

Drainage Systems for Flatwoods Citrus in Florida¹

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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.

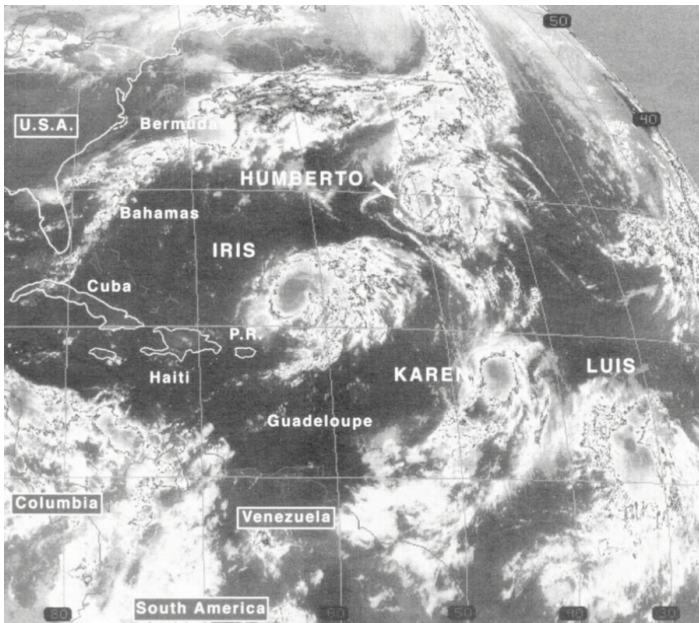


Figure 1. Satellite view of the "Parade of Storms" taken August 30, 1995 by the GOES-8 satellite in geosynchronous orbit 22,300 miles above the earth.

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

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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.



Figure 2. Spodic (organic layer) in Immokalee fine sand series soil.

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.



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.

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 than 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.



Figure 5. Advanced symptoms of water damage showing extensive defoliation and fruit drop.

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.



Figure 6. Healthy root system from flatwoods grove.



Figure 7. Severely damaged root system with few feeder roots from flatwoods grove.

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.



Figure 8. Aerial infrared map showing drainage facilities for grove.

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).



Figure 9. Double-row bed under construction.



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

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.

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.



Figure 12. Drainage pump station in citrus 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.



Figure 13. Water detention area within citrus grove.



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

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 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.

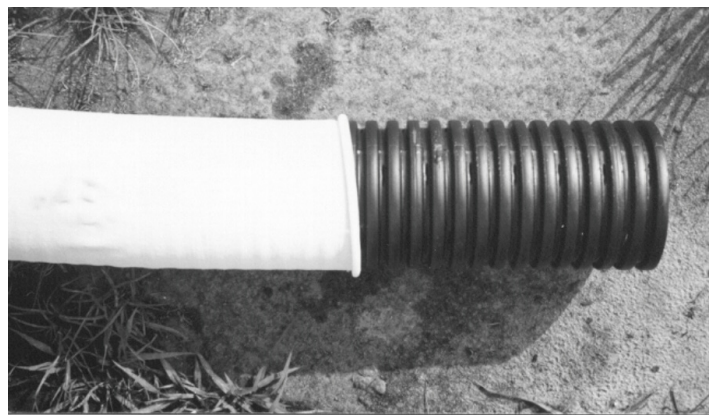


Figure 17. Four-inch corrugated drain tubing with polyester sock.

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).



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

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.

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.



Figure 19. Installing 4-inch corrugated drain tubing with PVC pipe discharge.

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

Eq. 1.

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

Equation 1.

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.



Figure 20. Laying corrugated drainage in citrus bed with plough-type drain installation machine.

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*, *Leptothrix*, 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.

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

Series	Order	Minimum		Maximum		Spacing increase for each extra inch of depth(ft.)	Oche potential
		Depth (inches)	Spacing (ft.)	Depth (inches)	Spacing (ft.)		
Adamsville	Entisol	46	71	58	149	6	slight
Blichton	Ultisol	40	53	52	99	4	severe
Bradenton	Alfisol	40	40	52	79	3	slight
Broward	Entisol	28	57	34	90	5	slight
Charlotte	Spodosol	46	71	58	149	6	moderate
Delks	Spodosol	40	56	52	102	4	moderate
Delray	Mollisol	46	71	58	149	6	slight
EauGallie	Spodosol	46	60	58	130	6	severe
Elred	Spodosol	46	54	58	112	5	moderate
Farmton	Spodosol	46	63	58	115	4	severe
Felda	Alfisol	46	61	58	133	6	slight
Floridana	Mollisol	46	60	58	108	4	severe
Ft. Drum	Inceptisol	46	60	58	125	5	slight
Hilolo	Alfisol	46	32	58	64	3	severe
Holopaw	Alfisol	46	71	58	146	6	moderate
Immokalee	Spodosol	46	67	58	116	4	severe
Jumper	Ultisol	46	55	58	101	4	slight
Kanapaha	Ultisol	46	71	58	112	3	moderate
Lawnwood	Spodosol	46	43	58	78	3	severe
Lochloosa	Ultisol	46	56	58	104	4	slight
Malabar	Alfisol	46	101	58	162	5	severe
Micanopy	Alfisol	40	45	52	80	3	severe
Myaka	Spodosol	46	56	58	120	5	severe
Narcoosee	Spodosol	46	69	58	134	5	severe
Nettles	Spodosol	46	66	58	125	5	severe
Nobleton	Ultisol	40	61	52	124	5	slight
Oldsmar	Spodosol	46	85	58	142	5	severe
Ona	Spodosol	46	85	58	142	5	severe
Parkwood	Alfisol	46	98	58	169	6	slight
Pendarvis	Spodosol	46	67	58	112	4	severe
Pepper	Spodosol	46	67	58	112	4	severe
Pineda	Alfisol	46	89	58	117	2	moderate
Pinellas	Alfisol	46	108	58	178	6	slight
Placid	Inceptisol	46	108	58	178	6	moderate
Pompano	Entisol	46	71	58	147	6	slight
Riviera	Alfisol	46	86	58	129	4	slight
Seffner	Entisol	46	72	58	126	4	moderate
Sparr	Ultisol	46	71	58	146	6	slight
St. Johms	Spodosol	46	74	58	125	4	severe
Susanna	Spodosol	46	73	58	110	3	severe
Tantile	Spodosol	46	86	58	131	4	severe
Tusawilla	Alfisol	46	56	58	112	5	severe
Valkaria	Entisol	46	71	58	145	6	moderate

Series	Order	Minimum		Maximum		Spacing increase for each extra inch of depth(ft.)	Oche potential
		Depth (inches)	Spacing (ft.)	Depth (inches)	Spacing (ft.)		
Vero	Spodosol	46	68	58	102	3	severe
Wabasso	Spodosol	46	70	58	115	4	severe
Wacahoota	Ultisol	46	91	58	121	2	severe
Wachula	Spodosol	46	85	58	128	4	severe
Waveland	Spodosol	46	56	58	86	2	severe
Winder	Alfisol	46	54	58	99	4	slight