Virginia Cooperative Extension
Virginia Tech • Virginia State University
Publication BSE-239P

Irrigation Scheduling in Humid Climates Using the Checkbook Method

Julie Shortridge, Assistant Professor and Extension Specialist, Biological Systems Engineering, Virginia Tech

Irrigation scheduling is the process of deciding when and how much water to apply to a field. The goal of irrigation scheduling is to improve irrigation efficiency by providing the right amount of water, at the right time, to replenish soil moisture levels and meet plant needs. Applying too little water can cause crop losses and yield reduction. However, applying too much water can waste money, fertilizer, and labor and can even decrease yields in some cases. In arid regions where irrigation is very common, little to no rainfall occurs during the growing season. In these regions, irrigation water can be applied at regular intervals and amounts (such as 1 inch per week). On the other hand, in humid regions like Virginia and the eastern United States, regular scheduling of irrigation will frequently result in overirrigation and wasted water and energy because we often receive substantial rainfall during the growing season. Irrigators in humid regions can save money by scheduling irrigation based on the amount of rainfall that occurs, allowing them to reduce fuel and labor costs.

One method for scheduling irrigation is to keep track of the amount of water in the soil that is available for plants. This is done by monitoring the water that enters the soil from rainfall and irrigation as well as the water used by the plants in a manner similar to balancing a checkbook. This method, called the "checkbook" or "water balance" method, doesn't require the purchase of any specialized equipment or tools, making it a cost-effective way to schedule irrigation. Other advantages of checkbook irrigation scheduling are that it doesn't require fieldwork or labor, and it can be used to estimate future irrigation needs. However, it does require paying close attention to weather, soil, and crop conditions, and the calculations involved can sometimes be challenging.

The other main approach to irrigation scheduling is by monitoring soil moisture levels. More details on monitoring soil moisture using sensors is provided in Virginia Cooperative Extension publication BSE-198P, "Understanding Soil Moisture Sensors: A Fact Sheet for Irrigation Professionals in Virginia" (Sample et al. 2016).

The goal of this publication is to outline the data required and the steps involved in irrigation scheduling using the checkbook approach. It also discusses software tools and apps that are available to make the calculations easier. The first section describes some of the benefits of irrigation scheduling. The second section describes different factors that influence the amount and timing of water needed. The third section describes the data required for checkbook irrigation scheduling and different ways of obtaining this data. The fourth section describes how to use this data to decide when and how much to irrigate, and the fifth section describes tools and resources that can help in performing these calculations. This information can help irrigators determine when to irrigate and how much water to apply in order to improve crop yields and farm profits.

The Benefits of Irrigation Scheduling

One benefit of irrigation scheduling is that it can help avoid water stress in crops and improve yields. Waiting to irrigate until crop stress is evident, or applying too little water, can hinder plant growth. For instance, studies on cotton have suggested that improper irrigation timing can result of losses up to $750 per acre (Vories et al. 2006). Avoiding water stress can be particularly challenging when irrigation must be managed across multiple crops and fields.

Irrigation scheduling can help growers meet water requirements across their fields in the most efficient way possible. Efficient irrigation, where only a minimal amount of water is lost to evaporation, runoff, or drainage below the root zone, is important because it reduces operating costs. Applying more water than

Produced by Virginia Cooperative Extension, Virginia Tech, 2018

VT/1118/VCE-239P

necessary wastes water, fuel, and money. Fuel costs are one of the largest operating expenses that an irrigator will face, especially if they are using diesel pumps or drawing from groundwater. Irrigation scheduling can greatly reduce the excess costs of wasting this water and fuel without negatively impacting plant growth. For example, research in Nebraska found that irrigation scheduling can reduce water and energy costs by 35% (Broner 2005). Irrigation scheduling also helps avoid nutrient and pesticide loss through runoff or deep percolation to groundwater, which can reduce fertilizer costs and improve water quality in local streams and rivers. Applying too much irrigation water can also lead to waterlogging, particularly in poorly drained soils, which can increase disease risks. Some crops, such as tobacco, are also very sensitive to excessive soil moisture and will produce lower yields and quality if too much irrigation is applied.

Factors That Influence Irrigation Needs

The amount of irrigation water needed at any given time is typically determined by crop water requirements, soil conditions, weather, and the irrigation system itself.

Crop Water Requirements

Every crop needs different amounts of water, which will vary depending on the specific variety grown and the stage of crop growth. Just as crop water needs will change as the plant grows and matures, the impacts of water stress also vary throughout the growing season. There are certain times when experiencing water stress can result in severe yield deficits and other times where water stress will result in only minor impacts. For example, corn is very sensitive to water stress in the tasseling and silking stages, but less sensitive to water stress in the vegetative growth periods. The depth of the plant's root system will also impact irrigation scheduling needs because this impacts the depths from which the plant can obtain water. At the same time, irrigation practices can impact root growth, particularly early in the growing season, and overirrigating early on can result in a shallow root depth that makes irrigation scheduling more challenging later. Table 1 presents information on critical periods for moisture stress in different crops, as well as their typical effective rooting depths. Additional crop-specific information on moisture stress is available in the NRCS North Carolina Irrigation Guide (NRCS 2010).

Soil Conditions

The field's soil will also impact the timing and amount of irrigation necessary. To understand how soil impacts irrigation needs, it is useful to know a few definitions, demonstrated in fig. 1.

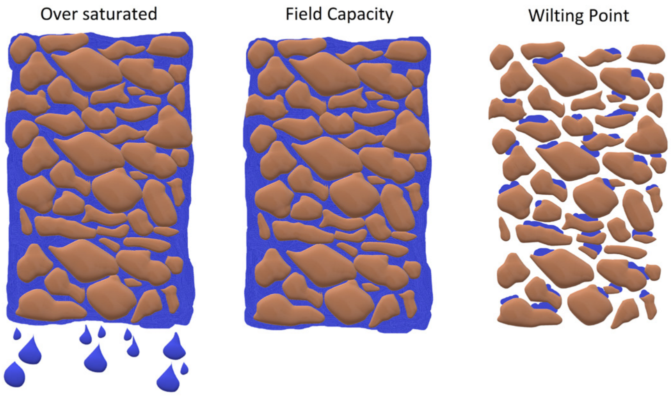

Figure 1. Soil moisture levels. Oversaturated soil contains more water than the field capacity, meaning that some will drain out due to gravity. Soil at field capacity is holding the maximum amount of water without draining. Soil at the wilting point will still contain some water, but it won't be accessible to plant roots.

Field capacity is the upper limit on the amount of water that can be stored in the soil. When soil moisture levels are greater than the field capacity, water will be drained by gravity and move below the root zone where it is no longer available to plants.

The permanent wilting point is the lower limit on the amount of water stored in the soil that can be accessed by healthy plants. When soil moisture drops below the permanent wilting point, plants will irreversibly wilt and die because even though water might be present in the soil, the plant's roots cannot extract it. Plants will begin to experience stress before this point, as water becomes more difficult to extract from the soil, but they will generally be able to recover.

Plant available water capacity is the amount of water between the permanent wilting point and the field capacity. This is the amount of water that can be managed with irrigation. Plant available water is usually expressed as an inch of water per inch of soil or an inch of water per foot of soil.

The amount of water that can be managed by irrigation is determined by the soil's plant available water capacity and the plant's rooting depth. For instance, a loamy sand has a plant available water capacity of 0.08 inches per inch of soil. For a plant with a root depth of 24 inches,

Table 1. Critical moisture stress periods and rooting depths for various crops (NRCS 2010).

Crop	Critical plant moisture stress period	Normal effective rooting depth (inches)
Beans, (dry, snap, green, pole)	During and immediately following bloom	24
Beans (lima)	During and immediately following bloom	30
Beets	During rapid root expansion	24
Blueberries	Transplanting and from bloom until harvest	24
Cantaloupe	Flowering and fruit development	18
Carrot	Seed germination, root expansion	18
Corn (grain and silage)	15 days prior to and 15 days after silking	36
Corn (sweet)	From silking through ear formation	30
Cotton	During and immediately after bloom stage	36
Cucumber	Flowering and fruiting	18
Eggplant	Flowering and fruiting	18
Grain (small)	At planting and 2 weeks before pollination and head formation	24
Greens	From just prior to maturation and during harvest	18
Melons	At pollination and 2-3 weeks afterward	36
Onion	Throughout growing season to just prior to harvest	18
Peanuts	Nut enlargement stage	24
Peas	From bloom through harvest season	18
Peppers	1-2 weeks prior to bloom to 2-3 weeks prior to end of harvest	18
Potato	4 weeks prior to harvest	18
Potato (sweet)	During rapid root expansion	24
Pumpkin	During fruiting	24
Sorghum (grain)	From boot to flowering stage	36
Soybeans	Pod filling stage	30
Spinach	From just prior to maturation through harvest	24
Squash (summer)	From bloom through harvest season	24
Squash (winter)	From bloom through harvest season	24
Strawberries	Transplanting, prior to and during harvest, and during fruit bud formation	12
Tobacco	Transplanting, knee-high to bloom, during harvest	18
Tomatoes	1-2 weeks prior to bloom to 2-3 weeks prior to end of harvest	24

the total amount of plant available water is 0.08 x 24 = 1.92, or about two inches. In sandy soil, the plant available water is typically around 0.06 inch of water per inch of soil, whereas in loamy soil, plant available water is about 0.20 inch of water per inch of soil. Table 2 presents a range of plant available water capacities for different soil types.

Weather

In most years, Virginia and the surrounding states receive large amounts of growing season rainfall. Avoiding irrigation shortly before or after rainfall occurs can lead to significant savings. However, it is not just rainfall that impacts irrigation water needs. Higher temperatures will increase the rate at which plants use water and will increase the amount of water lost to direct evaporation from the soil. Other weather factors, such as low humidity and high winds, also increase plant water use. And high winds can significantly impact the efficiency of sprinkler irrigation, with large volumes of water being lost to evaporation or wind drift away from fields. Obtaining good weather data — either through the use of an on-farm weather station or via weather products available from commercial or government sources — is important for accurate irrigation scheduling.

Irrigation System Characteristics

The irrigation system itself can impact the timing and amount of water needed. This can be particularly important for large irrigation systems. For example, large center pivots and traveling gun systems can take several days to cover an entire field. This requires that irrigators anticipate when irrigation will be needed at the last point that will be irrigated and start operating the pivot sufficiently early.

Irrigation systems also differ in their application efficiency, which is the percentage of water that leaves the irrigation sprinklers that is ultimately available for the plant to use. Drip irrigation is typically the most efficient, with efficiencies of about 90% when well-maintained and operated correctly. This means that 90% of irrigation water reaches the plant's root zone. On the other hand, travelling gun sprinklers often have an efficiency of only about 65% because water is lost to evaporation, drift, and runoff. Center pivots are typically in between, with efficiencies of about 70-80%. In less efficient irrigation systems, more water will have to be pumped and applied through the irrigation system to meet plant needs.

Information Required for Irrigation Scheduling

The goal of checkbook irrigation scheduling methods is to keep the amount of water available in the soil and the amount of water used by the plant in balance with each other. Irrigation should be applied when the plant available water becomes low. The amount of irrigation water applied should be enough to bring the plant available water up to a high level but typically not to full capacity, so there is some room for additional water in the soil if rainfall occurs after irrigation. Employing checkbook methods requires estimating three values: (1) the plant available water capacity of your soil, (2) the amount of water removed from the soil via evapotranspiration (ET), and (3) the amount of water that comes into the soil from rainfall and irrigation.

Plant Available Water Capacity

The first stage in checkbook irrigation scheduling is to estimate the soil's plant available water. This is estimated by multiplying the plant's rooting depth in inches by the soil's plant available water capacity in inches of water per inch of soil (table 2). This tells you how much water (in inches) your soil can hold that will be available to plants and is the maximum volume of water that can be managed by irrigation. For instance, a loamy sand has a plant available water capacity of 0.08 inch per inch of soil. For a plant with a root depth of 24 inches, the total amount of plant available water is 0.08 x 24 = 1.92, or about 2 inches. If more than 2 inches of water is applied to the soil, some of it will be lost to runoff or seepage below the root zone. Keep in mind that plant available water changes with soil depth. Most soils will have a layer that is slightly higher in clay content as one moves deeper into the soil, resulting in greater plant available water at these depths. In contrast, some soils in the Coastal Plain will decrease in clay content; hence, plant available water decreases. For a detailed description of your soils' available water capacity, reference your county's NRCS soil survey at https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/.

It is important to remember that in early growth stages, root zones are shallow and irrigation will likely be needed more frequently. Hardpan layers will also limit the rooting depth and the depth of irrigation water that can be managed. In sandy southeastern soils, it can often be challenging to manage irrigation beyond a rooting depth of 24 inches; even the actual plant roots may extend beyond this (Harrison 2012).

Table 2. Plant available water capacity for different soil textures, in inches of water per inch of soil (Andales, Chavez, and Bauder 2015).

Soil Texture	Plant Available Water Capacity		
	Low	Average	High
Coarse sands	0.05	0.06	0.07
Fine sands	0.07	0.08	0. 08
Loamy sands	0.07	0.08	0.10
Sandy loams	0.10	0.12	0.13
Fine sandy loams	0.13	0.15	0.17
Sandy clay loams	0.13	0.16	0.18
Loams	0.18	0.20	0.21
Silt loams	0.17	0.19	0.21
Silty clay loams	0.13	0.15	0.17
Clay loam	0.13	0.15	0.17
Silty clay	0.13	0.13	0.14
Clay	0.11	0.12	0.13

Plant Water Use

The second step in estimating a soil's water balance is to calculate the amount of water lost through evapotranspiration. ET refers to the water used by the plant through transpiration, as well as the water that evaporates directly from the soil surface or the plant canopy. This can be done using crop water curves, reference ET, or pan evaporation. Crop water curves estimate the amount of water used by a crop at different periods in its growth in inches per day or inches per week. An example of a crop water curve for cotton is shown in figure 2. Crop water curves for other crops are presented in Harrison (2012) and are available online at http://extension.uga.edu/publications/detail.html?number=B974&title=Irrigation%20Scheduling%20Methods. These crop water curves were developed for Georgia and thus actual water use in Virginia may differ, but they should still provide a good initial estimate. Sometimes these curves present the amount of water needed for each week after initial planting, and sometimes they present the amount of water needed for different growth periods (e.g., vegetative, reproductive) of the plant. In general, estimates based on the growth period of the plant will be more accurate because the plant's growth stage at a certain time period after planting could vary depending on the variety of plant and growing conditions from earlier in the season. For example, water requirements for cotton peak three to four weeks into the bloom period (fig. 2). While this will typically be around 11 to 12 weeks after planting, it is better to schedule irrigation based on visual confirmation of the plant's growth stage rather than the calendar date or number of days after planting.

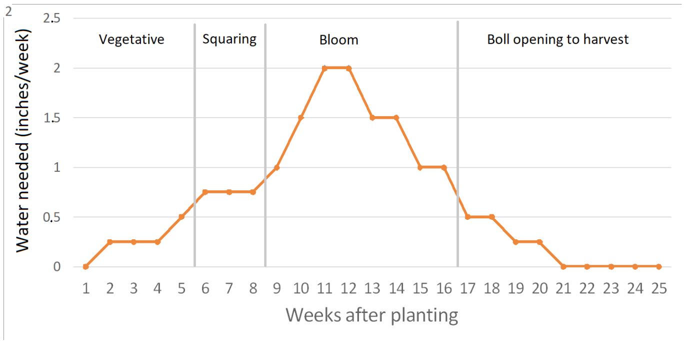

Figure 2. Crop water curve for cotton. Based on data from Collins and Edmisten (2018) and Whitaker et al. (2018).

Crop water use can also be estimated based on reference crop evapotranspiration. Reference crop ET is the amount of water that would be used by an extensive surface of well-watered grass. The National Weather Service provides five-day forecasts of reference ET for the entire United States on its Graphical Forecasts website (https://digital.weather.gov/). On the website, the NWS refers to this as forecast reference evapotranspiration (FRET). A sample image of this website is presented in figure 3. A user can find their location on the map to estimate reference ET; for example, in figure 3, the reference ET near Blacksburg is 0.12 inch per day.

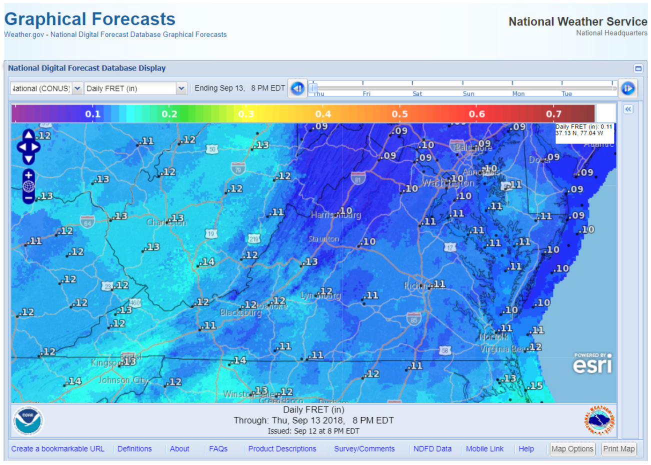

Figure 3. Screenshot from the National Weather Service's Graphical Forecast website showing reference crop evapotranspiration across Virginia.

To estimate crop evapotranspiration, the reference crop ET value is multiplied by a crop coefficient. Table 3 presents ET coefficients for different crops during the initial, midseason, and end of the growing season in a humid climate with moderate wind. Coefficients for additional crops, as well as other growing conditions, are included in "Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements" (Allen et al. 1998).

These coefficients are used by dividing the growing season into four periods:

1. Initial: The period from planting through early growth when the soil is not or is hardly covered by the crop (groundcover <10%). During this period, the crop ET coefficient is the initial value in table 3.

Table 3. Crop evapotranspiration coefficients (Allen et al. 1998).

Crop	Initial	Canopy development	Midseason	Maturation	End of season
Barley	0.30	0.725	1.15	0.700	0.25
Beets	0.50	0.775	1.05	1.000	0.95
Berries (bushes)	0.30	0.675	1.05	0.775	0.50
Broccoli	0.70	0.875	1.05	1.000	0.95
Carrots	0.70	0.875	1.05	1.000	0.95
Cantaloupe	0.50	0.675	0.85	0.725	0.60
Corn (field/grain dried before harvest)	0.30	0.750	1.20	0.800	0.40
Corn (sweet)	0.30	0.725	1.15	1.100	1.05
Cotton	0.35	0.775	1.20	0.900	0.60
Cucumber	0.60	0.800	1.00	0.950	0.90
Eggplant	0.60	0.825	1.05	0.975	0.90
Green beans	0.50	0.775	1.05	0.975	0.90
Lettuce	0.70	0.850	1.00	0.975	0.95
Melons (sweet)	0.50	0.775	1.05	0.900	0.75
Oats	0.30	0.725	1.15	0.700	0.25
Onions (dry)	0.70	0.875	1.05	0.900	0.75
Onions (green)	0.70	0.850	1.00	1.000	1.00
Onions (seed)	0.70	0.875	1.05	0.925	0.80
Peanuts	0.40	0.775	1.15	0.875	0.60
Peas (fresh)	0.50	0.825	1.15	1.125	1.10
Peppers (sweet bell)	0.60	0.825	1.05	0.975	0.90
Potato (sweet)	0.50	0.825	1.15	0.950	0.75
Pumpkin (winter squash)	0.50	0.750	1.00	0.900	0.80
Soybeans	0.40	0.775	1.15	0.825	0.50
Spring wheat	0.30	0.725	1.15	0.775	0.40
Squash (zucchini)	0.50	0.725	0.95	0.850	0.75
Strawberries	0.40	0.625	0.85	0.800	0.75
Tomatoes	0.60	0.875	1.15	0.975	0.80
Watermelon	0.40	0.700	1.00	0.875	0.75

2. Canopy development: The period from the initial stage to the time that the crop effectively covers the soil surface (groundcover of 70-80%). During this period, the crop coefficient will gradually increase from the initial value to the midseason value. As an approximation, the average of these two values can be used and is included in table 3.

3. Midseason: The period from full cover until the start of maturation when leaves begin to change color. During this period, the crop ET coefficient is the midseason value.

4. Maturation: Period from end of midseason until physiological maturity or harvest. During this period, the crop ET coefficient gradually changes from the midseason value to the end value. As an approximation, the average of these two values can be used and is included in table 3.

For example, during the initial stage, field corn has a crop coefficient of 0.3. Using the reference ET estimate of 0.12, this would mean that the water use by early-growth corn around Blacksburg on this day would be 0.12 x 0.3 = 0.036 inch per day, or about 0.25 inch per week. However, during midseason the crop coefficient for field corn is 1.2, so its water use would be 0.12 x 1.2 = 0.144 inch per day, or about 1 inch per week. An advantage of using reference ET is that it will account for changes in plant water use based on the weather at that location and time because certain conditions (such as high temperatures and high winds) can make crop water use higher or lower than the values reported in crop water curves.

A final method for estimating crop water use is pan evaporation data. Evaporation pans are sometimes present at local weather stations and reported in weather data from the National Weather Service (www.weather.gov) and the National Centers for Environmental Information (www.ncdc.noaa.gov/). Evaporation pan data reports the amount of water that evaporated from the pan in inches or millimeters. This amount is multiplied by a crop coefficient to estimate the amount of water used by the plant on that day. An advantage of using pan evaporation data is that it will account for changes in plant water use based on the weather at that location and time because certain conditions (such as low humidity or high temperatures) can make crop water use higher or lower than the values reported in crop water curves. However, pan evaporation data might not be available near your location, and using data from a weather station far away is not advised since conditions there might not be representative of your farm. Unless you are able to get pan evaporation data from a nearby weather station, the use of crop water curves or reference crop ET is preferable.

Water Applied From Rainfall and Irrigation

Checkbook methods also require an estimate of the amount of water that entered the soil from rainfall or irrigating. When rain occurs, you can estimate the depth of rainfall by viewing weather station data, if one is located nearby, or by using your own rain gauge. You can search for weather stations near your location on NOAA's Climate Data Online Search tool (www.ncdc.noaa.gov/cdo-web/search). Almost all weather stations will report daily rainfall totals. If no weather stations are located nearby, you can also install a rain gauge on your property. When using your own rain gauge, it is important to check it regularly because — depending on the design — water might evaporate or overflow from the gauge. After rainfall occurs, use this data to estimate the amount of water, in inches, that fell on the soil. If the amount of rainfall exceeded the plant available water capacity, then you can assume that some of the water was lost to surface runoff or percolation deeper than the root zone. Sometimes in heavy, intense storms, rainfall can fall more quickly than the soil can absorb it. In these cases, the full amount of rainfall won't enter the soil, and some will be lost to runoff. It is best to visually inspect your fields and soil during and after intense storms to see if this is happening.

It is also important to know how much irrigation water you apply in inches. Newer irrigation systems are often equipped with software that can estimate the depth of irrigation applied in inches for you. For other systems, you have to estimate irrigation depths using flow rates or catch cans. It is best to estimate your flow-rate using a flow meter installed on the system, since pumps can operate at different flow rates as they age or under different conditions. Flow rates are typically measured in gallons per minute. To convert a flow rate in GPM to inches of water, multiply the flow rate by the time the pump was run in hours and then divide by 453 times the irrigated area in acres:

$$\text{Water applied (inches)} = \frac{\text{(flow rate (GPM) x time (hours)}}{\text{453 x irrigated area (acres)}}$$

The water applied in inches can also be estimated using catch cans. This can be particularly valuable in systems like traveling guns, which often apply irregular amounts of water to different parts of the field. To do a catch-can assessment, place catch cans from 5 to 10 feet apart along the irrigated area. Run the irrigation system and measure the depth of water that accumulates in each can; take the average of these measurements to estimate the average depth of water applied.

Calculating Soil Water Balance

Once you know the soil's plant available water capacity, ET, and the amount of rainfall or irrigation applied, you can track the amount of water available in your soil day by day and determine when irrigation is necessary and how much to apply. An example of an irrigation water balance tracking table is shown in table 4. This table shows two weeks of plant available water, crop water use, rainfall, and irrigation amounts for a corn crop assumed to be at the early tassel and silking stage, where it uses 0.3 inch of water per day.

The table starts with a full water balance of 2.4 inches, assuming that the field just received a heavy irrigation or rainfall event. Each day, the plants use 0.3 inch of water, and on most days no irrigation or rainfall occurs. The ending water balance for each day is the starting balance minus the plant water use, plus rainfall and irrigation. The water balance deficit is the difference between the maximum plant available water and the ending water balance as a percentage of the maximum plant available water. The starting balance for the following day is the same as the ending balance from the current day. Although a few light rainfall events occur in the first week, the water balance continues to decline to a minimum of a 46% deficit on Aug. 22. At this point, 1.2 inches of irrigation is applied to bring the water balance back up close to the full plant available water capacity. Another 1.2 inches of irrigation is applied the next time

Table 4. Example of a water balance tracking table. All numbers are in inches, except for percent deficit in the far right column.

Soil type: Sandy loam
Plant available water capacity (PAWC): 0.1 inch/inch
Rooting depth: 24 inches
Maximum plant available water = PAWC x rooting depth: 2.4 inches
Crop water use: 0.3 inch/day (Assume corn during early tassel and silking stages)

Date	Starting water balance	Plant water use	Rainfall	Irrigation	Ending water balance	Water balance deficit (%)
16-Aug	2.4	0.3	0.0	0.0	2.1	13%
17-Aug	2.1	0.3	0.0	0.0	1.8	25%
18-Aug	1.8	0.3	0.5	0.0	2.0	17%
19-Aug	2.0	0.3	0.0	0.0	1.7	29%
20-Aug	1.7	0.3	0.1	0.0	1.5	38%
21-Aug	1.5	0.3	0.3	0.0	1.5	38%
22-Aug	1.5	0.3	0.1	0.0	1.3	46%
23-Aug	1.3	0.3	0.0	1.2	2.2	8%
24-Aug	2.2	0.3	0.0	0.0	1.9	21%
25-Aug	1.9	0.3	0.0	0.0	1.6	33%
26-Aug	1.6	0.3	0.0	0.0	1.3	46%
27-Aug	1.3	0.3	0.0	1.2	2.2	8%
28-Aug	2.2	0.3	0.0	0.0	1.9	21%
29-Aug	1.9	0.3	0.0	0.0	1.6	33%
30-Aug	1.6	0.3	2.0	0.0	2.4	0%
31-Aug	2.4	0.3	0.0	0.0	2.1	13%

that the deficit approaches 50% on Aug. 27. On Aug. 30 a large rainfall event (2.0 inches) occurs. Normally the water balance at the end of this day would be

$$1.6-0.3+2.0=3.3 \text{ inches}$$

However, 3.3 inches is greater than the maximum plant available water capacity of 2.4 inches. The soil can't store this volume of water, so some of this rainfall would be lost to either surface runoff or drainage below the root zone.

Assuming that the example in table 4 is using a center pivot system with 80% efficiency, they would have to irrigate with 1.5 inches of water to apply 1.2 inches to the root zone:

$$1.5 \text{ inches} \times 80\%=1.2 \text{ inches}$$

To estimate the time necessary to apply this amount of irrigation to a field assuming a given flow rate, multiply the depth of irrigation water needed by 453 times the irrigated area in acres, and divide this by the flow rate in GPM. For instance, assuming the field in the table 4 example was 30 acres in size and the pump rate was 1,000 gallons per minute, it would take 20.4 hours to apply 1.5 inches of irrigation that results in 1.2 inches applied to the root zone.

$$\text{Time needed} = \frac{(1.5 \text{ inches} \times 453 \times 30 \text{ acres})}{1000 \text{ GPM}} = 20.4 \text{ hours}$$

A common rule of thumb is to apply irrigation when the water balance deficit approaches 50% because plants can start to experience stress before the permanent wilting point (Evans, Cassel, and Snead 1996). In large fields, it will also help to ensure that soil moisture levels in the last parts of the field to receive irrigation don't drop too low, even if it takes several days to reach those plants. However, in some instances, greater depletions up to a 60-70% deficit can be acceptable, particularly in drought-tolerant crops like cotton and soybeans. On the other hand, water-sensitive crops like vegetables and crops during their critical growth stages might need to be irrigated at deficits as small as 20-30% (Al-Kaisi and Broner 2013).

In the example in table 4, irrigation was applied when the water balance deficit approached 50%, and the depth of water applied (1.2 inches) was equal to that deficit so that after irrigation, the soil was close to the full plant available water capacity. This is a good approach in critical growth periods and situations where there is no rainfall in the forecast, especially in sandy soils. However, irrigators can often save money by applying less water than the total deficit amount so that after irrigation, there is still room in the soil for additional rainfall if it occurs. For instance, on Aug. 27 the irrigator could have applied only 0.6 inch of water if they saw that heavy rainfall was forecast for Aug. 30. This would have resulted in a maximum deficit of 58% on Aug. 29 before the soil returned to the maximum plant available water capacity after the heavy rainfall on Aug. 30. This can save fuel costs during growth periods that are less sensitive to water shortages or during times where some rainfall is expected in the near future.

Early in the planting season, irrigation timing and depths should be managed not just to replenish soil moisture levels, but also to promote germination and root growth. After germination, small amounts of irrigation will need to be applied frequently if rainfall is insufficient to keep moisture levels in the shallow soil sufficiently high for germination. However, after germination when plant roots are developing, shallow irrigation can be detrimental because it will only wet the top portion of the soil and encourage shallow root development. Deeper but less frequent irrigation is often ideal in that it will promote the growth of deep root systems, which will improve plant water uptake later on.

Computational Tools

The calculations required for scheduling irrigation using water balance approaches can be cumbersome. In recent years, a number of computational tools and apps have been developed to help do these calculations and provide recommendations and alerts when irrigation is necessary. Sometimes, these tools even incorporate data on rainfall and evaporation at a user's specific location. Available tools include:

- Checkbook Irrigation Scheduling Worksheets – http://msue.anr.msu.edu/news/ irrigation_scheduling_tools_provided_by_purdue_and_msu_extension
  Purdue and Michigan State University Extension have developed water balance worksheets that can be filled out to help keep track of rainfall, irrigation, crop water use, and soil water content. These are organized similarly to table 4, but they also include places where a grower can record their soil's plant available water capacity and maximum allowable soil moisture deficit to keep this information organized.

- SmartIrrigation Cotton App – https://smartirrigationapps.org/cotton-app/cotton-app-development/

This smartphone app was developed by the University of Florida and University of Georgia, but it can be used in fields across the Cotton Belt. Users enter their field's location and soil type. The app downloads weather data for the location to estimate soil moisture levels and even send notifications when irrigation is recommended.

- Climate Smart Farming Water Deficit Calculator – http://climatesmartfarming.org/tools/csf-water-deficit-calculator/Cornell University's water deficit calculator can also be used in Virginia fields. This online tool allows users to input the location of their farm, soil type, and crop type. It then gathers weather data to produce a graph displaying whether or not crops are experiencing a water deficit.

Conclusions

Irrigation scheduling can help growers improve yields and save money. However, scheduling irrigation in humid climates like Virginia can be a challenge because the amount of irrigation needed depends on the crop, soil, and weather conditions at that moment in time. Checkbook methods allow irrigators to meet crop water requirements and avoid negative impacts on crop growth and yield without the use of expensive or specialized equipment. At the same time, they can prevent the waste of water, fuel, nutrients, and money that occurs from overirrigation, making the most economical use of a farm's irrigation system. This can result in healthier plants with minimal excess cost, ultimately improving a farm's bottom line.

Acknowledgements

The information presented in this bulletin was developed through support from USDA/NIFA under Award No. 2015-49200-24228. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of USDA/NIFA. The author would like to thank David Holshouser, associate professor and Extension agronomist, Virginia Tech; Guy Collins, Extension cotton specialist, North Carolina State University; Roy Flanagan, Virginia Cooperative Extension agent for Virginia Beach; and Dwayne Sanders, VCE agent for Surry and Sussex counties; for their review of this bulletin.

References

Al-Kaisi, M. M., and I. Broner. 2013. *Crop Water Use and Growth Stages*. Colorado State University Cooperative Extension. Fact sheet No. 4.715. http://extension.colostate.edu/topic-areas/agriculture/crop-water-use-and-growth-stages-4-715/.

Allen, R. A., L. S. Pereira, D. Raes, and M. Smith. 1998. Chapter 6, "Single Crop Coefficient." In *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements.* Food and Agriculture Organization of the United Nations. FAO Irrigation and drainage paper 56. Rome: FAO. www.fao.org/docrep/X0490E/x0490e0b.htm#crop%20 coefficients.

Andales, A. A., J. L. Chavez, and T. A. Bauder. 2015. *Irrigation Scheduling: The Water Balance Approach*. Colorado State University Extension. Fact sheet No. 4.707. http://extension.colostate.edu/docs/pubs/crops/04707.pdf.

Broner, I. 2005. *Irrigation Scheduling*. Colorado State University Cooperative Extension. Fact sheet No. 4.708. http://extension.colostate.edu/docs/pubs/crops/04708.pdf.

Collins, G., and K. Edmisten. 2018. "Points to Consider for Irrigating Cotton." North Carolina State University Extension. https://cotton.ces.ncsu.edu/2018/06/points-to-consider-for-irrigating-cotton-collins-edmisten/.

Evans, R., D. Cassel, and R. E. Sneed. 1996. *Soil, Water, and Crop Characteristics Important to Irrigation Scheduling.* North Carolina State University Extension. Publication AG-452-01. https://content.ces.ncsu.edu/soil-water-and-crop-characteristics-important-to-irrigation-scheduling.

Harrison, K. 2012. *Irrigation Scheduling Methods*. University of Georgia Cooperative Extension. Bulletin 974. http://extension.uga.edu/publications/detail.html?number=B974&title=Irrigation%20Scheduling%20Methods.

NRCS (National Resource Conservation Service). 2010. *North Carolina NRCS Irrigation Guide.* National Engineering Handbook Part 652, Irrigation Guide. https://efotg.sc.egov.usda.gov/references/public/NC/NC_Irrigation_Guide_Apr_2010.pdf.

Sample, D., J. Owen, J. Fields, and S. Barlow. 2016. *Understanding Soil Moisture Sensors: A Fact Sheet for Irrigation Professionals in Virginia.* Virginia Cooperative Extension publication BSE-198P. https://pubs.ext.vt.edu/BSE/BSE-198/BSE-198.html.

Vories, E. D., T. Teague, J. Greene, J. Stewart, E. Clawson, L. Pringle, and B. Phipps. 2006. "Determining the Optimum Timing for the Final Irrigation on Mid-South Cotton." In *Proceedings, National Cotton Council Beltwide Cotton Conference*. San Antonio, Texas. Jan. 3-6, 2006. CD-ROM.

Whitaker, J., S. Culpepper, M. Freeman, G. Harris, B. Kemerait, C. Perry, W. Porter, P. Roberts, D. Shurley, and A. Smith. *2018 Georgia Cotton Production Guide*. University of Georgia Cooperative Extension. www.ugacotton.com/vault/file/2018-UGA-COTTON-PRODUCTION-GUIDE-1.pdf.