Irrigation Management and Citrus Tree Response in a Humid Climate

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Ever since pioneers from the east first settled in the western United States, irrigation has been essential for agricultural development. In the western United States, where rainfall ranges from ≈ 50 to 500 mm, supplemental water was clearly needed to grow most traditional crops. Many large-scale government-sponsored irrigation projects helped agricultural development in areas west of long. 100°W (Clemings, 1996; Reisner, 1986). By diverting water hundreds of kilometers from sources to agricultural lands or towns, these projects helped promote population growth and allowed a number of western states to become some of the most important agricultural producers in the world, generating billions of dollars in income and providing thousands of jobs.

Although irrigation has been essential for the arid western United States for many years, only recently has it become economically worthwhile in the humid eastern United States. The objective of this paper is to discuss irrigation management in a humid climate, with particular emphasis on Florida citrus. Contrasts will be made with citrus grown in arid regions. Because of competing demands from population and industrial growth, alternate sources of water for agricultural irrigation will also be discussed. A major point will be that even in areas of high rainfall, irrigation can be beneficial.

Citrus trees are perennial evergreens that are successfully grown in both arid and humid climates. Citrus is a subtropical mesophyte that has several xeromorphic characteristics (Kriedemann and Barrs, 1981); leaves have a thick cuticle and no effective stomata on the upper (adaxial) surface, and plant water requirements are lower than those of several other major crops. Water use in midsummer ranges from 0.4 to 0.5 cm/day vs. 0.7 to 0.85 cm/day for apples (*Malus domestica* Borkh.) and many field crops (Shalhevet and Levy, 1990). Citrus stomata close when vapor pressure deficits or evaporative demands are high (Camacho-B. et al., 1974; Levy and Syvertsen, 1981). The water use efficiency of citrus is relatively high compared with that of other crops, and this is commonly attributed to the high resistance of citrus leaves to diffusion of water vapor (Mantell, 1977).

IS IRRIGATION REALLY NEEDED IN AREAS OF HIGH RAINFALL?

At first thought, the installation and operation of irrigation systems in areas of high rainfall seems unnecessary. For example, citrus is primarily grown in central and south-central Florida, areas that receive annual rainfall in the range of 1200 to 1400 mm. About 1200 mm per year are required to produce a reasonable crop of citrus. Hence, if annual rainfall matches the crop requirement, why irrigate? This opinion is best exemplified by economic reports from Florida in the 1950s. Savage (1953) indicated that irrigation of citrus in Florida in the manner usually done at that time was not economical. Later work by Koo (1963) and others showed that irrigation increased yield sufficiently to make it worth the investment. Why the change in opinion? The answer lies in rainfall variability, soil types, and improvements in irrigation management and technology.

Even though Florida's rainfall averages over 1200 mm per year, rainfall can be quite variable, ranging from 836 to 1758 mm in two successive years (Koo, 1963). In addition to being too much or too little, rainfall can be quite localized and does not necessarily come when needed. Florida, like several other tropical and subtropical regions, has a dry season and a wet season. Over 60% of the rain falls in the 4-month period from June to September. Flowering and fruit set are critical periods for citrus, and they occur during Florida's dry season. Inadequate rainfall during these periods can significantly reduce yields.

Coarse-textured soils are another reason why irrigation can benefit trees in a humid climate. Most of the soils used for citrus in Florida are sandy and have very low water-holding capacities. Water content at field capacity for some Florida citrus ridge soils can be as low as 6%, and available water can be as low as 0.049 cm³·cm⁻³ of soil. Available water in California and Texas citrus soils can be 2.5 to 3 times as great (Parsons et al., 1993). With this poor water-holding capacity, irrigation is necessary in the dry season to improve yield.

The third reason for irrigation benefits in a rainy climate is improved irrigation technology and management. While commonly practiced in the western United States, flood or furrow irrigation is suitable for Florida citrus only in coastal flatwoods regions that have impervious layers at a depth of 0.5 to 1.2 m. Furrow irrigation does not work in the well-drained ridge sands that are otherwise excellent for growing citrus. Hence, irrigation methods used prior to 1960 on ridge

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sands consisted of movable perforated pipes, volume guns, or overhead high-volume sprinklers (Smajstrla, 1993). These systems covered 100% of the soil surface area. During dry periods, overhead sprinklers were usually operated for 12 to 16 h every 10 to 14 d. Most growers would allow trees to wilt or would delay irrigation for several days in hopes that rain would come and eliminate the need for that irrigation cycle. Hence, irrigation was not always applied on a timely basis; water stress developed, and fruit yield decreased.

Koo (1963) showed that irrigation could increase citrus yields significantly even in a year when rainfall was well above normal. By keeping soil moisture above one-third depletion of available water from January through June and two-thirds depletion for the rest of the year, he increased yields over nonirrigated controls. Average 'Marsh' grapefruit (*Citrus paradisi* Macf.) yield was increased by 52%, while yields of 'Hamlin' and 'Valencia' oranges [*Citrus sinensis* (L.) Osbeck] were increased by 38% and 35%, respectively. Yield of 'Pineapple' orange was increased by only 14%. Dilution of soluble solids can occur at higher irrigation rates. Total soluble solids per hectare were increased by all irrigation treatments, but because of the dilution factor, the increase was not always proportional to the increase in fruit production.

Ironically, areas of high rainfall such as Florida can have periods of drought as well as periods of flooding. Population growth, particularly along the coasts, has led to greater competition for fresh water. Demands from urban communities, agriculture, and industry have placed greater pressure on the surficial and Floridan aquifers. Regulations on water use have increased and several areas are looking for new sources of water. A desalination plant will be constructed soon in the Tampa Bay area of west central Florida.

Use of reclaimed water will also increase. Technology is now available to make use of reclaimed water, or highly treated wastewater, even within small communities. Chlorination and additional treatment can produce reclaimed water with no color or odor that is excellent for irrigation. Citrus trees have been successfully grown for over 10 years with reclaimed water in the Water Conserv II project west of Orlando, Fla. (Parsons and Wheaton, 1996). Initial fears regarding potential problems with heavy metals, flooding, and disease have proved to be unfounded (Parsons et al., 1995). Other successful projects in Florida include urban irrigation of homeowner landscapes in St. Petersburg (Parnell, 1988) and irrigation of agronomic crops near Tallahassee (Roberts and Vidak, 1994). Reclaimed water use continues to increase in both humid and arid regions.

IRRIGATION SYSTEMS AND MANAGEMENT

Drip irrigation was introduced into Florida in the 1960s and was promoted as a low-cost irrigation system that conserved water. While drip irrigation has been effective for vegetable crops in many locations, it has worked acceptably only with Florida citrus in finer-textured flatwoods-type soils. On well-drained ridge sands, soil wetting with drip systems occurs in a narrow vertical pattern with insufficient horizontal spread to wet enough roots. Also, emitter plugging problems reduced the popularity of drip systems.

Microsprinkler irrigation was introduced into Florida in the early 1970s. Microsprinklers normally deliver 20 to 100 L/hour with a spray pattern ranging from 1 to 6 m in diameter. They wet more of the roots and usually have fewer plugging problems than do drip systems. When these systems were shown to provide some frost protection for citrus (Parsons et al., 1982), microsprinklers were installed on thousands of hectares of Florida citrus. Florida became the most rapidly growing microirrigation market in the United States during the 1980s when a series of five devastating freezes hit the state. Now the majority of Florida citrus acreage is irrigated with microsprinklers, primarily because of the dual advantage of regular irrigation plus frost protection.

On well-drained sands, a few roots from some citrus rootstocks can extend laterally as much as 15 m and to a depth of more than 6 m (Castle et al., 1993). However, because of the rainfall and slightly better water-holding capacity near the soil surface, 50% to 60% of the feeder roots are in the top 90 cm of soil (Castle et al., 1993). In Florida's rainy climate, roots of mature trees extend horizontally to cover much of the

total orchard floor. In contrast, roots in arid regions are usually restricted to the wetted pattern of the microirrigation system.

Even though irrigation can increase citrus yields in Florida, rainfall is still the primary source of water; irrigation is only a supplement. In Florida, 40 to 60 cm of irrigation are normally required to supplement rainfall. Rainfall distribution also has a strong effect on citrus yields in Florida (Smajstrla and Koo, 1984). In arid regions such as Arizona, irrigation is the primary source of water, and 135 cm of irrigation can provide good yields with only slight to moderate water stress (Hilgeman, 1977).

Drainage can be a problem in both arid and humid climates. Citrus cannot tolerate flooded conditions, so good drainage is essential. On the well-drained central ridge sands, drainage is usually not a problem, but maintenance of ditches and water furrows is necessary in the coastal flatwoods areas. Lack of good drainage has been a major problem in some desert irrigation projects. This is exemplified by accumulation of selenium and other toxic elements in the Kesterson area in California (Clemings, 1996).

In Florida, the area covered by the irrigation system has a major effect on yield (Koo, 1978; Smajstrla and Koo, 1984). Increasing the irrigated area under the canopy increased fruit production. Wetting 15% to 25% of the soil area under the canopy prevented wilting but did not increase trunk growth significantly, but wetting 70% to 80% significantly increased both trunk growth and fruit yield. Using drippers and microsprinklers to vary area coverage, Koo and Smajstrla (1984) showed that fruit production increased from 39% to 64% as ground coverage increased. Another study showed that drip, microsprinkler and overhead sprinkler irrigation increased fruit production 8%, 20%, and 72%, respectively, over nonirrigated controls (Koo, 1985).

Water relations are also influenced by area covered. At the end of a spring dry period, significant differences in leaf water potential were found among grapefruit trees irrigated with drip, microsprinkler, and overhead sprinkler systems. Trees irrigated with overhead sprinklers had the highest leaf water potential (least stressed) and stomatal conductance values. Greater stress occurred in drip irrigated trees, while stress on microsprinkler-irrigated trees was generally intermediate between overhead and drip systems (Zekri and Parsons, 1988). Similar results were found with leaf and fruit growth. Even in a year of high rainfall (1410 mm) the full-coverage overhead sprinklers increased fruit size by 9% to 20% and tree canopy area by 10% to 16% when compared to the drip and nonirrigated treatments, respectively (Zekri and Parsons, 1989).

In contrast with these results in humid Florida, Dasberg (1992) summarized several experiments in Israel comparing partial soil wetting using drip irrigation vs. spray irrigation with complete sprinkler coverage. In none of the examples did partial surface wetting affect yields on a long-term basis. Trees used the same amount of water regardless of irrigation method, and no water was saved by partial wetting. Irrigation frequency needed to be adjusted to changes in wetted volume. He suggested that the root system adapted rapidly to changes in the wetted area. In Texas, Swietlik (1990) found no improvement in growth, yield, or fruit size when microirrigation was compared with flood irrigation.

The reason why increased soil area coverage improves yields in Florida but has no effect in Israel or Texas probably relates to root distribution, soil water-holding properties, and irrigation management. With the high rainfall in Florida, roots in a mature grove extend throughout much of the top 30 cm of soil. Florida ridge sands have much lower water-holding capacities than the Israel loamy clay or Texas citrus soils where coverage has little or no effect (Parsons et al., 1993; Yagev, 1977). Water from drippers penetrates directly downward through Florida's well-drained ridge sands and wets very little of the extensive, horizontal root system. With drippers, not enough of the total root system is wetted to keep the trees from being stressed. Full coverage with overhead sprinklers wets the entire root system and reduces stress. In arid Israel, where the root system may be more restricted to the wetted volume and the soil holds more water, partial coverage may wet enough of the total root system to meet plant water needs. Boman (1996) pointed out that the area of soil wetted did not affect grapefruit yield in most years in the Florida flatwoods. Low

application rates (<1 mm/h) or large coverage areas can reduce application efficiencies because of greater evaporation. Irrigation system design and management can have a major influence on tree growth and yield.

Hilgeman (1966) compared transpiration and fruit growth of grapefruit in Florida vs. Arizona. He found that on sunny days, apparent leaf transpiration rates in Florida and Arizona were generally similar, even though temperatures were noticeably higher and vapor pressure deficits were about three times as high in Arizona. He attributed the high apparent transpiration in Florida to 1) high soil water content, 2) rough lemon (*C. jambhiri* Lush.) rootstock (a vigorous, deep-growing rootstock that explores a large soil volume), and 3) full hydration of the trees by dew and rainfall. In Arizona, he found similar transpiration rates but greater leaf water deficits and fruit shrinkage. He suggested that this was caused by 1) a relatively low soil water content, 2) a root system or water conduction capability that limited water to the leaves, and 3) high leaf water deficits that induced partial stomatal closure, which then reduced transpiration.

DEFICIT IRRIGATION FOR CITRUS?

Deficit irrigation is of particular interest in several deciduous orchard crops, but can water savings be realized by deficit irrigation of citrus? Water stress affects vegetative growth sooner than it affects fruit yield or size (Hilgeman, 1977). In Arizona, 175 cm of irrigation per year minimized stress and maximized citrus trunk and canopy growth. Moderate stress (135 cm per year) reduced trunk enlargement and canopy growth but had no significant effect on average yield or final fruit size (Hilgeman, 1977). Studies from Florida and Israel indicate that flowering and fruit set are the most critical periods for water stress. Stress in the spring can cause abscission of young fruit and reduce yield. However, studies in Florida, Arizona, and Israel have shown that irrigation can be reduced after the period of June drop, and that maintaining high soil water status throughout the year is not necessary (Mantell, 1977). Partially stressed trees grew less than the nonstressed controls, but cumulative yield was not affected as much in Israel (Goell et al., 1981). The stressed trees were more compact and had a higher cropping efficiency (fruit production per unit of canopy volume).

In Florida, flowering and early fruit set occur during the dry season, but the rainy season (June to September) corresponds well with the period of fruit enlargement. Savings in irrigation are possible in the fall when the dry season returns. However, because of variable rainfall throughout the year, deficit irrigation may not be consistently successful in Florida. While water can be saved by reduced irrigation in the fall and winter, excessive water stress then can exacerbate freeze damage (Koo, 1981).

For optimum production, irrigation is needed in both arid and humid climates. Improvements in microirrigation technology, better management practices, and increased use of alternate water supplies should lead to more effective irrigation water use in both climates.

CONCLUSIONS

In humid or rainy regions, irrigation was not considered to be necessary or economically justified for crop production prior to 1955. Since the 1960s, work in Florida has shown that irrigation can benefit citrus growth and yield even in a humid climate. The reasons for this include rainfall variability, soils with poor water-holding capacities, and improved irrigation technology and management. In arid climates, irrigation coverage is apparently less critical than in Florida, where increased coverage has increased yield. These differences are probably due to differences in soil type, rainfall, and volume of the root system. Reclaimed water has considerable potential for irrigation. For optimum citrus production, irrigation is needed in both arid and humid climates.

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