MICRO IRRIGATION SCHEDULING

by

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INTRODUCTION

Irrigation scheduling is determining (1) when to irrigate, and (2) how much water to apply. Irrigation scheduling is complicated by the fact that irrigation timing and the amount of water applied are not independent of each other. Both depend on numerous other factors such as: climate, soil, crop age, cultural practices, water-table depth, and water quality.

The objectives of the irrigator should be defined prior to establishing the appropriate method for irrigation scheduling. There are several possible objectives of irrigation:

1) maximize yield per unit of water applied,
2) maximize yield per unit of energy expended,
3) maximize yield per unit area, or
4) maximize net profit.

Maximizing yield per unit area is the most common approach, even if the actual objective is to maximize net profit. Profit maximization occurs at the point in which the marginal benefit of irrigation equals its marginal cost. In the short run, marginal costs relate only to variable costs. Since the variable cost of irrigation (pumping cost) in Florida is typically low, the uncertainties related to other factors of production often overwhelm this smaller variable. Thus irrigation is sometimes applied in excess of crop needs.

When water costs become high due maximum yield per unit of water (or energy) however, maximum yield per unit of water approaches zero, which likely would not be to scarcity or high pumping costs, then may be the objective. This could mean, (or energy) occurs when water applied the profit maximizing point. Rather than maximum yield per unit of water (or energy), the rational (economic) approach is to determine the optimum point of operation by marginal analysis. The optimum irrigation amount occurs when the benefit of the last unit of water applied equals its cost.

Determining when to irrigation is central to managing a micro irrigation system. The

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following factors should be considered when scheduling irrigations:

1) the design of the irrigation system,
2) soil moisture status,
3) volume of soil wetted, and
4) in some cases - power availability.

Irrigation scheduling decisions are limited by the capacity of the micro irrigation system. To minimize micro irrigation system costs, most systems are designed to operate for long periods of time each day. Usually the design is based on being able to replace peak crop water use each day. This may require that the irrigation system be operated for a time which approaches 24 hours per day during that peak water use period.

Also micro irrigation system are designed to be operated frequently, which makes it possible to keep the soil within the wetted volume at high moisture levels. This can provide optimum growing conditions for many plants and is the bases of improved yields that have often been observed with crops that are micro irrigated. Frequent irrigation is very important in Florida’s sandy soil since these soils have very little water holding capacity. The main purpose of each irrigation is to replace the water used by evapotranspiration since the last irrigation.

Since micro irrigation systems wet only a portion of the crop root zone, there is limited soil-water storing capacity. This fact makes irrigation management for micro systems on sandy soils even more critical. Excess application means the leaching of nutrients, while too little water applied results in water stress and yield reduction. Thus, there is a fine line that must be observe to be successful in using micro irrigation systems.

In some cases energy (electric) costs can be reduced by irrigating during off-peak energy use periods. This is a common practice in many western states where pumping cost represent a large component of irrigation costs. Pumping costs in Florida are usually relatively low since groundwater is near the surface. There are numerous approaches to irrigation scheduling which are outlined below. Typically, a combination of monitoring soil-water status and water budgeting is used.

SOIL-WATER MEASUREMENT METHODS

Soil-water content is defined as the amount of water contained by a soil on a weight or volume basis. Soil-water is of great importance to irrigation scheduling because it is the water stored in the soil that interacts with plants and the atmosphere. Several techniques and devices have been developed for measuring soil-water status. Techniques which. rely on sensors are of special interest because with the proliferation of inexpensive electronic controllers, this provides the possibility of high levels of automation.

Volumetric Method

A common way of expressing soil-water content is as the percentage of the volume of water in the bulk volume of soil and is usually referred to as volumetric water content:

$$\theta_v = V_w/V_s \qquad \text{Eq 3.1}$$

where,

θ_v = volumetric water content.
V_w = volume of water, and
V_s = bulk volume of soil.

The total water content of a soil is the sum of the bound and free water held in the soil. Most methods of soil-water monitoring measure total soil water; while plant available water is what is important for irrigation management.

Gravimetric Methods

Another way of the soil expressed as expressing soil water is gravimetrically: the weight of water in a fraction of the weight of the dry soil. Gravimetric methods involve taking a soil sample, weighing the sample, drying the sample in an oven, re-weighing it, and expressing the soil-water content as a percentage of the dry weight. The volumetric soil-water content can be obtained from the gravimetric water content by multiplying by the bulk density of the soil. Gravimetric methods are most often used as a standard against which other methods are compared. The gravimetric water content is related to the volumetric water content by:

$$\frac{\theta_v}{\beta}$$

$$\theta_g = \qquad \text{Eq. 3.2}$$

where,

θ_g = gravimetric water content,
β = bulk density of the soil.

Feel Method

The “feel” method is performed by taking a physical sample of soil and, then by observation and feel, estimating its water content. The primary advantage of this method is its low cost and simplicity. This method, however, has some serious disadvantages:

1) it is non-quantitative and subjective,
2) it does not give any lead time for irrigation, and
3) it is subject to misuse such as: only looking at the surface soil in a limited

area.

Given these limitations, the “feel” method is not recommended as the sole means of irrigation scheduling, but should still be used as verification of other methods.

Electromagnetic Methods

Electromagnetic methods are based on measurements of an electrical property of the soil that is closely related to soil-water. These methods generally rely on devising a circuit of known behavior in which the soil is a component that affects the behavior of the system. Because a measurement is made of an electrical property, calibration is usually necessary to relate the measured property to soil-water content. There are several types of electromagnetic methods, each with advantages and disadvantages.

Resistivitv Methods: Gypsum blocks are used to measure soil water content. The blocks are placed in the soil at the location where the water content measurement is desired. The porous blocks absorb water from the surrounding soil, and electrical resistance in the block corresponds to water content. The lower the resistance, the greater the water content. Gypsum blocks are sensitive to soil-water salinity including fertilizer salts. They also tend to be rather non-sensitive at soil-water tension below one bar; therefore, the practical use of this method in Florida is very limited.

Gypsum blocks should be located in the root zone. The number and depth depend on the crop. Three observation points are often recommended: the lowest point of the root system, midway from the surface, and a near surface. The blocks should be left in the soil undisturbed.

Gypsum blocks, and similar sensors, have the advantages that:

I) they allow continuous soil water measurement,
2) are economical,
3) once calibrated they require a minimum of calculations, and
4) they can be implanted easily in the soil.

Their main disadvantages are:

1) they deteriorate with time,
2) they do not work well with soils that have high porosities (such as Florida’s soils), and
3) they are sensitive to temperature and soil salts.

<u>Time Domain Reflectometry (TDR)</u>: TDR techniques rely on measurements of the propagation of electromagnetic waves through soil. The velocity of the wave and its attenuation depend on soil properties, especially water content and electrical conductivity. Generally, with the TDR technique a step voltage pulse is propagated along a transmission line, or more frequently along a pair of parallel transmission lines. The lines serve as conductors and the soil acts a conducting media. The lines have the function of acting as wave guides along which the signal propagates in the soil as a plane wave. The signal is reflected back at the end of the transmission line in the soil and is returned to the TDR receiver.

The propagation velocity is related to the soil-water, and the amplitude of the signal is related to water content of the soil.

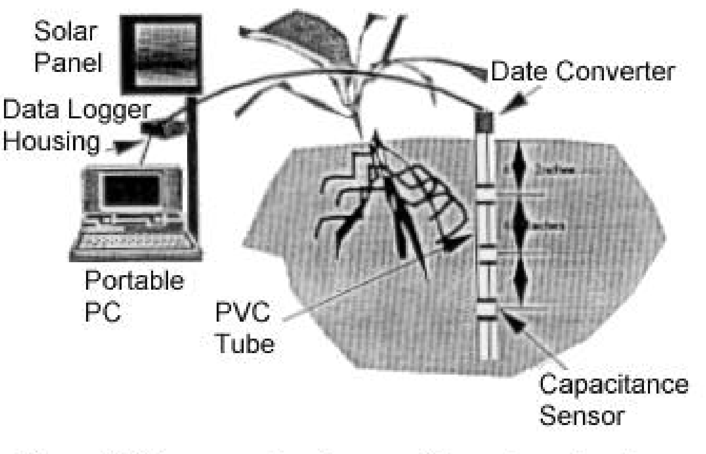

Figure 3.2 An example of a capacitance based system.

<u>Capacitive Methods</u>: Capacitive methods measure the dielectric constant of the soil using an electric circuit arrangement in which the soil is the dielectric media of one capacitor in a circuit (usually a resonance circuit of an oscillator). Capacitance-based sensors rely on the fact that water has a much higher dielectric constant than air or dry soil. Hence, changes in water content of the soil are reflected in changes in the dielectric constant of the soil. These sensors are not as

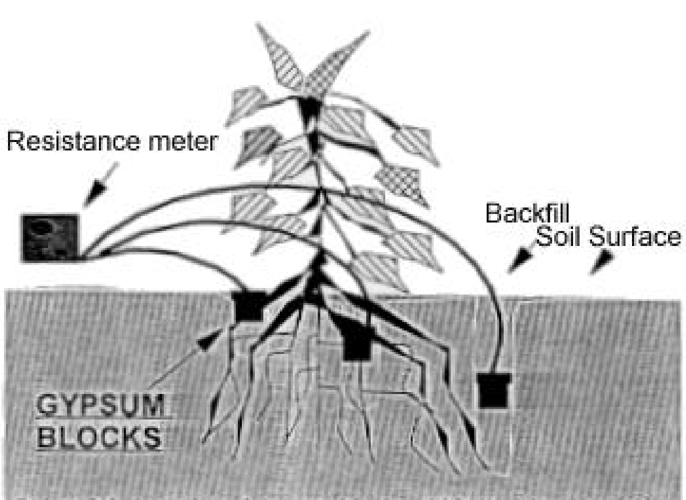

Figure 3.1 Location of gypsum blocks within the plant root zone.

sensitive as resistive type sensors to parameters other than water (i.e. salt). However, the relationship between the sensor's response and the soil's water content is not linear and is influenced by the type of soil, thus more complex calibration is required.

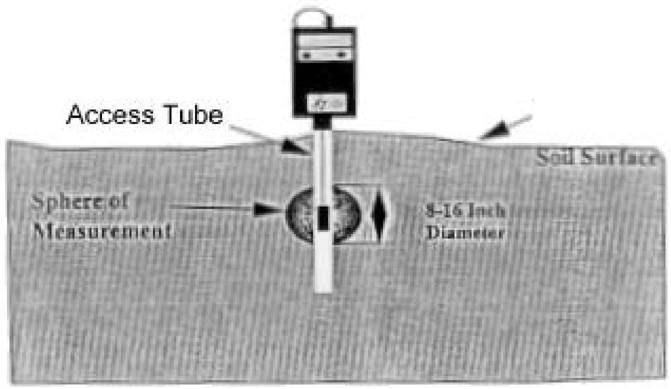

Figure 3.3 Neutron probe for measuring soil water content.

Nuclear Methods

Nuclear techniques depend on measuring the behavior of sub-atomic particles in soils. Sub-atomic particles are released from a low-level radioactive source in the soil or on the surface of the soil. Changes in the properties of these particles or changes induced by these particles are then monitored. These methods often require calibration for different soils since the behavior of the particles does not necessarily depend on the presence of water alone. For irrigation management, the neutron probe is the most commonly used instrument of this type.

Neutron Probe: With the neutron scattering method, a source of fast neutrons and a detector of thermal neutrons are employed. Fast neutrons are released in the soil from a radioactive source. The fast neutrons impact hydrogen atoms in the soil resulting in emissions of thermal neutrons. Thermal neutrons are then detected. Three processes are involved in the application: ?) fast neutron emission from a radioactive source; 2) moderation of the neutrons to thermal velocities by collisions in the soil medium and back-scattering towards the instrument; and 3) selective detection and counting of thermal neutrons at a point close to the source. Since most of the hydrogen atoms present in the soil are in water, this is very effective means of estimating soil water content.

Several high americium-beryllium widely used. Two energy neutron sources are used with this technique, such as (Am-Be) and radium-beryllium (Ra-Be). Am-Be is the one most types of neutron probes (depth probe and surface probe) are available commercially for soil-water measurements. The depth probe is generally a small cylinder that can be lowered into the soil through an access tube to the depth at which the water content is to be determined. The surface probe is placed directly on the surface of the soil and measures the average water content of the top few centimeters of soil. The reading obtained from both types of probes are averages soil water in the volume of soil around the probe (approximately 6-inches in radius).

Safety is a major concern of nuclear equipment users. The health hazard involved in using the equipment is small if the user follows the safety rules supplied by the manufacturer. Manufacturer's of the equipment state that if used safely and legally, the operator receives only a small fraction of the occupational exposure allowed by the Nuclear Regulatory Commission (NRC), which poses no health hazard. However, an operations license is usually required by state or federal government.

The neutron probe is a reliable method of observing changes in the soil-water content. Neutron probe sites need to be installed in replications to account for the spatial variability in soil conditions. Soil-water content can be accurately measured with this device; however, the neutron probe needs to be site calibrated. The neutron probe measures total water within the soil profile. Depending on the soil type, plant-available water varies as a percentage of total water (approximately 50 percent for sand).

The advantages of the neutron scattering method are:

1) it is nondestructive,
2) it is possible to obtain the profile of water content in soil,
3) water can be measured in any phase,
4) the system can be automated for one site to monitor spatial and temporal soil water, and
5) measurement is directly related to soil water.

The disadvantages are:

1) cost is relatively high,
2) the measurement depends on the geo-chemical properties of the soil,
3) care must be taken to avoid radiation hazard,
4) proper calibration is needed,
5) depth resolution is questionable (at near surface), and
6) it is labor intensive.

Tensiometers

A tensiometer consists of a liquid-filled porous cup and a vacuum gauge for measuring capillary tension or water potential. The liquid-filled porous cup is connected through a continuous liquid column to the vacuum gauge. The porous cup is normally constructed of ceramic and is filled with a liquid (usually water). Ethylene glycol-water solution is occasionally used in some applications where freezing conditions exist. Tensiometers respond to the suction force exerted by the soil on water. When a tensiometer is placed with the porous ceramic cup firmly in contact with the soil, water in the soil is connected to the water inside the column. If there is a difference in pressure between the water in the tensiometer and the soil-water, water transport through the ceramic cup will occur. When water in the soil and the column come to equilibrium, the pressure of the soil is equal to pressure in the column (and is usually negative). Tensiometers measure the matric potential, which is directly related to the energy required for plants to extract water from the soil. Tensiometers have been used for many years for

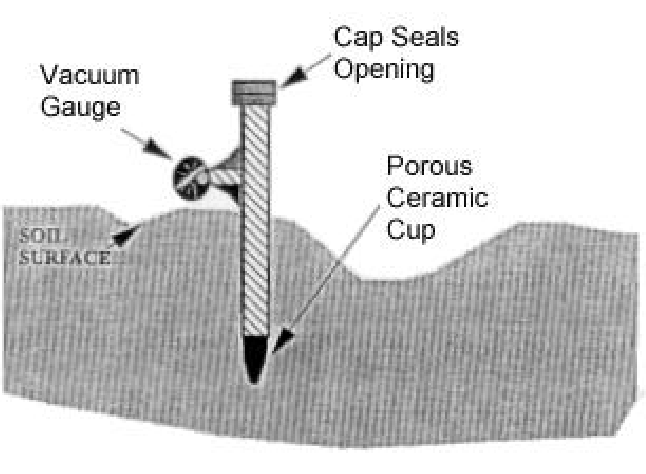

Figure 3.4. Components of a tensiometer.

monitoring soil-water status. Soil-water potential (SWP) is a useful index for characterizing the energy status of soil water with respect to plant water uptake. Tensiometers are devices that measure soil-water potential (sometimes described as soil-water tension). The effective operating range is from 0 to 80 chars. Calibration is not necessary since the tensiometer indicates soil-water potential directly (it does not include osmotic potential).

It is desirable to place two or more tensiometers at a location so as to describe the entire root zone. The tensiometer reading at which irrigation is needed will vary depending on the crop and the soil. In most Florida sandy soils, irrigation is initiated at a soil tension of approximately IO-20 chars. Therefore, tensiometers have a very narrow range of operation under Florida conditions.

Tensiometers require time to respond to changes in soil-water status because they measure water tension when the water in the soil and the water in the porous cup reaches equilibrium. The response time mainly depends upon: the conductance of the porous cup, the sensitivity of the vacuum gauge, the elasticity of the components, the amount of entrapped air, and the hydraulic conductivity of the soil in which the tensiometer is placed. The porous cup can also become plugged with biological growth or mineral precipitant.

The advantages of tensiometers are: 1) they are low cost, 2) they are easy to install and reasonably simple to maintain, 3) they can operate for long periods of time if properly maintained, 4) they can be easily adapted to automatic measurement by using pressure transducers or electric switch, and 5) they can be operated in frozen soils with ethylene glycol.

The disadvantages are: 1) tensiometers function to about 80 chars, which is a small part of the entire range of available water for most soils (not a problem in sandy soil); 2) they measure soil-water tension directly rather than soil-water content (knowledge of the soil-water characteristic curve is required to determine water content); 3) they display hysterical[3] behavior , 4) they are subject to breakage during installation or by farming activities; 5) they require regular maintenance depending on the range of measurements; and 6) they disturb the soil above the measurement point and can allow infiltration of

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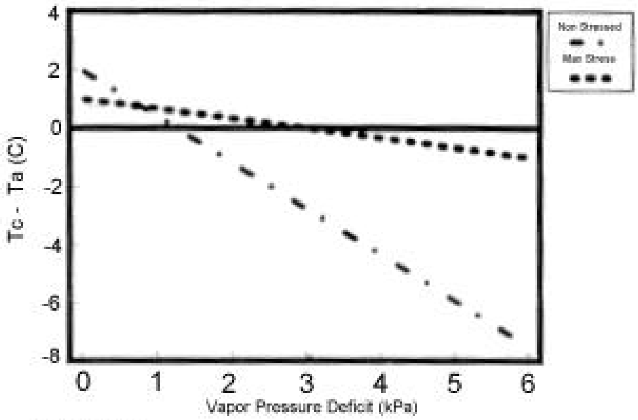
[3] Hysteresis refers to lag of effect when the forces acting on a body are changed.

irrigation water or rainfall along the stem.

PLANT WATER STRESS MEASUREMENTS

Direct measurement of plant-water stress is sometimes employed. This approach has the severe limitation that when plant stress is observed some yield reduction may have already occurred. These techniques are most often used to validate or calibrate other methods of irrigation scheduling.



Data SWFREC (1990)

Figure 3.5. Relationships from which the CWSI is determined.

Canopy Temperature

Since plant-water stress will result in reduced stomata1 conductance and an elevated leaf temperature, canopy temperature is a means of quantifying crop stress. The relationship between vapor-pressure deficit (VPD) and the difference between canopy and air temperatures ($T_c - T_a$) has been developed as an environmentally responsive indicator of plant water stress and is termed the Crop Water Stress Index (CWSI). Canopy and air temperature along with vapor pressure deficit can be measured with one device (**IR-Scheduler**)[4]. The CWSI can be calculated as follows:

$$\mathrm{CWSI} = [((T_c - T_a) - \mathrm{VPD})/({}^\wedge T_{Max} - \mathrm{VPD})] * 10 \qquad \text{Eq. 3.3}$$

where,

T_a = Air Temperature, °C
T_c = Crop Temperature, °C
VPD = [(Vapor Pressure Deficit * a) + b], MPa

${}^\wedge T_{Max}$ = Maximum observed ($T_C - T_a$) for crop, °C.
(a and b are constants for the specific crop)

The CWSI has been demonstrated to be a effective means of detecting plant stress on both agronomic and horticultural crops. Measurements of CWSI typically should be made between 1100 and 1400 hrs since CWSI is most reliable when solar radiation exceeds 60% of instantaneous clear day values. This instrument sensitive to wind and cloud cover, making its practical use very limited under conditions.

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[4] The use of product name does not imply endorsement.

Leaf Water Potential

Leaf-water potential (LWP) can be estimated by the pressure chamber technique. This method does not directly measure leaf water potential but measures the water potential in the plant xylem. However, in an excised leaf that has not experienced water loss, leaf and xylem potential should be near equilibrium. Measurement of LWP is primarily used as a research tool. It is too labor intensive for use in a commercial agricultural setting. The pressure chamber method is labor intensive and is not typically used for irrigation scheduling, but rather as a means of verifying the accuracy or calibrating of other methods by measuring the plant water status directly.

WATER-BUDGET METHODS

Estimating the crop water use and then replacing that amount of water by irrigation is a common method for irrigation scheduling and is known as water-budgeting. With a mature crop having a full canopy, transpiration is the major component in estimating crop-water requirements. The combination of transpiration and evaporation from the ground surface is known as evapotranspiration (ET).

The available soil-water content (SWC) is defined as the difference in soil water at the well-drained upper limit (field capacity) and the soil water retained within the root zone at any specific time. Scheduling irrigation by accounting for changes in the SWC can be effective. The SWC is computed by a water-budget accounting procedure, which is given as follows:

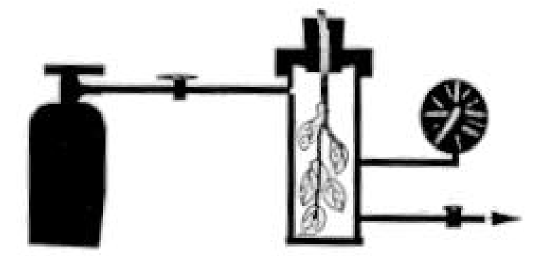


Figure 3.6. Pressure chamber for measuring plant water potential.

$$SWC_{i+1} = SWC_i - ET_c + IR + RE + U_f$$

Eq 3.4

where,

SWC_i = SWC on day (i),
ET_c = crop evapotranspiration,
IR = irrigation,
RE = effective rainfall, and
U_f = upflux from the water table.

Several approaches are commonly used for the water-budget method:

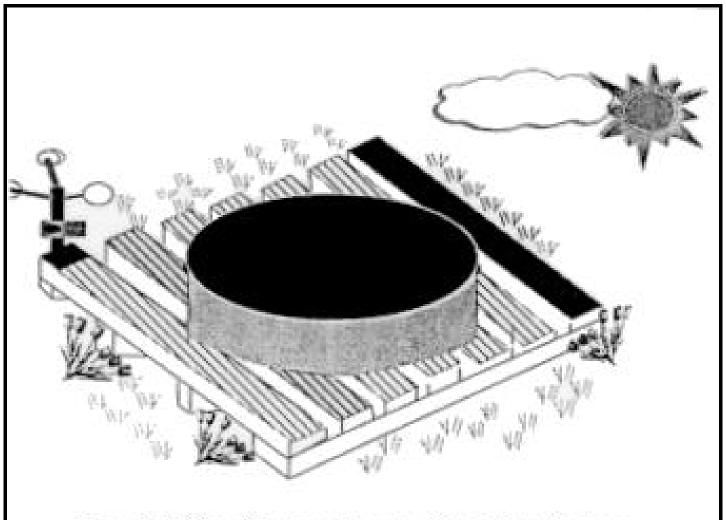


Figure 3.7. Class A Evaporation pan with windspeed sensor.

1) Computer models (i.e.. Commercial Software),
2) Spreadsheet accounting,
3) ‘Checkbook’ method, and
4) Graphical approach (IFAS Bulletin 208).

Determining Crop ET

The Crop Evapotranspiration (ET_c) can be estimated from daily reference evapotranspiration (ET_o), crop coefficients (K_c), canopy coefficient (C_p), and a water availability factor (S_m). Crop ET can be computed as follows:

ET_c = $ET_o * K_c * C_p * S_m$ Eq 3.5

where,

ET_o = reference ET,
K_c = crop coefficient,
C_p = canopy coefficient, and
S_m = soil water extraction factor (not used with the graphical method).

Estimating the Reference ET (ET,)

Reference evapotranspiration (ET,) is the rate of water use by a ‘well’ watered shot-t-cut uniform crop that completely shades the ground. Actual ET is usually less the ET_0. ET_0 is a meteorological parameter and is not affected by the crop.

An estimate of ET, can be made by numerous methods such as:

1) Penman Equation (i.e., SWFREC Weather Station),
2) Pan Evaporation,
3) ET Gauge,
4) Modified Blaney-Criddle method (monthly), and
5) Average annual monthly ET_0.

The penman method is considered to be the most accurate of the various methods of estimating evapotranspiration. However, due to the intensive data requirement for its computation, some of the other methods are more frequently used. Pan evaporation is available at various locations in Florida from which a reference ET can be estimated:

ET_0 = Kp x PE

where,

ET_o = reference (potential ET)
Kp = pan coefficient (0.75 in winter and 0.85 in summer),
PE = pan evaporation.

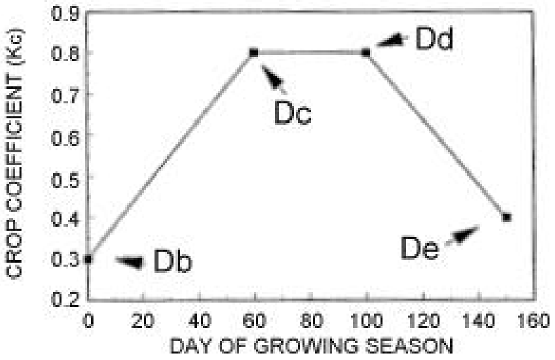
Crop Coefficients

Crop coefficients are specific to the crop but may be affected by variety, cultural practices, soil conditions, and year. One approach separates the growing season into three segments (rapid growth, mid-season, and late season). The length and starting date of each segment is adjustable. The shape of the combined functions with the three segments is shown in Figure 8. The time periods corresponding to each segment are identified as follows:

D_A = beginning of the irrigation season,
D_B = beginning of rapid growth (bud-burst),
D_C = beginning of mid-season (bloom),
D_D = end of mid-season (maturity),
D_E = end of late season (harvest or leaf-drop).
(plant growth stage indicators in parenthesis apply to many crops).

Table 1. Average monthly evapotranspiration and pan evaporation.

Month	Penman[1] Monthly (inches)	Penman Daily (inches)	Pan Evaporation[2] Monthly (inches)	Pan Evaporation Daily (inches)
January	2.20	0.07	3.40	0.11
February	3.10	0.10	4.00	0.13
March	4.20	0.14	5.90	0.20
April	5.50	0.18	6.60	0.22
May	6.20	0.21	7.20	0.24
June	6.40	0.21	6.30	0.21
July	6.30	0.21	6.40	0.21
August	5.80	0.19	6.20	0.21

 Figure 3.8. Typical crop coefficient functions for annual or deciduous crops.		0.17	5.20	0.17
September	5.10			
October	3.80	0.13	4.70	0.16
November	2.70	0.09	3.70	0.12
December	1.90	0.06	3.10	0.10
[1] Based on climatological date from Lakeland, FL				
[2] Based on data from Belle Glade, FL (1927-75)				

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The K_c for each segment is a linear function and is given as follows:

Rapid Growth $K_c = K_{c1} + (b1*(D_i-D_b)$ Eq 3.6

Mid Season $K_c = K_{c2}$ Eq 3.7

Late-season $K_c = K_{c2} + (b2*(D_i-D_D)$ Eq 3.8

where,

$b1 = (K_{c2}-K_{c1})/(D_c-D_B)$ Eq 3.9

$b2 = (K_{c3}-K_{c2})/(D_E-D_D)$ Eq 3.10

Date D_D reflects the combined length of the rapid growth and mid-season and determined from a percentage factor P_d given as follows:

$D_D = (P_d /100) * (D_E - D_B)$ Eq 3.11

The methods allows the user to change any of the above parameters to adjust the shape of the crop coefficient curve to site specific conditions. This results in more flexibility and allows for use with various crops and climatic conditions.

Time periods as represented by D_B, D_C, D_D and D_E will vary based on variety, time of year, climatic conditions, and other factors. The values for the D_B can be estimated by using the F_S values in Table 1. The initial emergence period, F_{S1} , the canopy development period is F_{S2} and the mid-season period F_{S3} . Values for P_d and the time period dates are determined by subtracting the appropriate F_S values from the estimated length of the growing season and adjusting the remainder in accordance to the planting date.

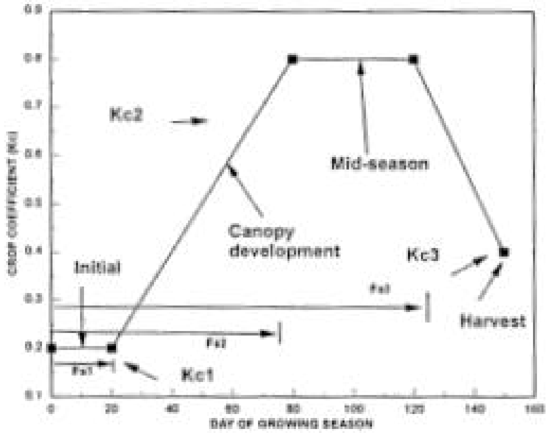

Figure 3.9. Segments of the crop coefficient function.

Table 2. Values for each of the ET factors for various crops.

Crop[1]	Fs1	Fs2	Fs3	Season Length (days)	K_{c1}	K_{c2}	K_{c3}
Beans	0.22	0.56	0.89	60-90	0.23	0.95	0.85
Carrots	0.20	0.50	0.83	90-125	0.23	1.05	0.71
Sweet Corn	0.22	0.56	0.89	80-110	0.23	1.05	0.95
Eggplant	0.22	0.54	0.84	130-140	0.23	0.95	0.85
Melons	0.21	0.50	0.85	120-160	0.23	1.11	0.65
Peppers	0.20	0.50	0.85	120-210	0.23	0.95	0.80
Potato	0.20	0.45	0.80	100-150	0.32	1.05	0.70
Straw-berries	0.10	0.40	1.00	150-180	0.40	0.70	0.70
Citrus	0.00	0.58	1.00	365	0.90	0.85	0.90
Grapes	0.00	0.42	0.73	170	0.25	0.78	0.35

[1] Sources: USDA/NRCS NEH, Section 15, Chapter 2 (1993).

Figure 3.10 compares the estimated crop coefficient to irrigation requirements for plastic-mulched drip irrigated tomatoes. These irrigation amounts were averages of three crop seasons in which tensiometers were maintained below 10 cbars of tension.

Canopy Factor:

For immature tree crops, a canopy factor should be considered when estimating the crop evapotranspiration requirement. Since cultural practices and crop variety effects canopy development, C_p can be a critically important factor. Based on data from young deciduous trees (which may need further adjustment and refinement for use with citrus), C_p is given as follows:

$$C_p = 3.05 + 2.56 * G_S - 0.016 * G_S^2 \qquad \text{Eq 3.12}$$

where,

G_s = percent of ground shaded at solar noon during mid-season.

A graphical presentation of Eq 3.11 is shown in Figure 3.11. Ground shaded or canopy development is a function of cultural practices, variety, row and plant spacing, and age of trees. Maximum value for C, is reached when approximately 60 percent of the ground is shaded at solar noon during mid-season.

Soil-Water Extraction Factor

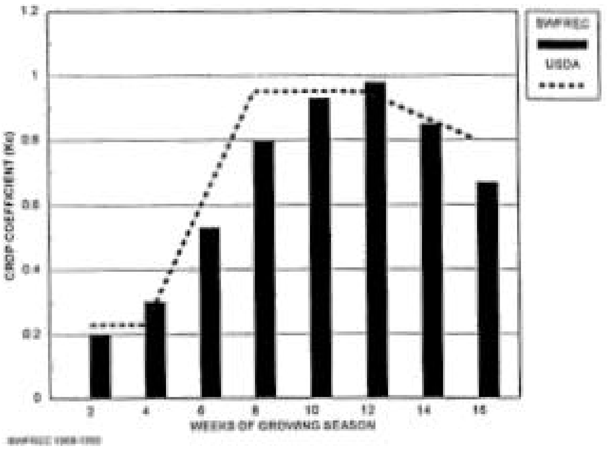

Figure 3.10. Crop coefficients for drip-irrigated tomatoes.

The modified Penman equation is frequently used to calculate ET_o from weather data, and it is based on a reference crop in which water is not limited. So long as there is adequate soil water, transpiration rates will depend primarily on the amount of energy available; however, when soil water becomes limited, the rate of crop ET will decrease. In actual scheduling of irrigation, water is often withheld to a point at which soil-water is limited. As the SWC approaches the limit of available water, there is a reduction in the

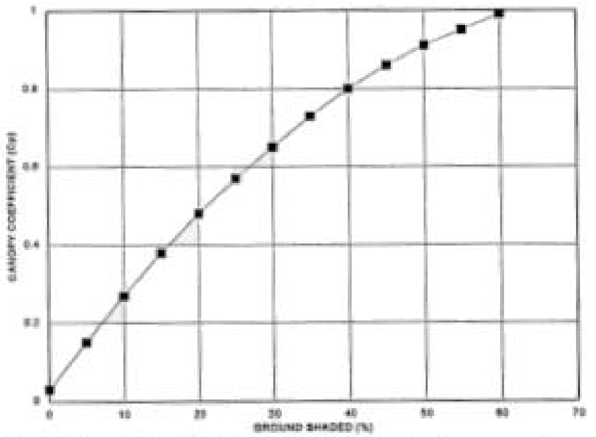

Figure 3.11. Graphical presentation of the canopy coefficient.

transpiration rate. This reduction can be estimated as follows:

$S_m = (A_w/100)^z$ Eq 3.13

where,

A_w = percent of available soil water remaining,

Z = a parameter to account for soil, crop, and ET_o, (use Z = ET_o).

The Z parameter represents the influence of the ET rates on soil-water extraction. At high ET rates, the limiting influence of the soil is greater. This relationship is a practical tool for approximating the influence of greater soil suctions on crop ET. However, because of the complexity of soil and plant factors, it is not a precise relationship. The following Z parameter is suggested: Z = ET_o for the day. Fig. 4 provides graphical interpretation of Eq. 10 at various ET rates.

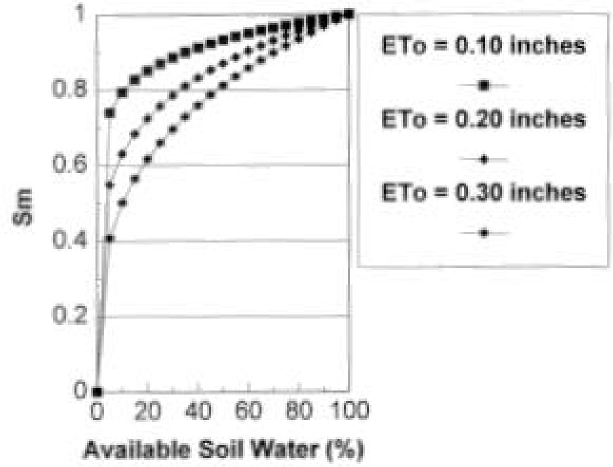

Figure 4. Soil-water extraction coefficient.

Water -Table Contribution

In humid climates, a water table near the root zone is often present. In south Florida flatwoods citrus groves, the water table typically provides significant amounts of water to meet evapotranspiration requirements. The rate of water supply by upward flux from the water table is a function of the soil type, distance to the water table, and the energy gradient. If the water table is too close to the root zone, a lack of aeration may result and adversely affect plant growth and yield. The rate and distance of water movement from a water table in a sandy soil was estimated by a graph adapted from Doorenbos and Pruitt (1977). Work is currently underway at several locations in Florida to characterize this water-table flux component. Since this work has not been completed, Eq. 11 was developed. Upward flux ,Uf, can be estimated:

$$Uf=2.6D_{wt}^{-1.45}$$

where,

$D_{w\,t}$ = Depth to the water-table (inches from the bottom of the effective root zone),

U_f = Upward flux (inches/day).

Fig. 5 compares Eq. 11 to the graph reported in the previous handout on soil-plant-water relations as Figure 11.

Accounting Procedure

Figure 6. Water budget worksheet.

Date	Rain (in)	Run-time (hours)	Eto (in)	Etc (in)	Soil-H_2O (%)	Soil-H_2O (in)	N. Probe (in)
01-Apr			0.15	0.09	85	6.77	6.8
02-Apr			0.21	0.14	84	6.63	
03-Apr			0.19	0.12	82	6.51	
04-Apr	0.10		0.15	0.10	82	6.51	
05-Apr			0.15	0.10	80	6.41	6.4
06-Apr			0.14	0.09	79	6.32	
07-Apr			0.17	0.11	78	6.21	
08-Apr			0.10	0.06	77	6.15	
09-Apr		1.5	0.15	0.03	88	7.00	6.9

Water budgeting for irrigation scheduling is a common practice in the Western U.S. In many areas of the arid West, rainfall seldom occurs during the growing season (i.e. many parts of California); however, in Florida, rainfall can occur at any time of the year. Rainfall and the presence of a water-table are part of irrigation scheduling in the flatwoods areas of Florida. This significantly complicates the budgeting procedure. Under the simpler western U.S. conditions, a ‘checkbook’ type accounting procedure is often employed. Fig. 6 is an example. Under the more complicated conditions of Florida, a computer program or a spreadsheet application can be used to perform the computations.