IRRIGATION SCHEDULING TO IMPROVE WATER- AND ENERGY-USE EFFICIENCIES

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Introduction

Much of the irrigation in the U.S. is practiced in arid regions where little or no rainfall occurs during the growing season. Under arid conditions, irrigation water can be applied at fairly routine intervals and in routine amounts.

However, North Carolina is located in a humid region where irrigation must be planned in conjunction with prevailing rainfall conditions. In humid regions such as ours, applying routine amounts of irrigation water at regular intervals will almost always result in overirrigation and the needless waste of water and energy.

You can make most efficient use of water and energy by applying the right amount of water to cropland at the right time.

Irrigation scheduling is the use of water management strategies to prevent overapplication of water while minimizing yield loss due to water shortage or drought stress. Many different crops are irrigated in North Carolina. These crops are grown under a wide range of soil conditions and production practices. Therefore, irrigation scheduling is an extremely important management practice for irrigators in North Carolina.

Importance of Irrigation Scheduling

Some irrigation water is stored in the soil to be removed by crops and some is lost by evaporation, runoff, or seepage. The amount of water lost through these processes is affected by irrigation system design and irrigation management. Prudent scheduling minimizes runoff and percolation losses, which in turn usually maximizes irrigation efficiency by reducing energy and water use. (Of course, in situations where not enough water was being applied, proper irrigation scheduling will increase energy and water use.)

You can save energy by no longer pumping water that was previously being wasted. When water supplies and irrigation equipment are adequate, irrigators tend to overirrigate, believing that applying more water will increase crop yields. Instead, overirrigation can reduce yields because the excess soil moisture often results in plant disease, nutrient leaching, and reduced pesticide effectiveness. In addition, water and energy are wasted.

The quantity of water pumped can often be reduced without reducing yield. Studies have shown that irrigation scheduling using water balance methods (to be discussed later) can save 15 to 35 percent of the water normally pumped without reducing yield. Maximum yield usually does not equate to maximum profit. The optimum economic yield is less than the maximum potential yield. Irrigation scheduling tips presented in popular farm magazines too often aim at achieving maximum yield with too little emphasis on water and energy use effficiencies. **An optimum irrigation schedule maximizes profit and optimizes water and energy use.**

Irrigation scheduling requires knowledge of:

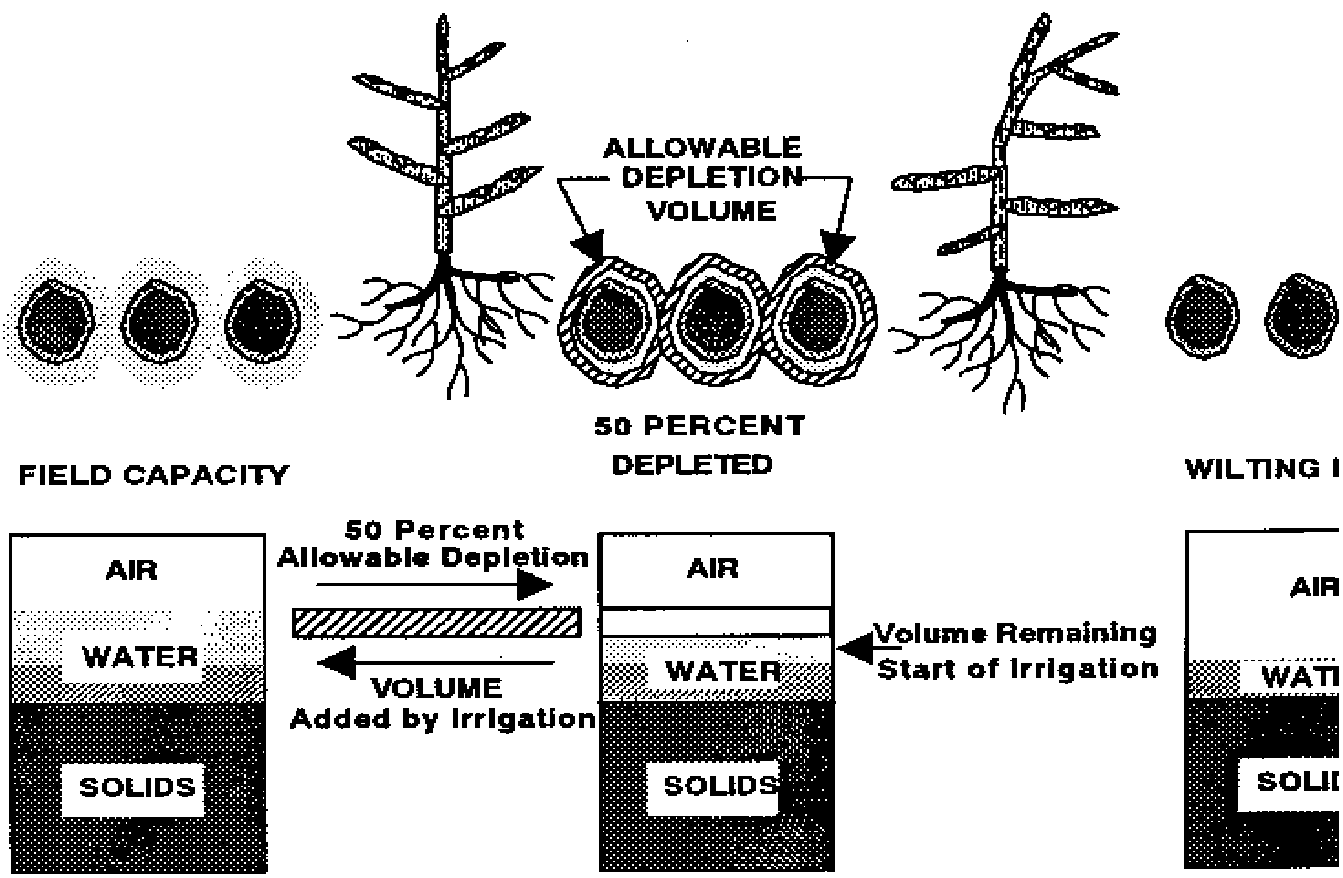
- the soil
- the soil-water status
- the crops
- the status of crop stress
- the potential yield reduction if the crop remains in a stressed condition.

In this publication, it is assumed that the reader understands these basic relationships. Their importance to irrigation scheduling is briefly summarized below. The terms that are normally used in irrigation scheduling are summarized in the box on the back cover. For more information on these subjects refer to Extension Publication AG-452-l, *Soil Water and Crop Characteristics Important to Irrigation Scheduling.*

Relating Soil-Water to Plant Stress

The amount of water that should be applied with each irrigation depends primarily on the soil and the amount of water it can retain for plant use, referred to as *plant-available water* (PAW). The amount of water removed from the soil by the plant since the last irrigation or rainfall is referred to as the *depletion volume.*

Irrigation should begin when the crop comes under water stress severe enough to reduce crop yield or quality. The level of stress that will cause a reduction in crop yield or quality depends on the kind of crop and its stage of development; the level varies during the growing season as the crop matures. For example, corn will tolerate more stress without causing a yield reduction when the stress occurs during the vegetative stage as opposed to the pollination stage. Thus, determining when to irrigate is a scheduling decision that should take into account the crop's sensitivity to stress.



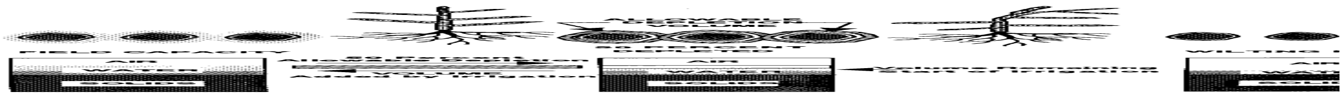


Figure 1. The relationship between water distribution in the soil and the concept of irrigation scheduling when 50 percent of the PAW has been depleted.

Recently, scheduling techniques have been developed that are based on the moisture status or stress condition of the crop. For example, to predict crop stress by infrared thermometry, the temperature of the crop's leaves is related to transpiration rate. Remote sensing of crop stress using infrared satellite imagery is another method being evaluated. Although these methods hold promise for the future, most of the work on them has been conducted in arid regions. Guidelines have not been developed for humid regions such as North Carolina.

In humid regions, the most reliable method currently available for es- timating when to irrigate is based on allowable depletion of PAW. The basic assumption is that crop yield or quality wili not be reduced if crop water use is less than the allowable depletion level. In North Carolina, 50 percent depletion of PAW is recommended for most soils (Figure 1). However, allowable depletion may range from 40 percent or less in some coarse, sandy soils to as high as 60 to 70 percent in some clayey soils. Drought-sensitive crops (such as vegetable crops) tolerate less depletion than drought-tolerant crops (like soybeans or cotton).

Influence of Rainfall

In humid regions, the irrigation frequency and the amount of water to apply are strongly influenced by seasonal rainfall. Efficiently and effectively supplementing rainfall is one of the greatest challenges to irrigation scheduling in North Carolina. During periods when no rainfall occurs, 1 inch of irrigation water may be required every three to four days. During a season when rainfall occurs frequently, irrigation may be needed only once or twice a month. In most years, the need for and frequency of irrigation falls between these extremes.

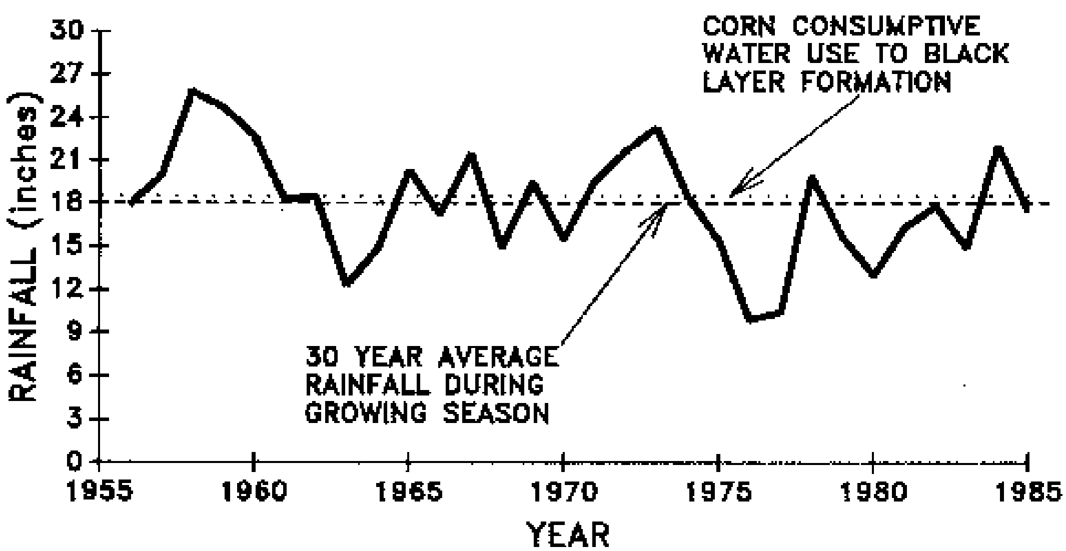


Figure 2. Rainfall during the growing season (April 10 to August 31) at the Raleigh-Durham airport from 1956 to 1985. Consumptive use is the total amount of water extracted by a corn crop during the growing season.

Figure 2 illustrates the annual variation in rainfall at the Raleigh-Durham airport during the corn-growing season for the 30-year period from 1956 to 1985. Notice that the average rainfall during the growing season was nearly equal to the cumulative consumptive use for a corn crop. On the average, then, enough rain-water was received to satisfy crop needs, suggesting that irrigation was unnecessary. But in some years more than enough rainfall was received, whereas in other years rainfall was not adequate and irrigation was needed. These data illustrate that the timing of rains is more important to irrigation decisions than the total amount of rainfall.

Corn planted between April 10 and 15 consumes the most water and is most susceptible to water deficits from June 5 to July 5. During that 30-day period, corn requires about 0.25 inches of water per day, or a total of 7.5 inches. Figure 3 shows that in only three years between 1956 and 1985 was rainfall adequate to satisfy the water needs of corn throughout this critical growth stage. The average 30-day rainfall was approximately 4 inches, indicating that the average amount of irrigation water required was 3.5 inches during the 30-day period. But routinely applying that average amount would have been suitable in only 10 out of the 30 years. In 10 of the years, applying 3.5 inches would have been inadequate, and in the 10 remaining years it would have been excessive. The annual irrigation requirements ranged from none to 7 inches.

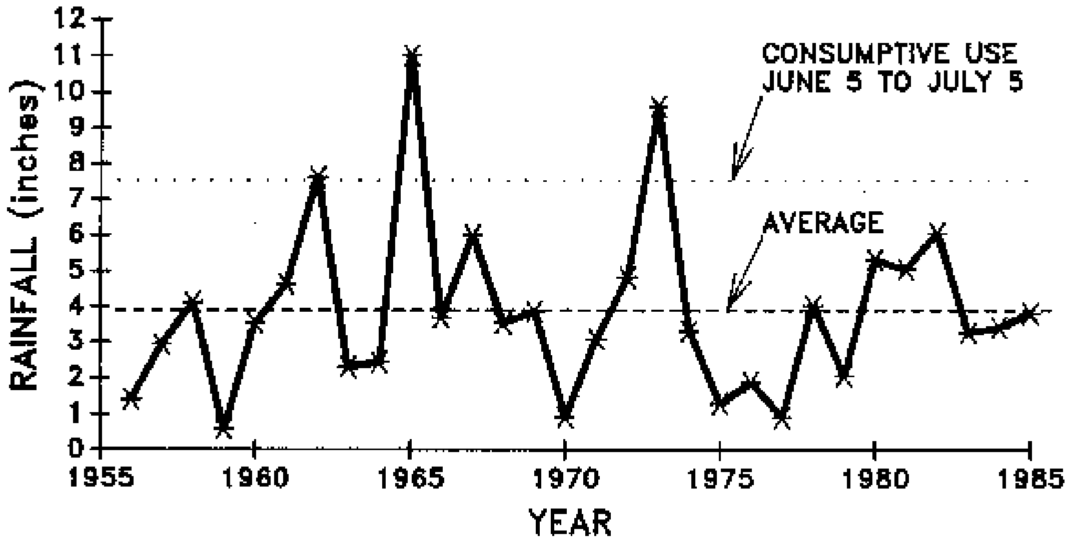


Figure 3. Yearly rainfall fluctuation at the Raleigh-Durham airport during the 30-day critical moisture period for corn (June 5-July 5) from 1956 to 1985. Consumption is the amount of water a corn crop would extract from the soil during the critical 30-day period if soil-water is not limiting.

Most irrigation systems have the capacity to satisfy crop needs in the driest year or at least in 9 out of every 10 years. In this example, the amount of irrigation water needed to satisfy crop demand during the critical growth phase in 9 out of 10 years was 6.5 inches, or more than 1.5 inches per week. Yet if this amount were applied every week, overirrigation would result 90 percent of the time. This example clearly shows that the weekly, monthly, and annual variability in rainfall must be taken into account when making irrigation decisions.

Irrigation Scheduling

Irrigation scheduling is the process of answering two basic questions:

- **Do I need to irrigate?**
- **How much water should I apply?**

Determining When to Irrigate

There are three ways to decide when to irrigate:

- measure soil-water
- estimate soil-water using an accounting approach (the check-book method)
- measure crop stress

Measuring Soil-Water. There are many different methods or devices for measuring soil water. These include thefeel method, gravitational method, tensiometers, electrical resistance blocks, neutron probe, Phene cell, and time domain reflectometer. These methods differ in reliability, cost, and labor intensity. For more information on the operation, reliability, and cost of these methods, refer to Extension Publication AG-452-2, *Measuring Soil-Water for Irrigation Scheduling: Monitoring Methods and Devices*.

Tensiometers and electrical resistance blocks are the most cost-efficient and reliable devices for measuring soil-water for the irrigation of North Carolina soils. Tensiometers are best suited for sandy, sandy loam, and loamy soil textures, while electrical resistance blocks work best in silty or clayey soils. You should be aware that the calibration curves and recommendations supplied by the manufacturer for these devices were developed for general conditions and are not adequate for specific soil conditions and fields. For best results, all soil-water measuring devices should be calibrated for the major soils in each field being irrigated. Calibration procedures for soil-water measuring devices are outlined in Extension Publication AG-452-3, *Calibrating Soil-Water Measuring Devices*.

Checkbook Method. The check-book method is an accounting ap- proach for estimating how much soil-water remains in the effective root zone based on water inputs and outputs (like a daily balance on a bank account based on deposits and withdrawals). Irrigation is scheduled when the soil-water content in the effective root zone is near the allowable depletion volume. Some of the simpler checkbook methods keep track of rainfall, evapotranspiration, and irrigation amounts. More sophisticated methods require periodic meas- urements of the soil-water status and moisture-use rates of the crop. Some methods may even require inputs of daily temperature, wind speed, and solar radiation amounts.

Checkbook methods require detailed daily record keeping, which can become time consuming for the more complex methods..One of the advantages of the checkbook approach is that it can be programmed on a computer. Computer programs have been developed to handle the accounting and provide timely and sometimes precise scheduling recommendations. Some of the more advanced programs can predict the effect of an irrigation or irrigation delay at a given growth stage on crop yield and maturity date. Computer programs can be very reliable tools for scheduling irrigation; however, it is very important to remember that the computer recommendations are only as good as the data you supply.

Regardless of the method used to estimate or measure soil-water, there will be occasions when the soil will have reached the "turn on" level of dryness, yet your judgment suggests that irrigation should be delayed. For example, if the crop has not reached the most critical stage and the water supply is in danger of being exhausted before the end of the irrigation season, then irrigation should be delayed. This delay may cause some reduction in yield or quality, but the reduction would be greater if the water supply became depleted before the crop reaches a more critical stage of growth. If a high probability of rain-fall has been predicted during the next one or two days, it may be advantageous to wait and see before starting to irrigate.

This decision must also take into account the capacity of the irrigation system. If the system is already being used to full capacity and water supplies are sufficient, then irrigate on schedule. If predicted rainfall does not occur, it is impossible to get back on schedule when the irrigation equipment is already being used to full capacity. A wait-and-see approach is practical only when the irrigation system is not being used at full capacity.

Determining How Much to Irrigate

Enough irrigation water should be applied to replace the depleted PAW within the root zone and to allow for irrigation inefficiencies. Root depth and root distribution are important because they determine the depth of the soil reservoir from which the plant can extract available water. About 70 percent of the root mass is found in the upper half of the maximum root depth. Under adequate moisture conditions, water uptake by the crop is about the same as its root distribution. Thus, about 70 percent of the water used by a crop is obtained from the upper half of the root zone. This zone is referred to as the *effective root depth.* This depth should be used to compute the volume of PAW. Irrigation amounts should be computed to replace only the depleted PAW within the effective root zone.

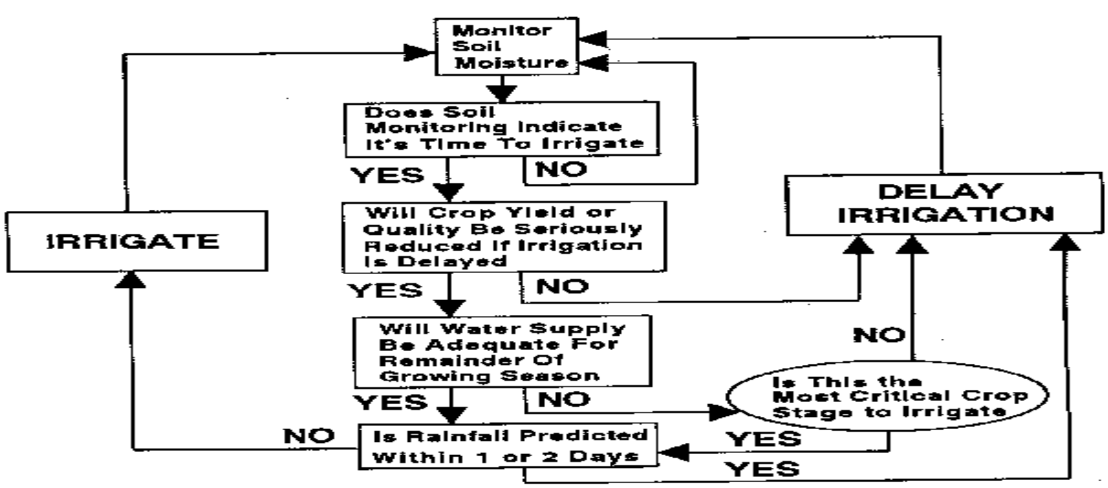
The depleted volume is referred to as the net amount of water to be replaced. Additional water must be applied to account for irrigation inefficiencies so that the desired (net) amount reaches the root zone. Inefficiencies might include leakage at couplings, surface runoff, or percolation below the effective root depth. Irrigation efficiency is typically 70 to 80 percent of the total water applied. Thus, if the net irrigation amount required to replace the depletion volume is 1 inch and the irrigation efficiency is 75 percent, the total amount of irrigation water needed to apply 1 inch of net water is approximately 1.3 inches (the net amount, 1 inch, divided by the irrigation effficiency of 0.75). This amount (1.3 inches) is referred to as the gross water application. For a discussion on strategies to maximize irrigation efficiency, refer to Extension Publication AG-452-5, *Irrigation Management Strategies to Improve Water and Energy Efficiencies.*

There may be occasions when only part of the depletion volume should be replaced by irrigation. For example, if irrigation replaces all the depletion volume, there is little or no PAW storage remaining within the effective root zone should a rainfall occur soon after the irrigation. In this situation, most of an ensuing rainfall amount could be lost through runoff or percolation. Applying only part of the scheduled amount of irrigation water in anticipation of rainfall will result in more efficient use of water and energy, although this approach may require more frequent irrigation.

Table 1. Determining When and How Much to Irrigate

Calculating When to Irrigate	Calculating How Much to Irrigate
Plant-available water PAW = field capacity− wilting point = 0.20 in./in.− 0.08 in./in. = 0.12 in./in.	Net irrigation amount (knee-high stage) = depletion volume times effective root depth = 0.06 in./in. x 8 in. = 0.48 in./irrigation
50 percent depletion of PAW = 0.12 in./in. x 0.50 = 0.06 in./in.	Gross water application = net amount divided by irrigation efficiency = 0.48 in./0.75 = 0.64 in./irrigation
Water content at 50 percent depletion water content (field capacity) minus allowable depletion = 0.20 in./in. - 0.06 in./in. = 0.14 in./in.	Net irrigation amount (tasseling stage) = 0.06 in./in. x 12 in. = 0.72 in./irrigation
Tension when water content is 0.14 in./in. read from plot (Fig. 5) at 0.14 in./in. = 30 cb	Gross water application = 0.72 in./ 0.75 = 0.96 in./irrigation

The above discussion has shown that determining when and how much to irrigate is a complex decision-making process. Critical elements of this process are summarized in Figure 4. Every irrigator must evaluate these critical elements daily to utilize water and energy effficiently and effectively. The following examples demonstrate two irrigation scheduling procedures recommended for North Carolina.



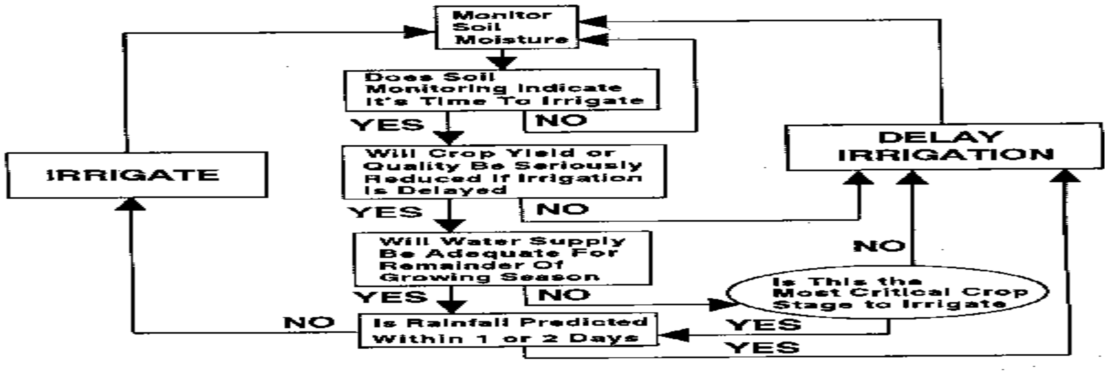


Figure 4. Daily decision process required to schedule irrigation effectively.

Irrigation Scheduling Examples

Calibrating soil-water measuring equipment and measuring soil-water are the first steps in developing an effective irrigation schedule. The information obtained allows you to determine when the soil-water content has reached the normal irrigation range. The calibration data are used to determine the readings of the soil-water measuring device at the allowable depletion volume, usually 50 percent depletion of PAW. Using a tensiometer for irrigation scheduling is demonstrated in the following example. A similar procedure is followed if electrical resistance blocks or one of the other soil-water measuring devices is used.

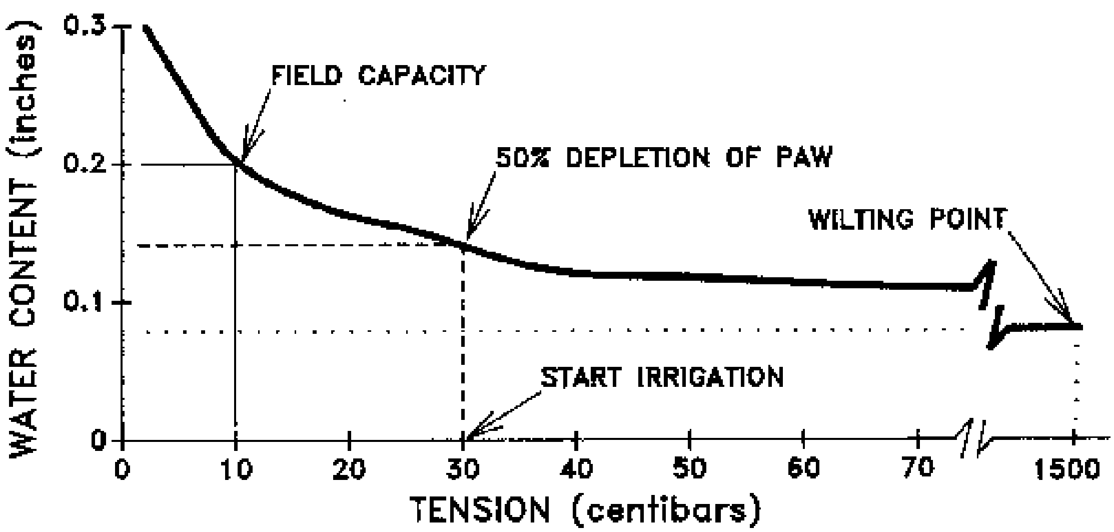


Figure 5. Calibration curve of water content versus tensiometer reading (tension). Field capacity is normally interpreted to be the point at which the rate of decrease of water content versus tension flattens out, in this case, about 10 cb.

Irrigation Scheduling Using Tensiometers

A calibration curve showing soil-water tension (tensiometer reading) versus water content for a sandy soil is plotted in Figure 5. From this graph, field capacity is estimated to occur where the steeper portion of the curve begins to flatten out, at about 10 centibars (cb). Field capacity occurs in a sandy soil about one day after a soaking rain. The water content at 10 cb is 0.20 in/in (0.20 in/in means each inch of soil depth contains 0.20 inches of water). The PAW of this soil as calculated in Table 1 is 0.12 in/in.; there- fore, the allowable depletion (one-half of PAW) is 0.06 in/in. The water content of the soil when irrigation should begin is 0.14 in/in. The corresponding tension at this water content is 30 cb. Therefore, irrigation water should be applied to this soil when the tensiometer reading reaches 30 cb.

At the time of irrigation, the effective root depth must be known in order to determine the total amount of irrigation water to apply and to install tensiometers or electrical resistance blocks at the appropriate depth. As discussed earlier, the effective root depth represents the depth of soil from which the plant extracts most of its water. The effective root depth increases during the growing season as the crop develops. It begins at zero at planting and increases to its maximum depth by the time the crop reaches its reproductive stage of growth, which occurs about midseason for most crops. In North Carolina, soil conditions usually limit the maximum effective root depth to about 12 inches. When irrigation is scheduled during early growth stages before maximum root development, assume that the rate of root elongation increases linearly from planting time up to the maximum effective depth of 12 inches at midseason. For example, corn reaches its maximum effective root depth of 12 inches at the tasseling growth stage, 60 to 65 days after planting. Before tasseling, the rate of effective root growth is about 0.2 inches per day (12 inches/60 days). Thus, at the knee-high growth stage, 40 days after planting, the effective root depth is about 8 inches (0.2 inch/day x 40 days).

Table 2. Example of Irrigation Scheduling Using a Simple Checkbook Approach[1]

Date	PAW in soil at start of day		Consumptive use for day[2]	Rainfall[3]	Net Irrigation	PAW in soil end of day		Comments
	(inches)	(% of PAW)	(inches)	(inches)	(inches)	(inches)	(% of PAW)	
5-31				1.00		1.44	100	Soaking rain, FC assumed
6-1	1.44	100	0.14			1.30	90	
2	1.30	90	0.15			1.15	80	
3	1.15	80	0.16			0.99	69	
4	0.99	69	0.17			0.68	47	
5	0.82	57	0.18	0.04		0.68	47	Time to irrigate
6	0.68	47	0.19	0.04	0.72	1.25	87	
7	1.25	87	0.20	0.15		1.20	83	
8	1.20	83	0.21	0.01		1.00	69	
9	1.00	69	0.22			0.88	61	
10	0.88	61	0.22			0.66	46	Time to irrigate
11	0.66	46	0.23		0.72	1.15	80	
12	1.15	80	0.23	0.20		1.12	78	
13	1.12	78	0.23			0.89	62	
14	0.89	62	0.24			0.65	45	Time to irrigate
15	0.65	45	0.24	0.08	0.72	1.21	84	
16	1.21	84	0.24	0.19		1.16	81	
17	1.16	81	0.24			0.92	64	
18	0.92	64	0.25	1.26		1.44	100	0.49 in. rain above FC
19	1.44	100	0.25	0.31		1.44	100	0.06 in. rain above FC
20	1.44	100	0.25			1.19	83	
21	1.19	83	0.25			0.94	65	
22	0.94	65	0.26			0.68	47	Time to irrigate
23	0.68	47	0.26		0.72	1.14	79	
24	1.14	79	0.26			0.88	61	
25	0.88	61	0.26			0.62	43	Time to irrigate
26	0.62	43	0.25		0.72	1.08	75	
27	1.08	75	0.25			0.83	58	(Critical stage, corn silking)
28	0.83	58	0.25		0.72	1.30	90	Irrigate sooner than 50%
29	1.30	90	0.25	0.21		1.26	88	
30	1.26	88	0.24	0.38		1.40	97	

[1] Sandy loam soil of calibration example. Effective root zone assumed to be 12 inches. Total PAW = 0.12 x 12 in. = 1.44 in. Irrigate at 50% of PAW. Irrigation amount based on 50% depletion of 1.44 inches, which is a net amount of 0.72 inches. Values shown do not include irrigation inefficiency.
[2] Consumptive use for corn from Figure 7. Planting assumed to be April 15, so June 1 corresponds to 45 days after planting.
[3] Rainfall from Raleigh-Durham airport, 1985.

The amount of water to be added at each irrigation is determined by multiplying the allowable depletion by the effective root depth. For example, if irrigation is scheduled when corn has reached the knee-high stage and the effective root depth is 8 inches, the irrigation amount is then 0.48 inches, as shown in Table 2. This represents the net (desired) irrigation amount. Assuming an irrigation efficiency of 75 percent, the gross water application amount is 0.64 inches. Once corn reaches the tasseling stage, the effective root depth has increased to 12 inches. The net irrigation amount at this stage is 0.72 inches and the gross water application is 0.96 inches.

Frequently, irrigation systems in North Carolina have been sized to apply approximately 1 inch of water every three to four days, which is a general rule of thumb to satisfy expected peak-use demands. This amount would be appropriate in the above example when corn has reached the tasseling stage. But notice that this amount of water is 50 percent more than should be applied at the knee-high stage. Few irrigators adjust their application amount during the growing season, which often results in over-irrigation early in the season. Applying the design system capacity of 1 inch at the knee-high stage in the above example would result in applying 0.24 inches per irrigation that would percolate below the effective root zone. Thus, the irrigation efficiency would be reduced from 75 percent to about 50 percent. This wastes water and energy.

Locating Soil-Water Measuring Devices

In general, soil-water should be measured at the center of the effective root zone. If the effective root depth is 12 inches, the soil-water measuring device should be installed at a depth of about 6 inches. When an irrigated field contains more than one soil type, at least one device should be installed within each major soil type in the field. The above calculations should also be made for each different soil. When stationary sprinklers are used (such as solid-set or permanent irrigation systems), the system should be managed such that an irrigation zone encompasses only soils with similar soil-water properties. In this manner, irrigation amounts can be adjusted according to the soil-water retention properties within a particular zone.

To check the computed irrigation amount, a second soil-water measuring device can be used at the bottom of the root zone to indicate when irrigation should stop. The two soil-water measuring devices are used as an on-off switch, as shown in Figure 6. One device (the shallow one) is installed in the center of the effective root zone and indicates when irrigation should start. The second device, installed at the bottom of the root zone, indicates when irrigation should stop. As soon as the root zone is rewetted to field capacity, water begins to percolate below the effective root zone. The percolation is indicated by a decrease in soil-water tension of the 'ower tensiometer. As soon as the tension reading on the deep tensiometer starts to decrease, irrigation should be stopped.

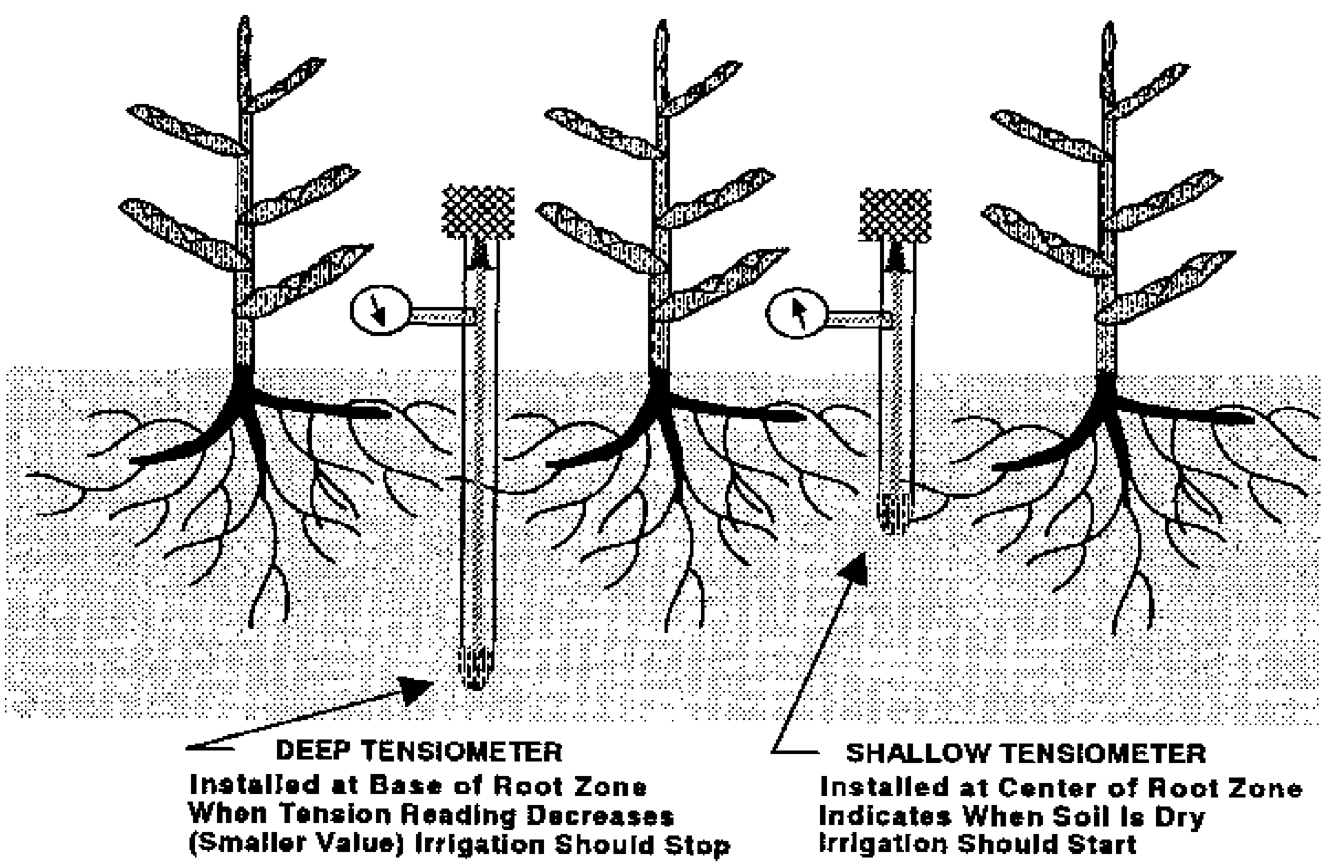


Figure 6. Use of two tensiometers to schedule irrigation. The upper tensiometer indicates when irrigation should start and the lower indicates when it should stop.

Scheduling irrigation is more difficult for mechanical-move type irrigation systems (center pivots or hard hose travelers) because the irrigator must anticipate the time required for the system to move across the field. In this situation, irrigation must be started sooner, typically after 30 to 40 percent depletion of PAW so that the last section irrigated will not be drier than 60 to 70 percent depleted. The situation is further complicated by rainfall events occurring during this period. The PAW content may be uniform following a rainfall, but depending on the time required for the system to make a complete cycle, PAW may vary across the field by 50 percent following irrigation.

Shallow tensiometers can still be used to determine when to irrigate, but irrigation must be started sooner so that the last portion to be irrigated does not become too dry. Deeper tensiometers should be located near the midpoint of the travel cycle. They should be monitored as the system passes to determine whether the proper amount of water is being applied. If no change in the tensiometer reading is observed as the system passes, too little water is being applied and the travel speed should be reduced. Likewise, if the tensiometer reading decreases before the system is 90 percent past the tensiometer, too much water is being applied and the travel speed should be increased. With mechanical-move systems, soil-water measurements are used in conjunction with the checkbook approach to schedule irrigation properly and account for the additional soil-water depletion that will occur while the system travels across the field.

Irrigation Scheduling Using the Checkbook Approach

The checkbook approach to irrigation scheduling involves a daily accounting of water withdrawals and additions to the effective root zone. The additions include rainfall and irrigation amounts and the withdrawals include crop water use, runoff, and percolation.

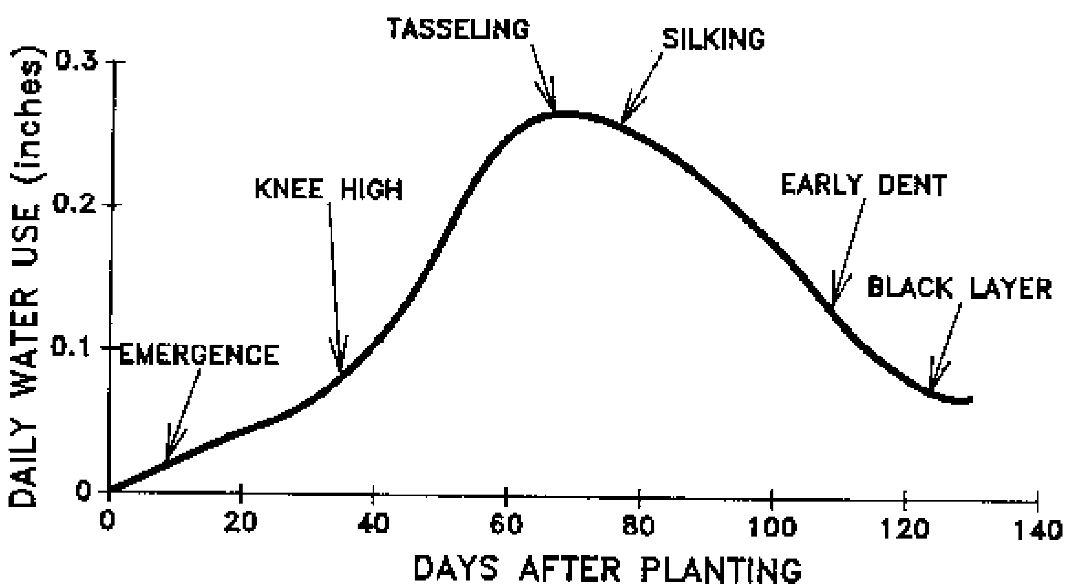


Figure 7. Daily water use by corn as influenced by stage of development. Irrigation scheduling decisions should be adjusted to reflect changes in water consumption by the crop during the growing season.

Rainfall and irrigation can be measured with rain gauges installed above the crop canopy in the irrigated field. Plant withdrawals can be estimated from crop soil-water use curves or by measuring pan evaporation. Moisture use curves such as those shown in Figure 7 indicate the amount of water (consumptive use) that a crop would remove from the soil if the atmospheric evaporative demand was high; that is, on a clear, warm day if the amount of water stored in the effective root zone is sufficient. When these conditions are not present, actual consumptive use will be less than the consumptive use values shown in Figure 7. For example, on a cool, rainy, or very overcast day, consumptive use may be near zero. Consumptive use rates should be adjusted to reflect prevailing weather conditions.

Daily pan evaporation measurements reflect the effects of prevailing weather conditions. Pan evaporation is approximately equal to *potential evapotranspiration* (PET). Evapotranspiration is the process by which water is lost from the soil surface by evaporation and by the transpiration process of plants growing on the soil. Potential evapotranspiratron (PET) is the maximum amount of water that could be lost through this process under a given set of atmospheric conditions, assuming that the crop covers the entire soil surface and that the amount of water present in the soil does not limit the process. However, when pan evaporation is used to estimate PET, a crop coeffficient is required to adjust the pan evaporation value to actual evapotranspiration (AET). AET is the actual amount of water removed from the soil and can be limited by the crop or by the water content of the soil.

Actual evapotranspiration equals PET (pan evaporation) for an actively growing crop that completely shades the soil surface (full crop canopy) and is growing in a soil near field capacity. But a young seedling does not transpire at the same rate as a crop with full canopy. In fact, during much of the growing season, AET is less than PET because the crop canopy is small or the crop is approaching senescence and not transpiring at its peak rate. The crop coefficient corrects for the difference between AET (as limited by the crop) and PET (a function of atmospheric conditions).

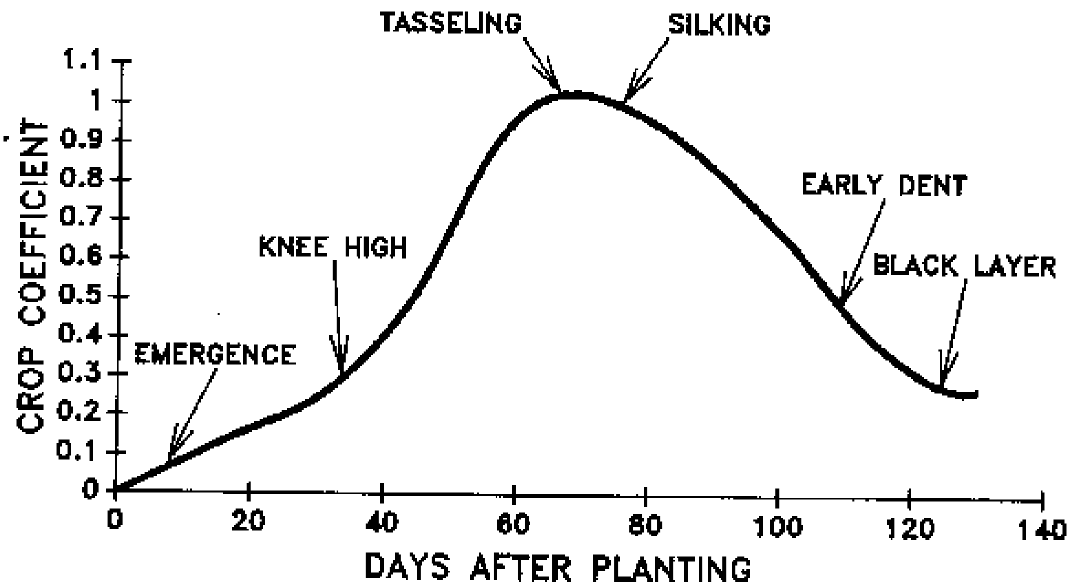


Figure 8. Crop coefficient curve for corn for adjusting pan evaporation to actual evapotranspiration of the crop. For most crops growing in soils with nonlimiting soil moisture, the coefficient will be 1 during the peak moisture-use period, indicating that AET is equal to evaporation from a screened Class A evaporation pan.

Crop coeffficients for many plants have been developed. An example crop-coefficient curve for corn is shown in Figure 8. AET can also be limited when the soil becomes too dry to supply water to plant roots so that the plant can transpire at PET. The plant undergoes temporary wilting when this occurs. The checkbook approach includes no corrective measures to account for soil limitations. It is assumed that the soil does not limit water supply to the crop as long as PAW is not depleted below 50 percent.

The National Weather Service records pan evaporation at several weather stations across the state. This information can be obtained from the local Extension Service offfice through the CAROLINE network. Pan evaporation can also be measured on site with a fairly large pan, such as a washtub. The pan should be covered with some type of screen or netting (with openings approximately 1 inch wide) to keep birds and animals from drinking the water. The most common source of error using the checkbook approach occurs in estimating water losses due to runoff end percolation losses; that is, estimating the effective rainfall or irrigation that remains in the effective root zone. These errors accumulate as the season progresses. For best results, it is necessary to measure soil-water several times during the growing season (preferably every two to three weeks) to make periodic corrections of the checkbook balance of soil-water.

To use the checkbook method, you must begin computations when the soil is at a known water content. Field capacity is the usual starting point and should be assumed to occur soon after a rainfall or irrigation of an amount large enough to wet the effective root zone. For many of the loamy soil textures found in North Carolina (root zone textures consisting of loamy sand, sandy loam, loam, or sandy clay loam), field capacity can be assumed to occur one day after rainfall or irrigation.

A simple checkbook approach for scheduling irrigation is shown in Table 2. Irrigation amounts are computed as shown in Table 2. Notice that many of the adjustments discussed above, which are needed to correct for potential errors, have been omitted. The checkbook method becomes time consuming and tedious but more reliable when these corrections are included. When data needed to make corrections are available, the use of a computer program is recommended.

Technical Assistance Is Available

While simple in concept, irrigation scheduling is rather complex in practice. As costs of energy and water continue to increase, irrigation scheduling will become increasingly important. By making more efficient use of both energy and water, irrigation scheduling can save you money. Your county Cooperative Extension Service and Soil Conservation Service can help with irrigation decisions. Their staff members know how to apply irrigation scheduling techniques. Irrigation consulting and scheduling services are also available in some areas.

Soil, Water, and Plant Terms Used in Irrigation Scheduling

Term	Definition
Field Capacity (FC)	The soil-water content after the force of gravity has drained or removed all the water it can, usually 1 to 3 days after rainfall.
Permanent Wilting Point (PWP)	The soil-water content at which healthy plants can no longer extract water from the soil at a rate fast enough to recover from wilting. permanent wilting point is considered the lower limit of plant- available water.
Plant-Available Water (PAW)	The amount of water held in the soil that is available to plants; the difference between field capacity and the permanent wilting point.
Depletion Volume	The amount of plant-available water removed from the soil by plants and evaporation from the soil surface.
Allowable Depletion Volume	The amount of plant-available water that can be removed from the soil without seriously affecting plant growth and development.
Effective Root Depth	The upper portion of the root zone where plants get most of their water. Effective root depth is estimated as one-half the maximum rooting depth.