

Section I

Understanding crop water use

When managing an irrigation system, it is important to have a good understanding of crop water use, why crops use water, and the factors that affect the rate of water use. That is because over estimating crop water use often leads to over-irrigation and nitrate leaching. Underestimating crop water use can lead to an unnecessary limitation of crop yield.

Evapotranspiration (ET)

Crop water use includes two parts: **evaporation** (E) from the soil surface and **transpiration** (T) from the crop leaves. It is difficult to separate transpiration from evaporation so the two components are measured or calculated together and the sum is called **evapotranspiration**, or **ET**. We will use ET and crop water use interchangeably. Over a growing season, 70% to 80% of all ET is made up of water that moves from the soil through the crop's root system and is transpired from the leaves. This is useful water since it cools the leaves and helps move nutrients from the soil into the plant, thus directly contributing to producing grain. The remaining 20% to 30% of ET is direct evaporation from the soil (*Figure I-1*).

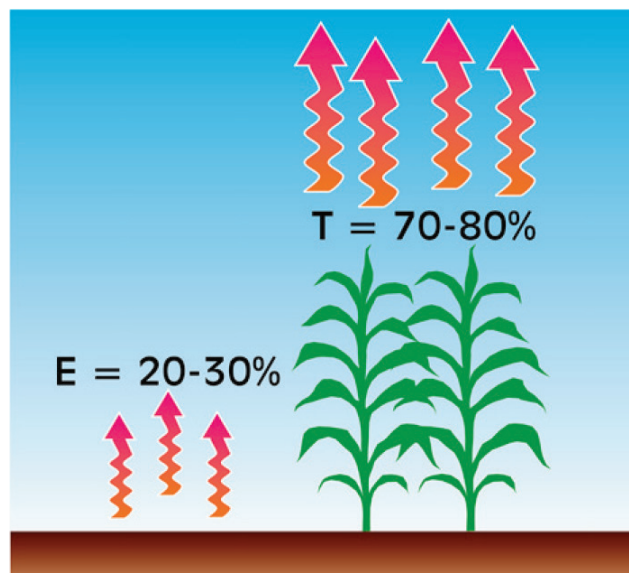


Figure I-1. Seasonal breakdown of the contribution of soil evaporation (E) and transpiration (T) for irrigated corn in Nebraska.

Evaporation is the change from liquid water to water vapor that can occur from soil and water surfaces.

Transpiration is the passage of water vapor through plant pores into the atmosphere.

Evapotranspiration is the combination of evaporation and transpiration that is often referred to as crop water use or crop ET.

The ratio of evaporation to transpiration changes as the crop grows and more of the soil surface is shaded by crop leaves. When crops are small, the portion of ET due to transpiration is minimal relative to soil evaporation. The surface area of the leaves is small and more of the soil surface is exposed. *Figure I-2* illustrates this idea with larger arrows representing more water leaving the soil through evaporation as compared to the small blue arrows representing the portion of ET transpired by the small plants.

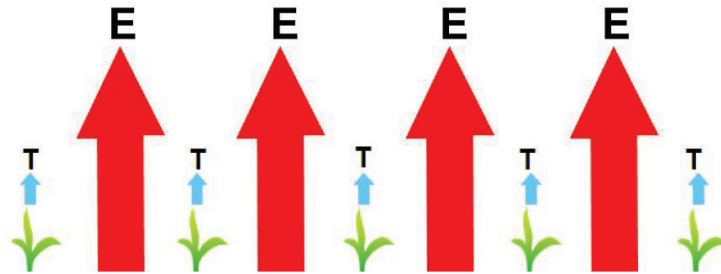


Figure I-2. Relative magnitude of ET components early in the growing season.

By the time that the crop reaches full canopy, the soil is mostly shaded and evaporation from the soil is minimized (*Figure I-3*). By midseason, leaf area is sufficient to cover the soil surface more than three times. Transpiration becomes the dominant component of ET and over 80% of ET is due to plant transpiration, though this varies depending on the cropping system and management practices.

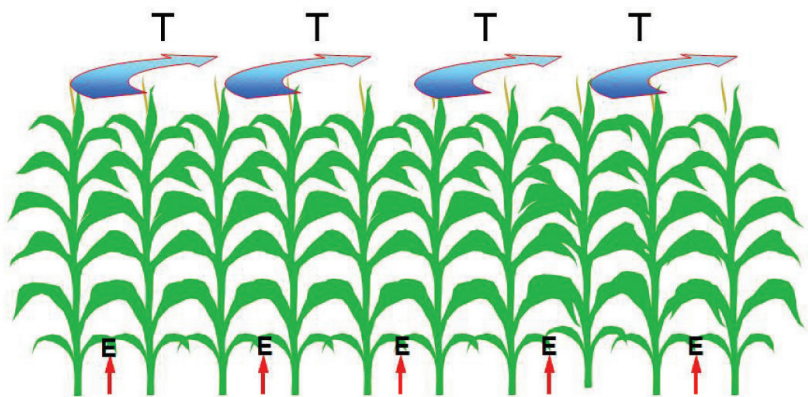


Figure I-3. Relative magnitude of ET components in the middle of the growing season.

Factors that affect ET

Since the primary reason for transpiration is to cool the plant, it is to be expected that climatic conditions are the driving forces behind the rate at which plants transpire. Air temperature and solar radiation are the two primary factors in the rate at which transpiration occurs. As air temperature and solar radiation increase, so does transpiration. ET will also increase with increased wind speeds to a point. When wind speeds get too high, the stomata close as a natural defense mechanism and transpiration actually decreases. Conversely, as relative humidity increases, transpiration will decrease.

Other factors that affect ET include plant species, canopy characteristics, plant population, degree of surface cover, plant growth stage, irrigation regime, tillage practices, planting date, maturity group of plant species, and soil water availability.

Crop characteristics influence water use

To demonstrate how crop characteristics influence water use, we include seasonal crop water use rate curves for corn and soybean (*Figure I-4*). At emergence most of the water use will be evaporation from the soil surface and overall ET will be less than 0.20 in/day. However, as the leaf area expands, the crop ET rate approaches 0.33 inches per day. Around beginning dent in corn or pod fill in soybean, plant leaves begin to lose their capacity to transpire at high rates; some leaves senesce and do not transpire water at all. Actual ET rates begin to fall off even though the corn and soybean crops are still at full cover. Overall, the difference in crop water use rates between corn and soybean depends of the relative maturity and planting date of the two crops.

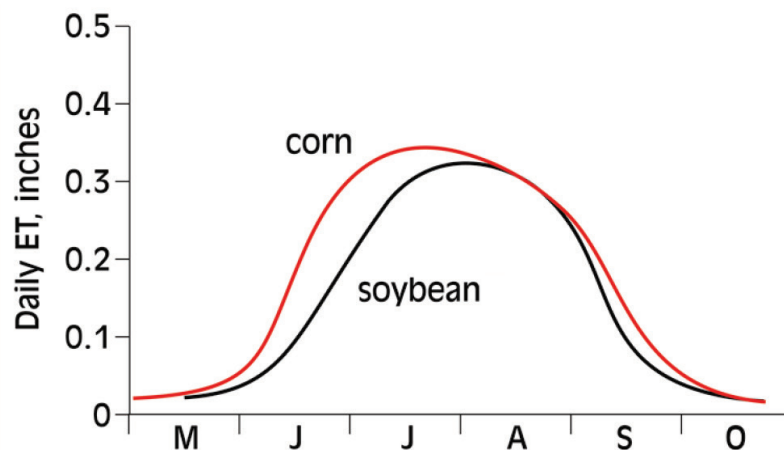


Figure I-4. Long-term average crop water use rates for corn and soybean from emergence to maturity.

Actual crop water use can be very different than the long-term average because of variability in the weather. This is shown in *Figure I-5*, where actual daily ET amounts across a particular growing season are compared with the long-term average for irrigated corn. In any year, long-term average values give only a rough approximation of actual crop water use and thus long-term averages do not provide an accurate estimate of the current year's crop water use rate. That's why irrigation scheduling is more accurate when using ET estimated from daily weather data rather than long-term average values.

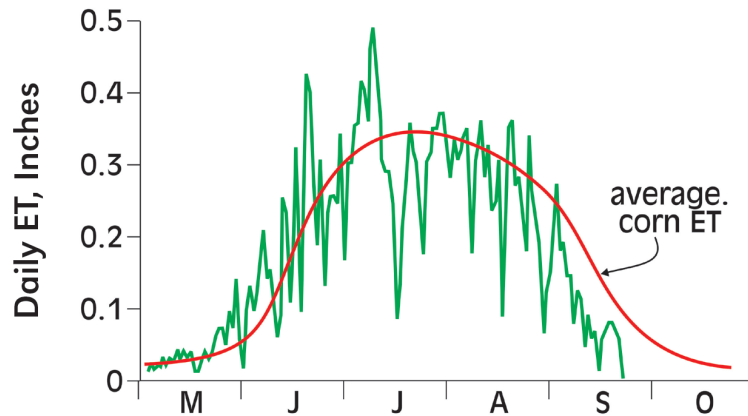


Figure I-5. Comparison of the long-term average ET rate for well-watered corn and the daily ET for a specific year.

Effect of residue

Leaving crop residue can have a significant effect on evaporation of water from the soil surface (*Figure I-6*). A University of Nebraska study found plots with residue removed would take 1.5-2.5 inches of irrigation to achieve the same yield as plots with over 80% residue cover on the soil surface. Also, at the end of the growing season, the plots with residue on the surface contained 1.5 inches more water in the top 4 feet of soil than did the bare plots. This means that the residue on the soil surface could save 3-4 inches of irrigation compared to bare soil.



Figure I-6. Crop residue cover following irrigated corn production.

Calculating ET

When irrigation is managed to meet crop water needs, the amount of water used by the crop over a given time is needed. However, water use by a crop in a specific field is difficult to estimate without collecting soil water content information. Another approach is to use a simple calculation of crop ET using estimated ET for a reference crop. Once we calculate or estimate ET for the reference crop, the ET for the any other crop can be determined using this simple equation:

$$ET_c = ET_r \times K_c$$

Reference crop ET is the water use based upon prevailing weather conditions. In Nebraska, the reference crop ET is based upon well irrigated alfalfa with at least 10 inches of growth and is estimated using the Penman-Monteith Equation

Crop Coefficient is a mathematical factor that converts reference crop ET to actual crop water use.

ET_c is the estimated crop water use, ET_r is the **reference crop water use** and K_c is the **crop coefficient**. The crop coefficient is a conversion factor that relates the ET of the reference crop to the crop of interest. The magnitude of the crop coefficient is not constant throughout the season. It changes depending on the growth stage and the relative maturity of the crop as well as some management practices.

The High Plains Regional Climate Center (HPRCC) monitors automatic recording weather stations (*Figure I-7*) throughout the region. Along with temperature and precipitation, these stations monitor solar radiation, relative humidity, and wind speed. These measurements allow HPRCC to make daily ET estimates for a reference crop at these locations. This information can be accessed online with a subscription fee at: www.hprcc.unl.edu/.

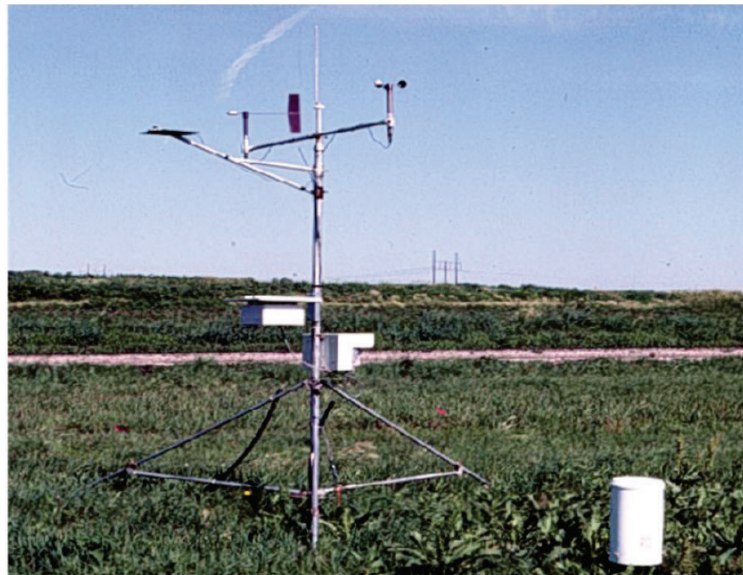


Figure I-7. Weather station used by the High Plains Climate Center to estimate crop water use.

A much more simple, but effective, method for measuring reference crop ET is with an atmometer (*Figure I-8*). Access information for Nebraska Extension publication dealing with installation and use of an atmometer is presented in the reference list for this section.

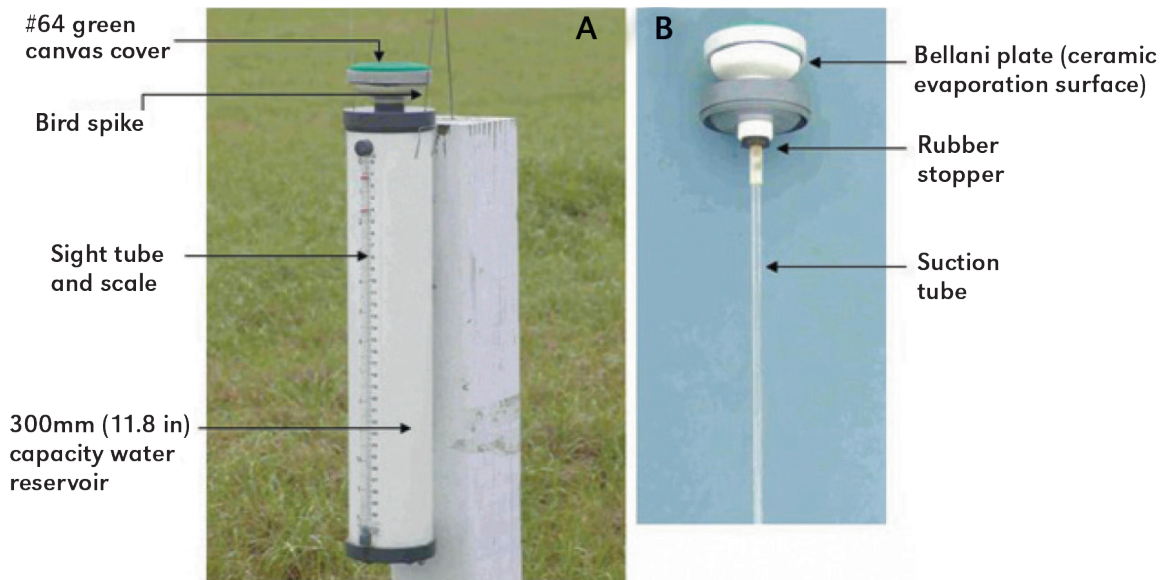


Figure I-8. ETgage used to estimate reference crop ET.

Once the math is completed to calculate the reference crop ET using the atmometer, a table of crop coefficients (K_c) is used to calculate the ET for any crop. Using the K_c found in *Table I-1*, we can use the ET_c equation. For example, if an ETgage is being used and the change in the water level in the sight gauge is 2.10 inches, and the crop is a field of soybean in the full-pod stage, the crop water use would be:

$$ET_c = 2.10 \text{ in.} \times 1.10$$

$$ET_c = 2.31 \text{ inches}$$

This can be done with daily or weekly intervals, but three- to seven-day intervals provide more accurate results. *Table I-1* shows the K_c for corn, soybean, and wheat. The UNL CropWatch site has tables of calculated weekly ET_c if ET_r and the crop growth stage are known for a broader range of crops. It can be found at: cropwatch.unl.edu/web/cropwatch/archive?articleID=1301988.

Table I-1. Crop Coefficients for corn, soybean, and wheat used to convert reference crop ET_r to crop ET.

Stage	Corn	Kc	Soybean	Kc	Wheat	Kc
1	2 leaves	0.10	Emergence	0.10	Emergence	0.10
2	4 leaves	0.18	Cotyledon	0.10	Visible crown	0.50
3	6 leaves	0.35	First node	0.20	Leaf elongation	0.90
4	8 leaves	0.51	Second node	0.40	Jointing	1.04
5	10 leaves	0.69	Third node	0.60	Boot	1.10
6	12 leaves	0.88	Begin bloom	0.90	Heading	1.10
7	14 leaves	1.01	Full bloom	1.00	Flowering	1.10
8	16 leaves	1.10	Beginning pod	1.10	Grain fill	1.10
9	Silking	1.10	Full pod	1.10	Stiff dough	1.00
10	Blister	1.10	Beginning seed	1.10	Ripening	0.50
11	Dough	1.10	Full seed	1.10	Mature	0.10
12	Beginning dent	1.10	Begin maturity	0.90		
13	Full dent	0.98	Full maturity	0.20		
14	Black layer	0.60	Mature	0.10		
15	Full maturity	0.10				

Annual ranges in crop water use

Total ET during the growing season will vary from year to year, just as the climate varies. *Table I-2* shows a range of seasonal water use that will cover about 90% of the years in Nebraska. Extremely cool and wet or hot and dry years can produce values outside the range presented in *Table I-2*.

Table I-2. Seasonal crop water use (ET) in Nebraska when water is not limiting.

Crop	Eastern	Central	Western
	----- inches/year -----		
Corn	21-24	22-25	25-28
Soybean	20-22	21-23	22-24
Dry edible beans	—	—	15-16
Sorghum	18-20	19-22	20-23
Winter wheat	16-18	16-18	16-18
Alfalfa	31-35	33-37	35-39
Sugar beet	—	—	24-26

Effect of plant population and relative maturity on ET

Plant population can affect crop ET, however, under irrigated conditions the impact is minimal. For example, if a corn hybrid typically planted under irrigation in Nebraska is seeded at two populations: a high population of 34,000 plants/acre and a low of 17,000 plants/acre, with adequate water and fertility, one would expect considerable yield difference between the two populations. However, the manager should expect little difference in ET. Unless the leaf area does not reach three times the soil surface area, significant water savings should not be anticipated. To achieve significant water conservation, populations have to drop below 14,000 plants/acre and major water conservation comes only when populations are in the range of 8,000 to 10,000 plants/acre.

Relative maturity can impact crop water use even if planted at the same plant population. Shorter season hybrids produce fewer leaves and have shorter vegetative and reproductive stages in development. On average, corn water use changes by 1.0 inches per year for every five days of relative maturity. Grain production decreases in a similar manner.

Available soil water effects on ET rates

The amount of available water remaining in the crop root zone can affect the crop ET rate and total seasonal water use. Under average conditions a plant can use 40-50% of the available soil water without reducing the ET rate. As the plant begins to extract the last 50-60% of the available water, the actual ET rate declines in comparison to a nonstressed crop. The plant responds to water stress by taking steps to conserve what is left, including closing of stomata (pores) in the leaves to limit water vapor loss and rolling the leaves so they will intercept less sun. After irrigation the ET rate will return to normal unless the plant was severely stressed prior to the irrigation event.

More Extension Publications (available at ianrpubs.unl.edu)

G1994, Estimating Crop Evapotranspiration from Reference Evapotranspiration and Crop Coefficients

G1850, Irrigation Management for Corn

G1579, Using Modified Atmometers for Irrigation Management

G1367, Irrigating Soybean

G1778, Irrigation Management and Crop Characteristics of Alfalfa

G2000, Tillage and Crop Residue Affect Irrigation Requirements

EC731, Producing Irrigated Wheat