Irrigation Water Management
Key Concepts and Practical Considerations

Background

In the early history of irrigation the biggest concern was conveying water from its source to the crop. Well-conceived solutions often provided seemingly unlimited quantities of water. Over time, increasing competition from neighboring irrigators and non-agricultural users gave birth to the notion of water conservation. Conservation needs have given rise to more sophisticated irrigation management practices and have helped us to understand that crops can do well with limited and controlled quantities of water. In fact, they often do better than with unlimited quantities of water due to the reduction of waterlogging, erosion, and other problems that can result from mass quantities of applied water.

Good irrigation system designers and managers must consider efficient water use as a major goal along with optimal crop production. While optimal crop production will always be a major key to success, growers must also factor such things as water costs, farm sustainability, and resource management when it comes to making sound irrigation management decisions. While some growing regions such as Washington's Columbia Basin benefit from consistent water supplies at relatively low costs, all irrigators will be increasingly required to defend their share of the water resource by demonstrating that it is necessary and wisely used.

All good irrigation management practices strive to answer the two most basic but critical questions.

- When should one irrigate?
- How much water should be applied during an irrigation?

This document will strive to provide a basic understanding of the key elements involved in properly answering these two questions.

Soil-Plant-Water Relationships

Before beginning a discussion on irrigation water management, it is important to have a basic understanding of the relationship between soil, plants, and water.

The role of soil from an agricultural perspective is to:

- Act as a water reservoir between rains and/or irrigations
- Act as a nutrient reservoir
- Mechanically support and stabilize plants

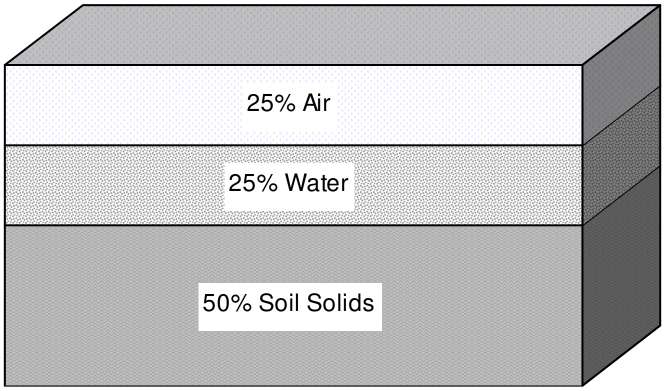
Soil Texture

Soil texture is determined by the ratios of various soil particle sizes. Soils are composed of a mix of clay particles (less than .002 mm diameter), silt particles (.05 to .002 mm diameter), and sand particles (2.0 to .05mm diameter). Soil texture can only be changed by extensive plowing to mix the texture of various soil depths, or by importing huge amounts of soil. In agriculture, deep plowing is common in some areas, but importation of soil is rare.

Soil Structure

The structure of a soil is determined by the way its various soil particles (sands, silts, and clays) are oriented. An ideal structure has large pore spaces throughout the root zone to allow the ready movement of both water and air. Soil structure can either be improved or degraded by irrigation and general agricultural management. Throughout the course of the growing season, irrigation practices can compact the top of the soil surface and change its structure by reducing pore spaces. This in turn affects infiltration rates (the soils ability to absorb or “intake” applied water), which can greatly reduce the amount of water that reaches the plants roots for uptake. These soil surface structure problems are usually difficult to see, but create a serious management issue.

A given depth of soil is typically arranged in various layers or “horizons”. Each horizon is different in terms of texture, structure, color, and percent organic matter. In general, nearly all organic matter is found within the top foot of soil. While it is probably more common for upper layers to be sandier than deeper layers, the reverse is not at all uncommon. Some regions such as the “Palouse” area in Washington State can have uniform soils for depths of 15 feet of more. A barrier or area of restricted permeability often exists at the point where two contrasting layers meet. (Sandy soils over clay soils or vice versa) This less permeable area can sometimes be beneficial if it occurs at the bottom edge of the root zone, but causes significant problems if it occurs within the root zone. The following figure is a visual representation of the typical air-water-soil proportions of a medium textured, well-managed soil at field capacity.



Typical air-water-soil proportions of a medium textured,
well-managed soil at field capacity.

Soil Water Terms

Soil Water Reservoir – Simply stated, the soil acts as a reservoir for moisture. The bottom of the reservoir is normally considered to be just below the bottom of the plant root zone. Any water below the root zone is unusable to the plants. The soil pore spaces fill up with water during an irrigation or rain event and empty due to plant use, evaporation from the soil surface, and deep percolation through the bottom of the root zone.

Saturation – Saturation occurs when the soil is completely filled with water. During saturation all of the air in the soil is replaced by water. In most cases, the soil profile rarely reaches true saturation except perhaps at the very surface and only for a short period of time directly after an irrigation or rain event. If a soil were to remain in a saturated state for a prolonged period of time it would lose its ability to support a crop because there would not be enough air available to the plants roots. Fortunately, gravity works to drain excess water from saturated soils in a timely manner. Sandier soils drain more quickly (a few hours), while heavy clay soils maintain a tighter hold on water and drain more slowly (several days or even weeks in extreme situations).

Field Capacity (FC) – Once free drainage has occurred after an irrigation soils reach their upper limit of storable water. This is known as field capacity. The relationship between saturation and field capacity can be visualized by picturing a bucket or container of soil that has had water slowly applied until all available pore spaces have been filled with water. In this state of saturation there is usually a visible “sheen” at the top of the soil surface. As holes are drilled in the bottom of the bucket water will drain out of the bottom of the bucket, first rapidly, then slowly until the drainage finally stops. The soil in the bucket would then be at field capacity and represents the maximum amount of water that soil can retain after gravity has done its work. For all soils, that amount of water remaining in the soil at field capacity is dramatically less than the amount of water in the soil at saturation. The generally accepted rule of thumb is that field capacity water content is about half as much as saturation water content.

Permanent Wilting Point (PWP) – This is the practical lower limit of plant-usable water in the soil. It is the soil moisture content at which plants begin to wilt and will not recover unless water is applied. It does not mean that there is no water remaining in the soil, but that the remaining water is held too tightly by the soil to be available to plants. For medium to heavy texture soils, a considerable amount of water will remain in the soil at permanent wilting point.

Available Water Holding Capacity (AWHC) – This is the amount of water held in the soil between field capacity and permanent wilting point. It is also frequently referred to as **Plant Available Water (PAW)**. The holding capacity of any soil is determined by its texture and structure. Available water holding capacity and total water holding capacity are not the same. Available water holding capacity is always something less than total amount of water that can be stored in a given soil. As a soil dries out, the remaining water is held in smaller and smaller pore spaces and has a greater resistance to extraction by the plant. When this resistance to extraction becomes greater than the vacuum force that a plant can exert, the remaining water becomes unusable. Although a sandy soil does not typically have a very large holding capacity, almost all of the water is readily available to the plant due to the low permanent wilting point of sandy soils. On the other hand, heavier soils hold more available water, but a larger percentage of the total water held is unavailable to the plant because heavier soils hold water "more tightly" than sandier soils.

Management Allowable Depletion (MAD) – This is the percentage of available water that an irrigator will allow to be depleted before irrigating and refilling the soil profile. Management allowable depletion is also frequently described as the "refill point". Smaller percentages of allowable depletion typically result in lighter, more frequent irrigations. There are several factors to consider when determining MAD, such as the rooting depth of the crop, the sensitivity of the crop to moisture stress, and the reliability of the water supply. Beyond crop-specific reasoning, irrigating too frequently may result in more total applied water over the course of the season because soil and plant surfaces are kept moist for a higher percentage of time, resulting in a greater amount of non-beneficial evaporation. In contrast, heavy irrigations often exceed the intake rate of a soil, resulting in unnecessary and non-beneficial runoff. Irrigators must strive to balance crop needs and soil characteristics when determining the frequency of irrigation and the amount of water to be applied. These parameters often vary over the course of an entire growing season and irrigations should reflect these variations.

Soil Moisture Depletion (SMD) – This represents the actual amount of moisture depletion at any particular time. It can be thought of as the amount of water necessary to fill the root zone back up to field capacity. In simple terms, when soil moisture depletion equals management allowable depletion (MAD), it is time to irrigate.

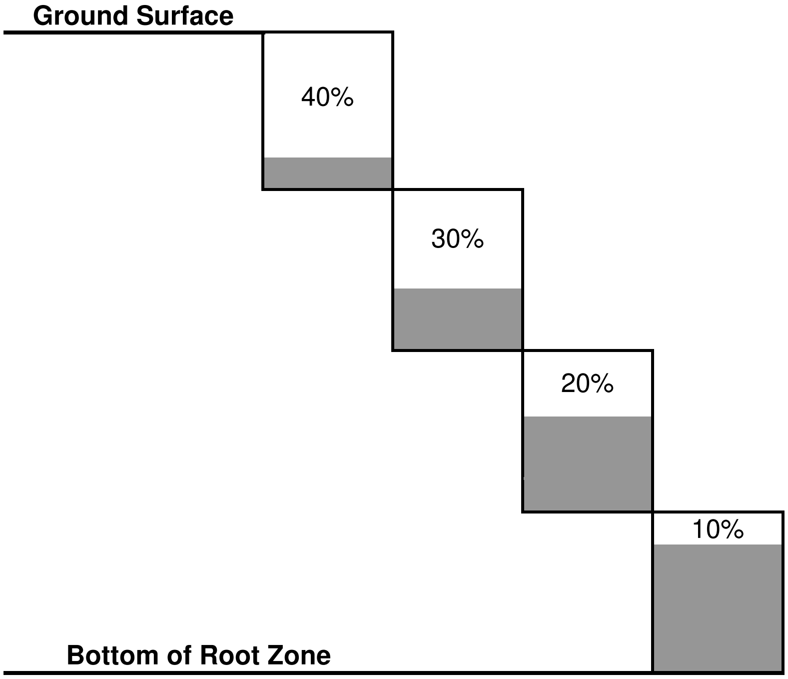
Basic Truths of Irrigation Water Management

1. As water is applied during an irrigation, each upper increment of soil must exceed field capacity (not saturation) before water will move down to the next depth. This is partly because gravity drainage begins to take effect at moisture levels above field capacity, which is the upper limit of storable water in the soil. It can be visualized as a series of stair-stepped buckets. When the top bucket becomes full, any extra water will spill over and begin to fill the next lower bucket.

2. Roots do not "hunt" for water. They will not travel several feet through a dry soil to search for moisture. Roots grow well in a healthy environment that supports growth. They prefer warm, moist soils with adequate nutrients and ample oxygen.

3. Water extraction patterns in a given soil tend to vary according to the crop, length of time, and the characteristics of the soil itself. Under normal conditions approximately 40% of the moisture extracted by the plant comes from top 25% of the root zone. Observing that plant root mass generally follows the same pattern can support this pattern for water extraction. Even though there is not a high percentage of water extracted from lower levels of the root zone, adequate moisture must be available for the total depth of the root zone. A lack of sufficient moisture at those lower levels may trigger an undesirable stress response in the plant, even if the top of the root zone has plenty of moisture. The following illustration depicts the typical water extraction pattern.

Soil Water Extraction Pattern



(Water used in the top 25% of the root zone represents 40% of the total water used)

4. With the same root zone depth and irrigated at the same percentage of depletion (MAD), the inches of water needed to refill the root zone of a clay soil will be greater than for a sandy soil.

5. Plant roots must have oxygen to function in normal conditions. Soil moisture that is maintained above field capacity for an extended period of time may not be conducive to good growth because the excess water will prevent necessary oxygen diffusion into the soil. This is often referred to as waterlogging. There must be a balance between water and oxygen availability. This is of greater concern in heavy soils. In fact, in certain regions where there are both heavy soils and high annual precipitation, much research has gone into oxygenating soils to reduce waterlogging and restore the proper balance. Coarse soils (larger pore spaces) allow oxygen to be available at greater depths. This is one reason root zones tend to be deeper on sandy soils than on clay soils.

6. Plant roots absorb nutrients via the soil water solution. The majority of plant nutrients exist in the upper portion of the root zone. Fertilizer applications also tend to locate supplemental nutrients in this same region. This placement of fertilizer corresponds with the previously discussed water extraction patterns; wherein, a large majority of plant absorption takes place in the upper regions of the root zone. Peak nutrient absorption takes place at optimal moisture content levels; therefore, even if a soil is not dry enough to stress the plant it may be too

dry for adequate nutrient intake. Soil waterlogging also limits proper nutrient absorption, especially nitrogen and phosphorous.

Evapotranspiration (ET)

Evapotranspiration is a term used to describe the sum of two components, **Evaporation (E)** and **Transpiration (T)**. It is important to understand these two concepts individually and how they relate to each other in order to understand why they are often grouped together under one term.

Evaporation is water that is converted from liquid to vapor, and which does not pass through the plant. Evaporation can only occur when water is available. It also requires that the humidity of the atmosphere be less than the evaporating surface (at 100% relative humidity there is no more evaporation). **Relative Humidity** is the ratio between the actual amount of water vapor held in the atmosphere compared to the amount required for saturation. It may occur from either a wet soil surface or a wet plant surface. Evaporation rates are dependent on the water surface area and both atmospheric and soil conditions. Soil and plant surface evaporation losses can represent a very high percentage of total applied water. Especially in arid regions if sprinklers are operated in frequent, short sets, or when plants are young and irrigated frequently to promote germination and emergence. With a fast-moving pivot, water applications may be so small per pass that only the plant canopy and soil surface become wet without any appreciable infiltration into the soil. The majority of that water is then lost to evaporation. By slowing the pivot as much as reasonably possible, evaporation losses may be reduced to less than 10% of total applied water. When evaporation rates are high, a much greater amount of total applied water is required to supply enough water to meet the needs of the crop.

Transpiration is water which passes from the soil into the plant roots, through the plant, and out through the leaves into the air. It remains in liquid form until it reaches the leaves and is converted into vapor. High transpiration rates are more than beneficial; they are critical in producing good crop yields, which is the main purpose of irrigation. Plants use tremendous quantities of water to maintain good health. Only about 2% of the water that enters the plant actually stays in the plant and used in the growth process. The rest is used to transport nutrients from the soil into the roots and carry them to the various cells of the plant and is used to keep plant tissues from becoming overheated.

Transpiration rates during any single day depend upon plant growth stage, weather conditions (temperature, relative humidity, solar radiation, and wind), the availability of soil water, and general plant health. Consider the following points:

- The hotter and drier the air, the higher the transpiration rate.
- The evapotranspiration process of converting liquid water into vapor requires large amounts of energy, which is provided by high quantities of solar radiation.

- As water vapor exits the plant leaves it generally forms a layer of vapor surrounding the leaves that is a few centimeters thick. As this vapor layer becomes saturated, transpiration slows. Wind can remove this layer and replace it with drier air, which then increases the potential for transpiration. Wind also increases evaporation rates in the same manner.

- Inadequate soil moisture reduces water uptake by the roots, which results in lower transpiration rates.

- When plants are unhealthy or stressed the leaf stomata (small pores on the underside of leaves) narrow and reduce transpiration by reducing the amount of water exiting the plant. This adaptation is necessary to limit the loss of water from plant tissues.

Transpiration and evaporation have an inverse relationship. Evaporation from areas surrounding the plant reduces transpiration, whereas the absence of evaporation from soil or wet plant surfaces increases it. Therefore, to maintain transpiration rates at desirable levels it may be necessary to keep evaporation to a minimum.

Distribution Uniformity (DU)

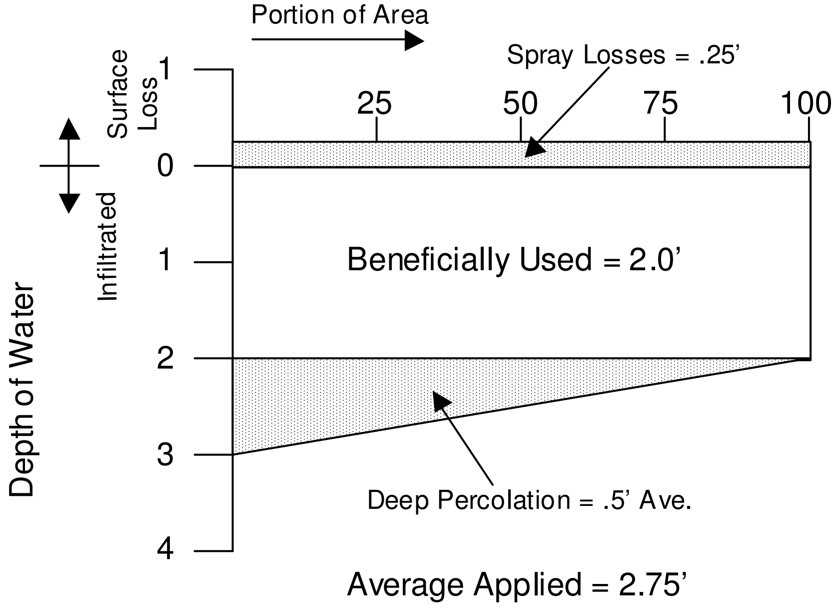
One of the major factors that influence total water use in agricultural irrigation is the level of application uniformity, also known as **Distribution Uniformity (DU)**, of a given irrigation system. DU is a concept of the evenness of application to each plant. It is field-wide uniformity that is pertinent, that is, the degree to which all of the plants in the entire field are supplied equally with water. If each plant receives the exact same amount of water, then we can say that the irrigation system is 100% uniform. In reality this does not occur, neither is it possible. All irrigation systems apply water at some percentage of uniformity less than 100%. This non-uniformity contributes to increased water usage over a large section of the system. In order to deliver the necessary amount of water to the least uniform (driest) portion of the field, all other areas of the field must be over-irrigated to some degree. Often, the wettest areas of the field are substantially over-irrigated. This excess water is not used or needed by the crop and is wasted in the forms of increased evaporation and/or leaching of water, and often chemicals, through the crop root zone and into the ground water supply.

For example, an irrigation system that is 75% uniform must over-irrigate the crop by an average of 30% to provide water to the driest portion of the field, with the wettest portion of the field actually being over-irrigated by about 65%. Not only does this waste water, the need to apply this excess water increases system operating hours and power consumption. In comparison, a 90% uniform system will over-irrigate the crop by an average of around 7.5%, with the wettest portion of the field being over-irrigated by about 25%.

Center pivot irrigation systems generally have distribution uniformities in the 75-85% range. Assuming a uniformity value in the middle of this range (80%), we find that <u>on average</u> the crop must be over-irrigated by about 25% to meet the irrigation requirements of the driest part of the field. Considering a base yearly crop requirement of 24 acre-inches/acre, the center pivot must apply 36 acre-inches/acre (the wettest part of the field) in order to apply the necessary 24 acre-inches/acre to the driest part of the field.

The fact that a center pivot irrigation system disperses water into the air requires us to make a further adjustment to our findings. Depending on specific wind conditions at the time of irrigation, a certain amount of the water dispersed into the air will not fall on the crop. In fact, it is generally recognized that when this spray loss is averaged over the entire irrigation season, about 10% of the dispersed water falls outside the desired area of irrigation or evaporates in the atmosphere before reaching the ground. Adjusting our 36 acre-inches/acre value up by 10% to account for spray losses results in a water usage of more than 39 acre-inches/acre for the season.

Center Pivot Irrigation System
Water Destination Diagram



An irrigation may be very uniform (have a high DU), but if the water applied is excessive, there may be unnecessary runoff and deep percolation, with a resulting low application efficiency (AE, defined in the next section). However, a high application efficiency with minimal underirrigation can only be achieved if the DU is also high. For this reason, conducting a field evaluation of the distribution uniformity of an irrigation system is the best starting point for evaluating and improving irrigation efficiency. Even if the DU of an existing irrigation system cannot be significantly improved, knowing how evenly the system applies water to the crop is critical to the irrigation management process. Some of the factors that may affect distribution uniformity, especially with sprinkler irrigation systems, include poorly designed sprinkler packages (nozzle size and pressure), sprinkler wear and plugging, wind, system travel speed, crop interference, and elevation changes, which may also cause changes in sprinkler trajectories.

Application Efficiency (AE)

In simple terms, irrigation efficiency is a measure of the amount of water beneficially used by the crop as a ratio of the total amount of water applied. In order to better understand irrigation efficiency it is important to understand what types of water consumption are considered beneficial. Generally, water consumed in order to achieve an agronomic objective is beneficial. Water consumption that does not benefit crop production is non-beneficial in terms of irrigation efficiency. The major component of beneficially consumed water is actual crop water use (evapotranspiration).

Beneficial Uses

- Crop Evapotranspiration (ET)
- Water Harvested with Crop
- Climate Control (Cooling or Frost Protection)
- Soil Preparation
- Seed Germination/Emergence
- ET from Wind Breaks or Cover Crops
- Some Deep Percolation for Salt Removal
- Some Extra Water Applied to Accommodate Chemigation Timing

Non-Beneficial Uses

- Excess Wet Soil and Plant Surface Evaporation
- Uncollected Tailwater
- Excess Deep Percolation (Over-Irrigation)
- Phreatophyte (Weed) ET
- Runoff
- Sprinkler Spray Drift and Droplet Evaporation

With center-pivot irrigation, the percentage of applied water lost to non-beneficial evaporation can partly be managed by optimizing the travel speed of the system. The slower the speed, the greater the application depth per pass. According to one study, approximately 0.15 inches of water will be lost to non-beneficial evaporation on each pass.

For a 0.5 inch pass, that represents 30% of the water applied
For a 1.0 inch pass, that represents 15%
For a 2.0 inch pass, that represents 7%

On the other hand, the greater the application depth per pass, the greater the probability of runoff. The correct machine speed throughout the season must be a compromise between runoff and evaporation losses.

Low irrigation efficiencies often result in:

1. Excess Pumping
2. Excess Fertilizer Application due to Deep Percolation
3. Low Crop Yields
4. Excess Water Costs
5. Reduction in the acreage which can be irrigated with a fixed volume of water available on a farm

Irrigation Adequacy

Application Efficiency alone is not a sufficient measure of irrigation water management because it is possible to attain a very high AE in a field by consistently underirrigating. This is because AE is a measure of how much applied water is beneficially used. In the case of underirrigation, a higher percentage of water is beneficially used by the crop because none is lost to deep percolation and evaporation is limited because plant and soil surfaces are not overly wetted. Underirrigation often occurs in the middle of the summer (peak water usage), because of reduced infiltration rates and/or underdesigned irrigation systems. Obviously, consistently underirrigating a crop is contradictory to the most basic goal of irrigation, which is optimizing crop production.

One must consider the **Irrigation Adequacy** of a specific irrigation event. Did a given irrigation event meet its target irrigation depth? Typically, the target irrigation depth is the amount of water necessary to refill the soil profile back to field capacity or some other pre-determined level. A well-timed and adequate irrigation occurs when the irrigation event is terminated at such time that the target depth is just met by the average of the lowest values in the irrigation distribution. Deep percolation losses would then be held to a minimum, and the application efficiency would be at a maximum without significant underirrigation. Any deep percolation would be due only to poor system distribution uniformity. The entire field would be at the same moisture content down to the bottom of the root zone. Extra water doesn't make soil "wetter"; it just leaves the bottom of the root zone as deep percolation.

If the irrigation is incomplete (does not refill the soil profile back to field capacity), the moisture content after an irrigation will be different at all points which have received less than Field Capacity (due to non-uniformity), even if the soil is uniform.

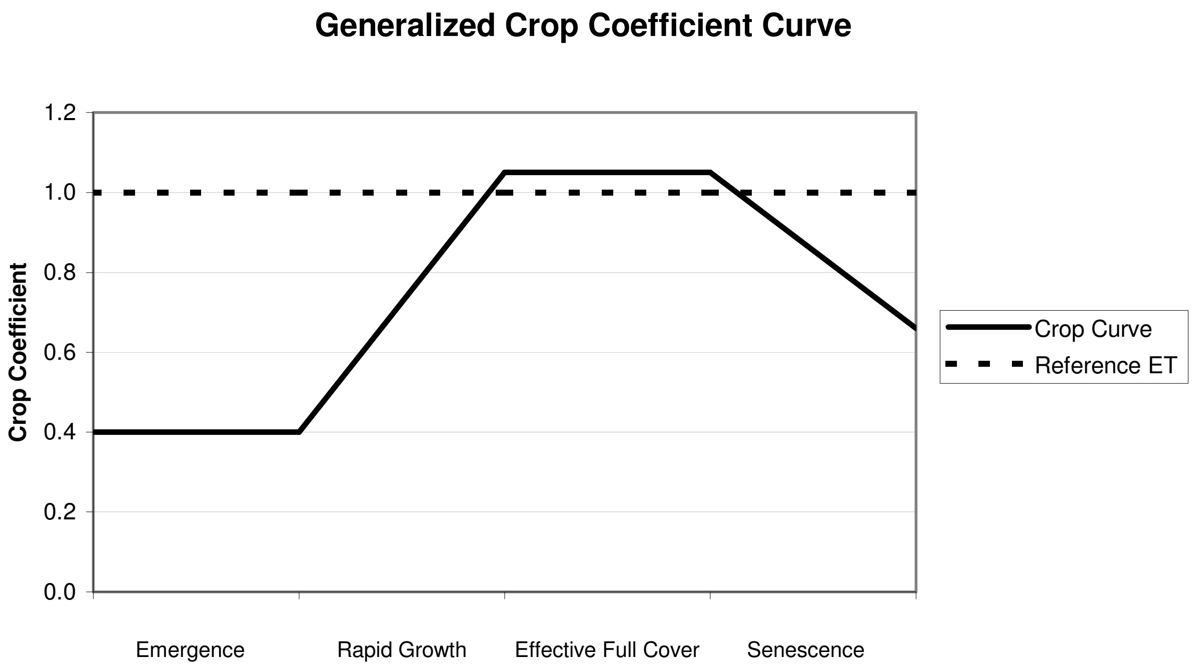
It is important to note that an "irrigation" may not necessarily be accomplished in one single pass or set. Often a complete irrigation is comprised of several consecutive passes or sets because applying the total amount of required water at once will result in excessive runoff, which wastes water and may negatively impact soil infiltration rates by changing the soil structure near the surface. The number of passes required to fill the profile is determined by the infiltration rate of the soil and the management allowable depletion (MAD), which determines the amount of water required for a complete irrigation.

Irrigation Scheduling

Water uptake rates are uniform across a field if plant health and vigor is uniform. It is the difference in soils in a field that may cause one part of the field to dry out faster (percentage-wise). Generally, one must schedule irrigations to meet the needs of the drier parts of a field to minimize plant stress throughout the field. The USDA/NRCS recommends managing soil moisture to meet the needs of the driest 25% of the field, rather than the absolute driest part of the field. Under this concept, a small fraction of the field remains slightly underirrigated, but the overall requirement is essentially satisfied in the field.

Crop Evapotranspiration (ET_c)

Crop ET is represents the water usage for a given crop. All crops have different water requirements and transpire at different rates. To accurately schedule irrigations for a given crop, it is essential to understand its unique water use characteristics. Much research has gone into tracking crop water usage at all growth stages throughout the growing season for hundreds of crops. Instead of having to keep track of all of the different crop water usage rates, the process is standardized by relating the water usage for each crop to a baseline or reference crop, such as alfalfa. A crop coefficient of 1.0 would signify that the crop is using the same amount of water as the reference crop for that time period. A value greater than 1.0 means that the crop requires more water than the reference crop, while a number less than 1.0 means that the crop needs less than the reference crop. These coefficients vary throughout the season because plants do not require the same amount of water at all phases of growth. When these coefficients are plotting throughout the growing season a crop coefficient curve is generated. A typical crop coefficient curve starts out low then begins to rise during emergence, with significant change between the beginning of rapid growth and effective full cover. It stays relatively constant during the effective full cover stage, and then declines as the plant begins senescence (begins to die). This is illustrated in the figure below.



Alfalfa is an ideal reference crop because it can be grown year-round. Alfalfa reference ET is not the same as "alfalfa hay ET" over a given period of time. Reference ET is for a condition of a specific crop height (usually about 12-18"), with no lack of moisture, no disease, no surface evaporation, and a mature crop. Alfalfa hay for production is stressed and very short after cutting, so at that time the alfalfa hay ET is considerably less than alfalfa reference ET. Immediately after an irrigation, alfalfa hay ET is higher than reference ET, due to the increased evaporation.

The next step is to locate a weather service (such as the "PAWS" system in Washington state) that either publishes historical reference crop ET rates or forecasts upcoming rates. These values should always be confirmed by monitoring soil moisture changes. Multiplying this reference rate by the appropriate usage coefficient for the crop under consideration will provide the irrigator with the amount of water that will be needed in the upcoming week. The total amount of water to be applied will need to be adjusted upward based on the distribution uniformity (DU) of the irrigation system.

Example

Given: Reference ET for the next week = 2.24"
Crop Coefficient = .87 (Typical of Grass or Timothy Hay)
Irrigation System Distribution Uniformity (DU) = 75% or .75

Find: Crop water requirement for upcoming week

Solution: (2.24 x .87)/.75 = **2.6" required**
Even though the crop actually requires 1.95" of water, 2.6" must be applied in order to apply 1.95" to the driest 25% of the field.

Other circumstances may need to be factored when making the final decision of how much water to apply. These include:

a. The availability of soil water in the root zone (A crop already under water stress conditions may not transpire as much water in order to limit the loss of water from plant tissues.)

b. Unexpected climatic conditions (Is the weather significantly different than what was forecasted?)

c. General crop health (Diseased or damaged plants may not require the same amount of water as healthy plants.)

Moisture Monitoring Systems

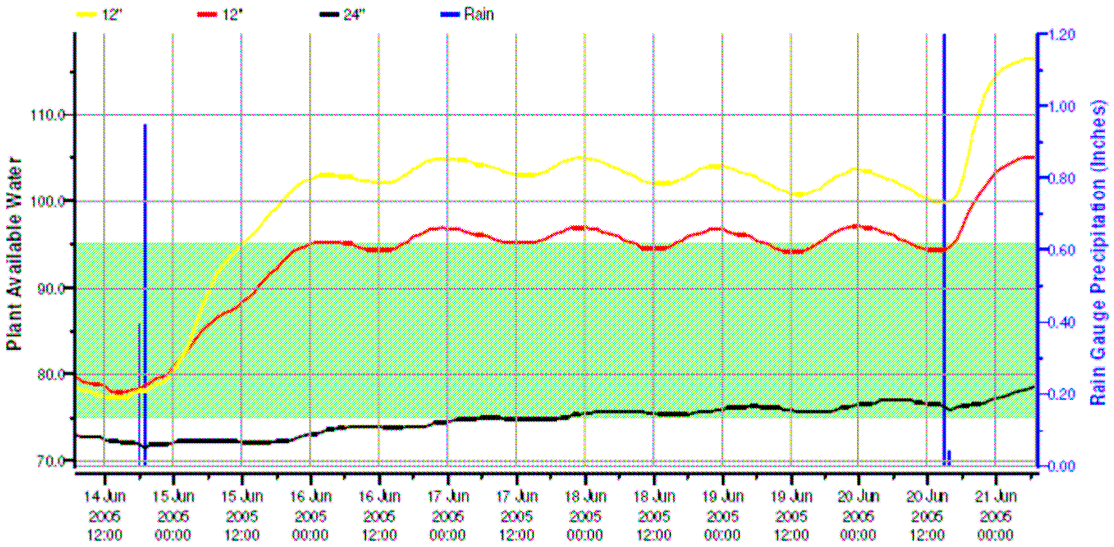
So how do we accomplish our goal of applying the proper amount of water at the right time? How do we know how much water is needed to refill the soil profile? How do we know how much water to apply at each irrigation event? A good moisture monitoring system is a key element in fulfilling the conservationist goal of determining and controlling the volume, frequency, and application rate of irrigation water in order to maximize crop production and minimize the potentially damaging effects of soil erosion (runoff) and groundwater contamination (deep percolation of chemicals and nutrients).

Moisture monitoring systems measure the water content in the soil. They are meant to complement and provide a degree of "measurability" to a grower's own visual evaluations of soil water availability. Although there are several different types of systems that measure water content using different methods, they all basically consist of some type of sensor that is either permanently (buried) or temporarily (slid into permanently buried "access" tube) placed in the soil. For most crops, the monitoring site is generally located in the middle of the plants on the top of the crop bed. It is normally best to establish sites at least 100 feet away from field boundaries in order to eliminate unusual edge effects. In center pivot systems, sites are best established inside the second outside tower, not including any "swing span" towers. When at all practical, it is also best to locate sites in the driest 25% of the field.

Water content information is typically presented in one of two formats. The more basic of the two data formats is the Volumetric Water Content (VWC), which represents the amount of water (by volume) in a given amount of soil. It is expressed as a percentage. For example, is a soil sample has a volumetric water content reading of 30, it means that 30% of the total volume is water and the other 70% is soil solids, organic matter, and air contained in soil pore spaces. Volumetric water content readings are essentially "raw numbers" because they have to be correlated to soil types in order to provide good decision-making information. Because different soil types have different water holding characteristics, a VWC reading of 10% may indicate somewhere near field capacity in a sandy soil (small water holding capacity) and somewhere near wilting point in a heavy soil (large water holding capacity).

The other common format for expressing water content is as a percentage of Plant Available Water (PAW). It takes volumetric water content readings one step farther by factoring known field capacity and wilting point water contents for a specific soil. The most water that can be available to the plant is the amount of water held between field capacity and permanent wilting point. For example, if the field capacity of a sandy soil correlates to a 17% volumetric water content and the permanent wilting point for the same soil correlates to a 6% volumetric water content, then the 11% between those two points is what is usable to the plant. In this case, a VWC reading of 14 would represent a plant available water measurement of about 73% because only 8% of the 14% would be available to the plant. (8/11=.73) Under this expression of water content, 100% represents field capacity and 0% represents permanent wilting point rather than absolute zero content. A plant available water reading of greater than 100% is possible right after a complete irrigation. Readings consistently above 100% may mean that field capacity has been underestimated.

Different types of moisture monitoring systems may yield different numbers, even if they are used on exactly the same site. The important thing is the consistency of the particular system and the ability to correlate those numbers to an accurate measurement of field capacity. Moisture monitoring devices are valuable tools if they are recognized as management aids and not the final answer. One of the most valuable components to an effective moisture monitoring system is a reliable datalogger. A datalogger is connected to the moisture sensor and continuously queries the device, usually about every 60 minutes or less. The reading is stored in the datalogger until it is downloaded, either manually or with the convenience of radio telemetry. The data is then used to create visual representations of the moisture status for that field. When the 60-minute data is plotted on a graph in relation to time, the grower can more easily establish trends in field moisture. This is much more difficult to do with a system that does not log data continuously, such as a neutron probe, which only provides a single data set for the exact time of the field visit and does not record data between field visits. The following image is a good example of the type of graphical data representation that is possible with a continuous logging moisture monitoring system. (The red, yellow, and black lines are moisture trendlines for specific sensors at specific depths. The blue bars represent irrigation events.)



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When continuous logging moisture monitoring systems include a rain sensor, even more critical decision-making information is available to the grower. The grower can observe the date, time, and amount of each irrigation, in graphical display with the soil moisture trendlines. The grower will then be able to establish the actual time between irrigations. With a center pivot system, the grower will know the exact revolution or "pass" time. He will also be able to determine the effectiveness of application amounts by observing the moisture response to irrigation events. He will be able to establish the amount of spray loss by comparing what the irrigation system is set to apply versus actual rain gauge readings. He will also be able to establish the number of irrigations necessary to achieve the desired response at different depths in the soil profile. In short, the grower will have the tools necessary to adjust pivot speed and apply the most ideal application amounts for the given crop, field, and weather conditions. He will have the decision-making support he needs to answer the two all-important irrigation management questions of when to irrigate and how much to apply at each irrigation.

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