Irrigation and Water Management

- Aquatic Weed Management in Citrus Canals and Ditches
- Control and Automation in Citrus Microirrigation Systems
- Drainage Systems for Flatwoods Citrus in Florida
- Irrigation Topics
- Managing Salinity in Florida Citrus
- Outline for Managing Irrigation of Florida Citrus with High Salinity Water
- Related Water Quality Topics Menu
- Water and Environmental Considerations for the Design and Development of Citrus Groves in Florida
- Water Management District Considerations for Florida Citrus Groves
- Water Resources for Florida Citrus
- Water Table Measurement and Monitoring for Flatwoods Citrus

Return to...

- Commercial Citrus Handbook
- Related Water Quality Topics Menu
Drainage Systems for Flatwoods Citrus in Florida

Brian Boman and Dave Tucker

Introduction

Water table levels fluctuate widely in the coastal Flatwoods areas of Florida during the rainy season due to the effects of variable soils, nonuniform rainfall, and high intensity rainstorms (Fig. 1). Drainage of the soil water is especially important in the wet season since citrus root damage may occur under prolonged conditions of high water table. Effective water management, which includes both irrigation and drainage on these poorly drained soils is essential for profitable citrus production.

Figure 1. Satellite view of the "Parade of Storms" taken August 30, 1995 by the GOES-8 satellite in geosynchronous orbit 22,300 miles above the earth.

Both surface and subsurface drainage are generally required for citrus grown in Flatwoods areas. Drainage systems in Flatwoods groves consist of systems of canals, retention/detention areas, open ditches, subsurface drains, beds, water furrows, swales, and the pumps required to move the drainage water. These systems require continued good maintenance in order to minimize the chances of root damage from prolonged exposure to waterlogged soils following high intensity rains. Drainage systems should generally be designed to allow water table drawdown of 4 to 6 inches per day, which should be adequate to prevent root damage.
Soil Water Dynamics

Research has shown that there is potential for water damage to citrus trees if roots are submerged in water for four days or more during frequent extended summer rains. During the cooler months of December through February, citrus trees can tolerate flooded conditions for longer periods than during the hot summer months.

In order to understand how citrus is damaged by flooding, one needs to understand the soil-water dynamics in a grove. In most Flatwoods soils, a clay or organic layer within 20 to 48 inches of the surface acts as a barrier to downward movement of excess water (Fig. 2). As a result, water must move laterally to be drained from saturated soils.

The rate at which water moves through soil in units of distance/time (in./hr or ft/day) is called hydraulic conductivity. Sands typically have saturated hydraulic conductivity of 20 inches per hour or more, while the saturated hydraulic conductivity of many Flatwoods soils with significant clay content is in the range of 0.1 to 0.2 inches per hour. Hydraulic conductivity varies tremendously with soil moisture content. For example, when saturated an Oldsmar fine sand soil has a hydraulic conductivity of about 20 inches per hour. The rate drops to less than 0.05 inches per hour at a tensiometer reading of about 85 cbar. Porosity is the volume of pores (air space) divided by the total volume of soil. The higher the porosity, the more water that will drain out of the soil when the water table is lowered.

Gravity is the force that moves water in saturated soils. Therefore, water in saturated soils moves from a higher level to a lower level. The difference in elevation between two free water surfaces is called the hydraulic gradient. The steeper the gradient, the faster water will drain from the soil. Excessive rainfall will cause a perched water table to develop above the hardpan in flatwoods soils. Rainfall that infiltrates moves downward to the free water surface (water table), and then must move laterally towards the water furrow for drainage to occur. As a result, a mounded (perched) occurs in the water table between the water furrows.

The time required for this mound of water to recede back to level conditions varies greatly with soil texture, and the condition and quality of the drainage system. The time may vary from 2 days in coarse-textured soils such as Pineda, Riviera, and Immokalee series soils to over a week in heavier textured soils such as Winder. Under normal conditions where drainage systems are adequately designed and maintained, water usually recedes at rates adequate to prevent root damage. Problems occur when heavy rainfall results in elevated water tables for several weeks. Once the soil is near saturation, it takes only a little rainfall to fill the available pore spaces in the soil, and the root zone becomes saturated. When the air is excluded, anaerobic conditions which promote root decay can develop.
If the surface runoff is removed quickly following rainfall events and the water furrows are free of water, the initial drawdown of the perched water table in the beds may be relatively fast. Since the difference in elevation between the free water surfaces in the bed middles and the water furrows is relatively large, maximum drainage rate will result. As the water drains from the beds, the height of the free water surface in the beds decreases, and the mounded water table becomes less pronounced. The rate of drainage from the beds will slow due to a decreased hydraulic gradient. A similar situation occurs when the water level in the furrows is relatively deep. The decreased gradient prevents water from draining from the beds at a high rate.

Observation wells are good tools for observing soil-water dynamics. They are the only reliable method for evaluating water-saturated zones in sites subject to chronic flooding injury. These wells can also be used to measure the rate of water table drawdown, which is the real key to how long roots can tolerate flooding. Observation wells constructed with float indicators allow water tables to be visually observed while driving by the well site. Local offices of the Natural Resources Conservation Service (NRCS) can assist with water table observation, well construction, and monitoring.

**Water Damage to Trees**

Short-term estimates during flooding stress can be obtained by digging into the soil and smelling soil and root samples. Sour odors indicate an oxygen deficient environment. The presence of hydrogen sulfide (a rotten egg odor) is an indication that feeder roots are dying.

Anaerobic bacteria (which grow only in the absence of oxygen) will develop rapidly in flooded soils and contribute to the destruction of citrus roots. In a field survey of poorly drained groves, toxic sulfides were formed by anaerobic sulfate-reducing bacteria at more than half the locations. Nitrites, formed by nitrate-reducing bacteria, and other organic acids that are toxic to roots were also found in these flooded soils.

Improper bed construction has been linked to areas with chronic root damage in several groves. Severe sulfide problems have often been found in grove areas that were developed over old swamps which were filled in before planting. Palmetto, cabbage palms, and other decomposable organic debris were frequently buried in these areas where land was leveled during preparation. It can take many years for Palmetto roots and stems to decompose in this environment. Certain organic acids in Palmetto, grass, and citrus roots provide a good source of energy for reducing bacteria which require both energy and sulfates in order to reduce sulfates to sulfides. Thus, it is possible for citrus roots to contribute to their own destruction by acting as an energy source for these bacteria. Only small amounts of sulfur (3 ppm) are required for the bacteria to function at peak capacity. The forms of sulfur used by the bacteria can be elemental sulfur, thiosulfate, sulfites, or sulfates which are usually present in all Florida soils.

Using topography alone as a diagnostic factor to assess potential for flood damage may be misleading. Flooding injury can occur in obvious spots such as poorly drained depressions (Fig. 3), but it may also be present where least expected. Flood injury has been observed on hillsides, on relatively high ground, on isolated areas of flat land, and even on raised beds. Hillsides may have pockets of clay. In flat areas, the problem may be impervious clay, marl, or organic-layered pockets that hold the water and prevent movement. Even beds in apparently uniform sandy areas can have buried palmetto roots and organic materials. These areas are subject to root damage since the soils are able to support bacteria which can quickly generate toxic hydrogen sulfide if flooded. Old pond sites are prone to severe flooding injury. Trees on the periphery of old pond sites are often damaged as much as those in the middle.
Drainage Systems for Flatwoods Citrus in Florida

Figure 3. Localized water damage to trees resulting from differences in water table levels.

Good drainage allows air to move into the soil and prevents oxygen-deprived conditions. Flooding stress is usually less when water is moving than when water is stagnant, for anaerobacteria cannot multiply if oxygen is present. Also, a higher subsoil pH may help to delay, for a few days at least, the death of citrus roots under flooded conditions.

With experience, flooding injury can be diagnosed during periods when groundwater levels are high. Even before there are visible tree symptoms, auguring and digging in the root zone may give an estimate of future tree condition. Indications of problems include high water tables with saturated soils in the root zones, sloughing roots, and sour odors in the soil. When the water table recedes, visible damage to the trees may become more obvious. New feeder roots appear and grow rapidly on trees that have survived and received adequate irrigation.

Symptom expression of damage may occur over a period of time depending on the severity of root damage. Symptoms usually start to show up after the water table drops and the soil dries out. Root damage symptoms include leaf yellowing, chlorosis, wilting, fruit drop, leaf drop, and dieback (Fig. 4). Often root damage is so severe that trees may go into a wilt even though water furrows are still wet (Fig. 5). Because the root system was pruned by the flooding, the full extent of damage may not be known for several months or until drought conditions occur.

Figure 4. Early symptoms of water damage showing foliage discoloration, wilt, plus leaf and fruit drop.
Figure 5. Advanced symptoms of water damage showing extensive defoliation and fruit drop.

Young trees are often more sensitive to flooding and may develop symptoms resembling winter chlorosis. More subtle symptoms include reduced growth and thinner foliage. This can occur at locations only a few inches lower in elevation that the surrounding area. Harvesting operations in a grove even after recent flooding may also further damage surface roots that have been injured by the flooding.

Hot, dry conditions following flooding will hasten the onset of stress and symptom expression. The reduced root system resulting from summer flooding is incapable of supporting the existing tree canopy. When this occurs, irrigation management becomes critical. Irrigation must provide moisture to a depleted (shallow) root system. Excessive water could compound existing problems. If root system damage is extensive and tree canopy condition continues to deteriorate with permanent wilt and foliage dieback, some degree of canopy pruning may be necessary to reestablish a satisfactory shoot/root balance.

Light frequent irrigations will be required until the root zone has been reestablished. Subsurface moisture should be maintained to promote root growth into the lower root zone. If root damage is severe, frequent irrigation may even be required throughout the winter months, especially if dry winds persist. If irrigation water is high in salts, frequent irrigations are essential to prevent salt buildup, which will compound the flooding problem.

When trying to assess flood damage, *Phytophthora* foot rot problems may also need to be considered. However, if *Phytophthora* was not a problem before the flooding, excess flooding will not necessarily create one. Therefore, do not make costly soil or foliar fungicidal applications for the control of foot rot and feeder root rot unless soil propagule counts reveal such treatments are warranted. Soil and root conditions should be evaluated after the flooding has subsided and the potential for fungal invasion has been determined. If there are high propagule counts, *Phytophthora* root rot can accentuate the consequences of flooding injury. While certain fungicides can help protect new roots during development if there is a *Phytophthora* problem, they will not bring dead roots back to life.

If flooding occurs, tree management must be intensified to minimize the effects of stress on water-damaged trees. Flooding will not always damage tree root systems (Fig. 6), but chronic water problems can result in massive root destruction (Fig. 7). Trees should be closely monitored for symptoms. Duration of flooding conditions, rate of water table drawdown, presence of sulfur or organic matter in the soil, nature of the soil, tree age, rootstock, and root condition are all factors to be considered when trying to evaluate flooding injury and manage tree recovery. Other cultural practices should be adjusted to minimize stress on water-damaged trees. Fertilization rates and schedules may need to be adjusted for flood-damaged trees. Light ground applied or foliar fertilizer applications on a more frequent schedule are preferred until the root system becomes re-established. Once the immediate drainage problem has been alleviated, the appropriate course of action is to wait, observe, and let tree response guide your actions.
Drainage System

On the Ridge, drainage is not usually required. In the Flatwoods the naturally high water table must be controlled and provision must be made for the rapid removal of excess surface water from rainfall. Control of the water table is achieved via the construction of evenly spaced ditches in addition to beds. The use of drain tiles may be employed, particularly in problem areas resulting from the general non-uniformity of soils. However, some growers routinely install drain tile to control the water table in addition to beds, swales and ditches.

The initial consideration of suitability of a drainage system on a particular area requires a topographic survey. Since most of the Flatwoods citrus areas are either nearly level or of basin-type topography, sufficient slope for gravity outfall probably won't exist. Therefore, a drainage pump for the outlet will most likely be needed. Aerial photographs along with the survey, should facilitate selecting a suitable site for the drainage sump in a low area of the grove (Fig. 8). Before constructing the drainage system, check with the appropriate water management district to ensure that the system will not impact wetlands.
A survey will also help determine if leveling of the land is required. Open ditches and water furrows may be required to remove the bulk of surface water. If shallow beds are to be constructed, they should be designed to minimize the quantity of earth moved in the leveling process. Drains should be installed in direction of greatest slope.

There are several important soil factors that should be obtained from a soil survey of the area prior to the drain design. These factors include:

1. Soil types

2. Thickness of various soil layers (especially clay)

3. Continuity of soil layers

4. Position of layers with respect to ground surface

5. Hydraulic conductivity and porosity of layers

Several water factors need to be considered to ensure a proper design of the drainage system. Historical records can be examined to determine the relationship between rainfall and water table fluctuations. The source of all water coming into an area must be determined. If the water table is built up by irrigation, it may indicate that there is an improper system design, and that better management or a change in design may alleviate some of the water table problems. Seepage from reservoirs and ditches is often a source of high water tables in nearby areas of the grove. Money spent on perimeter ditches or throw-out pumps may decrease the drainage requirement. If there are free-flowing artesian wells, they should be capped or plugged.

**Beds and Water Furrows**

Rows are typically oriented north-south and consist of beds constructed with vee-ploughs and/or motorgraders between water furrows that are generally 48 ft to 55 ft apart. Water furrows are cut 2 to 3 ft deep and the soil is mounded between them to provide a 2.5-3.5 ft bed height from the bottom of the water furrow to the crown of the bed (Fig. 9). Beds of these dimensions are the most common and they accommodate two rows of trees 22 ft to 28 ft apart (Fig. 10).

Single-row beds are used by some growers but are becoming increasingly rare. Wider, multiple-row (4-6) beds are sometimes used in areas where shallow fractured limestone is encountered. Prior to bedding, it is
advantageous to laser-level the land to facilitate rapid surface water removal by the swales.

Figure 9. Double-row bed under construction.

Figure 10. Young trees on double-row bed with water furrow in center.

**Lateral Ditches**

Lateral drainage ditches (Fig. 11) should be cut at right angles to the beds and water furrows and spaced no further apart than 1320 ft center to center. Topsoil spoil from the ditches can be used to provide fill for low areas in the adjoining fields. Subsoil spoil can provide a grove road base on either side of the lateral ditch. Swales drain into the ditches via 6-8 inch flexible polyethylene or rigid pipe that can be installed either before or after swale construction. A laser level is sometimes employed in this operation, but is not essential. The pipe is installed in the bottom of the water furrow and sloped to discharge approximately 1 ft above the bottom of the ditch. Ditch size will vary depending upon the area served and water management district criteria. In general, lateral ditches should have a minimum of 14-15 ft top width, 4 ft bottom width, 2:1 side slopes, and a depth of at least 5 ft.

Figure 11. Lateral drainage ditch with water furrow outlet pipes discharging into ditch.
Collector Ditches

Drainage water from several lateral ditches runs into collector ditches and is conveyed off-site. Gravity drainage is preferred if topographic relief allows. However, discharge pumps are required where there is insufficient relief (Fig. 12). Size of the collector ditches and any related pumping facilities is dependent on several factors, such as size of the area being served, soils, bed and water furrow design, and slope of ditches. The surface water drainage system should be designed to remove at least 4 inches per day from the grove.

Off-Site Discharges

The main grove runoff concerns center around effects on wetlands and water quality. In addition changes to surface water discharge rates must be addressed to meet criteria adopted by the Water Management Districts. A surface water management system for citrus production in the Flatwoods should be designed to remove at least 4 inches in 24 hours. Properly designed surface water management systems can minimize storm water runoff rates. Runoff rates are reduced by designing surface water detention areas that are interspersed between the grove area and the ultimate off-site discharge points. Typically these are diked off areas that receive inflow from the grove area either via gravity or pumped discharge (Fig. 13). Outflow from the detention areas (often called reservoirs) passes through discharge structures (Fig. 14) that are designed to restrict the flow rate to pre-development peak rates. Water levels thus build up in detention areas for a short period of time following major rainfall events.
Perimeter Ditch and Off-Site Discharge

In order to intercept and control the off-site water table and off-site surface flows, it is necessary to construct a perimeter ditch and dike. The dike is located external to the ditch. Frequently the ditches can serve as collector ditches. The actual size of the ditches depends on anticipated flow rates. High water tables or natural drainage from adjacent undeveloped properties may result in subsurface flow towards a grove. Pumps may be required in the perimeter ditches to intercept this seepage water in order to maintain satisfactory water table depths in the developed grove.

Discharges are normally controlled with some type of water control structure where the water depth and discharge rate can be regulated (Fig. 15). In areas prone to erosion or at changes in ditch direction, structures may be required to prevent scouring of banks (Fig. 16).

Figure 14. Weir structure used as outfall from water detention area.

Figure 15. Water control structure used to maintain water level and drainage rate from citrus grove.

Figure 16. Erosion control structure on grove discharge canal.
Tile Drainage

Design Considerations

Drain tiles may be installed for additional control of the water table. Perforated 4 inch diameter, flexible polyethylene pipe covered with a nylon fabric sock installed down the center of every other bed normally provides effective control. The pipe should be installed on a slope corresponding to the flow of the swales at depths averaging 3 ft to 4 ft or less depending upon the location of spodic or clay horizons. Generally speaking, drain tile should not be installed below the depth of the hard pan horizons.

Corrugated plastic drain tubing (Fig. 17) should meet the requirements of ASTM Standards F405 and F667, which, among other aspects define quality classes. Standard tubing is satisfactory for most agricultural applications. Heavy duty tubing is recommended where wide trenches are required, where side support is poor, in narrow trenches (where width is less than 3 pipe diameters wide), and where rocky soil conditions are expected.

Figure 17. Four-inch corrugated drain tubing with polyester sock.

Tubing normally used in agricultural operations is 4 inches or greater in diameter. The tubing is available in coils of various lengths, depending upon the diameter of the tubing. Water enters the plastic tubing through small openings located in the valleys between corrugations. The flexible drain tubing gains most of its load-bearing capacity by support from soil at the sides of the tubing. A load on top of the tubing causes the sidewalls to bulge outward against the soil. The soil resists the bulging, and the effect is to give the tubing a greater load-bearing capacity. The tubing must have sufficient strength to withstand the soil load without excessive deflection, collapse on top, or failure of the sidewalls.

Corrugated plastic drain tubing has several desirable characteristics. The tubing is light and flexible, weighing about 85 lbs per 250 ft of 4-inch tubing. The tubing allows good alignment in unstable soils. The flexibility of the tubing allows long lengths on each roll with few joints required in the field, making good installations relatively easy (Fig. 18).
Drainage Systems for Flatwoods Citrus in Florida

Soils

Soils that are satisfactory for citrus in Florida but need profile subsurface drainage are listed in Table 1. The actual soil characteristics of soil profiles have pronounced effects on depth and spacing of drains. It is common to find several different soil types in the same field so that adjustments in drain spacing may be necessary. The spacings at the minimum drain depth should result in a good rooting volume for the trees located midway between drain lines. Additional depth or closer spacing should result in additional rooting volume.

Drain Depth

The drain depth is often controlled by the depth of the outlet. Drains should be placed in the most permeable layer possible. However, the drain tubing should be installed at a constant slope, even if the tubing is located in a less permeable horizon for a portion of its length. The drains should have a minimum of 24 inches of cover to prevent collapse from traffic and heavy equipment.

Alignment

Changes in the horizontal direction should be minimized and made in such a way that the specified grade is maintained. Any change of alignment should be made with a gradual curve, the use of manufactured bends or fittings, or the use of junction boxes or manholes.

Drain Capacity

The drainage coefficient should be at least 0.5 to 0.75 inches per day for most groves. The design depth and spacings given in Table 1 are based on a drainage removal coefficient of 0.75 inches per day, which should provide a water table drawdown of 4 to 6 inches per day. This rate should be adequate to prevent root damage in most cases. If surface water must also be removed, the drainage coefficient should be doubled to accommodate the extra water which needs to pass through the drains. Approximately one inch of rainfall entering the soil can raise the water table as much as one foot.

Spacing

The spacing between drains depends on depth installed, hydraulic conductivity, and amount of water to be drained. When two (or more) drain lines are installed, each one exerts an influence on the water table and the drawdown curves intersect at the midpoint between the drains. As the drains are moved closer together, the curves intersect at a lower level at the midpoint between drains.

Figure 18. Rolls of 4-inch corrugated drainage tubing.
Grade

The grade (slope) at which the drain is installed should be based on site conditions, size of drain, and quality of installation. Minimum grades are:

4-inch = 0.10% (1.2 inches per 100 ft)

5-inch = 0.07% (0.8 inches per 100 ft)

6-inch = 0.05% (0.6 inches per 100 ft)

The maximum grade should result in a flow velocity not exceeding 3.5 feet per second (fps) for sand or sandy loam soils and 7.0 fps for clay soils. Velocities exceeding these rates require the installation of protective measures such as air vents or relief wells on the drain tile. A gradual variation of up to 0.1 foot from the specified grade is allowable in most cases.

Connections

Manufactured couplers or fittings should be used at all joints. All connections must be compatible with the pipe. All fittings should be securely joined so they cannot come apart in the installation process, and the envelope material or "sock" should be taped or secured to provide integrity to the entire drain after installation.

Outlet

Outfall from the grove site is a first priority. Sufficient engineering surveys must be conducted to determine the existence of a natural water outlet from the grove site before considering a drainage system. Permits might be required by Water Management Districts or other agencies before large quantities of water can be removed rapidly from poorly drained wetlands. Drainage outlets that discharge into state waters are considered point source discharges by local and state pollution control authorities, and approval to discharge into such waters should be obtained during the planning stage of a drainage or water management system.

A sump-and-lift-pump type outlet may be necessary for subsurface drainage, but it may significantly increase drainage system construction costs. Sumps should be located at low ends of collector ditches. Float-controlled pumps that allow automatic operation are preferred. The pump should be sized to remove the design capacity for the drained area. Drain outlets should be 6 inches above the normal water level in the ditch. In addition to sunlight weakening the plastic drainage tubing, it can be destroyed by fire or damaged by rodents or ditch maintenance procedures. Therefore, the discharge end should be rigid PVC (Fig. 19). At least 2/3 of the PVC pipe should be embedded in the ditch bank. The rigid outlet pipe may need an animal guard to keep rodents from entering and plugging the tubing.
Example

Determine drain spacing for an Adamsville fine sand series soil with trees planted at a 25 foot across-row tree spacing on 50 ft wide beds. The tree spacing must be selected so that the drain trench will fall between rows or in the middles of double beds rather than in water furrows. From Table 1, the minimum spacing for Adamsville is 71 ft at a depth of 46 inches. The drain spacing can increase 6 feet for each inch the drain is installed deeper than 46 inches.

Since beds are 50 ft wide, a spacing of 100 feet results when drains are installed in every other bed.

Determine the required depth when drains are installed at 100 foot spacing.

Extra width greater than minimum = 100 ft - 71 ft = 29 ft

\[
\text{Extra depth} = \frac{29 \text{ ft}}{6 \text{ ft/inch}} = 4.8 \text{ inches} \rightarrow \text{round to 5 inches}
\]

Eq. 1.

The trench would have to be lowered 5 inches.

The trench depth in Table 1 should be applied closer to the upper end rather than near the drain outlet. It is better to be too deep than too shallow. Clay subhorizons can limit the effective drain depth. In addition, drains placed directly in spodic horizons increase the risk of increased hydraulic entry resistance and biological clogging potential.
Installation Considerations

Most corrugated drainage tubing in Florida citrus groves is installed with plough-type machines (Fig. 20), which are generally capable of installing the tubing more economically than the slower chain-type machines.

Tubing should be installed so that it does not deflect more than 20% of its nominal diameter. The plastic tubing has reduced strength at high temperatures. During installation on hot sunny days, the temperature of the tubing can reach over 120°F. The strength of 4-inch tubing is reduced 50% when the temperature is raised from 70°F to 120°F. Therefore, precautions must be taken to prevent sharp impacts, heavy objects, or excessive pull on tubing during installation.

The strength of the tubing can also be reduced by stretching that may occur during installation. The amount of stretch during installation is influenced by the temperature, the amount and duration of drag encountered when the tubing is fed through the installation machine, and the stretch resistance of the tubing. Stretch should not exceed 5%, which reduces strength by about 11%.

Plastic tubing will float in water. During installation, it is essential that backfill material is placed around the tubing immediately and correctly if water is present so that the tubing does not get misaligned.

Care should be taken in all soils to prevent surface soil that contains organic material from being placed around the drain tubing. Likewise, the tubing should not be bedded in the organic layer of spodic soils. The organic material tends to trap iron and provide an energy source for the iron-reducing bacteria which cause ochre buildup.

Upon completion of installation, a map or aerial photograph with the drains located should be prepared immediately to identify the precise location of the drain lines. Drain lines can be located using a small rod (3/8 inch) with a sharpened tip to probe for the tubing. The probe may penetrate the tubing when it is found, but it will not seriously damage it as the hole will tend to close when the probe is withdrawn.

Drain Clogging

The main types of deposits associated with bacterial activity in subsurface drains in Florida are ochre and sulfur slimes. Iron deposits (collectively called ochre or iron oche) are the most serious and widespread. Ochre deposits and associated slimes are usually red, yellow, or tan in color. Ochre is filamentous (from bacterial filaments), amorphous (more than 90% water), and has a high iron content (2 to 65% dry weight). It is a sticky mass combined with an organic matrix (2 to 50% dry weight) that can clog drain entry slots, drain envelopes, and the valleys of the corrugations between envelope and inlet slots. Ochre often contains appreciable amounts of other minerals such as magnesium, sulfur, and silicon. Ochre can usually be detected at drain outlets or in manholes as a voluminous and gelatinous mass. Unfortunately, ochre may also be present in drain sublaterals, and not necessarily at the outlets. Under those conditions, it can usually be detected by excavation of poorly drained spots in a field. There are still disagreements concerning the physical, chemical, and biological factors contributing to ochre formation. For example, the gelatinous mass can trap fine soil particles so that ochre may contain more than 30% sand. In addition, old ochre can become crystallized and hard.

Sulfur slime is a yellow to white stringy deposit formed by the oxidation of the hydrogen sulfide that may be present in ground water. Soluble sulfides are oxidized to elemental sulfur, predominately by the bacteria Thiothrix niuea and Beggiatoa sp., so that globules of elemental sulfur are deposited within the filaments of
the bacteria. The fluffy masses of slime are held together by intertwining of the long filaments of the bacteria. Sulfur slime usually is not a serious problem in most agricultural drains. It is found most frequently in muck soils or in areas where the water used for irrigation contains hydrogen sulfide.

**Ferrous Iron in Ground Water**

Ferrous iron is a primary raw material for ochre formation, and it must be in solution in the ground water rather than just located on soil particles. Ferrous iron will be present in ground water of flooded soils only after the soil oxygen has been depleted. When that happens, certain iron-reducing bacteria attack and reduce insoluble ferric iron associated with mineral and organic soil particles. The biological action of the bacteria is energy-intensive, so that energy sources that can be utilized by bacteria must be present. This process cannot take place in a flooded soil without the action of specific bacteria. The bacterial bodies must be present and in direct contact with iron attached to soil particles.

There is often more ferrous iron in the ground water of sandy soils and organic muck soils than in loamy and clay soils. Sandy soils usually have the most ochre problems. Flooding sandy soils excludes air rapidly and less energy is required for bacteria to reduce iron to the soluble ferrous form. Sandy soils may receive sufficient organic carbon from plant roots or organic residues. Iron is often available from within sandy clay pockets and organic pans (spodic horizons). Organic and muck soils usually have sufficient iron and readily available organic carbon. Consequently, muck soils often have severe problems from ochre clogging.

Clay soils, unless mixed with organic matter, typically have little if any ferrous iron in the ground water. Even when flooded for extended periods, groundwater in clay soils generally has little ferrous iron since the suitable organic carbon level is often insufficient for strong iron reduction. In addition, the strong electrochemical bonds between the ferrous iron ion and clay particles prevent the ferrous iron ions from disassociating into the groundwater.

Soil pH is also a factor in potential ochre formation because the amount of ferrous iron is usually higher in the ground water at pH values below 7.0. Soluble ferrous iron flowing in ground water enters a different environment as it approaches the drain and passes through the drain envelope. If a low level of oxygen is present, certain filamentous and rod-shaped bacteria can precipitate some of the ferrous iron, forming insoluble ferric iron and incorporating it into ochre complex.

Ochre as a clogging factor may diminish or disappear over a period of 3 to 8 years if drains are maintained in a free-flowing condition. Many times ochre occurs rapidly and often can be detected at drain outlets within the first few months after drain installation. If drains can be maintained in working order, ferrous iron reaching them may diminish over a period of time.

**Processes of Ochre Deposition**

The minimum ferrous iron concentrations that can stimulate ochre formation is between 0.15 and 0.22 ppm. Iron-precipitating bacteria must be present for extensive clogging to occur, even when other conditions are just right for chemical precipitation of the iron. Iron alone does not have serious sticking properties. The reaction in drain tubes is a combination of bacterial precipitation and the incorporation of chemically precipitated iron into the sticky slimes of the bacterial masses involved in the ochre matrix.

There are several kinds of processes involved in ochre deposition. All of them do not occur under the same conditions. All of the reactions do require some oxygen to be present in the drain line.
Oxidation of the iron by certain bacteria predominantly on the outside of the organisms, as shown by electron micrograph pictures.

Auto-oxidation (chemical change) and precipitation with subsequent accumulation of the colloidal iron on the sticky surfaces of bacterial slimes.

Bacterially precipitated iron from complexed soluble organic-iron compounds.

The soluble complex before precipitation may be either ferrous or ferric iron. The most effective iron-precipitating bacteria in drain pipes have been groups consisting of long filaments, such as *Gallionella*, *Leptothris*, and *Sphaerotilus*. They can grow quite rapidly and the intertwined masses are capable of bridging small openings. There are certain rod bacteria, such as *Pseudomonas* and *Enterobacter*, that can precipitate iron, but the volumes of ochre produced are not as large as with the filamentous types.

Ochre can be found in drain filter envelopes, the zone abutting the envelope, the openings (slots or holes) in the drains, and within the drain tube itself. Most clogging in 4-inch diameter corrugated polyethylene tubing can be traced to sealing of the inlet openings and accumulations within the corrugation valleys, particularly when synthetic drain envelopes are used. Within the tubing itself, the heaviest accumulation of ochre appears to be in the lower third of the drain length, although the lower third is usually not the region of maximum ochre formation.

### Soil Conditions Contributing to Ochre Formation

The soils with the most potential for ochre formation are fine sands and silty sands, organic soils and soils with organic pans (spodic horizons), and mineral soil profiles with mixed organic matter. The least likely candidates for ochre hazard are silty clays and clay loams. When flooded, they are usually deficient in ferrous iron in the soil solution.

It is possible to estimate the maximum potential for ochre before installing drains, as well as to estimate whether specific soil types or profiles can be considered susceptible. The ferrous iron content of the groundwater flowing into a drain has been found to be a reliable indicator of the potential for ochre clogging. Analyzing the soils for total iron is of no value because the values do not indicate easily reducible soluble ferrous iron, nor the complex interactions between soil pH and soil type. Table 1 lists the potential for ochre formation for several soil types.

There are certain on-site observations that may give clues to potential ochre formation in advance of drainage. Surface water in canals may contain an oil-like film that is usually iron and may contain *tothrix* bacterial filaments. Gelatinous ochre may form on the ditch banks or bottoms of canals. Ochre may also form layers in the soil profile. In some locations, there may be iron concretions (iron rocks). The presence of spodic horizons (organic layers) suggest ochre potential, and most organic soils, such as mucks, have some potential for ochre problems.

### Measures to Minimize Drain Clogging

There is no known economical, long-term method for effectively controlling ochre clogging in drains. Although options are limited, the emphasis must be on living with the problem. It is necessary to follow certain practices to minimize the potential. All measures that minimize the development of anaerobic flooded conditions are acceptable. Closer spacings and shallower depths of drains may, for certain sites, be beneficial.
A drain envelope or filter is necessary for sandy soils. A graded gravel envelope is best, although it can become clogged under conditions of severe ochre potential. Thin synthetic fabrics are now used extensively in Florida. The principal materials installed are spun-bonded nylon, spun-bonded polypropylene, and a knitted sock. Surveys of selected drainage sites show that ochre clogging with the synthetic materials seems to occur first in the slots and valleys (the space between the envelope and slots) and can be present in amounts sufficient to cause drain failure. The spun-bonded fabrics also clog from ochre deposits in which the iron precipitating bacteria grow across the voids in the fabrics.

Larger openings in the drains increase the period before drain outflow may be severely restricted. The ochre may adhere to the frayed plastic edges abutting the water inlet slots. Cleanly cut inlet slots are essential. Small slots also limit the effectiveness of jet rinsing as a method for cleaning drains installed with synthetic envelopes. Care must be taken to ensure that the size of the opening or slot is compatible with graded gravel envelopes or base soil.

The use of high- and low-pressure water jetting has been successful in cleaning many drains clogged with ochre. Most of the commercial cleaning has been on drains installed in gravel envelopes. Pressures as high as 1,300 psi at the pump have been used, although pressures exceeding 400 psi in sandy soils may destabilize the sand around the drains and cause it to flow into the drain. Jetting nozzles should be designed for agricultural drains rather than municipal sewer lines. Jet cleaning has been unsatisfactory if delayed until the ochre has aged and become crystalline. Pressure requirements will exceed the 400 psi at the nozzle, which is suggested as the upper limit for sandy soils and synthetic envelopes.

**References**


## Tables

Table 1. Depth and spacing for 4-inch plastic drains with synthetic envelope (adapted from Ford et al., 1985).

<table>
<thead>
<tr>
<th>Series</th>
<th>Order</th>
<th>Minimum Depth</th>
<th>Minimum Spacing</th>
<th>Maximum Depth</th>
<th>Maximum Spacing</th>
<th>Spacing increase for each extra inch of depth</th>
<th>Oche potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adamsville Entisol</td>
<td>46</td>
<td>71 inches</td>
<td>58 inches</td>
<td>46</td>
<td>71 ft.</td>
<td>58 ft.</td>
<td>6 ft.</td>
</tr>
<tr>
<td>Blichton Ultisol</td>
<td>40</td>
<td>53 inches</td>
<td>52 inches</td>
<td>40</td>
<td>53 ft.</td>
<td>52 ft.</td>
<td>4 ft.</td>
</tr>
<tr>
<td>Bradenton Alfisol</td>
<td>40</td>
<td>40 inches</td>
<td>52 inches</td>
<td>40</td>
<td>40 ft.</td>
<td>52 ft.</td>
<td>3 ft.</td>
</tr>
<tr>
<td>Broward Entisol</td>
<td>28</td>
<td>57 inches</td>
<td>34 inches</td>
<td>28</td>
<td>57 ft.</td>
<td>34 ft.</td>
<td>5 ft.</td>
</tr>
<tr>
<td>Charlotte Spodosol</td>
<td>46</td>
<td>71 inches</td>
<td>58 inches</td>
<td>46</td>
<td>71 ft.</td>
<td>58 ft.</td>
<td>6 ft.</td>
</tr>
<tr>
<td>Delks Spodosol</td>
<td>40</td>
<td>56 inches</td>
<td>52 inches</td>
<td>40</td>
<td>56 ft.</td>
<td>52 ft.</td>
<td>4 ft.</td>
</tr>
<tr>
<td>Delray Mollisol</td>
<td>46</td>
<td>71 inches</td>
<td>58 inches</td>
<td>46</td>
<td>71 ft.</td>
<td>58 ft.</td>
<td>6 ft.</td>
</tr>
<tr>
<td>EauGallie Spodosol</td>
<td>46</td>
<td>60 inches</td>
<td>58 inches</td>
<td>46</td>
<td>60 ft.</td>
<td>58 ft.</td>
<td>6 ft.</td>
</tr>
<tr>
<td>Elred Spodosol</td>
<td>46</td>
<td>54 inches</td>
<td>58 inches</td>
<td>46</td>
<td>54 ft.</td>
<td>58 ft.</td>
<td>5 ft.</td>
</tr>
<tr>
<td>Farmon Spodosol</td>
<td>46</td>
<td>63 inches</td>
<td>58 inches</td>
<td>46</td>
<td>63 ft.</td>
<td>58 ft.</td>
<td>4 ft.</td>
</tr>
<tr>
<td>Felda Alfisol</td>
<td>46</td>
<td>61 inches</td>
<td>58 inches</td>
<td>46</td>
<td>61 ft.</td>
<td>58 ft.</td>
<td>6 ft.</td>
</tr>
<tr>
<td>Floridana Mollisol</td>
<td>46</td>
<td>60 inches</td>
<td>58 inches</td>
<td>46</td>
<td>60 ft.</td>
<td>58 ft.</td>
<td>4 ft.</td>
</tr>
<tr>
<td>Ft. Drum Inceptisol</td>
<td>46</td>
<td>60 inches</td>
<td>58 inches</td>
<td>46</td>
<td>60 ft.</td>
<td>58 ft.</td>
<td>5 ft.</td>
</tr>
<tr>
<td>Hilolo Alfisol</td>
<td>46</td>
<td>32 inches</td>
<td>58 inches</td>
<td>46</td>
<td>32 ft.</td>
<td>58 ft.</td>
<td>3 ft.</td>
</tr>
<tr>
<td>Holopaw Alfisol</td>
<td>46</td>
<td>71 inches</td>
<td>58 inches</td>
<td>46</td>
<td>71 ft.</td>
<td>58 ft.</td>
<td>6 ft.</td>
</tr>
<tr>
<td>Immokalee Spodosol</td>
<td>46</td>
<td>67 inches</td>
<td>58 inches</td>
<td>46</td>
<td>67 ft.</td>
<td>58 ft.</td>
<td>4 ft.</td>
</tr>
<tr>
<td>Jumper Ultisol</td>
<td>46</td>
<td>55 inches</td>
<td>58 inches</td>
<td>46</td>
<td>55 ft.</td>
<td>58 ft.</td>
<td>4 ft.</td>
</tr>
<tr>
<td>Kanapaha Ultisol</td>
<td>46</td>
<td>71 inches</td>
<td>58 inches</td>
<td>46</td>
<td>71 ft.</td>
<td>58 ft.</td>
<td>3 ft.</td>
</tr>
<tr>
<td>Lawnwood Spodosol</td>
<td>46</td>
<td>43 inches</td>
<td>58 inches</td>
<td>46</td>
<td>43 ft.</td>
<td>58 ft.</td>
<td>3 ft.</td>
</tr>
<tr>
<td>Lochloosa Ultisol</td>
<td>46</td>
<td>56 inches</td>
<td>58 inches</td>
<td>46</td>
<td>56 ft.</td>
<td>58 ft.</td>
<td>4 ft.</td>
</tr>
<tr>
<td>Malabar Alfisol</td>
<td>46</td>
<td>101 inches</td>
<td>58 inches</td>
<td>46</td>
<td>101 ft.</td>
<td>58 ft.</td>
<td>5 ft.</td>
</tr>
<tr>
<td>Micanopy Alfisol</td>
<td>40</td>
<td>45 inches</td>
<td>52 inches</td>
<td>40</td>
<td>45 ft.</td>
<td>52 ft.</td>
<td>3 ft.</td>
</tr>
<tr>
<td>Myaka Spodosol</td>
<td>46</td>
<td>56 inches</td>
<td>58 inches</td>
<td>46</td>
<td>56 ft.</td>
<td>58 ft.</td>
<td>5 ft.</td>
</tr>
<tr>
<td>Narcoossee Spodosol</td>
<td>46</td>
<td>69 inches</td>
<td>58 inches</td>
<td>46</td>
<td>69 ft.</td>
<td>58 ft.</td>
<td>5 ft.</td>
</tr>
<tr>
<td>Nettles Spodosol</td>
<td>46</td>
<td>66 inches</td>
<td>58 inches</td>
<td>46</td>
<td>66 ft.</td>
<td>58 ft.</td>
<td>5 ft.</td>
</tr>
<tr>
<td>Nobleton Ultisol</td>
<td>46</td>
<td>61 inches</td>
<td>58 inches</td>
<td>46</td>
<td>61 ft.</td>
<td>58 ft.</td>
<td>5 ft.</td>
</tr>
<tr>
<td>Oldsmar Spodosol</td>
<td>46</td>
<td>85 inches</td>
<td>58 inches</td>
<td>46</td>
<td>85 ft.</td>
<td>58 ft.</td>
<td>5 ft.</td>
</tr>
</tbody>
</table>
### Drainage Systems for Flatwoods Citrus in Florida

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil Type</th>
<th>Drainage</th>
<th>Water</th>
<th>pH</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ona</td>
<td>Spodosol</td>
<td>46</td>
<td>85</td>
<td>58</td>
<td>142</td>
</tr>
<tr>
<td>Parkwood</td>
<td>Alfisol</td>
<td>46</td>
<td>98</td>
<td>58</td>
<td>169</td>
</tr>
<tr>
<td>Pendarvis</td>
<td>Spodosol</td>
<td>46</td>
<td>67</td>
<td>58</td>
<td>112</td>
</tr>
<tr>
<td>Pepper</td>
<td>Spodosol</td>
<td>46</td>
<td>67</td>
<td>58</td>
<td>112</td>
</tr>
<tr>
<td>Pineda</td>
<td>Alfisol</td>
<td>46</td>
<td>89</td>
<td>58</td>
<td>117</td>
</tr>
<tr>
<td>Pinellas</td>
<td>Alfisol</td>
<td>46</td>
<td>108</td>
<td>58</td>
<td>178</td>
</tr>
<tr>
<td>Placid</td>
<td>Inceptisol</td>
<td>46</td>
<td>108</td>
<td>58</td>
<td>178</td>
</tr>
<tr>
<td>Pompano</td>
<td>Entisol</td>
<td>46</td>
<td>71</td>
<td>58</td>
<td>147</td>
</tr>
<tr>
<td>Riviera</td>
<td>Alfisol</td>
<td>46</td>
<td>86</td>
<td>58</td>
<td>129</td>
</tr>
<tr>
<td>Seffner</td>
<td>Entisol</td>
<td>46</td>
<td>72</td>
<td>58</td>
<td>126</td>
</tr>
<tr>
<td>Sparr</td>
<td>Ultisol</td>
<td>46</td>
<td>71</td>
<td>58</td>
<td>146</td>
</tr>
<tr>
<td>St. Johms</td>
<td>Spodosol</td>
<td>46</td>
<td>74</td>
<td>58</td>
<td>125</td>
</tr>
<tr>
<td>Susanna</td>
<td>Spodosol</td>
<td>46</td>
<td>73</td>
<td>58</td>
<td>110</td>
</tr>
<tr>
<td>Tantile</td>
<td>Spodosol</td>
<td>46</td>
<td>86</td>
<td>58</td>
<td>131</td>
</tr>
<tr>
<td>Tuscailla</td>
<td>Alfisol</td>
<td>46</td>
<td>56</td>
<td>58</td>
<td>112</td>
</tr>
<tr>
<td>Valkaria</td>
<td>Entisol</td>
<td>46</td>
<td>71</td>
<td>58</td>
<td>145</td>
</tr>
<tr>
<td>Vero</td>
<td>Spodosol</td>
<td>46</td>
<td>68</td>
<td>58</td>
<td>102</td>
</tr>
<tr>
<td>Wabasso</td>
<td>Spodosol</td>
<td>46</td>
<td>70</td>
<td>58</td>
<td>115</td>
</tr>
<tr>
<td>Wacahoota</td>
<td>Ultisol</td>
<td>46</td>
<td>91</td>
<td>58</td>
<td>121</td>
</tr>
<tr>
<td>Wachula</td>
<td>Spodosol</td>
<td>46</td>
<td>85</td>
<td>58</td>
<td>128</td>
</tr>
<tr>
<td>Waveland</td>
<td>Spodosol</td>
<td>46</td>
<td>56</td>
<td>58</td>
<td>86</td>
</tr>
<tr>
<td>Winder</td>
<td>Alfisol</td>
<td>46</td>
<td>54</td>
<td>58</td>
<td>99</td>
</tr>
</tbody>
</table>

### Footnotes

1. This is Document No. CH165 and Circular 1412, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: July 2002. Please visit the EDIS Web site at http://edis.ifas.ufl.edu for additional publications related to citrus water management. This document can be accessed as http://edis.ifas.ufl.edu/CH165.

2. B. J. Boman, Associate Professor, Department of Agricultural and Biological Engineering, Indian River REC-Ft. Pierce; and D. P. H. Tucker, Professor, Horticultural Sciences Department, Citrus REC-Lake Alfred. University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, Gainesville, FL 32611.
The Menu Page at the address:

"http://edis.ifas.ufl.edu/MENU_CH8A"

has been replaced.

In a few seconds you will be redirected to the new topical menu page.

Or you may click on the following link to go there directly:

http://edis.ifas.ufl.edu/TOPIC_Citrus_Irrigation

Please send email to the EDIS Website Mailbox for assistance if you do not find what you were looking for at the new location.
Citrus Irrigation

- Aquatic Weed Management in Citrus Canals and Ditches
- Control and Automation in Citrus Microirrigation Systems
- Drainage Systems for Flatwoods Citrus in Florida
- Economic Considerations for Florida Citrus Irrigation Systems
- Irrigation for Cold Protection
- Irrigation, Nutrition, and Citrus Fruit Quality
- Managing Salinity in Florida Citrus
- Microsprinkler Irrigation for Cold Protection of Florida Citrus
- Outline for Managing Irrigation of Florida Citrus with High Salinity Water
- Understanding Water Quality Parameters for Citrus Irrigation and Drainage Systems
- Water Quality Monitoring Programs for Environmental Assessment of Citrus Groves
- Water Table Measurement and Monitoring for Flatwoods Citrus

Return to...

- Citrus Water Management
- Irrigation by Crop
Citrus Water Management

- Citrus Irrigation
- Effects of Water and Nutrients on the Postharvest Quality and Shelf Life of Citrus
- Environmental Acts and Regulatory Agencies Affecting Citrus Groves in Florida
- Managing Salinity in Florida Citrus
- Water and Environmental Considerations for the Design and Development of Citrus Groves in Florida
- Water Management District Considerations for Florida Citrus Groves
- Water Resources for Florida Citrus
- Water Table Measurement and Monitoring for Flatwoods Citrus
- Drainage Systems for Flatwoods Citrus in Florida

Return to...

- Citrus
- Water Management for Agriculture
Control and Automation in Citrus Microirrigation Systems

Brian Boman, Steve Smith, and Bill Tullos

Introduction

Microirrigation (drip and microsprinklers) is the predominant method of irrigation for citrus in Florida. With chemigation, microirrigation systems can also provide an economical method of applying fertilizer and other agricultural chemicals on a timely basis. However, microirrigation systems require a higher level of management expertise than other irrigation methods. Microirrigation systems are more complex, require greater filtration and water treatment, and typically have high maintenance costs compared to other types of irrigation.

Irrigations generally must be scheduled more frequently with microirrigation systems, since they reach only a fraction of the root zone as compared to other types of systems. One way of managing the higher demands of microirrigation is the use of automation and central control systems. These technologies allow efficient control of water flows to various zones; injection of water conditioners, fertilizers, and agricultural chemicals; allow remote checks of system performance; control filter backflushing; and provide extensive records of water use. More sophisticated systems allow irrigations to be scheduled based on evapotranspiration (ET) calculations from nearby weather stations.

In many citrus microirrigation systems, a controller is an important and integral part of the irrigation system. Controllers can help to achieve labor savings in addition to applying water in the necessary quantity and at the right time to achieve high efficiency in water, energy and chemical uses. Irrigation controllers have been available for many years in the form of mechanical and electromechanical irrigation timers. These devices have evolved into complex computer-based systems that allow accurate control of water, energy and chemicals while responding to environmental changes and crop demands.

Control Strategies
Two general types of controllers are used to control irrigation systems: open control loop systems and closed control loop systems. Open control loop systems apply a preset action, such as is done with simple irrigation timers. Closed control loops receive feedback from sensors, make decisions and apply the results of these decisions to the irrigation system.

**Open Loop Systems**

In an open loop system, the operator makes the decision on the amount of water that will be applied and when the irrigation event will occur. This information is programmed into the controller and the water is applied according to the desired schedule. Open loop control systems use either the irrigation duration or a specified applied volume for control purposes. Open loop controllers normally have a clock that is used to start irrigations. Termination of the irrigation can be based on a pre-set time or may be based on a specified volume of water passing through a flow meter.

Open loop control systems are typically low in cost and readily available from a variety of vendors. They vary in design and complexity and often offer flexibility as to the number of zones and how irrigations are scheduled. The drawback of open loop systems is their inability to respond automatically to changing conditions in the environment. In addition, they may require frequent resetting to achieve high levels of irrigation efficiency.

**Closed Loop Systems**

In closed loop systems, the operator develops a general control strategy. Once the general strategy is defined, the control system takes over and makes detailed decisions of when to apply water and how much water to apply. This type of system requires feedback from one or more sensors. Irrigation decisions are made and actions are carried out based on data from sensors. In this type of system, the feedback and control of the system are done continuously.

Closed loop controllers require data acquisition of environmental parameters (such as soil moisture, temperature, radiation, wind-speed, etc) as well as system parameters (pressure, flow, etc.). The state of the system is compared against a specified desired state, and a decision whether or not to initiate an action based on this comparison. Closed loop controllers typically base their irrigation decisions on sensors that measure soil moisture status using sensors or use climatic data to estimate water use by plants. In some systems, both soil moisture sensors and climatic measurements are used.

The simplest form of a closed loop control system is that of an irrigation controller that is interrupted by a moisture sensor ([Fig. 1](http://edis.ifas.ufl.edu/CH194)). The sensor is wired into the line that supplies power from the controller to the electric solenoid valve and operates as a switch that responds to soil moisture. When sufficient soil-moisture is available in the soil, the sensor maintains the circuit open. When soil-moisture drops below a certain threshold, the sensing device closes the circuit, allowing the controller to power the electrical valve. When the controller attempts to irrigate, irrigation will occur only if the soil-moisture sensor allows it, which in turn occurs only when soil-moisture has dropped below acceptable levels.
Controllers

In the simplest form, irrigation controllers are devices which combine an electronic calendar and clock and are housed in suitable enclosure for protection from the elements. The controller provides a low-voltage output (typically 12 or 24 volts DC or 24 volts AC) to the valves and control devices for specific zones. As long as the voltage is applied, valves stay open and irrigation water is applied.

Most remote control valves are "normally closed" meaning that the valve is closed until the solenoid is actuated by the controller. A "normally open" control valve remains open until such time as the solenoid is actuated. Normally open valves are sometimes used as master valves in systems when it is desirable to have a continuously pressurized mainline but still have a primary valve that can be closed in the event of excessive flow or other alarm conditions.

Electromechanical Controllers

Electromechanical controllers (Fig. 2) use an electrically driven clock and mechanical switching (gear arrays) to activate the irrigation stations. These types of controllers are generally very reliable and not very sensitive to the quality of the power available. They generally are not affected by spikes in the power, and unless surges and brownouts are of such magnitude that they will damage the motor, they will continue to operate. Even if there is a power outage, the programmed schedule will not be lost and is generally delayed only for the duration of the power outage. However, because of the mechanically-based components, they are limited in the features they provide.

Figure 1. Switching tensiometer used to control irrigation system in microirrigated citrus grove.

Figure 2. Electromechanical controller.
Electronic Controllers

Electronic controllers (Fig. 3) rely on solid state and integrated circuits to provide the clock/timer, memory and control functions. These types of systems are more sensitive to powerline quality than electromechanical controllers, and may be affected by spikes, surges and brownouts. Spikes and surges are common in many areas of Florida where lightning tends to be frequent and intense. These type of systems may require electrical suppression devices in order to operate reliably. Because of the inherent flexibility of electronic devices, these controllers tend to be very flexible and provide a large number of features at a relatively low cost.

![Figure 3. Electronic controller.](image)

Features

The basic minimum features of any independent irrigation controller is to provide the time of day, a day-of-the-week calendar, the ability to change the time setting on each station, and a means of physically connecting stations to valve wiring. Some models offer features that make changes in programming relatively simple. For example, a desirable feature is percent scaling. This feature allows a multiplier to be applied to the time setting on every station. Older model controllers without such a feature require that every station's time be set individually, which is time consuming and frustrating to the user. Some controllers allow for different percent scaling on each program, or valve group, within the controller.

With percent scaling, the system operator can go to the controller, key in a new percent scaling factor, and know that the time settings on all zones have been automatically reset for the time setting on that station multiplied by the percentage. For example, assume a certain zone has a time setting of 4 hours. If the percent scaling factor is programmed to be 75%, then the valve will open for 4 hr x 75% = 3.0 hours. It is possible to easily make frequent program changes in response to tree, soil, cultural, and climatic factors when the percent scaling feature is available on the controller. For this reason, this simple feature can be very important in maintaining efficient irrigations.

Several designs of controllers are commercially available with many different features and over a wide range of costs. Most irrigation timers provide several of the following functions:

- A clock/timer that provides the basic time measurements by which schedules are executed.
- A calendar selector that allows definition of which days the system is to operate.
- A station time setting that defines the start time and duration for each station.
● Manual start functions that allow the operator to start the automatic cycle without disturbing the preset starting time.

● Manual operation of each station so the operator can manually start the irrigation cycle without making changes to the preset starting time.

● A master switch that prevents activation of any station connected to the timer.

● Station omission features that allow the operator to omit any specified number of stations from the next irrigation cycle.

● A master valve control feature that provides control to a master system valve. This function is used with certain types of backflow prevention equipment and also prevents flow to the system in case of failure in the system.

● Pump start features to allow a pump start solenoid to be activated whenever a station is activated, thus tying pump control with irrigation control.

Some controllers allow every station to be programmed independent of other stations, and some irrigation managers consider this feature to be quite important. Programming such a controller can be more complex and time consuming, but the flexibility may be worth it. Another feature provides for a single irrigation event to be broken up for brief periods of operation followed by brief periods of rest. In heavy soils, irrigating in this manner allows the irrigation application rate to more closely match the soil's intake characteristics. This type of control can also be important for drip systems in flatwoods areas where root zones are limited. For example, if a system needs to operate for 10 hours per day, the 10-hour duration might be broken into five 2-hour irrigation cycles separated by 2-hour non-irrigated periods. The water applied with this scenario will typically have more lateral movement and less vertical movement than if the water was applied in one setting. As a result, water will be used more efficiently, with less opportunity for leaching below the root zone of the trees. Other desirable features that are available on many of the more advanced controllers include provisions for:

● Multiple zones so that zones with young trees can be on completely separate operating schedules.

● Extended and flexible calendars that adapt to imposed restrictions that are mandated by water management districts such as every-third-day schedules or night-time only watering.

● Non-volatile memory that holds the time settings and program in the event of power loss.

● Easy setup and programming to allow input from rain and soil moisture sensors.

Selection Criteria

Some controllers allow the addition of a hand held remote to facilitate repairs. For example, if a maintenance person completes a repair and wants to check the valve or the system performance, a hand held remote device can be used to start the valve without going back to the controller. The time saving aspects of such a device can often show a direct payback.

When evaluating controllers to pick an appropriate system for a particular project, the following factors should be considered:
Cost, quality, and warranty.

Programming features.

Total number of zones and the number of zones that can be operated simultaneously.

Run time time increment.

Enclosure (suitability to outdoor or indoor installation).

Repair alternatives.

**Electrical Considerations**

Schedules must be programmed into the controller's memory where they are maintained as long as power is available. When a given zone or valve is to be opened, a voltage is applied between the controller's "common" position on the terminal strip and the solenoid for the valve. A volt-ohm meter can be used to verify that the voltage is available and that the controller is functioning as intended.

A terminal strip with a screw for each station provides the easiest approach to wire connections inside the controller (Fig. 4). Some controllers have a bundle of labeled wires that are attached to the appropriate solenoid using a wire nut. When voltage is applied to the station, the solenoid on the valve is actuated and allows the water passage in the pilot valve to open. The water pressure upstream of the valve is utilized to actually hydraulically open the valve. The voltage continues to be applied from the controller and the solenoid stays active or holds, for the full time increment set on the controller.

![Figure 4. Multi-colored low-voltage wiring used to connect controller to valves and other control devices.](http://edis.ifas.ufl.edu/CH194 (6 of 19) [11/11/2003 9:14:02 AM]

**Grounding and Surge Protection**

In general, a controller should be grounded and should be protected from electrical surge (Fig. 5). The manufacturer should be consulted as to the specific recommendations for each piece of equipment. Solid-state electronics are more susceptible to lightning and power fluctuations than the older electro-mechanical designs. However, these factors should not deter one from considering solid state controllers due to their flexibility. Controller manufacturers will generally recommend:

- 8-foot copper clad ground rods installed next to the controller with the controller wired to ground using...
a heavy gauge wire and suitable connectors (three ground rods in a triangular grid can be used in order to achieve the recommended earth ground of 5 ohms or less).

- A metal oxide varistor (MOV) installed on each valve wire to protect against electrical surge
- A MOV on the primary power input side to protect the controller's electronics

![Figure 5. Typical grounding for 110 VAC controller.](http://edis.ifas.ufl.edu/CH194)

**Low Voltage Wire Characteristics**

Wiring used between the controller and the electric valve must be designated for direct burial (UF-underground feeder, describes wire that is suitable for direct burial by the National Electric Code).

To make maintenance easier, each controller in the system should use a consistent wire code scheme. Typically white is used for the common wire, while the control wire is some other unique color. A uniquely colored wire (as opposed to a whole bundle of wires having the same color) can be quickly located anywhere in the system. When there are many wires of the same color, wires must be checked one at a time to find the desired wire. A voltage (from a transformer or battery) can be applied and checked with a volt-ohm meter to identify specific wires.

For smaller projects having short wire runs, it is often practical to use multi-strand cable. Multi-strand cable is commonly available with 4-, 6-, 8-, 10-, and 12-wires. Wires should be labeled at the controller to indicate the valve to which they are attached.

**Wire Sizing**

Typical wire sizes used in irrigation systems range from 8 to 18 American Wire Gauge (AWG) sizes. Normally, 18 AWG is the smallest size used in irrigation systems (approximately 0.04 inch diameter) and 8 AWG is the largest (approximately 0.13 inch diameter).

The major valve manufacturers have developed wire sizing procedures for their valves as an assist to irrigation system designers. It is best to utilize their resources when available because some of the procedure is based on testing of their valves and using their performance criteria. Sometimes valve wire is sized for reasons other than electrical properties. Many maintenance personnel consider 14 AWG wire to be the minimum acceptable size for a purely subjective reason -- they believe a heavier (14 AWG or 0.06-inch diameter) wire is less likely to be damaged or cut when mainline or wire repairs are made.

The allowable voltage drop is the controller output voltage (typically 12 or 24 VDC or 24 VAC) minus the...
minimum solenoid operating voltage (manufacturer specific). The inrush current is the current necessary to initially open the solenoid valve and this current increases as the water pressure increases because the solenoid works against the pressure. Wire resistance increases as the cross-sectional area of the wire decreases and the length of run increases. Wiring used in low voltage control circuits should be sized based on the following electrical properties:

- Allowable voltage drop.
- Inrush current.
- Wire resistance.

Wire Installation

Low voltage wiring should be installed below the mainline pipe in the irrigation system. The mainline pipe can protect the wiring from cutting or nicking. When wire is not protected by the mainline, it should be installed in conduit. A warning tape installed about 6 inches deep in the trench can provide further protection and an alert to excavators. Wire should also be installed in conduit when there is good chance of damage due to excavations or rodents. Wiring installed above grade should generally be in electrical conduit. High voltage and low voltage wire should always be installed in separate electrical conduits.

Control and common wire should be looped at 45 and 90 degree turns in the trench to provide for expansion and contraction of the wire as the ground temperature changes. The wires should be taped at 6- to 10-foot intervals to keep the wire together as a bundle. A nice installation technique at the valve is to produce an expansion coil by wrapping 2 to 4 feet of wire around a shovel handle or 1-inch pipe to produce a coil which has the appearance of a spring (Fig. 6). A further benefit of this technique is to allow the valve top to be removed without disconnecting the wires.

![Figure 6. Coiled control wire and water proof connectors at remotely-activated electric valve.](http://edis.ifas.ufl.edu/CH194 (8 of 19) [11/11/2003 9:14:02 AM)]

All underground wire connections are made with waterproof connectors. There are many styles of water-proof connectors available. Select one that allows for a firm connection of the two (or three) wire ends and seals the connection in silicon rubber or a similar durable and water proof material. In larger systems with long wire runs, wire splices may be necessary at places along the mainline where there are no valves. In this case, wire splices should always be grouped together and installed in a valve box. The location of splices should be recorded on the as-built irrigation drawings at the completion of the installation.

Trouble Shooting
Understanding the electrical characteristics of control systems facilitates trouble shooting of problems. Necessary tools and supplies include a volt-ohm meter, wire cutters and strippers, water proof wire connectors, and wire in various gauges and colors. Some irrigation controllers provide hints or even station lights that indicate shorts to ground in the control wire for a particular valve. Broken wires can often be tracked with equipment designed to find faults and shorts to ground. This equipment can also assist in finding valves or components that have been buried below ground.

Sensors

A sensor is a device placed in the system that produces an electrical signal directly related to the parameter that is to be measured. In general, there are two types of sensors: continuous and discrete. Continuous sensors produce a continuous electrical signal, such as a voltage, current, conductivity, capacitance, or any other measurable electrical property. Continuous sensors are used when just knowing the on/off state of a sensor is not sufficient. For example, to measure pressure drop across a filter (Fig. 7) or determine tension in the soil with a tensiometer fitted with a pressure transducer (Fig. 8) requires continuous-type sensors.

![Figure 7. Control panel for automatically backflushing filters based on pressure differential between inlet and outlet of filter.](image)

![Figure 8. Tensiometer fitted with pressure transducer to provide continuous feedback of soil tension status.](image)

Discrete sensors are basically switches (mechanical or electronic) that indicate whether an on or off condition exists. Discrete sensors are useful for indicating thresholds, such as the opening and closure of devices such as valves, alarms, etc. They can also be used to determine if a threshold of an important state variable has been reached. Some examples of discrete sensors are a float switch to detect if the level in a canal is below a minimum desirable level (Fig. 9), or a switching tensiometer (Fig. 10) to detect if soil moisture is above a desired threshold. When combined with time, pulses from switches can be used to measure rates such as the volume of fuel, water or chemical solution passing through a totalizing flow meter with a magnetically activated switch.
Sensors are an extremely important component of the control loop because they provide the basic data that drive an automatic control system. Understanding the operating principle of a sensor is very important. Often, sensors do not react directly to the variable being measured. The ideal sensor responds only to the sensed variable, without responding to any other change in the environment. It is also important to understand that sensors always have a degree of inaccuracy associated with them and they may be affected by other parameters besides the "sensed" variable.

Some of the variables that are often measured in computer-based control systems are: flow rate, pressure, soil-moisture, air temperature, wind speed, solar radiation, relative humidity, conductivity (total salts) in irrigation water, and pH of irrigation water.

The measurement of flow rate in the mainline ([Fig 11](#)) is one of the most important measurements in an irrigation system. Flows that are out of range, either high or low, can be reported and acted upon. Flow sensors can be read remotely by control system hardware designed with this feature or by adding interface hardware. Typically, flow sensors utilize a paddle or propeller inserted into the water stream that turns with the RPM (revolutions per minute) directly related to the flow velocity. Electrical pulses are generated by the sensor relative to the RPM. Remotely read flow meters of this type are often added even if existing manually-read flow meters are already included in the system (sometimes required by the water management districts). High flow or low flow alarms are possible when the flow meter is integrated with the control system.
Software used with the control system can continually check on the flow rate in the system and compare it to pre-defined acceptable levels. High flow conditions indicate pipe failures or stuck valves. Since the results of broken mainlines can be disastrous (erosion, washouts, etc.), systems are often programmed to shut down when high flows (25-30% above normal) are detected. A high flow condition, recognized by the central controller, can close a master valve or shut the pump down to prevent further flow. Such action, when coupled with an alarm report issued to the central computer operator, can be quite effective in responding to a high flow and subsequently effecting a timely repair.

Wind sensors can prevent or terminate irrigation if a specified wind develops and is sustained. Rain sensors can prevent irrigation during or after significant rain. Soil moisture sensors can prevent irrigation when adequate soil moisture is already present. Sensors can be used to detect pressure and shut the system down if the pump is not primed or initiate flush cycles in filters.

Figure 12 shows a simple and low cost rain sensor. Rain causes the porous disks in the device to swell and open a micro-switch. The switch remains open as long as the disks are swollen. When the rain has passed and the ET rate is back up, the disks dry out and the switch again closes. This device can be implemented in two ways. With central control the switch closure can be read by the central system which in turn can be programmed to effect a rain shutdown at one or more sites. With an independent controller, the device can be installed at or near the controller and as a switch on the common wire. In this way, irrigation is prevented because the circuit is not completed when the switch is open.

A/D Interface

Since computer systems work internally with numbers (digits), the electrical signals resulting from the sensors must be converted to digital data. This is done through specialized hardware referred to as the Analog-to-
The A/D interface converts discrete signals resulting from switch closures and threshold measurements into digital format, either 0 or 1. Continuous electrical (analog) signals produced by the sensors signals are converted to a number related to the level of the sensed variable. The accuracy of the conversion is affected by the resolution of the conversion equipment. In general, the higher the resolution, the better the accuracy.

An 8-bit resolution A/D board is capable of dividing the maximum input voltage in \(2^8\), or 256 increments. For example, if a pressure sensor produces a voltage signal ranging from 0 to 5 volts for a range of pressure of 50 psi, an 8-bit resolution A/D board will be able to detect a change in voltage of about \(5/256\) volts which will result in measurable increments of \(50/256\), or 0.2 psi. If the resolution of the A/D board was 12-bit, the board would be able to detect a change in voltage of about \(5/2^{12}\) volts, or a measurable increment of \(50/4096\), or 0.01 psi.

Computer-based Irrigation Control Systems

A computer-based control system consists of a combination of hardware and software that acts as a supervisor with the purpose of managing irrigation and other related practices such as fertigation and maintenance. Generally, the computer-based control systems used to manage microirrigation systems can be divided into two categories:

- Interactive systems that collect and process information from various points in the system, and allow manual control of the system from a central point by remote operation of valves or other control devices.
- Fully automatic systems that control the performance of the system by automatically actuating pumps, valves, etc. in response to feedback received from the monitoring system. These systems use closed control loops which include:
  - Monitoring the state variables (pressure, flow, etc.) within the system.
  - Comparing the state variables with their desired or target state.
  - Deciding what actions are necessary to change the state of the system.
  - Carrying out the necessary actions.

Performing these functions requires a combination of hardware and software that must be implemented for each specific application.

Interactive Systems

Interactive systems are usually built around a microcomputer, either a standard personal computer (PC) or a specially designed unit. The information is transferred into a central unit either directly from sensors in the pipeline or from intermediate units which collect the data from a number of sensors and then process and store them temporarily for further transfer to the central computer. These systems have features that enable the operator to transmit commands back to the various control units of the irrigation system. The field devices...
such as valves (Fig. 13), regulators, pumps, etc. are fitted with electrically operated servo-devices which enable actuation of the pumps, closing and opening of valves, and adjusting pilot valves of flow regulators. This type of system permits the operator to govern the flow from the central computer by controlling flow parameters such as pressure and flow rate, according to specific needs at the given time, and to receive immediate feedback on the response of the system.

Figure 13. Hydraulically actuated control valve with vacuum and pressure relief valves downstream.

Automatic Systems

In fully automated systems (Fig. 14), the human factor is eliminated and replaced by a computer specifically programmed to react appropriately to any changes in the parameters monitored by sensors. The automatic functions are activated by feedback from field units and corrections in the flow parameters by control of devices in the irrigation system until the desired performance level is attained. Automatic systems can also perform auxiliary functions such as stopping irrigation in case of rain, injecting acid to control pH, sounding alarms, etc. Most control systems include protection in emergencies such as loss of the handled liquid due to pipe burst. They close the main valve of the whole system or of a branching, when an unusually high flow rate, or an unusual pressure drop is reported by the sensors.

Figure 14. In-field controls for a centrally-controlled citrus irrigation system including: 1) on-site communication, data storage, and control device; 2) valve, pump, and accessory controllers; 3) phone connection; 4) sensor decoders; 5) flow monitors; 6) pressure and water level monitors; 7) manual over-rides; 8) power conditioning and surge protection.

Selection of a Central Control System

In determining the best control system for a specific project and management group, the first thing to recognize is that an informed decision will be time consuming. If the end user already has favorable experience, training, or familiarity with a specific control system, manufacturer, or distributor, he/she should
probably make decisions based on the experience. If the end user is open and unbiased and wishes to make a sound decision based on an objective evaluation of capabilities, costs, and overall effectiveness, then he/she should be prepared to put appropriate time into the effort to determine the most suitable system for his/her specific needs.

Centralized Irrigation Control

Water shortages and rising power costs demand increased attention to sound water management. Large groves functioning under one management group should be particularly alert to their water management strategy. Centralized irrigation control is not only an appropriate tool for improving water management but other objectives can be accomplished at the same time.

There are many central control systems to choose from and the user base is very large and geographically diverse with hundreds of systems throughout the country. Basic technical capabilities, reliability, and cost effectiveness have been demonstrated repeatedly to the satisfaction of even the most skeptical.

An irrigation central control system can be simply defined as a computer system which operates multiple controllers, sensors, and other irrigation devices from one central location. Today's central control system can monitor conditions in the system and surrounding areas, then control the equipment to properly respond to the conditions. This "monitor and control scenario" allows for complete system automation wherever parameters can be defined for system operation. The system can operate without personal intervention.

The monitor function of a central control system may consist of many different sensors: wind sensors, weather stations, and rain sensors are just a few of the options available. These sensors monitor their respective areas and report current conditions. The system can respond if any of the conditions are outside pre-defined limits. An example of sensor operations is the ability of the system to monitor rainfall. If rain occurs in a given area, the system can automatically turn off the irrigation in that area and report its actions to the central control system.

Controlling the system from the central location allows all system operations to be programmed and monitored easily and efficiently. Control actions such as adjusting watering times at all sites for seasonal fluctuations can be accomplished easily by one person from each location.

Central Control Components

Central control systems consist of a central computer, communications equipment, field controllers, and sensors. The central computer is usually located in the irrigation manager's office. The communications equipment is located both at the computer and at the field devices. Communications equipment can consist of telephone modems, radio modems, or fiber-optic modems. A middle manager device called the cluster control unit, which receives information from the central computer, is located on-site to monitor and control the system equipment. These field devices are connected to irrigation valves, sensors, and other field equipment.

Weather stations can be monitored by the central computer to gather weather information and automatically calculate irrigation watering times. By gathering weather data and automatically adjusting the system, large amounts of water and money can be saved.

Most central control systems run on PC-compatible computers. In general, a faster computer with more RAM is required than in the past. Most new users purchase a high speed computer that has plenty of hard disk
capacity, additional RAM, CD drives, and a suitable backup system.

Certain minimum capabilities can be assumed from most of the central control systems available now. Most systems provide reliable radio and telephone communication with remote sites, percent scaling to quickly accomplish day-to-day and system-wide changes in scheduling, and greatly expanded instrumentation possibilities that are limited only by imagination and budget. Percent scaling is usually possible at multiple levels. For example, a percent scaling factor may be applied globally to the entire system and another percent scaling factor may be applied to individual sites.

**Figure 15** represents a central control system coupled with an on-site weather station or an accessible local weather station network. Together, the control system and the management system offer the potential of scheduling irrigations more closely and reactively than with any other approach. In the representation, climatic data are gathered from a weather station, and the daily reference evapotranspiration rate ($ET_o$) is calculated and utilized in making irrigation decisions. Irrigations can be rescheduled daily or even during the course of a single day to accommodate rainfall, changes in ET, or even subjective judgments on the part of the system operator or irrigation manager.

![Figure 15. Schematic of central control system with weather station input to control irrigation events.](image)

In fact, many central control systems can be configured to automatically use $ET_o$ data to calculate crop water use and make adjustments to the run times of each zone. Whether or not a given project should be configured to perform in this way depends on people and management philosophies. While such a control system is capable of managing irrigation effectively without intervention by personnel, regular inspection (e.g. daily) by knowledgeable operators may prevent serious problems from developing.

**New Capabilities**

Users do have numerous new capabilities to consider in central control. The look and feel of systems has been constantly improved--some dramatically improved. Pop down menus, point and click (mouse) applications, and icon-driven menus are now common. New capabilities come quickly in response to wish lists from current or potential users.

Specialized consultants are available to help with initial data input and long term modifications and advice. Their services include determination or measurement of: lateral precipitation rate, soil infiltration rates, lateral flow rates, and system hydraulic limitations. The initial control program can be developed and entered based on design drawings, field work, or a combination of both. Most consultants are available to provide follow-up support, training, and trouble shooting.

Some manufacturers provide an accreditation program to train and expand the knowledge base of consultants.
actively working with central control systems. Certification by the manufacturer is a means of promoting the service and an indication of the competence and proficiency of the consultant. Consideration should be given to the reputation of the consultants, manufacturer representatives, and dealers with regards to support and service once the equipment is installed.

**Differing Philosophies**

A look at the overall philosophy of system operation can be enlightening and helpful in evaluating different systems. The control or management hierarchy built into the system and components is indicative of the system's basic philosophy. As a potential user, it is important to understand this philosophy to assure that it can be used and applied or adapted to current irrigation practices. A change in management style to match the imposed style of the system is probably not desirable.

The philosophy of some control systems includes a system with middle management. The central system communicates with a site having a cluster control unit (or CCU) at the site (Fig. 16). The CCU is in turn linked by hard wire or radio to a satellite controller. The satellite controller contains the terminal strip where the control and common wires are connected to valves. The CCU contains a computer (making it programmable and smart) and provides the middle management role in placement and hierarchy within the communication link. The CCU contains all the programs or schedules for a site. In addition, the CCU can perform actions such as closing valves in response to a high flow condition without communicating with the central computer.

![Figure 16. Communication components of centralized computer-controlled system.](image)

In contrast, other systems are exemplary of a direct central to satellite management and communication philosophy. The central communicates by radio or telephone directly to satellite controllers. The satellite controller may see an alarm condition (say a high flow condition at a flow meter) and the satellite reacts, reporting actions taken when polled by the central. The central itself is programmed automatically to contact the site following each irrigation cycle. This communication process is full two-way communication between the central and the satellite controller.

**Distinguishing Capabilities**

Exciting new features have become available including:

- A communication approach configured by site (telephone to farm, radio to a another farm, etc.).
- Alarms or alpha-numeric messages sent directly to pagers worn by maintenance personnel.
- Automated interrogation of weather stations and automatic ET data utilization.

- Prediction of soil moisture storage based on the checkbook or water balance method of irrigation scheduling.

- User-developed condition statements (if, then, else commands) used to create specific alarms.

- Multi-tasking environments which set the stage for dramatically expanded features in the future.

### Operation of Control Systems

The information supplied from most irrigation systems is usually in the form of pressure and flow rate data. In some systems, additional parameters such as the level in a canal or pond, or an indication of a booster are used. The sensors supplying the information are mainly pressure gauges and flow meters with transducers adapted for telemetry and microswitches for level indication. Where transfer distances are short, the data can be supplied to the central computer as an analog output, by variation of the electric potential. Such data transfer requires an individual connection for every sensor or switch, making the installation rather expensive and complicated. Therefore, in control systems involving long transfer distances, the data are encoded near the transducer units for transfer by a single channel.

In direct transfer systems, the central unit collects the instantaneous data by scanning the sensors, one after another. Depending on the number of various sensors, the scan may last several seconds or more, so that the data received from a specific sensor reach the central computer intermittently, the interval between readouts depending on the scanning speed. The central unit receiving the data from a sensor averages four or five consecutive readings, in order to avoid recording accidental transient data peaks or dips which may occur throughout the scanning period and bias the output. The average is then processed by the computer and usually compared to the time parameter for calculation of flow rates or for totaling the flow volumes. The processed data can be displayed digitally or graphically, stored on magnetic media for further reference and printed as necessary.

Larger systems use intermediate field units (Fig. 14, No.1) which can collect data, each from a small number of sensors, reducing the scan period. The partially processed data are then transferred into the central unit by the same scanning method. Often the intermediate units can also act as self-contained computers, which can be specially programmed for either data display or for automatic control of the piping sector assigned to them. Such operation is independent of their main function of transferring data from sensors to the central computer or of conveying commands from the central computer to the various control devices.

The control systems are usually powered through the central unit, which is sometimes plugged directly into the main electric utility line, but more often connected through a rechargeable battery with a trickle charger. In order to ensure continuous operation of the control system and to avoid loss of data in case of power failure, an uninterruptible power supply unit and a lightening protector are included in the power units (Fig. 5, No.8).

Where utility supply power is not available, power for the control system can be provided by solar panels or from generators on diesel units. Intermediate control units, which are typically located far from standard power lines, are frequently powered this way. Wiring of an irrigation control system should be done by a competent professional to insure that safety requirements are met and that the system meets the necessary codes. Most problems with irrigation controllers can be traced to poor electrical installation, particularly lack of adequate grounding. Wherever electronic components are used it is important that both signal and powerlines are
protected from power surges.

Communication between various units of the control system can be by wire or wireless. Data encoded by pulse requires two- or three-wire telephone cable in which one strand usually serves for energy supply from the source. For radio transmission the units are provided with radio transceivers, operating on the usual personal phone frequencies. One common practice is to connect the various sensors by wires to the intermediate unit, which then encode the data and forwards them to the central computer by radio or by wire. Where possible, the central computer and each field unit is provided with a modem and the data transmitted by ordinary telephone utility cables.

**Economics of Computer Control Systems**

Before any control system is chosen, an analysis of management and control alternatives should be performed. Project issues can typically be broken down into six categories:

- Control system factors.
- Communication factors.
- Existing Irrigation system factors.
- Management factors.
- Water factors.
- Economic or annual cost-of-money factors.

The primary control system factor, from the economic perspective, is cost. This includes the initial, installed cost of the control system and annual operating costs. The same is true of communication in that the initial cost and annual cost of communication must be determined to understand the respective cost implications. Telephone tends to have a lower initial cost than radio, but radio tends to have a lower annual cost. Only a thorough analysis indicates which is most cost effective. Further, if a particular control system is only suitable with radio, or conversely with telephone, then the system must be analyzed with this limitation in mind.

An inventory of the existing irrigation system is necessary. The number, location, and relative size of existing independent controllers must be known before a replacement concept can be developed. Historic applications and practices must be known in order to compare past practice with future practice. Water factors include the current availability and unit cost of pumping water in addition to the projected future availability and rate increases.

The historic ET rate for the area must be known to ascertain management alternatives and develop a water management strategy. The annual costs that may be effected by central control implementation must be determined and economic factors such as rate of inflation, cost of money, and economic life must be estimated.

All of these factors can best be analyzed with a spreadsheet. A sensitivity analysis on the data can often provide much insight into the decision process. Oftentimes, other factors such as reliability, ease of use, dealer support, and maintenance requirements are more important than overall cost.
References


Footnotes

1. This is document No. CH194 and Circular 1413, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: July 2002. Please visit the EDIS Web site at http://edis.ifas.ufl.edu for additional publications related to citrus water management. This document can be accessed as http://edis.ifas.ufl.edu/CH194.

2. B. J. Boman, Associate Professor, Department of Agricultural and Biological Engineering, Indian River Research and Education Center, Ft. Pierce; Steve Smith, Aqua Engineering, Inc.; and Bill Tullos, Rain Bird Sales, Inc. Cooperative Extension Service, Institute of Food and Agricultural Sciences, Gainesville, FL 32611.

The Institute of Food and Agricultural Sciences is an equal opportunity/affirmative action employer authorized to provide research, educational information and other services only to individuals and institutions that function without regard to race color, sex, age, handicap, or national origin. For information on obtaining other extension publications, contact your county Cooperative Extension Service office.

Florida Cooperative Extension Service / Institute of Food and Agricultural Sciences / University of Florida / Christine Taylor Waddill, Dean

Copyright Information

This document is copyrighted by the University of Florida. Institute of Food and Agricultural Sciences (UF/IFAS) for the people of the State of Florida. UF/IFAS retains all rights under all conventions, but permits free reproduction by all agents and offices of the Cooperative Extension Service and the people of the State of Florida. Permission is granted to others to use these materials in part or in full for educational purposes, provided that full credit is given to the UF/IFAS, citing the publication, its source, and date of publication.
Irrigation for Cold Protection

- Cold Protection by Irrigation: Dew Point and Humidity Terminology
- Uses Of Water In Florida Crop Production Systems

Return to...

- Irrigation
- Cold Protection and Chilling Damage
- Citrus Irrigation
Uses Of Water In Florida Crop Production Systems


Water has many important and beneficial uses in Florida agricultural crop production systems. The most obvious beneficial use of water is that applied for crop evapotranspiration requirements. However, water required for crop cooling, cold protection, irrigation system maintenance, crop fertigation and chemigation, salt leaching, water table management, crop establishment, field preparation, soil/dust erosion control, and other uses provide benefits that may be essential for crop production. When natural rainfall is insufficient, water is supplemented from either surface or groundwater sources to meet agricultural demands. While this list may not be complete, these uses should be considered when determining the water use requirements of agricultural production systems.

This publication introduces and describes each of the aforementioned water uses for Florida production systems. However, individual requirements will vary with crop type, cultural practices, and site conditions. Other publications are planned to provide greater detail on these topics for the major Florida crop/commodity groups. This information is required by irrigation and crop production system managers and designers, and by water management district personnel so that crop water needs can be confidently and sufficiently estimated.

IRRIGATION EFFICIENCIES

In water management, the term efficiency generally relates to the fraction of the resource that is diverted or used from a given source (surface or groundwater) that is beneficially used. Diverted water which is unused or recovered after irrigation and returns to the source can alter the efficiency of the system. Thus, when the term efficiency is used it is necessary to provide a clear understanding of the type of water use, the sources, and system characteristics.

Application Efficiencies (Ea)

Irrigation application efficiency is generally defined as the ratio of water stored within the root zone of the
crop, and thus available for use by the crop, to the amount delivered by the irrigation system. Values of irrigation application efficiency are generally reported for properly designed and well-managed systems irrigating mature crops under average irrigation conditions.

Irrigation system application efficiencies must be known so that the systems can be properly designed and managed. The Ea must also be known by water managers to estimate the gross irrigation requirements necessary to meet the crop evapotranspiration (ET) requirements. This definition does not include other beneficial uses of water.

**Water Use Efficiencies (Eu)**

Water use efficiency may be defined as: (1) the water use per unit of crop yield produced, or (2) the ratio of the amount of water which was beneficially used for crop production to the amount diverted from the water source. These terms are described in greater detail in Florida Cooperative Extension Service Bulletin 247.

The first definition is typically used when making economic or yield comparisons as functions of water use or irrigation system type. For water management purposes, the second definition is often more meaningful. Minimizing the waste of water can be achieved by maintaining high values of Eu. This definition, however, requires that all beneficial uses of water be identified and defined for each crop production system.

**Comparing Ea and Eu**

Irrigation application efficiencies can only be high if the water applied can be stored in the soil and available for crop use. Thus, Ea is reduced when irrigation amounts which exceed the soil water-holding capacity are applied or when irrigations occur on a soil which is at or near field capacity. Sometimes irrigations must be performed with wet soil conditions for the benefit of the production system. Examples include irrigation applications for freeze protection, leaching or salinity control, and crop cooling. These applications normally occur when the soil is already wet.

Because irrigation for other beneficial purposes may be necessary when the soil is already wet, Ea may be low while Eu remains high. Examples include: 1) fertilizer applications that must be made through an irrigation system; 2) irrigation system maintenance applications (especially chlorination or other chemical applications) that are a periodic requirement; 3) and other similar irrigation applications which are made for purposes other than meeting the ET requirements of the crop.

In the following sections of this paper, various uses of water in Florida crop production systems are described. Because these uses are beneficial for crop production, the associated water use efficiency remains high when water is applied for these purposes. All of the uses described are not appropriate for all Florida crop production systems. Likewise, the amounts of water required for each purpose may vary widely, or some uses may not be appropriate for all production systems.

**USES OF WATER**

**Evapotranspiration (ET)**

Climatic factors including solar radiation, air temperature, relative humidity, and wind levels create conditions which result in water movement from crops, water surfaces, and soil surfaces. This movement or transfer of
water from the liquid to vapor form is called evapotranspiration (ET) and is required for crop cooling, growth, and development. Crop ET is discussed in detail in Florida Cooperative Extension Service Bulletin 840 and Circular 822. Agricultural systems such as orchard and field crop operations, container and greenhouse grown plant operations, and ponds for crop, livestock, and aquacultural operations all require irrigation for water supplements when rainfall amounts are not sufficient to meet ET demands.

Crop water deficits created by the evapotranspiration demand can induce a stress on plants and reduce growth and development and may in turn affect the yield and quality of the crop. Supplemental irrigations are scheduled to eliminate or reduce the level of stress on the crop. Florida Cooperative Extension Service Circulars 431, 487 and 872, and Bulletins 208, 245, 249 and 254 discuss irrigation scheduling methods and practices for crop production in Florida. Many types of irrigation systems exist for use in crop production and are discussed in Florida Cooperative Extension Service Circulars 533, 808 and 821.

Ponds are used to provide a water source for crop irrigation, livestock drinking and washing needs, and are used in aquacultural production systems. Ponds are also used as settling basins to remove suspended materials from a water supply system (Florida Cooperative Extension Service Fact Sheet AE 65). They can act as a primary filter for certain water sources used with microirrigation systems. Because ponds are typically exposed areas of water, they are subjected to the same environmental conditions as a crop and consequently water evaporates in response to the environmental demand. These losses will vary with the size of the pond and may not be very large but must be accounted for in the water budgeting process.

**Crop Cooling**

Sometimes the plant cannot provide water at rates sufficient to meet the ET demand, even though soil or growth media water levels are satisfactory. When this occurs, plants are stressed and start to lose turgor, wilt, and growth is reduced.

This inability to meet the water demand may be due to an insufficient root system compared to the leaf area or due to internal plant or leaf water transport capacities. Small or insufficient root systems compared to leaf area are common on young plants or plant propagation cuttings. Different plant varieties have different water transport resistances. Under similar conditions some plants can transport water to the leaves at rates sufficient to meet the demands while other plants must overcome greater internal resistances resulting in less than sufficient rates. Overhead irrigation can cool the crop and reduce stress levels by providing water to the leaf surfaces which may evaporate and thus satisfy the evapotranspiration demand.

Another need for crop cooling exists when warmer than normal temperatures are experienced during winter and early spring months of the year. These conditions may initiate early flowering. Subsequent frost or freeze conditions could damage the flowers or young fruit. Therefore, cooling irrigations are used to maintain plant temperatures at lower levels, thus inhibiting early flower development.

**Cold Protection**

While the environment can become too hot for some plants, it can also become too cold for others. Irrigation for frost and freeze protection is common in Florida. Excessively low temperatures may damage the entire plant, leaves, flowers or fruit of certain plant varieties. Water can be applied to the crop in the form of overhead irrigation to provide heat to the crop and to maintain the crop at non-damaging temperature levels.

Because the irrigation water is warmer than the air, some heat is provided by the temperature of the water, on
the order of 1 calorie per gram of water per degree C of temperature difference. However, the majority of the heat is provided when the water freezes, releasing 80 calories of energy per gram of water. If water is not provided at rates sufficient to balance the heat losses of the crop, excessive damage can occur from the evaporation of water from the plant surface. This process can consume 596 calories of energy per gram of water evaporated. Thus, under certain conditions, inadequate irrigation levels for frost/freeze protection can be more damaging than no irrigation at all.

More information on cold protection can be obtained from Florida Cooperative Extension Service Circular 348 and Fact Sheets FC 24, FC 69, FC 75 and FC 76.

**Maintenance**

All working systems require some type of periodic maintenance for proper and continued operation. Irrigation systems are no exception and must be properly maintained to ensure that they will operate as designed and when needed. Improper operation can result in non-uniform water and fertilizer distribution as well as insufficient or excessive application amounts of these inputs in attempts to meet the needs of the crop.

The level and type of maintenance will vary with the system. For example, the maintenance associated with the flood type of systems may be quite minimal, such as a pre-season system operational check and leak detection. However, the more efficient microirrigation systems generally require higher maintenance levels. Typical maintenance activities may include:

- Initial and periodic flushing of the irrigation system to remove settled and accumulated debris,
- Pre-season system operation checks,
- Regular chemical treatment and water amendment,
- Periodic leak detection, and
- Back-flushing of the filtration system.

Some of these activities can occur during normal irrigation cycles, but some may require a special irrigation activity to perform the intended maintenance task. For example, consider a microirrigation system that has been operated for a certain period of time and its next irrigation cycle is to be used for a chlorination treatment. Rainfall delays the need to irrigate. However, bacterial organisms within the irrigation system will continue to grow and clog the system unless treated. Thus, a maintenance irrigation cycle may become necessary.

**Fertigation**

Fertigation and other chemigation activities involve the application of chemicals (fertilizer or other) into the irrigation system and use the irrigation system to convey the chemical to the crop. Because microirrigation systems can place water with high levels of uniformity in the crop root zone, they are particularly adapted to chemigation.

Fertigation can be used to provide nutrients to the crop as needed. This can improve the overall fertilizer application efficiency and reduce the amount of nutrients leached out of the crops root zone. However, situations may arise which would reduce the apparent application efficiency of the irrigation system. For
example, a fertigation cycle may be necessary during a period when rainfall provides sufficient water to meet the evapotranspiration requirements of the crop. Thus, the irrigation system is operated solely to transport nutrients to the crop.

The time required for the fertilizer (or chemical) to travel from the injection point to the most distant part of the hydraulic network (which includes, mains, submains, lateral and drip tubes) must be considered for any chemigation event. Flow velocities within the pipes directly affect the travel time. Properly designed irrigation systems use a maximum flow velocity of five feet per second to avoid surge pressures (water hammer - see Florida Cooperative Extension Service Circular 828) within the system. In actuality, flow velocities may vary from 6 feet per second to less than 2 feet per second, and maximum travel distances may exceed 2000 feet of pipe, even in well designed systems. The travel time along this length could range from 5 to 15 minutes or more. In addition, injection periods may last from 30 to an excess of 60 minutes. Therefore, the total irrigation time for a fertigation cycle would include initial system pressurization, plus chemical travel time to the most distant part of the field, plus chemical injection time, plus the travel time again to flush the chemical from the lines. This irrigation time may exceed the required operation time to meet only the evapotranspiration requirements of the crop.

**Leaching Requirement**

Some plants have greater salt tolerances than others and may not be affected by increased soil salinity levels. However, excessive soil salinity levels can reduce plant growth and development on plant varieties with lower tolerance levels. Soil salinity levels can increase from residual fertilizer salts or from irrigating with saline water. As the plants take water out of the soil for evapotranspiration, salts remain in the soil. Without rainfall or excessive irrigation, soil salinity levels will increase with time to toxic levels. Therefore, periodic leaching irrigations may require scheduling to over-irrigate and move the excess salts out of the root zone of the crop. These irrigations supply water in excess of the root zone water holding capacity, resulting in a downward flow of saline water. However, this is a beneficial use of water for the crop production system.

**Water Table Management**

Some agricultural fields, greenhouse operations, and aquacultural operations may require that high water tables be maintained for crop, cultural, or environmental conditions. These water uses may be necessary and very effective for these types of agricultural operations.

Agricultural fields with naturally high water tables may not require much additional water to increase and maintain the water table level for crop production. The water table may be managed at some distance below the soil surface or for a certain depth over the soil or production surface. Water table management may be used for field preparation, crop establishment, weed control, nematode control, crop water requirements, or subsidence or soil oxidation control in the case of muck soils.

Greenhouse and other intensely managed vegetable and ornamental operations may use water table management or even hydroponics for irrigation in highly controlled settings. Some containerized plant operations use growing or production bays with impermeable floors or benches. Water is ponded in the production bays, and after sufficient water rises into the containers for irrigation, the areas are drained. Additional areas are flooded using the recycled drainage water. After the last bay is flooded, the water is recirculated back to the source and treated for re-use.

Florida has several aquacultural operations ranging from production of fish (catfish, tilapia, etc.) or crustaceans (crayfish and prawns) for consumption, to tropical fish for aquariums. Many of these industries
use outside ponds for their production areas. Sometimes the natural water supplies of rainfall, surface runoff, or naturally high groundwater levels are not sufficient to maintain the ponds at the proper management levels. Supplemental water is then required to augment the ponds for proper management and operation. Florida Cooperative Extension Service Bulletin 257 discusses the use of farm ponds in Florida agricultural production systems.

**Crop Establishment**

Water is applied for crop establishment to germinate seeds or to minimize stress levels on young plants. This application is basically used for crop cooling as discussed in a previous section. However, this use is only in the early stages of plant growth to allow the plants to develop a well established root system for future growth and development. For example, strawberries which are set as bare-rooted transplants, commonly use overhead irrigation to cool the transplants for the first 10 to 14 days in the field until a root system is established. This may require daily irrigation events of 8 to 10 hours each. Similarly, many ornamental plants are derived from cuttings from stock plants. The cuttings are placed in a growth media and are misted with water several times per day until a root system is established.

Other plant establishment requirements exist with young plants or transplants after initial placement in the fields. These young plants already have a root system, but one which is generally restricted in size from the container within which it was grown. Excess water is sometimes necessary to minimize the initial shock of transplanting until the root system expands sufficiently for normal crop support.

**Field Preparation**

Many of Florida's agricultural production systems require moist soil or growth media conditions for field preparation operations. These operations include soil bed formation, fumigation, and soil or growth media capillary establishment.

Field operations which use bedded cultures require that the soil moisture be sufficient to maintain the pressed or formed bed shape. If natural rainfall has not been sufficient, supplemental water is required. In addition, some soil fumigants require maintenance of certain soil moisture conditions, and systemic herbicides and pesticides may require supplemental irrigation for maximum effectiveness of the applied chemical.

Sandy soils and other growth media with relatively large particle interstices or capillaries, require initial uniform wetting and establishment prior to operation of the drip system. This initial wetting 'primes' the capillaries with water allowing improved operation of the drip systems and other capillary distribution irrigation systems. Without this initial 'priming', water distribution could be very poor, resulting in potentially low application efficiencies, low application uniformities, and potential reduction in plant growth and development.

**Soil Erosion and Abrasion Control**

Dry soil conditions can present problems with wind erosion. Under windy conditions, dry, loose soil particles can become dislodged and airborne. This had been a serious problem in other parts of the country prior to implementing erosion control conservation practices, such as wind breaks and cover crops. Many microirrigated fields result in dry row middles and other non-cropped areas of the field. Similarly, fields between crop cycles may have bare, non-cropped soil conditions which become susceptible to drying and potential erosion.
Airborne soil particles, particularly sands, can also become abrasive to plants and fruit. These abrasions may provide an entrance on the surface of the plant tissue for plant pathogens or they may simply scar the surface of the fruit. Either situation can result in lower quality plants and fruit.

Drought tolerant cover crops may assist in preventing erosive conditions by taking advantage of natural rainfall. However, sometimes these crops may need initial irrigation water for germination or a periodic irrigation during periods of very low or infrequent rainfall.

Other Beneficial Uses

Other beneficial uses of water include overhead irrigation for crop washing, water applications to unpaved road areas to improve field traction conditions, and water for crop chemical sprayers. The amounts of water usually associated with these applications are generally small, but are still necessary, reasonable, and beneficial. In addition, uses such as crop washing or chemical applications may reduce the amount of water consumed from the growth media for evapotranspiration.

SUMMARY

Uses of water in agricultural production systems were listed and discussed. A common misunderstanding is to consider crop evapotranspiration as the only required or beneficial use of water in agricultural production. Many other uses are necessary, reasonable, and beneficial for crop production, but are often neglected as part of the water budget for the cropping system. As allocations of water resources become more restrictive, the need to identify and quantify each of the appropriate uses increases in importance. An under estimation of the true water requirements of the production system, could result in reduced production, economic losses, or regulatory consequences associated with pumpage in excess of permitted quantities.

SELECTED AND RELATED REFERENCES


---

**Footnotes**


2. Gary A. Clark, Associate Professor, Extension Water Management Specialist, Gulf coast REC, Bradenton; A.G. Smajstrla and F.S. Zazueta, Professors of Agricultural Engineering, Gainesville; F.T. Izuno, Associate Professor, Extension Water Management Specialist, Everglades REC, Belle Glade; B.J. Boman, Associate Professor, Agricultural Engineering, Ft. Pierce AREC, Ft Pierce; D.J. Pitts, former Assistant Professor, Extension Water Management Specialist, SW Florida REC, Immokalee; and D.Z. Haman, Associate Professor, Extension Water Management Specialist, Gainesville: Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville FL 32611.

The Institute of Food and Agricultural Sciences is an equal opportunity/affirmative action employer authorized to provide research, educational information and other services only to individuals and institutions that function without regard to race color, sex, age, handicap, or national origin. For information on obtaining other extension publications, contact your county Cooperative Extension Service office.

Florida Cooperative Extension Service / Institute of Food and Agricultural Sciences / University of Florida / Christine Taylor Waddill, Dean

---

**Copyright Information**
Uses Of Water In Florida Crop Production Systems

This document is copyrighted by the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) for the people of the State of Florida. UF/IFAS retains all rights under all conventions, but permits free reproduction by all agents and offices of the Cooperative Extension Service and the people of the State of Florida. Permission is granted to others to use these materials in part or in full for educational purposes, provided that full credit is given to the UF/IFAS, citing the publication, its source, and date of publication.
Introduction

Water is one of Florida's most valuable resources. It is generally abundant, as the state typically receives about 175 billion gallons per day (150 bgd in rainfall and 25 bgd inflow from Georgia and Alabama). Fresh water supplies come from extensive subsurface beds of porous rock (aquifers) and from fresh water lakes, streams and reservoirs. Florida's aquifers contain more than a quadrillion gallons of water, which is 30,000 times the average daily discharge of Florida's 13 largest rivers.

There is, however, a tremendous variability in the source of supply (rainfall). Most of the potential supply must be left in the hydrologic system for nonconsumptive uses such as navigation, recreation, and aesthetics, or to provide a habitat for fish and wildlife, or because it cannot be economically used. In addition, water is not evenly distributed in the state. The densely populated coastal areas of the peninsula have much less available water than interior, northern regions. Thus, the potential for conflict over the allocation of water is a growing concern in Florida.

Withdrawal of water for consumptive use continues to rise. More than 50% of the total fresh water used in Florida comes from groundwater, and more than 90% of the public rely on groundwater supplies for their drinking water. Of all the fresh water withdrawn in Florida, only about one-third is consumed by evaporation, transpiration, or production processes. The remaining two-thirds are returned to the environment, either to surface streams or to aquifers.

Groundwater and the Hydrologic Cycle

The continuous circulation of water from land and sea to the atmosphere and back again is called the hydrologic cycle (Fig. 1). Inflow to the hydrologic system is primarily rainfall. Outflow occurs as runoff, evaporation, transpiration by plants, and outflow from groundwater into wells, rivers, springs or oceans.
Components of the hydrologic cycle include evaporation, transpiration, condensation, precipitation, interception, infiltration, percolation, runoff and storage. Brief descriptions of these processes follow:

**Evaporation**

The change of water from a liquid to a gaseous state is called evaporation. Evaporation rate is affected by solar radiation, air temperature, vapor pressure, wind, and atmospheric pressure. Evaporation occurs from raindrops, free water surfaces, such as seas and lakes, water settled on vegetation and soil, and from human activities. During evaporation, moisture is moved into the atmosphere as water vapor.

**Condensation**

The change of water from a vapor to a liquid state is termed condensation. Water vapor condenses onto small airborne particles to form dew, fog, and clouds. Condensation occurs when the temperature drops to the dew point temperature or when the amount of vapor in the air is increased to the water vapor saturation point.

**Precipitation**

The fall of water particles from the atmosphere to the ground is precipitation. It occurs in two forms. In the coalescence subprocess, a larger lead drop, that reaches a critical size in the air, attracts a number of smaller drops to create precipitation. In the ice-crystal subprocess, ice develops under freezing temperatures in clouds and attracts water droplets that evaporate and condense on the crystals. Precipitation may fall onto both bodies of water and land.

**Interception**

The interruption of the movement of water on the land surface is called interception. It takes place by vegetation or through storage in canals, reservoirs, and lakes. In addition, rainwater is stored on the surface of leaves and other organic materials up to their maximum storage capacity, above which the excess water falls to the ground. Water is also intercepted through evaporation.

**Infiltration**

The movement of water from the air into the soil surface is called infiltration. The amount of water transfer depends on the texture and structure of the soil, the soil moisture content, and the atmospheric concentration of water.
Percolation

Percolation is the movement of water through the soil by gravity and capillary forces. Water in the zone of aeration is called vadose water. Water in the zone of saturation is called groundwater. The two zones meet at the water table. Percolation contributes to both underground water storage and to water movement.

Transpiration

The transfer of water from plants to the atmosphere as vapor through leaf openings is called transpiration. The amount of transpiration depends on the plant species and the amount of light exposure, temperature, humidity, wind, and time of year. Transpiration increases movement of water to the atmosphere. Areas that have healthy plants that shade the ground will have increased transpiration and reduced soil evaporation compared to areas with bare soil.

Runoff

The flow of water from drainage basins to surface streams is runoff. It occurs in three main forms. Surface runoff takes place on the land surface through both natural and manmade channels. Subsurface runoff occurs from water that has infiltrated and moves laterally into canals and ditches. Groundwater runoff results from water percolates into the water table and moves with the general flow of the water table.

Storage

Water is naturally stored in the atmosphere, on the surface of the earth, and in the ground. Water movement though surface and ground storage depends on the geologic features of the storage locations.

Vadose Zone

Between the land surface and the water table is the unsaturated (vadose) zone where both water and air occur in the soil pores. Water in the unsaturated zone is either taken up by plants, evaporated, or drained by gravity into the saturated zone. In the flatwoods soils of Florida, the unsaturated zone is typically only the top 10 to 40 inches of the soil profile during the dry season, and it may be non-existent during the wet season when the water table is at or above the ground surface. In the sandy soils of the Central Florida Ridge, however, the vadose zone can extend to a depth of 100 feet or more.

Groundwater Zone

In the saturated groundwater zone (water table), all pores and crevices are filled with water, and all of the air has been forced out. Water seeping into this zone is called recharge. Groundwater can occur either as an unconfined (phreatic) aquifer or as a confined (artesian) aquifer. In an unconfined aquifer, the water table forms the upper boundary of the aquifer, and the water level in a well will rest at this level. Water infiltrating from the surface has the potential to move rapidly into an unconfined aquifer; thus, there is potential for contamination from surface activities. In an unconfined aquifer, groundwater moves by gravity from areas of high water table elevation to areas of lower water table elevation.

Confined aquifers (Fig. 2) are overlain by an impermeable, or semipermeable confining layer, and are typically under pressure. Therefore, the level to which water will rise in a tightly cased well is above the top of its upper confining layer (artesian well). If the water level rises above the land surface, it is called a flowing...
Water Resources for Florida Citrus

Artesian well.

Figure 2. Typical hydrogeology of the surficial water table aquifier and the confined Floridian Aquifer system (with artesian wells) in South Florida.

Water in confined aquifers moves from areas of high potentiometric head (as measured by the level to which water will rise in a tightly cased well) to areas of low potentiometric head. Confined aquifers are less susceptible to contamination from local surface activities because infiltrating water typically moves very slowly through the confining layer. However, the confining layers may be fractured and missing in many places. Thus, contaminated water may move horizontally on top of the confining layer for some distance before entering the confined aquifer through a breach in the confining layer.

Major Florida Aquifers

The most important aquifers that yield large quantities of water to wells, streams, lakes, and springs in Florida are shown in Fig. 3. The primary source of groundwater for most of the state is the Floridan aquifer. In coastal areas and in South Florida, the top of the Floridan Aquifer is often several hundreded feet below the surface, and it underlies surficial aquifers. The Floridan is one of the most productive aquifers in the United States. However, in many areas Floridan Aquifer wells have high salinity levels, making them undesirable for citrus irrigation.

Figure 3. Major groundwater aquifers used for irrigation in Florida.

In many areas, the Floridan Aquifer is confined by low permeability sediments of the Hawthorne formation (Fig. 4). The Hawthorne formation is absent in the north central part of the state along the Ocala Uplift. In this area the aquifer is unconfined, and thus receives recharge from water infiltrating from the surface.
The origin of subsurface flow to the Floridan Aquifer in northern Florida is from Alabama and Georgia. In peninsular Florida, subsurface Floridan flow originates in the Central Uplands of the state. In many coastal areas, the potentiometric surface (water level in a tightly cased well) is above the land surface; thus artesian flow occurs in wells or along geologic openings (springs).

The unconfined Biscayne aquifer underlies an area of about 3,000 square miles in Dade, Broward, and Palm Beach Counties. This aquifer is 100 to 400 feet thick near the coast, but thins to a thickness of only a few feet further inland. Water in the Biscayne aquifer is derived chiefly from local rainfall. However, during dry periods recharge can come from canals linked to Lake Okeechobee. A shallow, unconfined aquifer is present over much of the state, but in most areas it is not an important source of groundwater because a better supply is available from other aquifers. However, where water requirements are small, this aquifer is tapped by small diameter wells. In South Florida the shallow aquifer is a major source of groundwater in Martin, Palm Beach, Hendry, Lee, Collier, Indian River, St. Lucie, Glades and Charlotte Counties. The water in this shallow aquifer is derived primarily from local rainfall.

**Sources of Groundwater Contamination**

Florida's unique hydrogeologic features of a thin soil layer, high water table, porous limestone, and large amounts of rainfall, coupled with its rapid population growth, result in a groundwater resource extremely vulnerable to contamination. Nonpoint sources, which have potential for contributing to groundwater contamination, include coastal saltwater bodies, urban storm water, agricultural practices, and mining.

Since Florida is peninsula between two bodies of salt water, there is a potential for salt water intrusion into the fresh groundwater supply. Salt water is more dense than fresh water and thus exerts a constant pressure to flow into the fresh water aquifers. As long as fresh water levels in the aquifer are above sea level, the fresh water pressure limits the inland movement of the salt. Overpumping of coastal wells, however, can increase salt water intrusion. If water is pumped out faster than the aquifer is replenished, the pressure of the fresh water is decreased. This causes the level at which the salt water and fresh water meet to rise in the aquifer, degrading the fresh water quality. The problem of salt water intrusion is aggravated by periods of drought during which there is not enough rainfall to replenish the fresh water aquifers.

Figure 5 shows areas of Florida where the Floridan Aquifer which contain chloride concentrations greater than 250 mg/l. In South Florida, where the Floridan Aquifer is artesian and underlies the Biscayne and shallow aquifers, its saline water may recharge the overlying fresh water aquifers, increasing their salt content. This type of recharge may occur naturally by upward seepage through the confining layer or it may be increased by flowing artesian wells.
Reclaimed Water Use on Citrus

The main studies using reclaimed municipal wastewater to irrigate young and mature orange and grapefruit trees in Florida have been conducted at the Water Conserv II project near Orlando and at a citrus grove adjacent to an Indian River County wastewater treatment plant near Vero Beach. Other smaller reclaimed water facilities are located in Pasco, Polk, Manatee, Sarasota, and Okeechobee Counties and involve primarily individual growers and local treatment facilities.

The Water Conserv II project provides citrus growers with a long-time source of reclaimed water (20-year contract) to be used for irrigation of young and mature citrus trees. Water is provided free, although growers must absorb costs associated with connection to the system and purchase of water meters. Growers have the option of refusing water four weeks per year, but only two weeks consecutively. Water that is not applied to groves during high rainfall periods is diverted to rapid infiltration basins (RIBs), where it percolates through the sand and eventually reaches the aquifer. Water quality is regulated very strictly. The water may not have detectable levels of fecal coliforms or viruses and must have <30 mg/L biochemical oxygen demand (BOD) and 25 mg/L total suspended solids (TSS).

In the Water Conserv II study, trees receiving reclaimed wastewater had similar or greater yields and improved tree vigor compared to trees receiving well water. High application rates of reclaimed water (100 inches per year) decreased acid, juice content, and soluble solids (Brix and solids per box). By reducing water stress, high application rates of reclaimed water promoted greater canopy growth and yield.

In contrast, tree vigor and fruit quality were not different for mature grapefruit trees which received reclaimed water or canal water growing in the flatwoods area near Vero Beach. Yields, however, were higher for the reclaimed water treatments in one season, but the effect was variable. No adverse effects of applying high levels of reclaimed water were noted at either site.

The composition of reclaimed municipal wastewater at the Water Conserv II and Indian River County sites varied through the season. Water from both sites was low in heavy metals, reflecting the urban nature and lack of heavy industry in these areas. The water at both sites was quite similar in most characteristics, with the exception of significantly higher sodium, chloride, magnesium, and boron levels at the Vero Beach facility. After 12 years at Conserv II and 3 years at Vero Beach, no adverse effects on tree growth and development or yields have been observed related to elevated levels of these elements.

The reclaimed water provided some nutritional value from constituents that wasn't removed in the treatment process. These nutrients were present at low levels. However, when reclaimed water was applied at high rates...
(1-1.5 inches per week) in order to dispose of as much water as possible per unit of land area, the cumulative amount of the nutrients applied can be significant. Therefore, rates of nitrogen, phosphorus, and potassium fertilizers applied by traditional methods may often be reduced. For example, about 65% of the nitrogen needed to produce a fresh grapefruit crop in the Indian River area was applied with the reclaimed water at the Vero Beach site. Considerable amounts of phosphorus and potassium were also provided by the reclaimed water at both sites.

**Horizontal Wells**

In recent years, horizontal wells (Fig. 6) have become an economical water supply alternative for areas with shallow watertables. Horizontal wells have been installed as primary water supplies for golf courses, citrus groves, ornamental nurseries, commercial landscapes, and vegetable farms. Traditional water supplies for these operations have come from deep aquifers.

Concerns about slow recharge and aquifer depletion in the deep aquifers have made it difficult to get permits to use this water in many areas. In addition water withdrawn from deep wells in the Floridan Aquifer is often highly mineralized and poorly suited for irrigation purposes. In contrast, the surfical aquifers generally have much less mineralization and have rapid recharge rates. The lower aquifer transmissivity and large drawdown caused by high-volume conventional vertical wells make tapping this resource unfeasible in many areas.

Horizontal wells typically utilize 6 to 10 inch diameter perforated drain (recovery) pipe installed 15-20 feet below the ground surface. Due to the high cost of installation, horizontal wells have traditionally been reserved for high-value projects where wells were installed to drop and/or maintain a lowered water table for construction purposes. However, recently developed installation machinery has made the cost of horizontal wells competitive with other water supply sources.

**Horizontal Well Installation**

The current technology allows extraction from groundwater aquifers at depths to about 25 feet. The installation machine digs the trench, lays the recovery pipe, places drain envelope media (if required), and backfills in one operation (Fig. 7).
Typical installations use 400-800 ft of 8-inch diameter perforated recovery pipe (heavy-duty polyethylene tubing), normally installed with a double polyester filter (Fig. 8). A pumping riser extends from the recovery pipe to the surface. This pumping riser is normally either 8- or 10-inch PVC pipe, depending on well capacity. The end of the well opposite the pumping header is brought to the surface with nonperforated tubing. This cleanout end is normally capped, but it can also be used for pumping.

The actual well configuration is adaptable to the site conditions. Wells are installed at depths which are deemed most suitable from preliminary test and observation wells, which measure capacity and drawdown. Wells may be installed as "L" shaped, with the recovery tubing extending one direction from the pumping header, or as a "T" shape, with the recovery tubing extending in opposite directions from the header.

Multiple wells may be connected to a single riser to increase capacity or minimize drawdown. Wells normally use either submersible pumps (located in the PVC pumping riser) or aboveground centrifugal pumps, depending on pumping needs and user preferences. Well capacities vary widely, depending on user needs, recovery tubing length, pump horsepower, and the nature of the aquifer. Studies have shown that the extent of the water table depression and rate of recovery following pumping are dependent upon the rate at which the well is pumped. Sustained flow rates over 1,800 gpm have been achieved in some areas with single wells.

References


Footnotes

1. This is document No. CH162 and Circular 1420, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: August 2002. Please visit the EDIS Web site at http://edis.ifas.ufl.edu for additional publications related to citrus water management. This document can be accessed as http://edis.ifas.ufl.edu/CH162.

2. Brian Boman, Associate Professor, Department of Agricultural and Biological Engineering, Indian River REC-Ft. Pierce; and Larry Parsons, Professor, Horticultural Sciences Department, Citrus REC-Lake Alfred. University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, Gainesville, FL 32611.

The Institute of Food and Agricultural Sciences is an equal opportunity/affirmative action employer authorized to provide research, educational information and other services only to individuals and institutions that function without regard to race color, sex, age, handicap, or national origin. For information on obtaining other extension publications, contact your county Cooperative Extension Service office.

Florida Cooperative Extension Service / Institute of Food and Agricultural Sciences / University of Florida / Christine Taylor Waddill, Dean

Copyright Information

This document is copyrighted by the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) for the people of the State of Florida. UF/IFAS retains all rights under all conventions, but permits free reproduction by all agents and offices of the Cooperative Extension Service and the people of the State of Florida. Permission is granted to others to use these materials in part or in full for educational purposes, provided that full credit is given to the UF/IFAS, citing the publication, its source, and date of publication.
Irrigation, Nutrition, and Citrus Fruit Quality

Mongi Zekri, Thomas A. Obreza and Robert Koo

Introduction

Florida has the highest citrus fruit quality standards in the world. The most important quality factors for Florida citrus growers, production managers, processors, and packers include fruit juice content, soluble solids and acid concentrations, soluble solids-acid ratio, fruit size, and color. Florida citrus growers discern between quality factors for the fresh and processing markets. For example, fruit size, shape, color, and maturity date are most important for fresh fruit, but high juice content and soluble solids are desired for processing fruit. Fruit quality is affected by several factors including cultivar, rootstock, climate, soil, pests, irrigation, and nutrition.

The effects of irrigation and nutrition on fruit quality are important and should be understood and taken into consideration by citrus growers and production managers to increase profitability and enhance sustainability and worldwide competitiveness. In general, excessive irrigation and fertilization reduce fruit quality. Therefore, supplying sufficient nutrition and using sound irrigation scheduling techniques should be high-priority management practices for every grower. Citrus trees require a properly designed, operated, and maintained water management system and a balanced nutrition program formulated to provide specific needs for maintenance and for expected yield and fruit quality.

Irrigation contributes to the efficiency of fertilizer programs. Citrus trees with sufficient water and nutrients grow stronger, better tolerate pests and stresses, yield more consistently, and produce good quality fruit. On the other hand, excessive or deficient irrigation or fertilization may result in poor fruit quality.

The most important management practices influencing fruit quality are irrigation and nitrogen, phosphorus, potassium, and magnesium nutrition. Some micronutrients like boron and copper can also affect fruit quality, but only if they are deficient in the tree. In general, when any nutrient element is severely deficient, fruit yield and fruit quality will be negatively affected.
Effects of Specific Elements

Trends in fruit quality response to increasing nutrient and water availability are described and summarized below:

**Nitrogen (N)**

- Increases juice content and color, total soluble solids (TSS), and acid concentration.
- Increases TSS per box and per acre. However, excessive N, particularly with inadequate irrigation, can result in lower yields with lower TSS per acre.
- Decreases fruit size and weight.
- Increases peel thickness and green fruit at harvest.
- Increases incidence of creasing and scab but decreases incidence of peel blemishes like wind scar, mite russeting, and rind plugging.
- Reduces stem-end rot incidence and green mold of fruit in storage.

**Phosphorus (P)**

- Reduces acid concentration, which increases TSS-acid ratio. Phosphorus rates have no effect on TSS per box but may increase TSS per acre due to increase in fruit production in soils that are low in plant-available P.
- Increases number of green fruit but reduces peel thickness.
- Increases expression of wind scar but reduces that of russeted fruit.

**Potassium (K)**

- Potassium produces mostly negative effects on juice quality except for TSS per acre. Potassium increases fruit production, therefore producing more TSS per acre.
- Decreases juice content, TSS, TSS-acid ratio, and juice color.
- Increases acid content.
- Increases fruit size, weight, green fruit and peel thickness.
- Reduces incidence of creasing and fruit plugging. In storage, reduces stem-end rot.

**Magnesium (Mg)**
- Slightly increases TSS per box and per acre, and TSS-acid ratio.

- Slightly increases fruit size and weight, but decreases rind thickness.

**Irrigation**

- Increases juice content and TSS-acid ratio.

- Reduces TSS and acid concentration. TSS per box decreases, but TSS per acre may increase due to yield increase.

- Increases fruit size and weight, increases green fruit at harvest but decreases rind thickness.

- Increases incidence of blemish from wind scar, scab and *Alternaria* brown spot, but reduces rind plugging.

- Reduces stem-end rot incidence but increases incidence of green mold in storage.

**Summary**

Specific effects on juice and external fruit qualities are summarized in Table 1. This summary is based on numerous field experiments conducted over many years that evaluated the response of oranges to irrigation and fertilization practices. Most of these effects were consistently observed, but some of them appeared to depend on local conditions and growing regions. These observations are useful in developing a strategy to improve fruit quality for a particular variety or location.

For more information on nutrition and irrigation effects on citrus, see [http://edis.ifas.ufl.edu/TOPIC_Citrus_Nutrition_and_Fertilization](http://edis.ifas.ufl.edu/TOPIC_Citrus_Nutrition_and_Fertilization) and [http://edis.ifas.ufl.edu/TOPIC_Citrus_Irrigation](http://edis.ifas.ufl.edu/TOPIC_Citrus_Irrigation).

**Tables**

Table 1. Effects of mineral nutrition and irrigation on citrus fruit quality.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Mg</th>
<th>Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juice Quality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juice Content</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Soluble Solids (SS)</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Acid (A)</td>
<td></td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>
Irrigation, Nutrition, and Citrus Fruit Quality

| SS/A Ratio | - | + | - | + | + |
| Juice Color | + | 0 | - | ? | 0 |
| Solids/Box  | + | 0 | - | + | - |
| Solids/Acre | + | + | + | + | + |

**External Fruit Quality**

| Size       | - | 0 | + | + | + |
| Weight     | - | 0 | + | + | + |
| Green Fruit| + | + | + | 0 | + |
| Peel Thickness | + | - | + | - | - |

Increase (+), Decrease (-), No change (0), No information (?)

---

**Footnotes**

1. This document is SL 207, a fact sheet of the Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. First printed: April 2003. Please visit the EDIS Web site at [http://edis.ifas.ufl.edu](http://edis.ifas.ufl.edu).

2. Mongi Zekri, Multi-county Citrus Extension Agent, PO Box 68, LaBelle, FL 33975; Thomas A. Obreza, Professor, Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611-0290; and Robert Koo, Emeritus Professor, Citrus Research and Education Center, Lake Alfred, FL 33850.

---

The Institute of Food and Agricultural Sciences is an equal opportunity/affirmative action employer authorized to provide research, educational information and other services only to individuals and institutions that function without regard to race color, sex, age, handicap, or national origin. For information on obtaining other extension publications, contact your county Cooperative Extension Service office.

---

Florida Cooperative Extension Service / Institute of Food and Agricultural Sciences / University of Florida / Christine Taylor Waddill, Dean

---

**Copyright Information**

This document is copyrighted by the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) for the people of the State of Florida. UF/IFAS retains all rights under all conventions, but permits free reproduction by all agents and offices of the Cooperative Extension Service and the people of the State of Florida. Permission is granted to others to use these materials in part or in full for educational purposes.
provided that full credit is given to the UF/IFAS, citing the publication, its source, and date of publication.