CROP WATER USE REQUIREMENTS and WATER USE EFFICIENCY

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EVAPOTRANSPIRATION (ET)

Evaporation (from soil or water surfaces) and transpiration (from plant surfaces) require that water be converted from liquid to vapor. Heat (energy) is required to vaporize the liquid. The vaporization of water is influenced by: 1) Amount of energy at the vaporization surface, 2) Extent and nature of the vaporization surface, and 3) Water supply at the vaporization surface.

Energy used in evapotranspiration (ET) comes from two sources: 1) The sun (solar radiation) and 2) The horizontal movement of warm and dry air masses (advection). Reference (Potential) ET is estimated by using weather data, and establishes the evaporative demand or evaporative potential of the atmosphere for a stated reference crop. In the western US, alfalfa is the most common reference crop. In Europe, well-maintained, irrigated grass is typically the reference crop. The alfalfa reference crop is about 18 inches tall, actively growing with no water stress conditions, and with relatively little soil surface evaporation (a relatively dry soil surface). The Penman and Jensen-Haise equations, with alfalfa the reference crop, are two of many such equations for estimating Reference ET by using weather data.

Calculated Reference ET is then adjusted for crop conditions through use of an ET crop coefficient curve (ratio of actual crop ET to reference crop ET). Conditions of growth pattern, crop architecture, and leaf surface area influence the ET coefficient curve of crops. Each crop has its own unique ET coefficient curve. An ET coefficient curve for corn is presented in Figure 1, with reference ET calculated by the Jensen-Haise equation (alfalfa the reference crop). In this example (Figure 1), advance through the corn growing season is on the basis of fraction of thermal units.

Calculated Reference ET is further adjusted for conditions of soil water availability. Actual crop ET is at the maximum of crop adjusted-Reference ET when soil water is readily available. As soil water becomes less available, actual crop ET reduces in comparison to crop adjusted-Reference ET. Therefore, the downward adjustment of ET because of water stress conditions is a more pertinent consideration in dryland and limited irrigation environments than with full irrigation. This reduction is accounted for through use of the available soil water coefficient (water stress factor). There are several ways of expressing the water stress factor, with the logarithm reduction method (presented in Figure 2) the most common.

Therefore,

Actual crop ET = Reference crop ET x Crop ET coefficient x Soil water stress factor

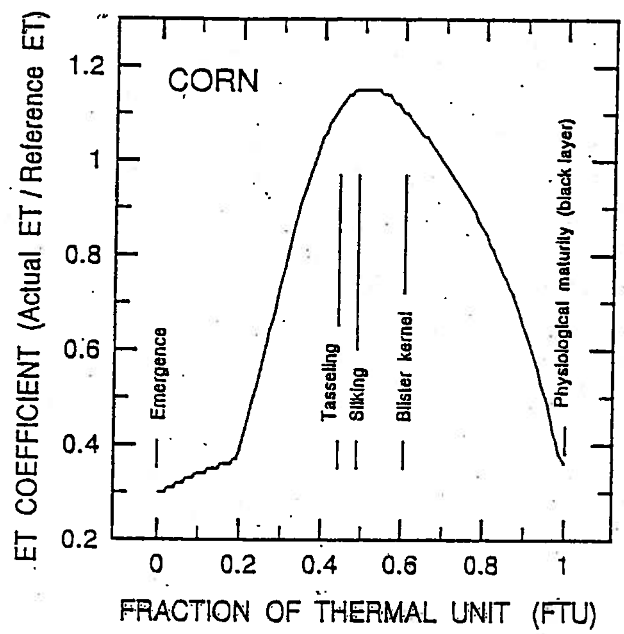


Figure 1. ET crop coefficient curve for corn (ratio of field-measured ET to Jensen-Haise reference ET on the vertical axis vs. fraction of thermal units on the horizontal axis).

With ET being an energy-driven process, energy levels cap the possible crop ET for an individual day at about 0.50 to 0.55 inches. For time intervals of about 1 week, average daily ET will max out in the range of 0.30 to 0.33 inches/day for corn, sorghum, soybean, and wheat; whereas sunflower will max out at about 0.38 inches/day (Hattendorf et al., 1988).

A typical pattern of ET during the corn growing season is illustrated in Figure 3. Measured ET is on the vertical axis (in inches/day on the right-side axis) and fraction of thermal units on the horizontal axis. These data were collected near Scandia, KS (Gordon et al., 1995). Data points are for measurement intervals of about 1 week and data were collected over several growing seasons.

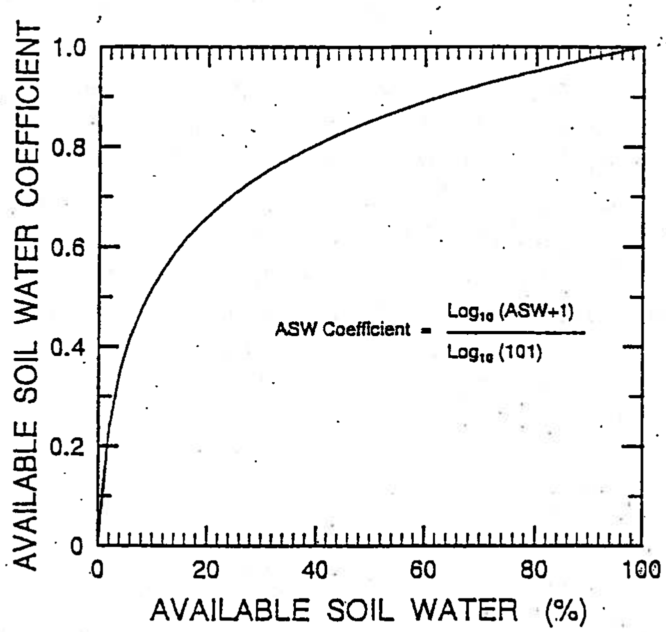


Figure 2. Illustration of the logarithm reduction method used to reduce actual crop water use (ET) estimates based on water stress levels. The soil water stress factor (available soil water coefficient) is on the vertical axis and the percent of available soil water is on the horizontal axis.

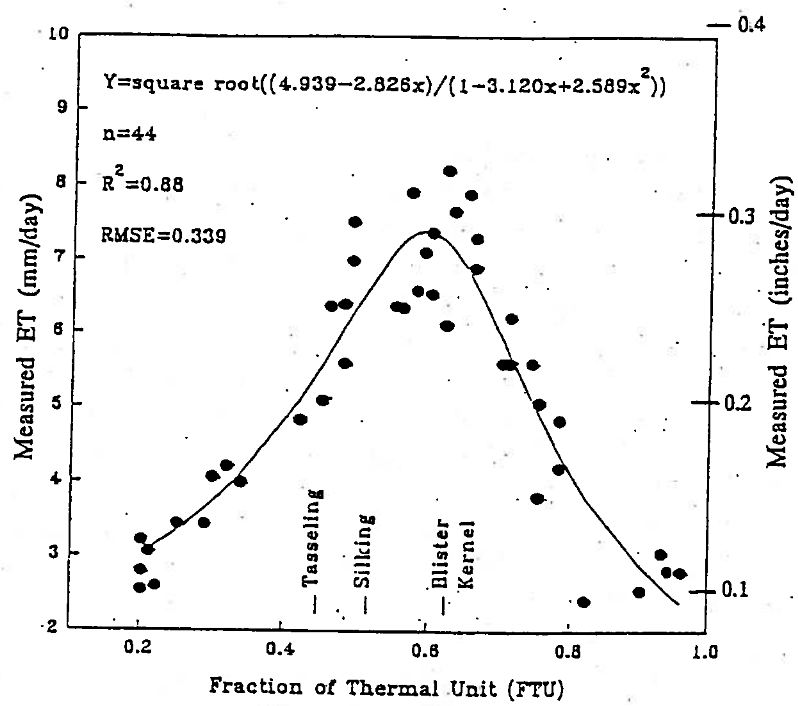
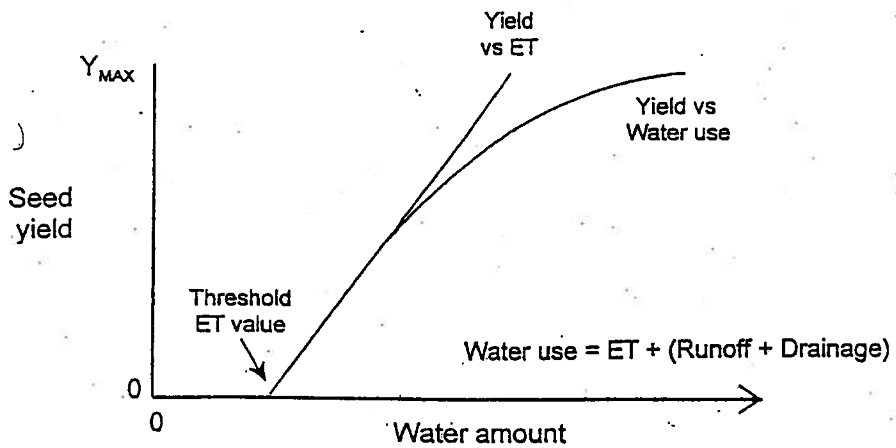


Figure 3. Measured evapotranspiration (ET) of corn vs. fraction of thermal units, 1984-1991, Scandia, KS.

CROP YIELD versus ET RELATIONSHIPS

The diagram immediately below illustrates the general relationships between seed yield and water amount (ET or water use). As used here, ET refers to evapotranspiration while water use refers to ET plus losses by runoff and internal drainage from the soil profile. Seed yield vs. ET is a linear relationship, although variability can and does exist. Seed yield vs. water use (ET + Runoff + Drainage) is typically a curvilinear relationship. The seed yield vs. ET relationship is more transferable among geographic locations than is the seed yield vs. water use relationship that is more influenced by soil and landform characteristics that influence runoff and drainage.



The following table lists values of "Threshold ET", "Maximum ET for a typical full-season variety", "Slope of seed yield vs. ET", and "Slope of long-term seed yield vs. ET" for five crops from research in western Kansas by Stone et al. (1995) and Khan (1996). "Threshold ET" is the ET necessary to move into the seed producing segment of the yield vs. ET relationship. That is, at the "Threshold ET" value and below, seed yield is zero. "Maximum ET" gives the upper value of ET expected for full-season varieties with good water conditions (no water stress). The "Slope of yield vs. ET" gives the seed yield increase per inch of ET in the seed producing segment of yield vs. ET. This would be the expected yield increase due to water (ET) in a year with no out-of-the-ordinary yield reducing factor such as hail, frost, insects, etc. Because out-of-the-ordinary yield reducing events do occur, the "Slope of long-term yield vs. ET" is less than the yield vs. ET slope for an individual good year.

The "Threshold ET" value is of critical importance in assessing if seed yield will likely be obtained in drier crop environments. Within the four summer row crops of the following table, "Threshold ET" is 5.4 inches for sunflower, 6.9

inches for sorghum, 9.0 inches for soybean, and 10.9 inches for corn. The water stress sensitivity of growth stages of various crops is also important in assessing their suitability for drier environments. The "Slope of yield vs. ET" is important in assessing the response of crops to irrigation that is converted into ET. Within the four summer row crops of the table below, yield response per inch of ET is 218 lb/acre/inch for sunflower, 330 lb/acre/inch for soybean, 683 lb/acre/inch for sorghum, and 946 lb/acre/inch for corn.

Crop	Max. ET for full-season variety	Threshold ET	Slope of yield vs. ET	Slope of long-term yield vs. ET *
Corn	25 inches	10.9 inches	16.9 $\frac{bu/acre}{inch}$	13.3 $\frac{bu/acre}{inch}$
Grain sorghum	21 inches	6.9 inches	12.2 $\frac{bu/acre}{inch}$	9.4 $\frac{bu/acre}{inch}$
Sunflower	22 inches	5.4 inches	218 $\frac{lb/acre}{inch}$	150 $\frac{lb/acre}{inch}$
Winter wheat	24 inches	10.0 inches	6.0 $\frac{bu/acre}{inch}$	4.6 $\frac{bu/acre}{inch}$
Soybean	24 inches	9.0 inches	5.5 $\frac{bu/acre}{inch}$	4.5 $\frac{bu/acre}{inch}$

* Long-term (multi-year) slope is less than full slope due to yield reducing factors such as water stress, hail, frost, insects, etc.

YIELD RESPONSE TO WATER (STRESS FACTORS)

The following table gives the relative yield response (decrease) per unit of ET deficit (water deficit) during growth periods of five crops. The values should be compared within a crop to get the relative weighting of water stress sensitivity of various growth periods for the individual crop. That is, within corn, an inch of ET deficit during flowering decreases grain yield 3.8 times as much as an inch of ET deficit during the vegetative growth stage (0.53/0.14 = 3.8). Within grain sorghum, an inch of ET deficit during flowering decreases grain yield 2.0 times as much as an inch of ET deficit during the vegetative stage (0.42/0.21 = 2.0). Along with the sensitivity to water stress in corn being greatest during flowering, daily water use is greatest during flowering through about the milky-fluid growth stage (Figure 3). These two factors working together produce the need for water in corn during flowering.

Relative yield response per unit of ET (within a crop) to water deficit during selected growth periods.

Crop	Growth period: Vegetative	Flowering	Yield formation	Ripening
Corn	0.14	0.53	0.19	0.14
Grain sorghum	0.21	0.42	0.21	0.16
Sunflower	0.25	0.42	0.27	0.06
Winter wheat	0.19	0.51	0.25	0.05
Soybean	0.10	0.40	0.50	—

The relative weighting of water stress sensitivity within a crop is illustrated in the previous table. Those relative weightings of water sensitivity give insight into the growth periods of most critical water need for those five crops. On average, rainfall during the most sensitive growth periods will give the greatest yield benefit. Also, limited irrigation should be timed to avoid water stress at the most sensitive growth stages. On average, that will give the greatest yield benefit from a limited water resource. The timing of limited irrigation for maximum seed yield benefit (on average) is given in the table below.

Timing of limited irrigation for maximum seed yield benefit.

Crop	Initiation of limited irrigation....	To avoid (lessen) water stress particularly during
Corn	Near (prior) or at tasseling	Silking
Grain sorghum	Head extension	Flowering
Sunflower	Head development	Disk flowering
Winter wheat	Head extension	Flowering
Soybean	Mid to late pod set	Early to mid bean fill

A consideration of the suitability of crops for rainfed-only management in drier environments starts with an examination of the "Threshold ET" and water stress sensitivity values. The suitability of crops for limited irrigation management in drier environments is influenced by the factors of "Threshold ET" , water stress sensitivity, and crop response to added water ("Slope of yield vs. ET"). The suitability of crops for full irrigation management in drier environments is primarily driven by the crop yield response to water ("Slope of yield vs. ET").

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Water Savings from Crop Residue in Irrigated Corn

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Introduction

During the past 10-15 years, there has been a great deal of emphasis in sprinkler applications to move closer to the target. The thinking has been to decrease the exposure to potential evaporation in the air. At the same time sprinkler manufacturers have produced heads with lower operating pressures producing fewer fine spray particles leaving far fewer particles subject to evaporation. The result is that application efficiencies have improved.

What remains are the same wet soil surfaces beneath the crop canopies. We need to spread the water to gain infiltration, but then evaporation from the soil surface takes over after irrigation stops. It has been assumed that evaporation from the soil surface in irrigated crop canopies is relatively small. The objective of this paper is to report on some of the research in the area of evaporation from soil surfaces.

Evaporation-Transpiration Partition

Transpiration, or the process of water evaporating near the leaf and stem surfaces, is a necessary function for plant life. It is literally the final driving force for water flow through the plant. It provides plant cooling. Transpiration relates directly to grain yield in the crops we produce. Transpiration rates are driven by atmospheric conditions and by the crop's growth stage. As a crop grows it requires more water until it matures and generally reaches a plateau. Daily weather demands cause fluctuations in transpiration as a result. Soil water begins to limit transpiration when the soil dries below a threshold generally half way between field capacity and wilting point. Irrigation management usually calls for scheduling to avoid water stress.

Evaporation from the soil surface may have some effect on transpiration in the influence of humidity in the crop canopy. However, the mechanisms controlling evaporation from soil are independent of transpiration. The combined processes of evaporation from soil (E) and transpiration (T) are measured together as