proc. 42:149-153.

Stanley, C.D. and B.K. Harbaugh. 1983. Estimating daily water use for potted chrysanthemum using pan evaporation and plant height. HortScience 19:287-288.

Stanley, C.D., B.K. Harbaugh, and J.W. Prevatt. 1983. The advantages and disadvantages of trickle irrigation for cut-flower chrysanthemum production. Univ. Fla. Bradenton AREC Res. Rpt. BRA1983-4.

Stanley, C.D. and B.K. Harbaugh 1989. Poinsettia irrigation based on evaporative demand and plant growth characteristics. HortScience 24:937-939.

Stanley, C.D., G.A. Clark, J. W. Prevatt, B.K. Harbaugh and A.J. Overman. 1992. Microirrigation of flowering ornamental crops in humid regions. USDA Southern Coop. Series Bul. 364.

Swietlik, D. 1992. Yield, growth, and mineral nutrition of young Ray Ruby grapefruit. J. Amer. Soc. Hort. Sci. 117:22-27.

Thompson, B.D. 1959. Strawberry production. Fla. Agr. Expt. Sta. Annu. Rpt. p. 166.

U.S. Dept. of Agriculture. 1992. Agricultural statistics, 1992. USDA, U.S. Government Printing Office, Washington, D.C.

Zekri, M. and L.R. Parsons. 1988. Water relations of grapefruit trees in response to drip, microsprinkler, and overhead sprinkler irrigation. J. Amer. Soc. Hort. Sci. 113(6):819-823.

Zekri, M. and L. R. Parsons. 1989. Grapefruit leaf and fruit growth in response to drip, microsprinkler, and overhead sprinkler irrigation, J. Amer. Soc. Hort. Sci. 114:25-29.