# GROWER'S GUIDE:

## Using PET for Determining Crop Water Requirements and Irrigation Scheduling

**Contents**

## I. HOW TO USE PET

To calculate the water requirements of a crop, we multiply the PET times the crop coefficient using the following equation:

**PET** x **Kc** = **crop water requirements** (equation 1)

where:

> **PET** is the sum of daily PET over the time period of interest, such as the 3-day total, the weekly total, etc.
>
> **Kc** is the crop coefficient corresponding to the current stage of crop growth.

Example 1: the 5-day PET total is 1.32 inches. My sorghum is in the "heading" growth stage. What are the water requirements? (Note: from Table 1, the "heading" crop coefficient is 1.10)

> 1.32 inches x 1.10 = 1.45 inches

Thus, I need to apply 1.45 inches to replace the water used by the sorghum in the last 5 days.

### Adjusting for Irrigation System Efficiency

It may be necessary to increase the amount of irrigation water in order to compensate for poor irrigation system efficiency. Irrigation system efficiency is defined in Section V of this guide. Table 4 gives the typical ranges of on-farm irrigation systems.

To adjust for irrigation system efficiency, use the following equation:

**PET** x **Kc** ÷ **Eff** = **irrigation water requirements** (equation 2)

where:

> **Eff** is the overall efficiency of the irrigation system.

Example 2. I am irrigating with a low-pressure center pivot. I estimate that my overall system efficiency is 85%. What are my irrigation water requirements for the sorghum in example 1?

> 1.32 inches x 1.10 ÷ 0.85 = 1.71 inches.

### Adjusting for Rainfall

Rainfall reduces the amount of water we must supply by irrigation to meet plant water requirements. However, not all rainfall becomes available for use by plants and crops. Depending on such factors as soil type, duration and intensity of rainfall, soil moisture levels, etc., a portion of the rainfall will be lost to runoff and deep percolation (water moving below the root zone).

In irrigation scheduling, the term "*effective rainfall*" refers to that portion of rainfall which infiltrates and is stored in the root zone. Effective rainfall must be estimated for each field and rainfall event. The irrigation requirement determined with equations (1) or (2) should be reduced by the amount of effective rainfall.

Alternatively, soil moisture monitoring devices can be use to determine soil moisture levels and to determine when irrigations should be re-started following rains.

## II. WHERE TO FIND PET INFORMATION

For persons with Internet access, PET and weather information is provided for about 10 locations in Central and South Texas on the Texas PET Web Site. The address is:

http://texaset.tamu.edu

Persons without Internet access should contact their water district or County Extension Agent to see if this information is being provided locally in another way.

Persons on the Texas High Plains should contact the Texas A&M Research and Extension Center in Amarillo at (806) 359-5401 about subscription to the High Plains PET Network where PET data is sent out every three days by FAX.

## III. WHAT IS POTENTIAL EVAPOTRANSPIRATION (PET)?

Evapotranspiration (**ET**) is a measurement of the total amount of water needed to grow plants and crops. This term comes from the words *evaporation* (i.e., evaporation of water from the soil) and *transpiration* (i.e., transpiration of water by plants). Different plants have different water requirements, so they have different ET rates.

Since there are thousands of cultivated plants, we have tried to simplified matters by establishing a standard ET rate for general reference and use. The standard is referred to as the potential evapotranspiration (PET). This is the *potential* ET since we are assuming the crop is in a deep soil and under well watered conditions. The standard crop we are using is a cool season grass which is 4-inches tall. The technical term for this is the "***Potential Evapotranspiration of a Grass Reference Crop***" or "***PET***" for short.

PET depends on the climate and varies from location to location. Special weather stations are used to collect the climatic data for calculating PET, including temperature, dew point temperature (relative humidity), wind speed, and solar radiation.

The water requirements of specific crops are calculated as a percentage of the PET. This "percentage" is the called the <u>crop coefficient</u> (Kc). Crop coefficients depend on the type of crop and its stage of growth. Detailed information on crop coefficients are given later.

We are using the Penman-Monteith method to calculate PET from the weather station data. This is one of a number of methods that can be used to determine PET and ET. Several organizations, such as the International Committee on Irrigation and Drainage and the Water Requirements Committee of the American Society of Civil Engineers have proposed establishing the Penman-Monteith method as a world-wide standard. Such a standard would help facilitate the sharing of PET data and development of crop coefficients.

## IV. CROP COEFFICIENTS

Potential Evapotranspiration (PET) is an estimate of the water requirements of a 4-inch grass in a deep soil growing under well watered conditions. The water requirements of other crops are determined from PET through crop coefficients (Kc). Crop coefficients vary for different crops. They also change depending on the growing stage of the crop.

Unfortunately, we only have verified crop coefficients for the Texas North High Plains for cotton, sorghum, corn and wheat (see Tables 1-3). These coefficients were developed by the North Plains PET Network Project Team. Another source is the FAO (Food and Agriculture Organization of the United Nations) who has published a long list of generalized crop coefficients which are used throughout the world where local values are not available (see Tables 5&6).

### **<u>Choosing and Using Crop Coefficients</u>**

For cotton, sorghum and corn, I recommend using the North High Plains crop coefficients. These have been verified in research and on-farm irrigation studies, and should vary no more than about 10% for other parts of the state.

The North High Plains crop coefficients are listed by stage of growth in Tables 1-3. Please note that these dates are provided as a general guide only, as crop growth rate is affected by many factors including variety, current weather, soil moisture conditions, etc.

For other crops, refer to the FAO Crop Coefficients until researchers are able to verify coefficients for specific regions in Texas. For many crops, we would expect these general coefficients to be within about 10%.

### **<u>Soil Moisture Monitoring</u>**

I highly recommend soil moisture monitoring using gypsum blocks, watermark sensors, tensiometers, the "feel" method, or other devices for measuring the current water status in the root zone. This provides an excellent check to ensure that irrigations are keeping up with crop water demand.

## V. IRRIGATION SYSTEM EFFICIENCIES

No irrigation system is 100% efficient. For sprinkler irrigation systems, we can lose anywhere from 10% to 40% of the water in the air before the water reaches the ground depending on wind and other weather conditions. The amount of water lost to spray drift is referred to as theapplication efficiency.

For drip and surface irrigation system, our biggest concern is how evenly distributed the water is over the field or along laterals and rows. This is referred to as the distribution efficiency. The term overall efficiency is a combination of both the application and distribution efficiencies.

The normal ranges in on-farm overall efficiencies are listed in Table 4. Under some situations, we will need to increase the amount of irrigation to compensate for water lost due to the inefficiencies of the system.

Table 1. Sorghum Crop Coefficients.

| **GROWTH STAGE**[1] | **$K_C$** | **DAYS AFTER PLANTING**[2] |
|---|---|---|
| Seeding | 0.40 | 3 - 4 |
| Emerg | 0.40 | 5 - 8 |
| 3-leaf | 0.55 | 19 - 24 |
| 4-leaf | 0.60 | 28 - 33 |
| 5-leaf | 0.70 | 32 - 37 |
| GPD | 0.80 | 35 - 40 |
| Flag | 0.95 | 52 - 58 |
| Boot | 1.10 | 57 - 61 |
| Heading | 1.10 | 60 - 65 |
| Flower | 1.00 | 68 - 75 |
| S Dough | 0.95 | 85 - 95 |
| H Dough | 0.90 | 95 - 100 |
| Blk lyr | 0.85 | 110 - 120 |
| Harvest | 0.00 | 125 - 140 |

[1]Sorghum will bloom at different times depending on locating , planting date, and maturity of the variety.

[2]The Days After Planting are for a medium-early to medium late variety.

Table 2. Cotton Crop Coefficients.

| **GROWTH STAGE** | **$K_C$** | **DAYS AFTER PLANTING** |
|---|---|---|
| Seeding | .07 | 0 - 10 |
| $1^{st}$ Sqr | .22 | 32 - 40 |
| $1^{st}$ Blom | .44 | 55 - 60 |
| Max Blom | 1.10 | 70 - 90 |
| $1^{st}$ open | 1.10 | 105 - 115 |
| 25% open | .83 | 115 - 125 |
| 50% open | .44 | 135 - 145 |
| 95% open | .44 | 140 - 150 |
| Pick | .10 | 140 - 150 |

Table 3. Corn Crop Coefficients.

| **GROWTH STAGE**[1] | **$K_C$** | **DAYS AFTER PLANTING** |
|---|---|---|
| Seed | 0.25 | 0 - 5 |
| Emerg | 0.35 | 5 - 8 |
| 4-leaf | 0.45 | 24 - 28 |
| 5-leaf | 0.70 | 29 - 34 |
| 6-leaf | 0.85 | 35 - 40 |
| 8-leaf | 1.00 | 43 - 46 |
| 10 leaf | 1.15 | 51 - 58 |
| 12-leaf | 1.20 | 57 - 65 |
| 14-leaf | 1.25 | 65 - 75 |
| Tassel | 1.25 | 72 - 82 |
| Silk | 1.30 | 75 - 85 |
| Blister | 1.30 | 85 - 95 |
| Milk | 1.30 | 95 - 105 |
| Dough | 1.20 | 100 - 110 |
| Dent | 1.00 | 110 - 120 |
| ½ mat | 0.90 | 115 - 125 |
| Blk lyr | 0.70 | 125 - 135 |
| Harvest | 0.00 | 140 + |

[1] Note: 50% silking occurs in 85 days in Corpus Christi/Coastal bend area and in 75 days in the Uvalde area.

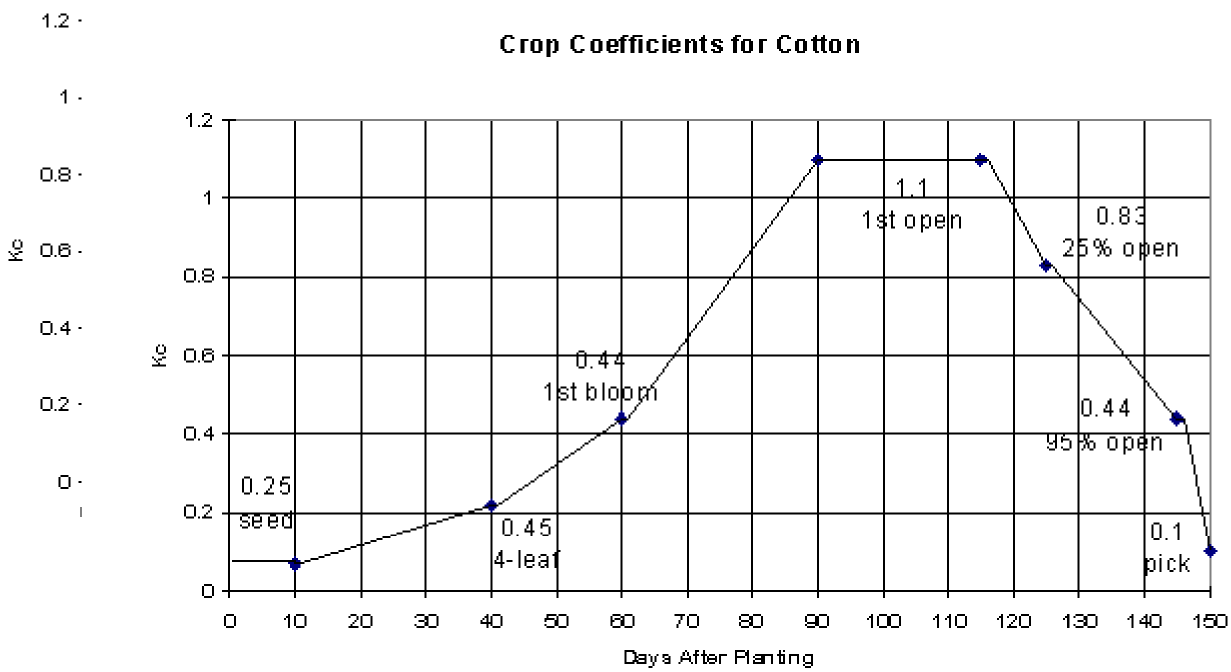
Table 4. Typical overall On-Farm Efficiencies

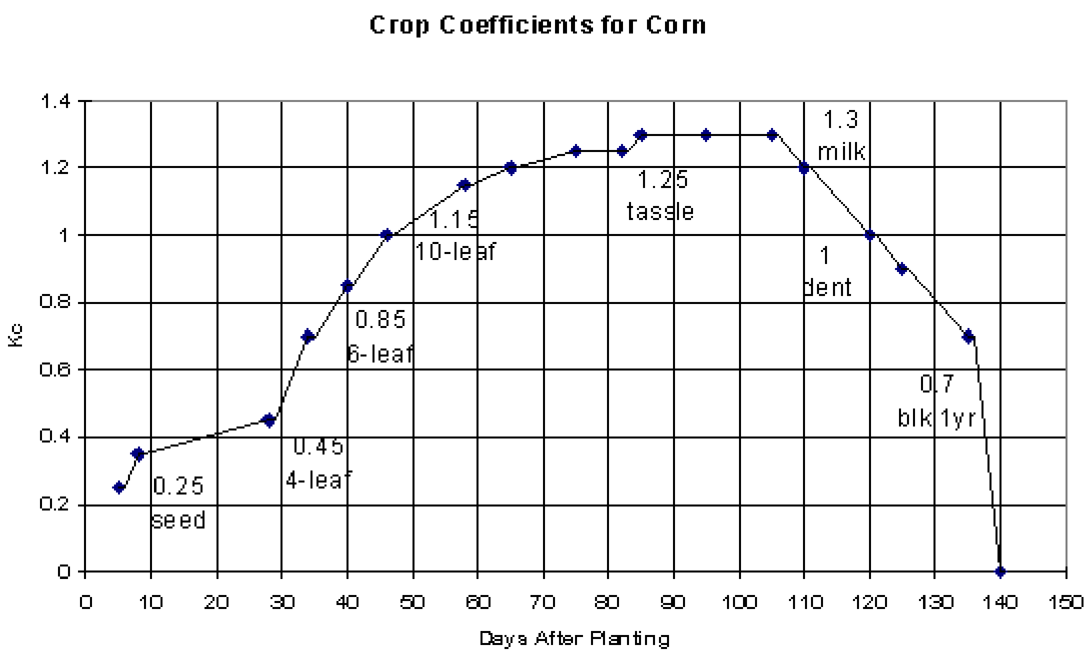
| System | Overall Effeciency |
| --- | --- |
| Surface | 0.50 - 0.80 |
| a. average | 0.50 |
| b. land leveling and delivery pipeline meeting design standards | 0.70 |
| c. tailwater recovery with (b) | 0.80 |
| d. surge | 0.60 - 0.90[1] |
| Sprinkler | 0.55 - 0.75[3] |
| Center Pivot | 0.55 - 0.90[3] |
| LEPA | 0.90 - 0.95 |
| Drip | 0.80 - 0.90[2] |

1. Surge has been found to increase efficiencies 8 to 28 percent over non-surge furrow systems.

2. Trickle systems are typically designed at 90 percent efficiency; short laterals (<100ft) or systems with pressure compensationg emitters may have higher efficiencies.

3. Under low wind conditions.


Crop Coefficients for Cotton
0.25
seed
0.45
4-leaf
0.44
1st bloom
1.1
1st open
0.83
25% open
0.44
95% open
0.1
pick
Kc
Days After Planting


Crop Coefficients for Corn
0.25
seed
0.45
4-leaf
0.85
6-leaf
1.15
10-leaf
1.25
tassle
1.3
milk
1
dent
0.7
blk 1yr
Kc
Days After Planting

## VI. FAO CROP COEFFICIENTS

With the FAO method, crop coefficients (Table 5) are represented by straight lines connecting four general growth stages, as indicated in the following figure. Table 6 gives a more detailed explanation of the crop coefficient values and their respective growth stages.

Table 5. FAO Mean Crop Coefficients, $K_c$, for Arid Climates[1]

| CROP | $K_{c1}$[2] | $K_{c2}$ | $K_{c3}$ |
|---|---|---|---|
| Alfalfa Hay[3] | 0.30 | 1.25 | 1.10 |
| Artichokes | 0.95 | 1.00 | 0.95 |
| Asparagus | 0.30 | 0.95 | 0.30 |
| Banana, 1st year | 0.50 | 1.15 | 1.10 |
| Banana, 2nd year | 0.70 | 1.20 | 1.10 |
| Barley, Wheat, Oats | 0.30 | 1.15 | 0.20 |
| Beans, Green | 0.40 | 1.00 | 0.90 |
| Beans, Dry and Pulses | 0.40 | 1.15 | 0.35 |
| Beets, Table | 0.40 | 1.05 | 0.95 |
| Berries | 0.30 | 1.05 | 0.40 |
| Carrots | 0.50 | 1.10 | 0.80 |
| Castor Beans | 0.40 | 1.15 | 0.50 |
| Celery | 0.35 | 1.10 | 1.00 |
| Citrus | 0.65 | 0.80 | 0.65 |
| Citrus w/cover or weeds | 0.70 | 1.05 | 1.05 |
| Clover Hay[3] | 0.60 | 1.20 | 1.05 |
| Coffee | 0.90 | 0.90 | 0.90 |
| Conifer Trees | 1.20 | 1.20 | 1.20 |
| Corn, Field | 0.40 | 1.15 | 0.60, 0.35[4] |
| Corn, Sweet | 0.40 | 1.15 | 1.05 |
| Cotton | 0.40 | 1.20 | 0.65 |
| Cucumber, Fresh Market | 0.35 | 0.95 | 0.75 |
| Cucumber, Machine Harvest | 0.35 | 0.95 | 0.95 |
| Crucifers[5] | 0.40 | 1.05 | 0.90 |
| Dates | 0.95 | 0.95 | 0.95 |
| Deciduous Orchard | 0.50 | 1.00 | 0.65[6] |
| Deciduous Orchard w/cover or weeds | 0.80 | 1.25 | 0.85[6] |
| Eggplant | 0.40 | 1.05 | 0.85 |
| Flax | 0.30 | 1.10 | 0.20 |
| Grapes | 0.30 | 0.80 | 0.40 |
| Grass Pasture | 0.80 | 0.80 | 0.80 |
| Groundnuts | 0.40 | 1.05 | 0.60 |
| Hops | 0.30 | 1.00 | 0.60 |
| Kiwi | 0.30 | 1.05 | 1.05 |
| Lentil | 0.30 | 1.15 | 0.25 |
| Lettuce | 0.30 | 1.00 | 0.95 |
| Melons | 0.40 | 1.00 | 0.75 |
| Millet | 0.30 | 1.10 | 0.25 |
| Mint | 0.60 | 1.10 | 1.10 |
| Olives | 0.40 | 0.70 | 0.70 |
| Onion, Dry | 0.50 | 1.05 | 0.80 |
| Onion, Green | 0.50 | 1.00 | 1.00 |
| Open Water | 1.15 | 1.15 | 1.15 |
| Palm Trees | 0.95 | 0.95 | 0.95 |
| Peas, Fresh | 0.40 | 1.10 | 1.05 |
| Peas, Dry/Seed | 0.40 | 1.10 | 0.30 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Peppers, Fresh | 0.35 | 1.05 | 0.85 | Spinach | 0.30 | 1.00 | 0.95 |
| Pistachios | 0.20 | 1.10 | 0.40 | Squash | 0.30 | 0.95 | 0.75 |
| Potato | 0.40 | 1.10 | 0.75[8] | Strawberries | 0.40 | 0.90 | 0.70 |
| Pumpkin | 0.40 | 1.00 | 0.75 | Sugar Beet | 0.30 | 1.15 | 1.00[9] |
| Radishes | 0.30 | 0.85 | 0.80 | Sugar Cane | 0.40 | 1.25 | 0.70 |
| Rice | 1.10 | 1.25 | 1.00 | Sunflower | 0.30 | 1.15 | 0.35 |
| Safflower | 0.35 | 1.15 | 0.20 | Tea | 1.00 | 1.00 | 1.00 |
| Sorghum, Grain | 0.30 | 1.05 | 0.50 | Tomato | 0.40 | 1.20 | 0.65 |
| Sorghum, Sweet | 0.30 | 1.20 | 0.50 | Walnut Orchard | 0.50 | 1.00 | 0.65 |
| Soybeans | 0.35 | 1.10 | 0.45 | Winter Wheat | 0.30 | 1.15 | 0.20 |

Footnotes to Table 5.

[1]Values for $K_{c2}$ and $K_{c3}$ represent those for an arid climate ($RH_{min}$ ~ 20%) with moderate wind speed (0-5 m $s^{-1}$, averaging 2 m $s^{-1}$) and are used for general irrigation water requirements. For humid or windier conditions, Kc2 and $K_{c3}$ can be modified as follows:

$$K_{c2}=K_{c2\ table} - 0.0015\ RH_{min} + 0.01\ U_2$$

$$K_{c3}=K_{c3\ table} - 0.0015\ RH_{min} + 0.01\ U_2 \text{ when } K_{c3} > \text{ or } = 0.4$$

$$K_{c3} = K_{c3\ table} + 0.001\ (RH_{min}-20) \text{ when } K_{c3} < 0.4$$

[2]General values for $K_{c1}$ under infrequent soil wetting (~each 10 days). $K_{c1}$ is a function of wetting interval and potential evaporation rate during the initial and development periods.

[3] The coefficients for hay crops represent immediately following cutting; full cover; and immediately before cutting, respectively. An overall mean coefficient for alfalfa hay which takes into account cutting effects is 1.05 and for clover is 1.00. $K_{c3}$ for alfalfa seed, which is never cut for forage or hay is about 0.5.

[4] The first $K_{c3}$ value is for harvest at high grain moisture. The second $K_{c3}$ value is for harvest after complete field drying of grain (to about 18%).

[5] Crucifers include cabbage, cauliflower, broccoli, and Brussel sprouts.

[6] The $K_{c3}$ value represents the $K_c$ prior to leaf drop.

[7] Cool season grass varieties include dense strands of bluegrass, ryegrass, and fescue. Warm season varieties include bermuda grass and St. Augustine grass. The 0.90 values for cool season grass represent a 0.06 to 0.08m height under general turf conditions.
[8] The $K_{c3}$ value for potatoes is about 0.40 for long season potatoes with vine kill.
[9]The $K_{c3}$ value for sugar beets is 0.60 if no irrigation occurs during the last month.

Table 6 . FAO Generalized Crop Growth Stages

| $K_c$ Values | Growth Stage | Description |
|---|---|---|
| $K_{c1}$ | Initial | The average $K_C$ value from planting to about 10% ground cover. |
| $K_{c1}$-$K_{c2}$ | Rapid Growth | From 10% ground cover to 75% cover or to peak water use, which ever comes first. |
| $K_{c2}$ | Mid season | The average value from the end of the rapid growth stage until water use begins to decline due to crop aging. |
| $K_{c2}$-$K_{c3}$ | Late season | From when $K_C$ begins to decline until harvest or when water use ceases or becomes minimal. |
| $K_{c3}$ | Harvest | The average value at harvest or the end of the water use season. |

**Note:** For the rapid growth and the late season stage, it is assumed that KC values increase or decrease linearly with time.

## VII. ACKNOWLEDGEMENTS

Information on crop growth periods, time periods after planting, and other advice provided by Charles, Stickler, Associate Professor and Extension Agronomist, Texas A&M Center-Uvalde.

## For More Information

For more information on the Penman-Monteith equation and other methods for determining PET, see the book: Evapotranspiration and Irrigation Water Requirements, edited by M.E. Jensen, R.D. Burman, and R.G. Allen. Published by the American Society of Civil Engineers, New York, NY. 1990. 332pp.

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