SOIL PHYSICAL PROPERTIES AND WATER TABLE MANAGEMENT

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INTRODUCTION

Although groundwater underlies the entire state of Florida, a water table will directly influence the growth and production of citrus trees only when it is shallow with respect to the soil surface, i.e. in close proximity to the root zone. Shallow water tables are generally associated with citrus grown in the flatwoods areas of Florida's east coast and southwest regions. These are normally wet areas where trees are planted on raised beds to assure that a sufficient unsaturated soil volume is available for rooting.

The management of a flatwoods citrus water table is critically important for tree root health during periods of excessive rainfall. Drainage, or the lowering of a high water table, is accomplished through a network of shallow and deep ditches which remove both surface and sub-surface water. Citrus roots will normally not be damaged by free water which has risen into the root zone if the drainage system has the capacity to lower the water table at a rate of about 6 inches per 24 hours.

Prior to the occurrence of water shortages and increased competition for water between urban and agricultural interests, most flatwoods citrus groves were irrigated using some variation of seepage irrigation or water table control. The process involves raising the naturally-occurring shallow water table during periods of dry weather by back-pumping water through the drainage network. This irrigation method requires extremely large volumes of water in order to be effective, although most of the water is returned to the system rather than being subjected to evaporation or seepage losses.

Currently, mandated water conservation efforts have placed emphasis on the use of low-volume or micro irrigation for flatwoods citrus, especially in newly-planted groves. No back-pumping of water through grove ditches is required with this method, however the ditches still need to be constructed and maintained for drainage purposes. Consequently, the ditch network is always in "drainage mode" when micro irrigation is used. Since little or no free water is normally visible in the furrows between the grove beds (except after heavy rainfall), it becomes easy to overlook the possibility that a shallow water table may still exist underneath the beds at a reasonably close distance to the root zone.

A shallow water table will exist naturally in the flatwoods due to high annual rainfall, little topographic relief, and the existence of a slowly-permeable subsurface soil layer (spodic or argillic horizon). It is maintained by rainfall, seepage irrigation, or overuse of sprinkler/micro irrigation, and its depth with respect to the soil surface will depend on factors such as consistency and volume of rainfall, depth to restrictive layer, capacity of drainage system, and climatic conditions.

Static or fluctuating free water in the soil, if close enough, has the ability to rise into the root zone of a crop at a sufficient rate to contribute significantly to the evapotranspiration (ET) requirements of that crop. This is known as capillarity or upward flux. It is the objective of the following sections of this paper to define and describe the physical properties of soil which influence both downward and upward water flow, and to illustrate their relevance in the relationship between grove water management and water table fluctuation.

SOIL AS A POROUS MEDIUM

Physical properties of soil

A mineral soil is a porous mixture of inorganic particles and decaying organic matter with voids (pores) in between that hold air and water. Larger mineral fragments are sometimes coated with colloidal material such as clay or organic matter.

Where larger particles dominate the mineral fraction (as in most of Florida), the soil is sandy and is known as light soil; where the mineral colloids dominate, the soil has clayey characteristics and is known as heavy soil. The terms "light" and "heavy" do not refer to soil weight but to the ease at which the soil is tilled.

Soil TEXTURE is concerned with the size of the mineral particles (the relative proportions of particles of various sizes in a given soil); soil STRUCTURE is the arrangement of soil particles into groups or aggregates.

Soil texture and structure are important because they govern the retention and movement of water in the soil as well as the transport of dissolved components (fertilizers, pesticides, etc.) in the water.

Sands are packed together such that the pores between the individual particles are large. As the silt and clay content increases, the smaller overall particle size creates smaller pore sizes.

Size of pores: Two types of individual pore sizes occur in soil - MACRO and MICRO. There is no sharp cutoff point, but pores smaller than about 0.06 mm in diameter are considered micropores and those larger as macropores. Macropores allow the ready movement of air and water; micropores are usually filled with water in field soils and do not permit much air movement into or out of the soil. The water movement is restricted primarily to slow capillary movement. Coarse-textured soils are dominated by macropores, while fine-textured soils without stable granular structure are dominated by micropores.

Large pores can conduct more water, more rapidly than small pores, and exert a smaller suction on water than fine pores. Suction is a measure of the energy required to remove water from a given pore. Therefore, it is easier to remove water from a large pore than from a small pore. Tensiometers can provide a measure of the suction with which soil water is held.

The pore size distribution for a given soil can be derived from the relationship between suction and pore size (each pore size is associated with a particular suction at which the pore can be emptied): the volume of water that is released by a soil sample between two different suctions is a measure of the volume of the pores which have sizes corresponding with these two suctions.

Capillary fundamentals and soil water

Capillarity is a familiar phenomenon, a typical example being the movement of a fluid up a wick when the lower end is immersed in the fluid. Capillarity is due to two forces: the attractive force of the fluid (in this case, water) for the solids on the walls of the channels through which it moves (adhesion), and the surface tension of water, which is largely due to the attraction of water molecules for each other (cohesion).

Capillarity can be demonstrated by placing one end of a fine glass tube in water. The water rises in the tube, and the smaller the tube bore, the higher the water rises. The water molecules are attracted to the sides of the tube and start moving up in response to this attraction. The cohesive force between individual water molecules assures that the water not directly in contact with the side walls is also pulled up the tube.

Capillary forces are at work in all moist soils. However, the rate of movement and the rise in height are less than one would expect on the basis of soil pore size. One reason is that soil pores are not straight like glass tubes, but are tortuous. Also, some soil pores are filled with air, which may be entrapped, slowing down or preventing the movement of water by capillarity.

Retention of water in soil

The pore space in soil is usually at least partially filled with water. When all pores are water-filled, the soil is said to be water-saturated. Unsaturated conditions occur when water is present only in the finer pores while the larger pores are air-filled. This can be explained by considering the capillary processes discussed above.

As a soil dries out, water leaves some of the pores which then become air-filled. Because water is removed easiest from large pores, they empty first. The smaller the pore, the greater the suction by which the water is held. It is more difficult to remove water from the finer pores, thus they remain water-filled until the soil dries out further. It is important to know how strongly water is held by the soil (the suction with which it is held) at any given time, because this governs not only the rate of water movement but also the availability of water to plants.

The suction that soil water exists under can best be measured in the field with a tensiometer, which in its simplest form consists of a water-filled porous cup that is in contact with the soil at one end, and a suction gauge at the other end. The two are connected by a water-filled tube. Upon installation, water is drawn out of the porous cup by the unsaturated soil and a suction develops within the tensiometer that is measured by the suction gauge. At equilibrium, the suction registered on the gauge is equal to the suction that the soil is exerting on the water around the porous cup. The drier the soil, the greater the suction, and the higher the tensiometer gauge reading. A saturated soil will register no soil suction, with tensiometer reading equal to zero.

Different soils will hold different amounts of water at the same soil suction level. Differences among soils are likely because of different pore-size distributions. Soils with larger pores can retain less water at a given suction than soils with smaller pores. This is because the smaller pores act as narrower capillaries, exerting greater suction on soil water than can be exerted by larger pores. These differences can be illustrated by observing the soil water characteristic curve for a number of soils. An example of this curve for several different soil textures is shown in Fig. 1.

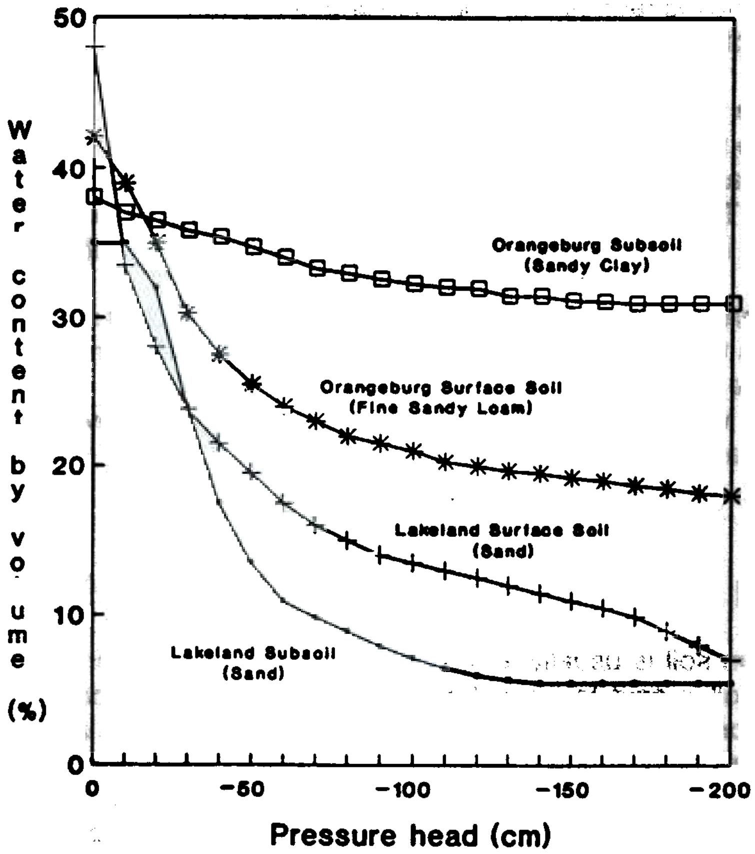

Fig. 1. Soil water characteristic curve for four soils.

Movement of water in soil

Two factors cause water to move in soil: 1) gravity, and 2) the soil suction due to capillary forces. The hydraulic head at a given point in the soil is equal to the potential for gravity to move water plus the potential for suction to move water. The direction and rate of water flow depend on differences in hydraulic head between different points in the soil.

Not only is head difference important between two points, the distance between the two points is also important. Expressed in terms of weather phenomena, we may observe a gentle breeze when high and low pressure areas are far removed from each other. When the same high and low pressure areas are in close proximity, however, much stronger winds prevail. So too with water flow in soils. The hydraulic head difference between two points in the soil must be divided by the distance between them to obtain the "gradient" of the head between the two points. Direction of flow will be from a zone of higher hydraulic head to a zone of lower head.

In order for water to actually move from one point to another in response to a difference in hydraulic head, the soil must be permeable enough to allow the movement to occur. Hydraulic conductivity is a measure of this ability of a soil to transmit water. The larger the conductivity of a soil, the greater will be the movement of water through it at any given hydraulic gradient. A soil has maximum conductivity when it is saturated, since under this condition all pores have the ability to conduct water. (Water can flow through a pore only if it already has water in it.) As a soil dries out and the larger pores empty, the conductivity decreases because only a portion of the pores (the smaller, water-filled ones) can move water through them.

Field soil moisture terminology

Maximum retentive capacity - During heavy rainfall, a soil may become saturated with water and ready downward drainage will occur. At this point (saturation, or a reading of zero on a tensiometer), the soil has its maximum retentive capacity.

Field capacity - After the rain has stopped, there will be a continued relatively rapid downward movement of some of the water in response to the hydraulic gradient. After a period of time, this downward movement will become negligible. With respect to the water that is left, the soil is said to be at field capacity. At this time water has moved out of the macropores, and its place has been taken by air. The micropores are still filled with water and can supply plants with needed moisture.

The time that it takes a soil to reach field capacity will depend on its pore-size distribution. Sandy soils dominated by macropores will reach field capacity quickly (1 day). Finer-textured soils will take 2-3 days to reach field capacity. A reading of about 10 cb on a tensiometer would indicate that field capacity has been reached in sandy soil.

Soils in the flatwoods area of Florida may be greatly slowed in reaching field capacity as defined above due to the presence of a shallow water table. The above definition assumes a freely-draining profile; that is, there is no accumulation of water deeper in the profile to impede downward drainage. Most flatwoods soils are subjected to high water tables at least part of the year, thus true field capacity following rainfall may never be reached due to upward soil water movement from the water table due to capillarity. A quasi-equilibrium state may be reached where partial drainage has taken place, which could be interpreted as a form of field capacity. In this case, the soil would be wetter than in the case of "normal" field capacity, with corresponding tensiometer readings in the range of 5-9 cb.

WATER TABLE BEHAVIOR UNDER FLATWOODS CITRUS BEDS

A flatwoods citrus shallow water table will fluctuate in response to a number of environmental factors including rainfall, evapotranspiration, and irrigation. The magnitude of the fluctuation will depend on the initial water table level, soil water content and hydraulic characteristics, effectiveness of the drainage network, intensity and consistency of rainfall, rate of evapotranspiration, and type and intensity of irrigation. A combination of these factors will determine if the water table is close enough to the citrus tree root zone to contribute to tree water requirements.

Rainfall. A shallow water table can rise in response to rainfall amounts as low as 0.15 inches with the right set of conditions. Low soil water-holding capacity will allow a large fraction of many rainfall events to percolate downward until the water table is reached (Fig. 2). A downward flux greater than the rate of drainage off of the restrictive soil layer will cause the level of free water to build up above it. As a general rule in sandy soil profiles, one inch of rain will raise a shallow water table approximately 10 inches.

As stated earlier, water tables which have risen into the citrus tree root zone need to be drained at a rate of about 6 inches in 24 hours in order to avoid root damage. Seepage-irrigated groves are more prone to temporarily flooded conditions due to the water table being artificially high, while micro irrigated groves are less susceptible because they are always in "drainage mode".

Evapotranspiration. If subsurface free water is within about 36 inches or less from any part of a citrus tree root zone in sandy soil, it is likely that part of the water used by the trees is made available through upward water flux from the water table. This water use via ET will increase the water table drawdown rate. A water table that exists about 18-24 inches below the soil surface can normally provide the upward flux capacity to supply the entire evapotranspirative need of citrus (Fig. 3). This is the principle behind seepage irrigation, but with this type of irrigation the drawdown due to ET is compensated for by additional pumping. Shallow water tables which have risen due to rainfall can also have the same effect. While a water table that has originated from seepage irrigation will remain in close proximity to the root zone for a relatively long period of time, a water table originated from rainfall will be more transient due to drainage as well as upflux losses. If a shallow water table drawdown rate is higher during the daytime hours (i.e. the period during the day when most of the ET takes place) than during the nighttime hours, this gives an indication that the citrus trees are obtaining water through the upward flux process (Fig. 4).

Irrigation. Seepage irrigation is a water table control method which attempts to supply the entire water requirement of citrus trees through the upward flux process. Sprinkler or micro irrigation methods should not affect the level of a shallow water table if scheduled properly, since ideally all of the water applied using these methods will remain held in the root zone. However, mismanagement of these systems (i.e. overirrigation) can cause a shallow water table to rise, resulting in the leaching of soluble plant nutrients and wasting of water. Soil profiles which are composed of very coarse sand are most susceptible to this occurrence, due to the large pore sizes. Even drip irrigation can impact the water table level under the right set of circumstances (Fig. 5). Consistent overirrigation can actually maintain the level of a shallow water table under a citrus bed.

Current micro irrigation scheduling methods in use in Florida do not take into account water which might be available through upward flux from a shallow water table. Both field and theoretical data suggest that upward flux does contribute some of the ET requirements of citrus trees, with the amount depending on the water table level. Research efforts are underway to examine the role of shallow water tables in irrigation scheduling in the Florida flatwoods. In the meantime, growers need to be aware of the level at which a shallow water table may exist under their groves, and the installation of monitoring wells is recommended.

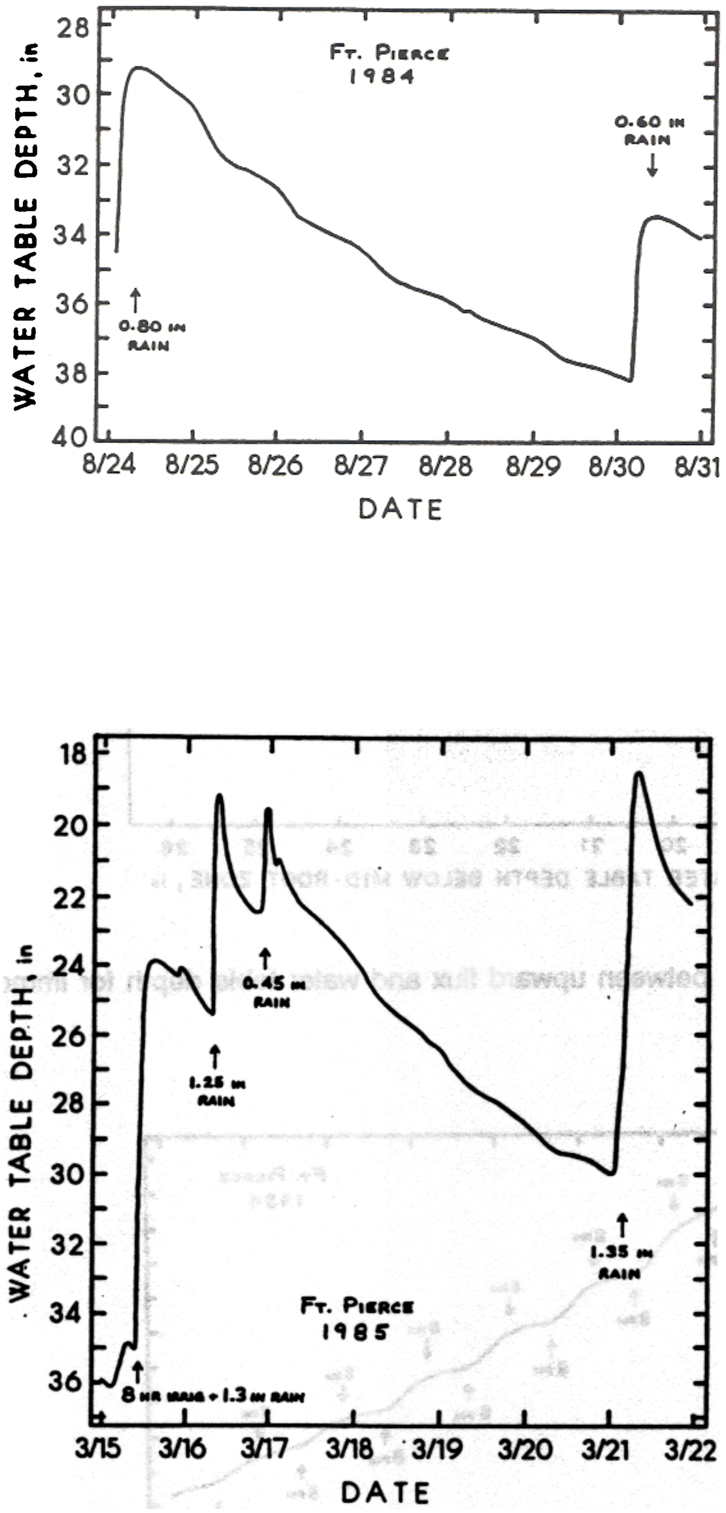

Fig. 2. Examples of shallow water table response to rainfall.

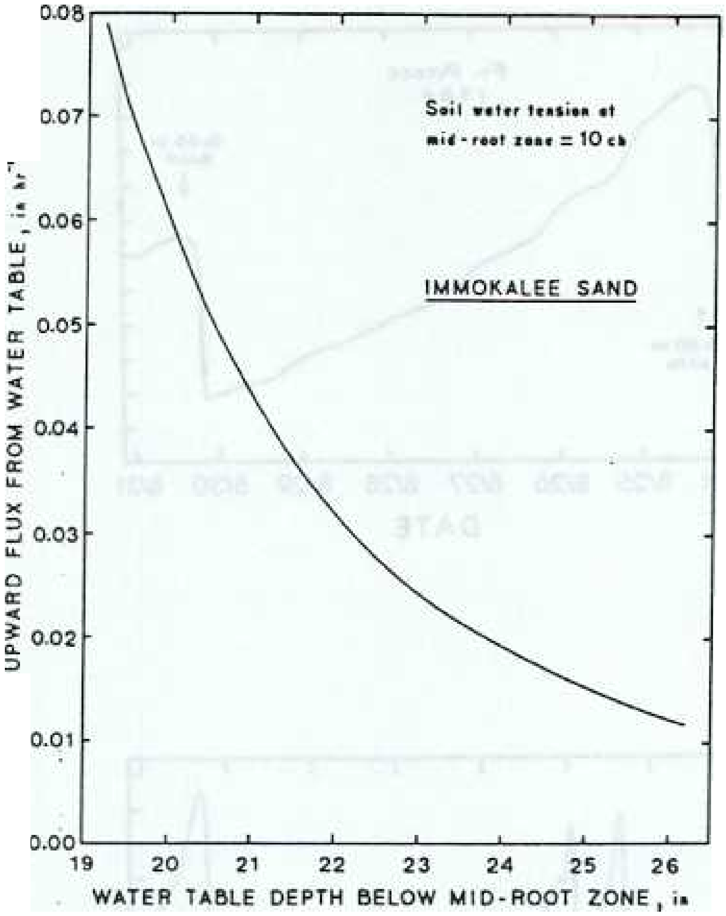

Fig. 3. Relationship between upward flux and water table depth for Immokalee sand.

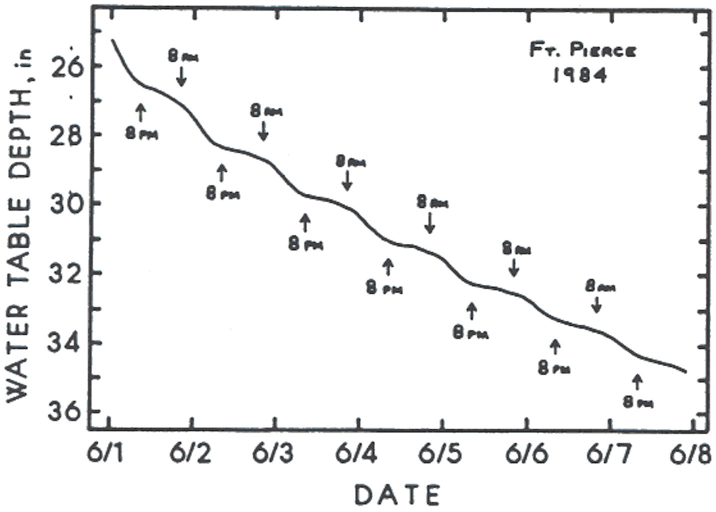

Fig. 4. Diurnal fluctuation of shallow water table drawdown during rain-free period.

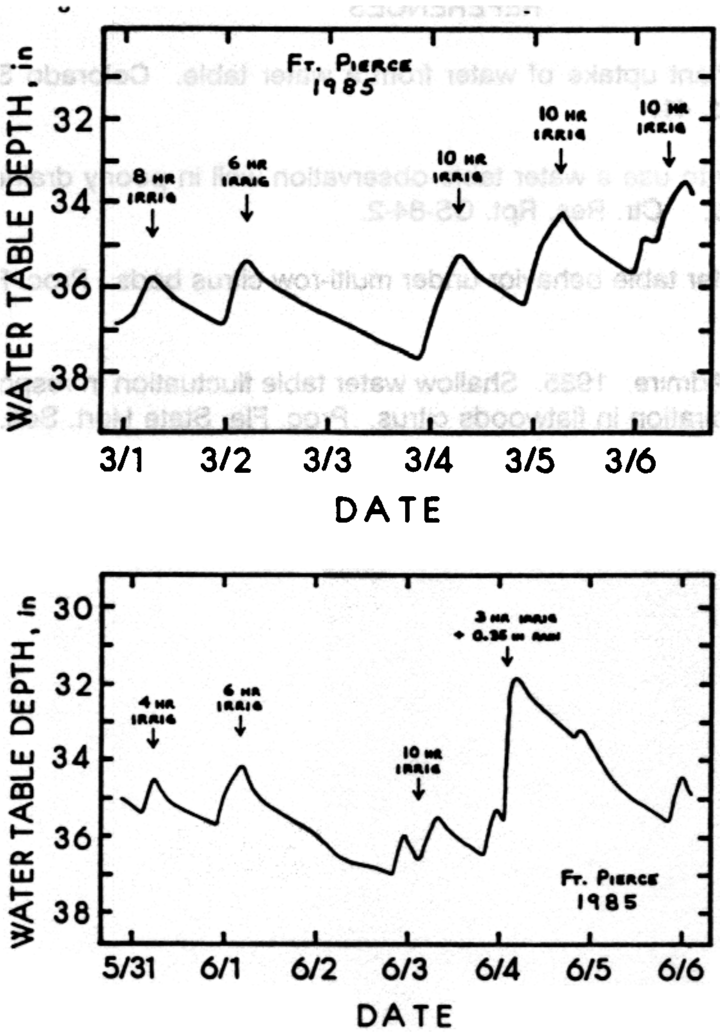

Fig. 5. Examples of shallow water table response to low-volume irrigation.

Water table management. There is a water-conserving management technique pertaining to shallow water tables that can be used in flatwoods citrus groves. While normally in "drainage mode" throughout the wet season, a grove drainage system may be used to limit the outflow of water accumulated through rainfall during the transition period to the dry season (i.e. early fall). This will keep the shallow water table closer to the root zone for a longer period of time, and upward flux may temporarily prevent the need for application of irrigation water. This situation should be reversed during the transition period between the dry and wet seasons in the late spring. A drainage system which is set to accumulate rain water should be set to lower the water table and provide more soil storage capacity for summer rains. Water table monitoring wells and tensiometers can aid in determining the effectiveness of these practices.

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