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Basic Irrigation Scheduling in Florida [1]

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Proper irrigation scheduling is the application of water to crops only when needed and only in the amounts needed; that is, determining when to irrigate and how much water to apply. With proper irrigation scheduling, crop yields will not be limited by water stress from droughts, and the waste of water and energy used in pumping will be minimized. Other benefits include reduced loss of nutrients from leaching as a result of excess water applications, and reduced pollution of groundwater or surface waters from the leaching of nutrients.

Irrigation is practiced to provide water when rainfall is not sufficient or timely to meet water needs of a crop. For most agricultural crops, yield or quality reductions result from water stress. Therefore, if water is available and if it is relatively low in cost, as is the case in Florida, irrigations are normally scheduled to avoid plant water stress.

Despite Florida's large average rainfall of 5260 inches per year, irrigation is practiced extensively. Irrigation is necessary because of the nonuniform distribution of rainfall, the very limited water-holding capacities of typical sandy soils, and the extreme sensitivity of many specialty crops to water stress. These factors and the economic losses from under-or-over-irrigation require that irrigations be scheduled as efficiently as possible.

This publication discusses irrigation scheduling for crops grown on typical Florida deep sandy soils so that shallow water tables do not contribute to crop water use. Thus, irrigation events must periodically occur to replenish water in the crop root zone. Water budgeting for water table management on poorly drained soils, called subirrigation or seepage irrigation, is discussed in IFAS Extension Circular 769, "Water Budgeting for High Water Table Soils", available from IFAS County Extension Offices. In seepage irrigation, water is applied to maintain a high water table just below the crop root zone.

DETERMINING WHEN TO IRRIGATE

Because the objective of irrigation is to maintain a favorable plant water environment for crop growth, the plants themselves are the best indicators of the need for irrigation. Instrumentation exists which could allow an irrigator to measure plant water status and to anticipate water stress. However, such instrumentation is expensive, requires special

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training for use, and is primarily used only for research purposes. Commercial field scale use of such instruments is generally not practical.

Another indicator of plant water stress is the visual appearance of the plant. Unfortunately, however, yield reduction has already occurred by the time most agricultural crops show wilt symptoms. Growth ceases in many crops before visual wilting occurs, and yield reduction may have occurred for some time before wilting is seen.

Finally, there are time lags associated with applying irrigation water. Because several zones might be irrigated from a single pump, many irrigation systems cannot quickly replenish water in the crop root zone. Many hours or days may be required. Therefore, the need to irrigate must be anticipated because of limitations of the irrigation system. This problem is compounded in Florida by the low water-holding capacities of most agricultural soils and by the shallow root zones of many crops.

When to irrigate can also be determined by calendar methods (for example every 5 days), by crop growth stage (for example, every 5 days during early vegetative growth stage, and every 3 days during peak growth stage), or by similar methods based on long-term average irrigation requirements. However, these methods fail to consider the effects of climatic variability on daily crop water use. Therefore, the use of long-term average values may not be adequate during periods of hot, dry days, while over-irrigation may occur during periods of cool, overcast days, especially if rainfall is not considered. Day-to-day climatic conditions are highly variable during much of the year in Florida because of cloud cover and the random nature of rainfall.

Because of the limitations of scheduling irrigations based on plant indicators, irrigations are most often scheduled based on the soil water status. Three procedures may be used: 1) a water balance procedure based on the estimated crop water use rate and soil water storage, 2) a direct measurement procedure based on instrumentation to measure the soil water status, and 3) a combination of the above two methods in which soil water status instrumentation is used with a water balance procedure. These procedures require a knowledge of the crop water requirements, effective root-zone, soil water-holding capacity, and irrigation system capabilities in order to schedule irrigations effectively.

CROP WATER REQUIREMENTS

Water is used in a cropped field in several ways: 1) assimilation into the plant and plant fruit, 2) direct evaporation from the soil or other surfaces, 3) transpiration, which is the loss of water vapor from plant leaves, and 4) other beneficial uses such as leaching of salts, crop cooling, and freeze protection. Usually less than 1% of the water used in crop production is assimilated into the plants. Other beneficial uses (category 4, above) may be significant, but they depend on factors other than maintaining adequate soil water content, and they will not be considered in this publication.

Most of the water applied to meet the water requirements of a crop is used in evaporation and transpiration. Evaporation and transpiration are important for cooling a crop in order to maintain temperatures in the range that permits photosynthetic activity and crop growth to occur. Transpiration also helps transport nutrients into and through plants.

The combination of evaporation and transpiration is called evapotranspiration (ET). Because the amount of water assimilated by a plant is very small as compared to ET, ET is often considered to be the crop water requirement -- the amount of water required by a growing crop to avoid water stress.

Delivering water to a crop in the field results in losses which increase the amount of water that must be pumped to supply the crop water requirement. Losses may occur because of inefficiencies in the conveyance system, evaporation and wind drift (especially if water is sprayed through the air), surface runoff, or percolation below the root zone. These losses can be minimized through good management practices, but they are impossible to completely eliminate. They must be considered when determining the total (or gross) irrigation water requirement.

In humid areas such as Florida, a large part of the crop water requirement can be provided by rainfall. Effective rainfall, rainfall that is stored in the root zone and available for crop use, directly reduces the amount of water which must be pumped for irrigation.

FIELD WATER BALANCE

The water balance of a field during and after irrigation is shown in Figure 1 . In Florida, runoff losses are normally negligible for properly designed irrigation systems because of the high infiltration rates of the sandy soils. Conveyance losses can be eliminated by delivering water to the field in pipes rather than open channels.

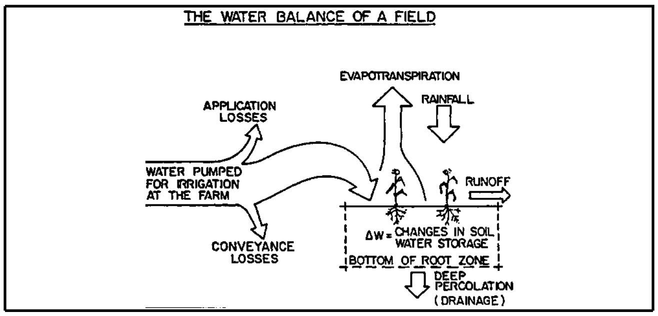

Figure 1 .

Application losses, including evaporation and wind drift, can occur during irrigation, especially from sprinkler irrigation systems. These losses are, however, relatively small during periods of low radiation, low wind velocities, and high humidities. Also, water which evaporates during application, or which is intercepted and later evaporates from soil, plant, or other surfaces is not entirely lost. Rather, some evaporation during application compensates for ET by reducing ET that would have occurred if the intercepted water had not evaporated.

Evaporation and wind drift losses can be minimized by irrigation at night, early mornings, and late afternoons when climatic conditions are not severe. However, cultural conditions such as disease must be considered for crops in which wet foliage may promote mold, fungus, bacteria, or other growths which could reduce yields. Deep percolation losses from well-designed irrigation systems can be minimized by good irrigation management. If water is applied uniformly and the water-holding capacity of a soil is not exceeded, water losses to deep percolation will be minimized. If saline water is used for irrigation, it may be necessary to leach excess salts from the crop root zone by adding water in excess of the soil water-holding capacity. However, water for leaching should be required only during extended dry periods in Florida because rainfall normally leaches salts.

If the losses shown in Figure 1 are kept to a minimum, most of the irrigation water applied will evaporate or transpire in response to the climatic demand. Unfortunately, rainfall is relatively unpredictable, and rain which immediately follows an irrigation is not very effective. Irrigation can be minimized by anticipating rainfall and providing soil storage capacity (that is, irrigating to less than field capacity to leave room for rainfall storage when the probability of rainfall is high) to increase rainfall effectiveness.

WATER BUDGET IRRIGATION SCHEDULING

Two questions must be answered in order to schedule irrigations: 1) When to irrigate?, and 2) How much water to apply? A water-budget procedure can be used to answer both questions.

From Fig. 1, the crop root zone can be visualized as a reservoir where water is temporarily stored for use by the crop. Inputs to that reservoir occur from both rainfall and irrigation. If the capacity of the soil-water reservoir (the volume of water stored in the crop root zone) and the daily rates of ET extraction from that reservoir are known, the date of the next irrigation and the amount of water to be applied can be determined. Thus, ET and soil-water storage capacity in the plant root zone are the basic information needed to use the water-budget method for irrigation scheduling.

Understanding Evapotranspiration

Evaporation is the change of water from liquid to vapor form. Energy is required for evaporation to occur. If field surfaces, such as the leaves of well-watered plants or wet soils, are moist, the amount of water vaporizing and moving into the atmosphere in a humid region such as Florida is mainly determined by the energy available from solar radiation. Thus, the solar radiation level is the main climatic factor that determines the ET rate, although air temperature, humidity, and wind also affect ET rates. For these reasons, ET rates are higher in summer when daily solar radiation levels and temperatures are high.

Exceptionally low relative humidity and high winds will increase ET rates above normal. Hot dry winds may raise the ET rates of isolated irrigated fields by 25 percent or more above the normal, although such periods are usually brief.

The most significant crop factors that affect ET from a well- watered crop are the crop species, the stage of growth, and the plant size or leaf area on which radiation is incident. Methods of expressing plant size and leaf area include the degree of ground cover or percent canopy coverage. ET rates are greatest when the entire soil surface is covered by the crop canopy.

Many crops do not totally shade the ground, especially during their early stages of growth, and evaporation from the dry soil surface between plants is normally low. This is especially true for sandy soils which act as a mulch to greatly reduce evaporation when the surface dries.

When the crop canopy is not complete, the ET rate is strongly influenced by the area of leaf surface that intercepts sunlight, that is, the percent of soil surface shaded by the crop. For this reason, ET for row crops during early growth stages and that of many orchards and vineyards is less than the ET that would occur from a complete canopy. As growth increases, ET reaches its maximum at nearly complete ground cover. ET measurements indicate that when the percent of ground covered by the canopy is above 60-70 percent, full ground cover and full ET rates can be assumed.

Immediately after an irrigation, evaporation from the wet soil occurs at approximately the same rate as full cover ET, but as the soil dries, rates of evaporation are quickly reduced. Thus, frequency of irrigation is important in determining evaporation losses from the soil, especially when the entire soil surface is wetted. There are both positive and negative aspects to evaporation from sandy soils-the soils are self-mulching and evaporation rates are quickly reduced when the soil surfaces dry, but, because of their low water-holding capacities, the surfaces must be wetted more frequently than those of finer-textured (heavier) soils because more frequent irrigations are required.

Estimating Evapotranspiration

Because climatic conditions largely determine ET, various methods based on meteorological factors have been developed to estimate ET rates. A summary and discussion of several ET equations and their modifications for Florida conditions were presented by a committee of IFAS researchers (Jones et al., 1984). The ET estimation equations which can be applied on a daily basis for irrigation scheduling require inputs of measured or estimated solar radiation. The Penman equation, which is believed to be the most accurate for Florida conditions, is also mathematically complex and difficult to use manually. For this reason, computer software (Zazueta, 1990) which calculates ET from climatic and crop factors is the approach often used to solve the Penman equation.

One of the simpler methods of estimating daily ET in the field is by measuring evaporation from a free-water surface, since a correlation exists between crop ET and evaporation from free water. The standard water surface commonly used is the National Weather Service Class A evaporation pan surrounded by a well-watered short grass. The ratio between potential ET (ET for a well-watered short green grass crop) and evaporation from a well-maintained evaporation pan is typically assumed to be about 0.8 in a humid area such as Florida. Crop ET is estimated by multiplying potential ET by water use coefficients (Kc) for specific crops, growth stages, and management factors. Kc values for many crops that are grown in Florida have been published by Doorenbos and Pruitt (1977), Jones et al. (1984), and SCS (1993).

When a complete crop canopy exists, the daily ET can be estimated by multiplying the measured pan evaporation by 0.8. This procedure can be used as a "rule of thumb" if more specific crop coefficient data are not available.

Soil-Water Storage

During irrigation, water infiltrates (penetrates) the soil surface. It is then distributed in the soil by gravity and soil capillary forces (attraction of water molecules to soil particles). As the soil becomes wetter, gravitational forces dominate and water drains downward through the soil. Drainage is rapid at first, but after one to two or three days (depending on soil type, layering, etc.) it decreases to a very small rate so that, for practical purposes, it may be neglected. At this time, soil moisture in the root zone may be considered to be in storage; it can be depleted primarily by plant transpiration or evaporation from the soil surface. This upper limit of water storage in the soil is called "field capacity" (FC). Field capacity in typical Florida sandy soils commonly occurs within one or two days after a large rainfall or irrigation because of the rapid movement of water in sandy soils.

A practical lower limit of soil water may be defined as the soil-water content below which severe crop water stress and permanent wilting occurs. This lower limit has been defined as the permanent wilting point (PWP). While plants may remove some water below this level, such extraction has little or no significance in irrigated agriculture, although it may be crucial for plant survival. In fact, yield reduction typically occurs long before PWP is reached.

The difference between FC and PWP is called the available water capacity (AWC). Table 1 presents typical values of AWC for various soil types. Most of the major irrigated soils in Florida are in the top category (sands and fine sands) in Table 1 . Local soil surveys and irrigation guides available from the Natural Resources Conservation Service, NRCS, (formerly Soil Conservation Service, SCS) provide information on specific Florida soil types. Available water capacity may also be estimated in the field by applying a known amount of water to the soil when the profile water content is near PWP, observing the volume of soil wetted, and calculating the volume of water stored per unit volume of soil.

Once AWC is known, the total depth of water available (AW), and thus the capacity of the soil-water reservoir, can be obtained by multiplying AWC by the crop effective root zone depth. For layered soils, AW is calculated by adding the multiples of AWC and depths of all soil layers contained in the crop root zone.

The effective root depths of Florida agricultural crops can be estimated from crop production guides or the SCS Florida Irrigation Guide (1982), but site specific conditions will also affect root depths. The best way to determine effective root zone depths is by digging and observing where most of the roots are located. The effective root zone is that zone where most of the roots actively involved in water uptake are located -- this is normally the upper 1 to 3 ft of the soil profile, depending on the crop being grown. In a humid area such as Florida, irrigations should be concentrated in this upper portion of the crop root zone where the great majority of the crop roots are located.

Allowable Soil Water Depletion

The allowable soil water depletion is the fraction of the available soil water that will be used to meet ET demands. As ET occurs, the soil water reservoir begins to be depleted. As the soil dries, the remaining water is held more tightly by capillary forces in the soil, making it more difficult for the plant to extract it. For this reason ET will start to decrease long before the PWP is reached. Since the lower ET will generally reduce yields, growers should irrigate before the root zone water content reaches a level that restricts ET.

The critical soil water depletion level depends on several factors: crop factors (rooting density and developmental stage), soil factors (AWC and effective root depth), and atmospheric factors (current ET rate). Therefore, no single level can be recommended for all situations, however, allowable depletions of 1/3 to 2/3 of the available soil water are commonly used to schedule irrigations. The smaller allowable depletions are required for sensitive crops and at critical stages of growth. The greater depletions are allowed for less sensitive crops and at less-critical growth stages. As a "Rule of Thumb", an allowable water depletion of 1/2 of AWC should be used if more specific data are not available.

The Water Budget

The water-budget procedure is also called a water balance or bookkeeping procedure. It is similar to keeping a bank account balance. If the balance on a starting date and the dates and amounts of deposits and withdrawals are known, the balance can be calculated at any time. Most importantly, the time when all funds (or water) would be withdrawn can be determined so that a deposit can be made to avoid an overdraft (or an irrigation can be scheduled to avoid water stress).

The water budget equation for irrigation scheduling on a daily basis can be written as shown in Equation 1 .

$$\Delta S = R + I - ET - (D + RO)$$

where

ΔS = change in soil water storage (inches),
R = rainfall measured at the field site (inches),
I = irrigation applied (inches),
ET = evapotranspiration estimated pan evaporation or other method (inches),
$D + RO$ = drainage and runoff, calculated as rainfall in excess of that which can be stored in the soil profile to field capacity (inches)

Equation 1 .

The soil water storage on any day (I) can be calculated from the soil water on the previous day (I-1), plus the rain and irrigation, and minus the ET, drainage, and runoff that occurred since the previous day as shown in Equation 2 .

$$S(i) = S(i - 1) + R + I - ET - (D + RO)$$

where

$S(i)$ = today's soil water storage (inches),
$S(i - 1)$ = yesterday's soil water storage (inches), and all other terms are as previously defined

Equation 2 .

The starting point for irrigation scheduling is often after a thorough wetting of the soil by irrigation or rainfall. This brings the soil reservoir to full capacity so that S(I) is equal to AW. If a large rain or irrigation does not occur, the initial available soil water storage must be measured or estimated.

Daily measurements or estimates of ET are subtracted from the available soil water until the soil water storage has been reduced to the allowable depletion level. At that point an irrigation should be applied with a net amount equivalent to the accumulated ET losses since the last irrigation. The soil reservoir is thus recharged to fullcapacity, and the depletion cycle begins again.

Figure 2 shows a sample of a water budget for a Florida sandy soil with a total available water depth of 1.5 inches in the plant root zone. It was assumed that a management decision was made to irrigate when 2/3 of the available soil water (1.0 inch) was depleted. In this example, that level of depletion occurred after 4 days. At that time, an irrigation should be scheduled to replenish the 1.0 inch of soil water storage that was depleted.

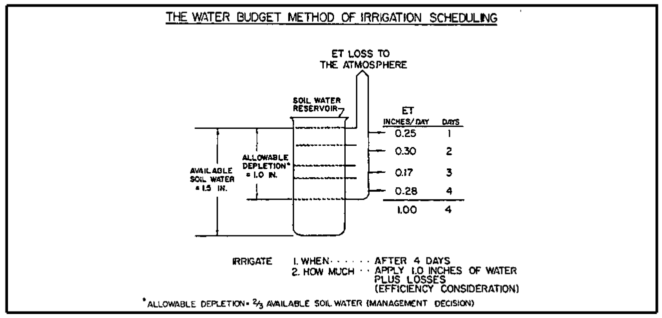

Figure 2 .

The water budget procedure also accounts for rainfall. Rainfall is entered into Fig. 2 in the same way as an irrigation application. That is, it refills the soil profile and raises the soil water content. If large rainfalls occur, only that portion required to restore the soil water content to field capacity will be effective. Greater amounts of rain will either run off of the soil surface or drain below the plant root zone. The management decision concerning the level of allowable water depletion (AWD) is one that must be made by each irrigation manager. The AWD will vary depending upon soil, crop, and climatic factors. Commonly it will vary during the growing season. For example, AWD may be set at 2/3 during non-critical crop growth stages, but it may be decreased to 1/3 during critical growth stages such as during fruit set. Decreasing AWD increases the frequency of irrigation (but decreases the amount per irrigation) to provide a more favorable crop root environment and reduce water stress during critical growth stages. Decreasing AWD will require larger irrigation requirements because the soil will be maintained wetter and thus rainfall will be less effective. More frequent irrigations will also increase evaporation from the soil surface.

The capacity of the root zone reservoir and allowable depletion levels can be estimated before the start of a growing season. For annual crops the capacity will change as the season progresses and as crop root zones expand. For mature perennial crops such as citrus, the root zone may be considered to be a constant for the given soil conditions.

The soil depth to be managed for irrigation must be refined by field experience. For example, experience in many parts of the world has shown that the citrus root zone to be irrigated should be much less than the 5 to 8 ft depths to which a portion of the plant roots penetrate. Rather, the irrigated zone should be the upper 2 to 3 ft of the root zone where the majority of the roots actively involved in water uptake are located. This practice also has the advantage of allowing some soil water storage capacity for rain.

Daily ET values for specific water use periods should be estimated from pan evaporation or ET equations. If current daily ET estimates are not available, soil moisture sensors or evaporation pans can be used. The use of long-term average ET data (Smajstrla et al., 1984) will result in scheduling errors because day-to-day ET rates are highly variable. Long-term average ET data can be used as a guide for daily ET estimates, but they will need to be modified for climatic variabilities. That is, they will need to be increased during hot, dry periods, and decreased during periods of mild weather.

SOIL-MOISTURE INDICATORS FOR IRRIGATION SCHEDULING

Devices for monitoring soil moisture have been available for many years. Among them, tensiometers are the instruments most commonly used for scheduling irrigations. Gypsum blocks are also used on a limited basis, but they are not very effective in the range required for irrigation scheduling on typical Florida sandy soils. Both of these instruments register the status of water in the soil, in terms of soil-water tension, at the depth at which the device is placed. They have the advantage of providing a direct measurement of the soil water status rather than relying upon estimates of ET to calculate the soil water content. When placed in the plant root zone, they indicate the soil water status that the plants are experiencing. Disadvantages of soil moisture sensors include their cost, labor requirements for reading and servicing, and the need for periodic calibration. They also measure soil water status at a point rather than for the whole field, thus many instruments may need to be installed to accurately represent a given field.

Details of the use, cost, advantages and disadvantages of soil moisture sensors are given in IFAS Extension Circular 532, "Measurement of Soil Water for Irrigation Management".

Details of the use of tensiometers are given in IFAS Extension Circular 487, "Tensiometers for Soil Moisture Measurement and Irrigation Scheduling", available from IFAS County Extension Offices.

When using tensiometers, no single soil-water tension level can be recommended as indicating the need for irrigation in every situation. For the same reasons that allowable soil water depletion is not constant for all crops and conditions, critical soil water tension also varies with soil and crop conditions and management objectives. The level also varies with depth of placement of the tensiometer. However, in typical Florida sandy soils, crop water stress is normally avoided when irrigations are scheduled in the range of 10-20 centibars (cb) in the upper portion of the crop root zone where most of the roots actively involved in soil water extraction are located. Lower readings should be used for crops that are more sensitive to water stress. Field experience is required to refine the interpretation of instrument readings for a given crop and management system.

Tensiometers or other soil-moisture monitoring instruments are most effectively used in combination with ET data. The instruments are read to determine when to irrigate, and the ET data are used to calculate the volume of water lost since the last irrigation. From this, the volume to be replaced can be determined.

IRRIGATION WATER MANAGEMENT

Good on-farm water management practices include not only precise irrigation scheduling, but also knowing (or being able to accurately measure) the volume of water applied to each field. For example, if the field associated with the irrigation scheduling example in Fig. 2 was 40 acres of citrus which is irrigated with an overhead sprinkler system in 4 sets of 10 acres each, and if the application efficiency for the overhead system was 75% (25% of the water applied is assumed to be lost to evaporation, wind drift, and nonuniform application during sprinkling), the depth of water to be pumped at each irrigation would be 1.0 inches/0.75 = 1.33 inches. The volume of water required for each 10 acre set would be 1.33 inches times 10 acres = 13.3 acre-inches or approximately 362,000 gal.

Flow meters can accurately measure irrigation water to verify that the correct amount was applied. Meters are available with registers in units of either gallons or acre-inches. Flow meters can easily pay for themselves with savings in fuel costs for irrigation pumping. More information on irrigation flow measurement is available in IFAS Extension Bulletin 207, "Agricultural Water Measurement", available through IFAS County Extension Offices.

Good farm irrigation management requires that an irrigation system be capable of applying water in sufficient quantities to meet the crop's water requirements and with high uniformity to minimize waste. Nonuniform irrigation will cause excess water to be applied in some areas while

other areas will not get enough.

Irrigation systems are more expensive if they are designed to provide a high degree of uniformity. Thus, there is a temptation to sacrifice uniformity when systems are purchased on the basis of competitive bids. The system manager should recognize that operating costs will be greater or yield losses will result when systems which apply water and chemicals nonuniformly are operated. A lower initial system cost which sacrifices uniformity of water application may be false economy. Techniques for field evaluation of the uniformity of water application by irrigation systems are available as IFAS Extension Bulletins 265 and 266, "Field Evaluation of Microirrigation Water Application Uniformity" and "Field Evaluation of Irrigation Systems: Solid Set or Portable Sprinkler Systems", respectively, available from county extension offices.

SUMMARY

Proper irrigation scheduling will help to assure efficient use of water and energy in crop production. Irrigation scheduling methods that are currently applicable in Florida are 1) a water budget method requiring estimation of daily ET and soil water content, and 2) the use of soil moisture measurement instrumentation. Techniques for estimating ET, determining soil water storage, determining allowable water depletions, and water budgeting were described. When properly used and combined with efficient methods of water application, these techniques should also result in increased production and profits.

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Table 1.

Table 1. Available water capacity for various soil types.

	Available Water Capacity (AWC)	
Type of soil	range (inches/ft)[1]	average (inches/ft)
Sands and fine sands	0.4 to 1.00	0.75
Moderately course--textured sandy loams to fine sandy loams	1.00 to 1.50	1.25
Medium texture--very fine sandy loams to silty clay loam	1.25 to 1.75	1.50
Fine and very fine texture--silty clay to clay	1.50 to 2.50	2.00
Peats and mucks	2.00 to 3.00	2.50

1. Inches of water per foot of soil depth.