C R O P S E R I E S

IRRIGATION

Crop Water Use and Growth Stages no. 4.715

by M.M. Al-Kaisi and I. Broner[1] (Revised 2/09)

Quick Facts...

Water stress during critical growth periods reduces yield and quality of crops.

Crop water use (ET) at critical growth stages can be used in irrigation scheduling to avoid stressing crops.

Crop water use (ET) is weather dependent as well as soil, water and plant dependent.

Periodically check soil water at different depths within the root zone and at different growth stages to avoid stressing the crop during critical growth stages.

Colorado State University

Extension

Crop water use, also known as evapotranspiration (ET), is the water used by a crop for growth and cooling purposes. This water is extracted from the soil root zone by the root system, which represents transpiration and is no longer available as stored water in the soil. Consequently, the term "ET" is used interchangeably with crop water use. All these terms refer to the same process, ET, in which the plant extracts water from the soil for tissue building and cooling purposes, as well as soil evaporation.

The evapotranspiration process is composed of two separate processes: transpiration (T) and evaporation (E). Transpiration is the water transpired or "lost" to the atmosphere from small openings on the leaf surfaces, called stomata. Evaporation is the water evaporated or "lost" from the wet soil and plant surface.

Significant evaporation can take place only when the soil's top layer (1 to 2 inches) or plant canopy is wet. Once the soil surface is dried out, evaporation decreases sharply. Thus significant evaporation occurs after rain or irrigation. Furthermore, as the growing season progresses and canopy cover increases, evaporation from the wet soil surface gradually decreases. When the crop reaches full cover, approximately 95 percent of the ET is due to transpiration and evaporation from the crop canopy where most of the solar radiation is intercepted.

Crop water use (ET) is influenced by prevailing weather conditions, available water in the soil, crop species and growth stage. At full cover, a crop will have the maximum ET rate (reference ET) if soil water is not limited; namely, if the soil root zone is at field capacity. Full cover is a growth stage at which most of the soil is shaded by the crop canopy.

In a more technical term, the crop is at full cover when the leaf area is three times the soil surface area under the canopy. At this growth stage, the crop canopy intercepts most of the incoming solar radiation, thereby reducing the amount of energy reaching the soil surface.

Different crops reach full cover at different growth stages and times after planting (See *Scheduling Irrigations: A Guide for Improved Irrigation Water Management Through Proper Timing and Amount of Water Application*, USDA, Soil Conservation Service, ARS and Colorado State University Cooperative Extension, 1991, page 32).

In order to standardize ET measurements and calculations, a reference crop ET (ET_r) is used to estimate actual ET for other crops. In humid and semi-humid areas where water usually is not a limiting factor, grass is used as a reference ET crop. In arid or semi-arid areas, alfalfa is more suitable as a reference ET crop because it has a deep root system, which reduces its susceptibility to water stress resulting from dry weather.

Actual evapotranspiration (ET_a) is the water use of a particular crop at a given time. ET_a of an annual crop reaches its maximum at full cover, and can be higher or lower than ET_r, depending on the crop. In Colorado, alfalfa is used as the reference crop. Corn at full cover has a maximum water use rate, ET_a, of 93 percent of alfalfa ET_r, while sugar beets have a maximum ET_a rate of 103 percent of alfalfa ET_r.

Estimating Crop Water Use

Actual crop water use, ET_a, can be measured directly by using several research methods or indirectly by measuring changes in soil water content with time. However, these methods are expensive, tedious and can be done only in research settings. Therefore, ET_r is theoretically and empirically correlated to weather parameters to generate ET models that estimate ET_r from weather parameters.

ET equations most often used in Colorado are the Penman and Jensen-Haise models. These models were checked and calibrated for local conditions and give reliable estimates of ET_r. The Jensen-Haise equation uses temperature and solar radiation measurements, while the Penman equation uses temperature, solar radiation, wind run and humidity.

Actual evapotranspiration, ET_a, can be calculated from reference ET by multiplying ET_r by the crop coefficient (KC). A crop coefficient is the ratio between ET_a of a particular crop at a certain growth stage and ET_r. If the crop coefficient is smaller than one, the crop uses less water than reference ET and vice versa.

Crop coefficients depend on the stage of growth and usually are presented as a function of time following planting. Crop coefficients are measured using lysimeters for different crops and are shown in fact sheet 4.707, *Irrigation Scheduling: The Water Balance Approach*. These coefficients represent average conditions — namely average weather.

In years that are significantly different from the average year, actual crop development may exceed or lag behind the average crop development rate. Therefore, when using crop coefficients in an irrigation scheduling scheme, some adjustments of the average curve to actual crop development may be needed. The crop coefficient of an annual crop is small at the beginning of the growing season, gradually increases as the crop develops, and may decline as the crop matures.

Effect of Soil Water on ET

Crop water use also is influenced by the actual soil water content. As soil dries, it becomes more difficult for a plant to extract water from the soil. At field capacity (maximum plant-available water content), plants use water at the maximum rate. When the soil water content drops below field capacity, plants use less water. This phenomenon is described by the soil coefficient (KS), which is a function of soil water content (see 4.707). The soil coefficient often is used in irrigation scheduling schemes to adjust the actual ET to reflect soil water conditions.

After rain or irrigation, actual ET is higher than when the soil or crop surface is dry. When the soil or crop surface is wet, the evaporation portion of ET increases significantly, resulting in a higher actual ET, especially early in the growing season. This actual ET rate can be larger than reference ET. This phenomenon is described in irrigation scheduling schemes as an additional evaporation coefficient (KW). This coefficient adjusts actual ET (upward) to reflect wet soil surface conditions.

Each soil type can hold different amounts of water while acting as a water reservoir for plants. Estimating the soil water content and information on maximum water holding capacities of different soils are given in 4.700, *Estimating Soil Moisture.*

Managing Irrigation According to Growth Stages

Crops are different in their response to water stress at a given growth stage. Crops summarized according to their sensitivity to water stress at various growth stages (Tables 1 and 2) reveal the importance of these stages in making the irrigation decision.

Crops that are in the sensitive stage of growth should be irrigated at a lower soil water depletion level than those that can withstand water stress. If a crop is last in the irrigation rotation and is at a sensitive stage of growth, the recommended strategy may be to apply partial or lighter irrigations in order to reach the end of the field before the sensitive crop is subjected to water stress.

Such a strategy can be used with sprinkler systems, but this may lead to unfavorable soil moisture conditions at the lower soil depths. When soil is repeatedly watered to only shallow depths, the lower soil depths tend to develop a soil moisture deficit that exceeds the allowable soil moisture depletion level at that particular growth stage. Therefore, quick soil moisture assessment at various soil depths to determine the actual water use is essential in irrigation scheduling as related to growth stages.

Crop appearance is considered one of many field indicators that can be used in irrigation scheduling. A crop suffering from water stress tends to have a darker color and exhibits curling or wilting. This is a physiological defense mechanism of the crop that is evident on hot, windy afternoons when the crop cannot transpire fast enough, even if the water is readily available in the soil. If the crop does not recover from these symptoms overnight, the crop is suffering from water stress. Any changes in crop appearance due to water stress may mean a reduction in yield. However, using this indicator alone for irrigation scheduling is not recommended if a maximum yield is desired.

This indicator is inferior for modern agriculture due to the inability to determine the actual crop water use. However, ignoring it at the critical growth stages may lead to yield reduction. Using the growth stage as a field indicator in irrigation scheduling should be coupled with more sensitive and accurate methods of determining the crop water use, such as soil moisture measurements and ET data. The main advantage of this indicator is to provide direct and visual feedback from the crop.

Different crops have different water requirements and respond differently to water stress. Crop sensitivity to water stress varies from one growth stage to another. Table 1 is a summary of critical growth stages during which major crops in Colorado are especially sensitive to water stress.

A good irrigation scheduling scheme should consider sensitivity of the crop to water stress at different growth stages. This is accomplished by using a coefficient termed the Management Allowable Depletion (MAD), which is the amount of water allowed to be depleted from the root zone before irrigation is scheduled. The MAD is usually given as a percentage of maximum water holding capacity of the soil. At the time of irrigation, the soil water deficit should be less than or equal to the MAD.

The goal of any irrigation scheduling scheme is to keep the water content in the root zone above this allowable depletion level. This ensures that the crop will not suffer from water stress and will produce maximum potential yield. In Table 2, suggested MADs for selected crops are given for different growth stages. This information can be used in an irrigation scheduling scheme by using the appropriate MAD for each growth stage to trigger irrigation.

Table 1: Critical growth stages for major crops[1].

Crop	Critical period	Symptoms of water stress	Other considerations
Alfalfa	Early spring and immediately after cuttings	Darkening color, then wilting	Adequate water is needed between cuttings
Corn	Tasseling, silk stage until grain is fully formed	Curling of leaves by mid-morning, darkening color	Needs adequate water from germination to dent stage for maximum production
Sorghum	Boot, bloom and dough stages	Curling of leaves by mid-morning, darkening color	Yields are reduced if water is short at bloom during seed development
Sugar beets	Post-thinning	Leaves wilting during heat	Excessive full irrigation lowers sugar content of the day
Beans	Bloom and fruit set	Wilting	Yields are reduced if water short at bloom or fruit set stages
Small grain	Boot and bloom stages	Dull green color, then firing of lower leaves	Last irrigation at milk stage
Potatoes	Tuber formation to harvest	Wilting during heat of the day	Water stress during critical period may cause cracking of tubers
Onions	Bulb formation	Wilting	Keep soil wet during bulb formation and dry near harvest
Tomatoes	After fruit set	Wilting	Wilt and leaf rolling can be caused by disease
Cool season grass	Early spring, early fall	Dull green color, then wilting	Critical period for seed production is boot to head formation
Fruit trees	Any point during during growing season	Dulling of leaf color and drooping of growing points	Stone fruits are sensitive to water stress last two weeks prior to harvest

[1]Taken from *Colorado Irrigation Guide*, Natural Resources Conservation Service.

Table 2: Management allowable depletion (MAD) at the root zone of selected crops at different growth stages.

Crop	Growth stages	MAD(%) in root zone	Effect of water stress
Alfalfa	Emergence-lst cut	65	Yield reduction
	lst cut-2nd cut	50	
	2nd cut-3rd cut	40	
	3rd cut-4th cut	60-70	
Pinto beans	Emergence-aux. budding	60-70	Yield reduction
	Flower-bud filling	55	
	Bud filling-maturity	60-70	
Potatoes	Early veg. period	40-60	Many jumbo and lower yield
	Tuber bulking period	30-40	
	Ripening period	65	
Corn	Emergence-12 leaf	60-70	Yield reduction of 11.5 bu/A-in water deficit
	12 leaf-dough	50	
	Dough-maturity	60-70	
Small grains	Emergence-first node	65-70	Yield reduction of 6-8 bu/A-in of water deficit
	First node-flowering	40-60	
	Milk ripe-maturity	50-70	
Soybeans	Before flowing	65-70	Yield reduction
	First flower-first pod	60-65	
	First pod-maturity	60-70	

[1]M.M. Al-Kaisi, Colorado State University regional water management specialist, Akron, Colorado, and I. Broner, Extension irrigation specialist and associate professor, bioresource and chemical engineering.