DETERMINATION OF CROP COEFFICIENTS (K_C) FOR IRRIGATION MANAGEMENT OF CROPS

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ABSTRACT

Weighing lysimeters are used to measure crop water use during the growing season. By relating the water use of a specific crop to a well-watered reference crop such as grass, crop coefficients (K_C) can be developed to assist in predicting crop needs using meteorological data available from weather stations. Seven lysimeters, consisting of undisturbed 1.5 x 2.0 x 2.2 m deep soil monoliths, comprise the Texas Agricultural Experiment Station - Uvalde lysimeter facility. Six lysimeters, weighing about 14 Mg, have been placed each in the middle of a one hectare field beneath a linear LEPA irrigation system. A seventh lysimeter was established to measure reference grass ET_O. Corn, sorghum, spinach, onion, cotton, and wheat were grown over the last five years in the lysimeter fields. Daily water use was measured on 5-min intervals. Crop water requirements, K_C determination, and comparison to existing FAO K_C values were determined over a 2 or 3 year period depending on the crop.

Keywords. Weighing lysimeters, ET measurement, Crop coefficients.

INTRODUCTION

In semiarid and arid lands and areas where water usage is regulated due to ecological protection programs, limited resources, and competitive demand (Barrett, 1999), agricultural water users must plan an annual water budget. Water for agricultural, urban and industrial use in the Austin – San Antonio – Uvalde corridor is pumped from the Edwards aquifer. This aquifer is in a class by itself being unique in terms of containment, recharge, and political sensitivity. The regulation of this aquifer, however, is portent to the regulation of all aquifers in Texas. In 2007, Senate Bill 3 of the 80th session of legislature imposed a maximum draw of 705.5 million m^3 of water per year from the Edwards aquifer. Since 50% of the water drawn from the aquifer is for agricultural use, agricultural water conservation strategies are of utmost importance in the Edwards region. Mild climatic conditions in this region allows for a variety of economically important crops to be grown year-round under irrigation, including corn, cotton, wheat, spinach, and onions. Determining crop water requirements specific to each crop is key in providing growers with information to a) select which crops to grow and b) determine the timing and quantity of irrigation events.

In 2000, growers in this region irrigated 40,000 ha (Texas Water Development Board, 2001). From preliminary studies carried on at the Texas Agricultural Experiment Station, it is estimated that approximately 62 million to 74 million m^3 of groundwater could be conserved each year by implementing proper irrigation techniques and scheduling. To optimize irrigation events, crop water requirements throughout the growing season must first be determined.

The use of on-site microclimatological data and crop coefficients enables the determination of crop water use and dissemination of such information to growers in a reliable, useable, and affordable format. Crop coefficients (K_C) are the ratio of the evapotranspiration of the crop (ET_C) to a reference crop (ET_O). ET_O may be measured directly from a reference crop such as a perennial grass or computed from weather data. Weighing lysimeters are employed to measure ET_O and ET_C directly by detecting changes in the weight of the soil/crop unit. Weather data is used to compute ET_O via equations such as the FAO Penman-Monteith. By utilizing the following equation, all that is needed to provide growers with real time irrigation recommendations (ET_C) are local weather stations.

$$ET_C = K_C \times ET_O \qquad (1)$$

According to Allen et al. (1998), crop type, variety, and developmental stage affect ET_C. The objective of this multiyear project is to determine crop water use (ET_C) and develop crop coefficients (K_C) specific to multiple phenological stages for row and vegetable crops grown in the Wintergarden region of Texas.

MATERIALS AND METHODS

The Wintergarden region of Texas is located on the South Texas Plains, receives approximately 660 mm yr^{-1} of precipitation, and has a growing season of approximately 214 to 275 d. The lysimeter facility at the Texas Agricultural Experiment Station located in Uvalde, Texas, USA (29° 13’ N, -99° 45’ W; elevation 283 m), includes seven weighing lysimeters constructed between 2001 and 2006. Construction details and resolution are described by Marek et al. (2006). Each lysimeter is 1.5 m x 2.0 m in surface area and 2.2 m deep. The surface area of the lysimeters accommodates the common row spacing utilized in the region. The soil monoliths in the lysimeters represent soils within an 80 km radius of the research station. Microclimatological data are collected every 6 s with 15 min output and the weight of each lysimeter is sampled every 1 s with 5 min output.

Microclimatological data are collected by a standard Campbell Scientific, Inc. (Logan, Utah, USA) weather station. (The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.) Changes in lysimeter weight are measured as changes in mV output of the load cell attached to the Avery Weigh Tronix (Fairmont, Minnesota, USA) scale beneath each lysimeter. The calibration of mV output to weight change represented as mm water is described in Marek et al. (2006).

A Campbell Pacific Nuclear Corp. (Martinez, California, USA) 503 DR Hydroprobe Moisture Depth Gauge was used to quantify volumetric soil water content of soil in the lysimeters during the growing seasons at 10 cm increments to a depth of 1.2 m. During the 2007 cotton growing season, one Agrilink C-Probe (Thebarton, South Australia, AU) sensor was added to each cotton lysimeter. The C-Probes measured volumetric soil water content at 10 cm increments to a depth of 1.5 m.

The crops grown over the last five years in the crop lysimeters used in the determination of K_C are reflected in Table 1.

Table 1. Crops grown at the Texas Agricultural Experiment Station – Uvalde for determination of K_C and associated seasonal data.

Crop	Variety	Planting Year	Plant-Harvest (M/D)	Precipitation (mm)	Irrigation (mm)	Growing Degree Days
Corn	32H39	2002	3/29 - 8/7	489	405	2426.8
	30G54	2003	3/18 - 8/11	322	349	2542.3
	30G54	2004	3/10 - 8/18	350	92	2598.7
Spinach	DMC16	2002	10/21 - 1/19	205	141	840.3
	DMC16	2003	11/20 - 2/27	60	130	821.7
Onion	Legend	2002	11/21 - 5/28	80	57	1808.8
Cotton	DP555	2006	4/12 - 9/7	75	604	2429.5
	DP555	2007	4/16 - 10/18	581	76	2547.7
Wheat	Ogallala	2005	11/18 - 5/19	58	434	3238.9
	Ogallala	2006	11/17 - 6/6	327	220	3365.3

RESULTS

The aim of this project is the determination of crop coefficients (K_C) for all crops grown in the Wintergarden region and to determine exact plant water usage or crop evapotranspiration (ET_C). Irrigation scheduling can then be improved for private consultants and growers to avoid water over use and to more precisely meet the crop water demand to produce greater yields, crop quality, and enhanced water use efficiency. Results from these experiments are in the following figures and tables:

Corn crop coefficients:

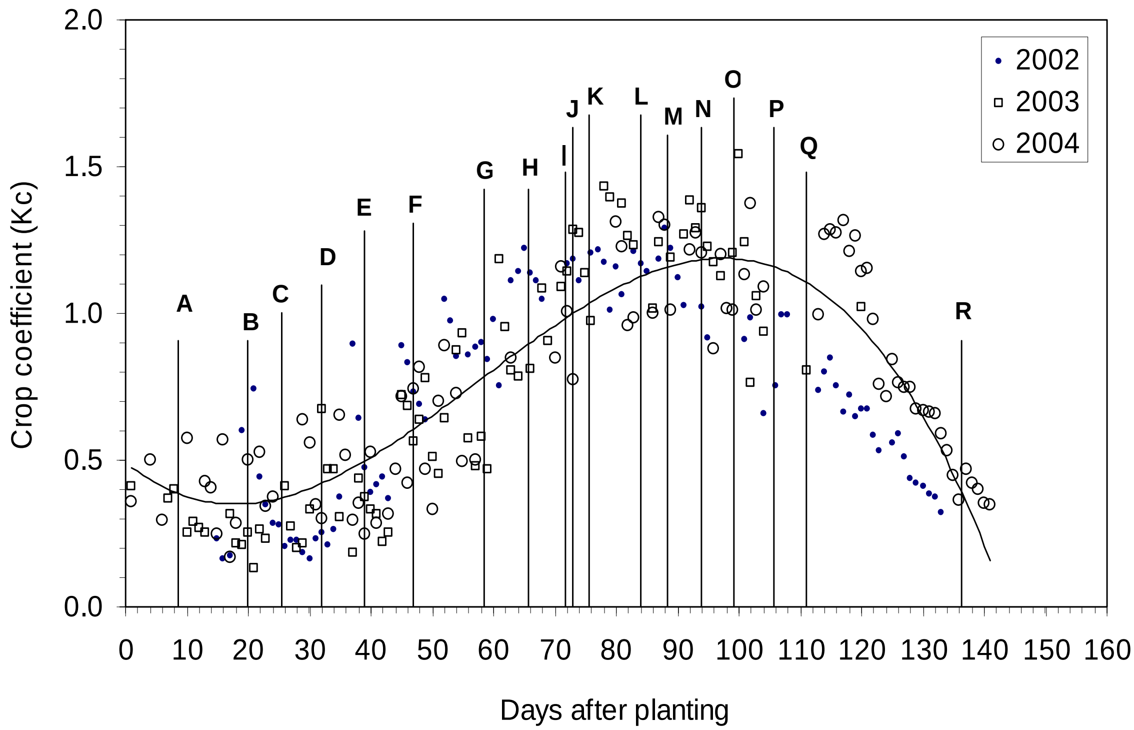

Figure 1. Corn crop coefficients as a function of days after planting in 2002, 2003 and 2004 at Uvalde, TX. Vertical lines represent 3-yr-average growth stages: A – emergence; B – 2 leaf; C – 4 leaf; D – 5 leaf; E – 6 leaf; F – 8 leaf; G – 10 leaf; H – 12 leaf; I – 14 leaf; J – tassel; K – silk; L – blister; M – milk; N – dough; O – dent; P – 1/2 mature; Q – black layer; R – harvest.

Table 2. Corn crop coefficients (K_C) determined at Uvalde, Texas in comparison to those from Bushland, Texas and from FAO.

Texas

Growth stage	Uvalde	Bushland
Emergence	0.35	0.35
2-leaf	0.35	0.45
4-leaf	0.40	0.70
6-leaf	0.45	0.85
8-leaf	0.55	1.00
10-leaf	0.70	1.15
12-leaf	0.80	1.20
14-leaf	0.90	1.25
Tassel	1.00	1.25
Silk	1.00	1.30
Blister	1.05	1.30
Milk	1.15	1.30
Dough	1.20	1.20
Dent	1.20	1.00
1/2 mature	1.20	0.90
Black layer	1.15	0.70

FAO

Growth stage	K_C
K_C ini	0.30
K_C mid	1.20
K_C end	0.35

Spinach crop coefficients:

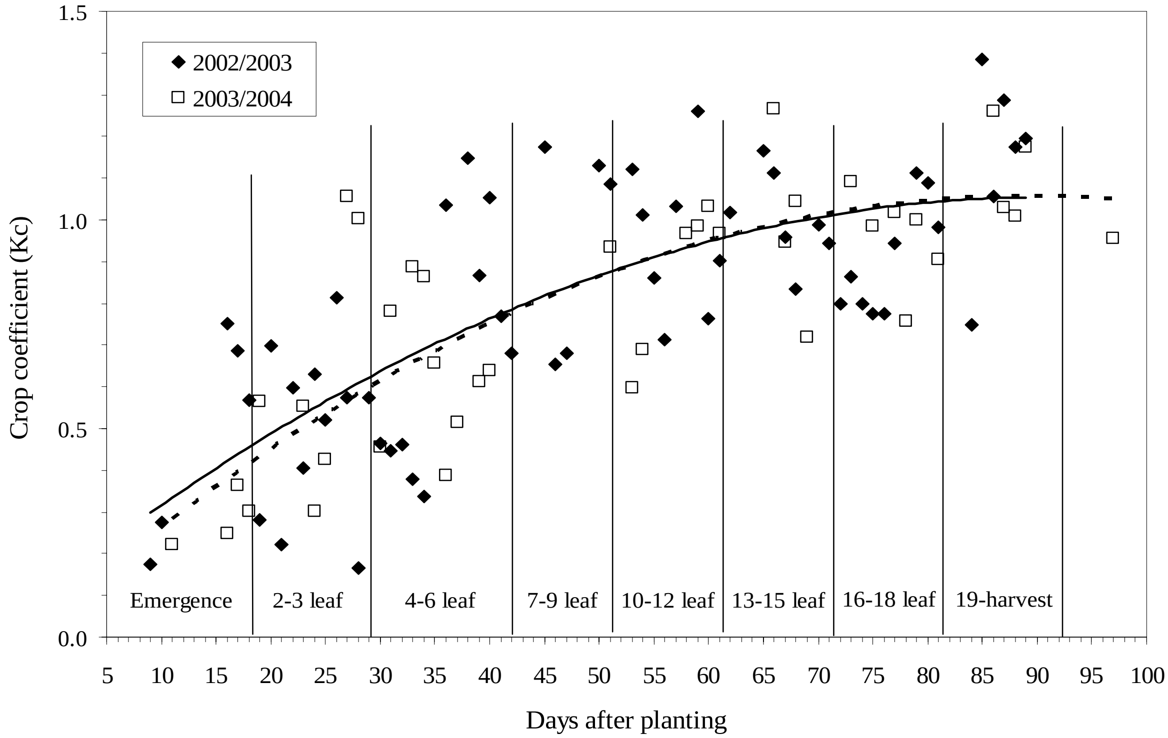

Figure 2. Spinach crop coefficients as a function of days after planting in 2002/2003 and 2003/2004 season at Uvalde, TX. Vertical lines represent 2-yr-average growth stages.

Table 3. Spinach crop coefficients determined at Uvalde, Texas in comparison to FAO.

South Texas

Growth Stage	2002	2003
Emergence	0.35	0.35
2-3 leaves	0.55	0.50
4-6 leaves	0.70	0.70
7-9 leaves	0.80	0.85
10-12 leaves	0.90	0.90
13-15 leaves	0.95	1.00
16-18 leaves	1.00	1.05
19 - harvest	1.05	1.05

FAO

Growth stage	K_C
K_C ini	0.70
K_C mid	1.00
K_C end	0.95

Onion crop coefficients:

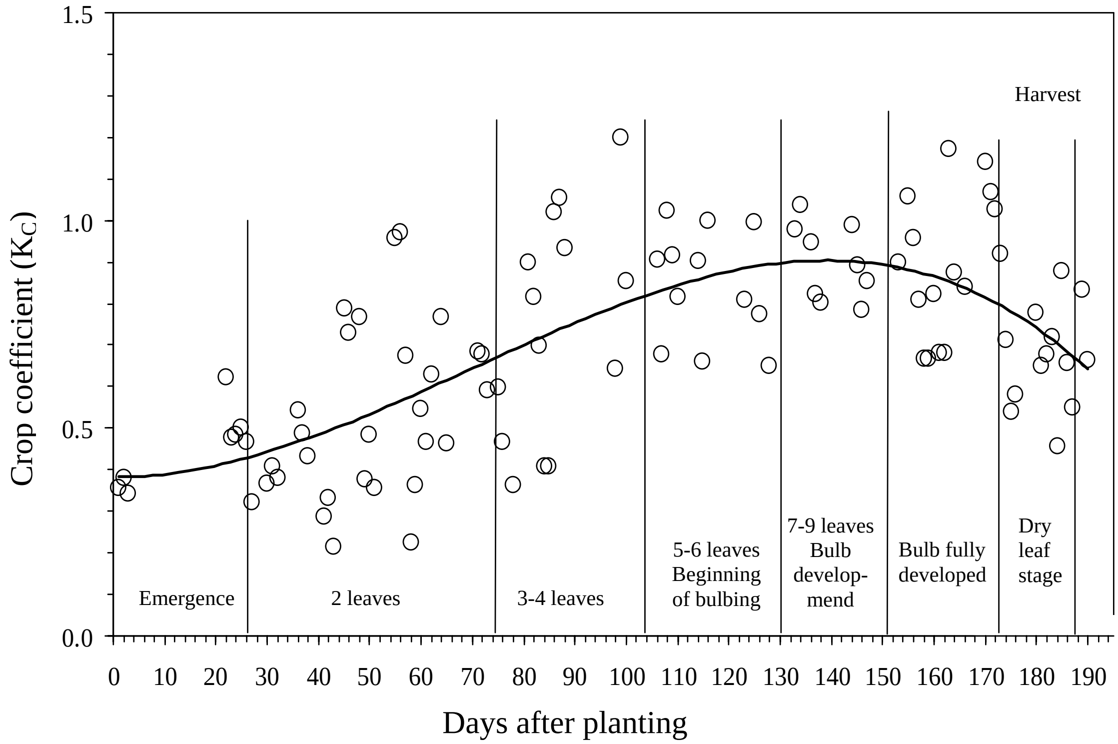

Figure 3. Onion crop coefficients of onion as a function of days after planting in 2002/2003 at Uvalde, TX.

Table 4. Onion crop coefficients determined at Uvalde, Texas in comparison with those from FAO.

South Texas

Growth Stage	Uvalde
Emergence	0.40
2 leaves	0.55
3-4 leaves	0.75
5-6 leaves Beginning of bulbing	0.85
7-9 leaves Bulb development	0.90
Bulb fully developed	0.85
Dry leaf stage	0.70

FAO

Growth stage	K_C
K_C ini	0.70
K_C mid	1.05
K_C end	0.75

Cotton crop coefficients:

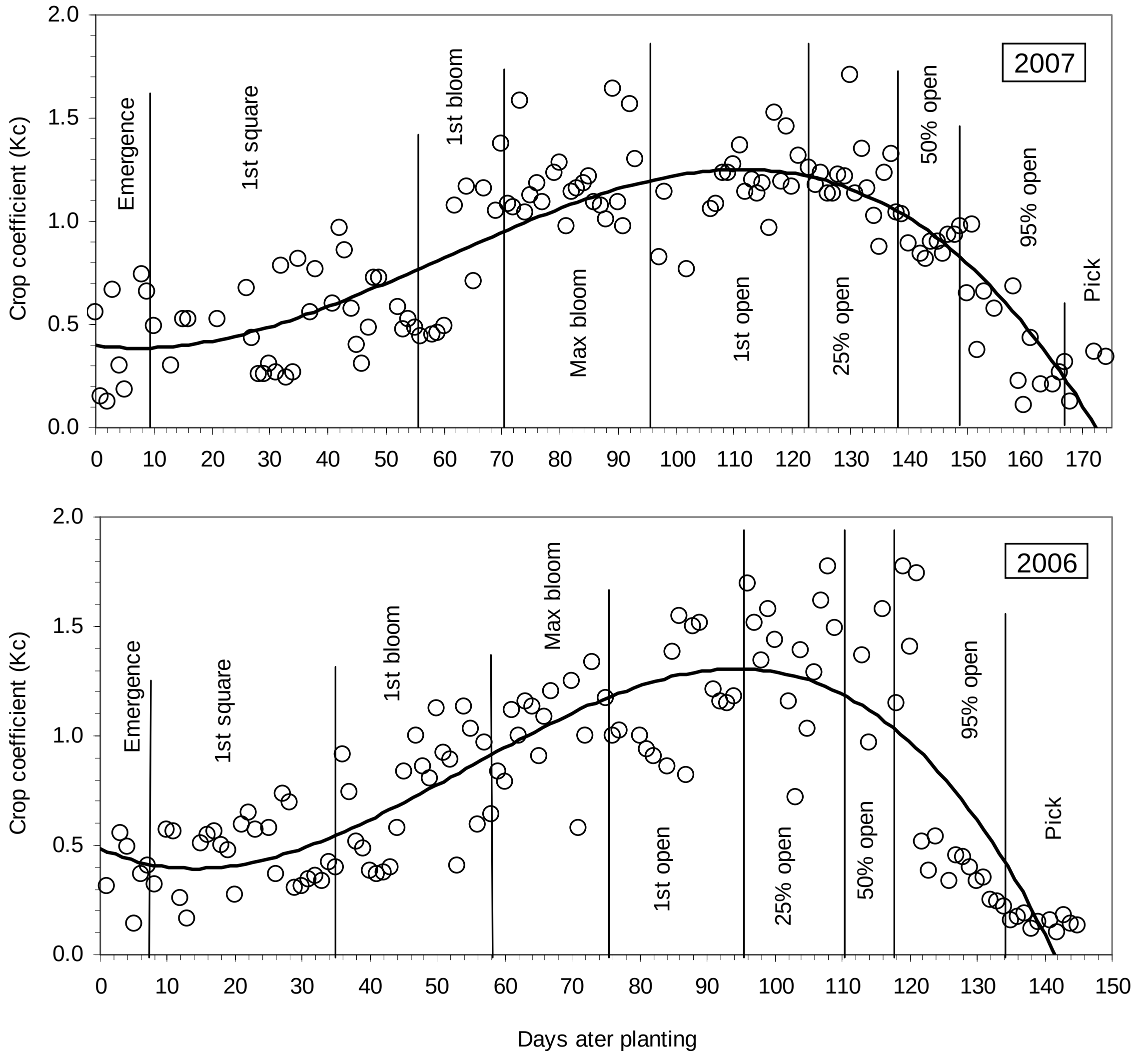

Figure 4. Crop coefficients of cotton as a function of days after planting in 2006 and 2007 at Uvalde, TX.

Table 5. Cotton crop coefficients (K_C) determined at Uvalde, Texas and comparison to those from Bushland, Texas and from FAO.

Texas

Growth Stage	Uvalde	Bushland
Emergence	0.40	0.22
1st square	0.45	0.44
1st bloom	0.80	1.10
Max bloom	1.08	1.10
1st open	1.23	0.83
25% open	1.25	0.44
50% open	1.05	0.44
95% open	0.60	0.10
Pick	0	0

FAO

Growth stage	K_C
K_C ini	0.35
K_C mid	1.15-1.20
K_C end	0.75-0.35

Wheat crop coefficients:

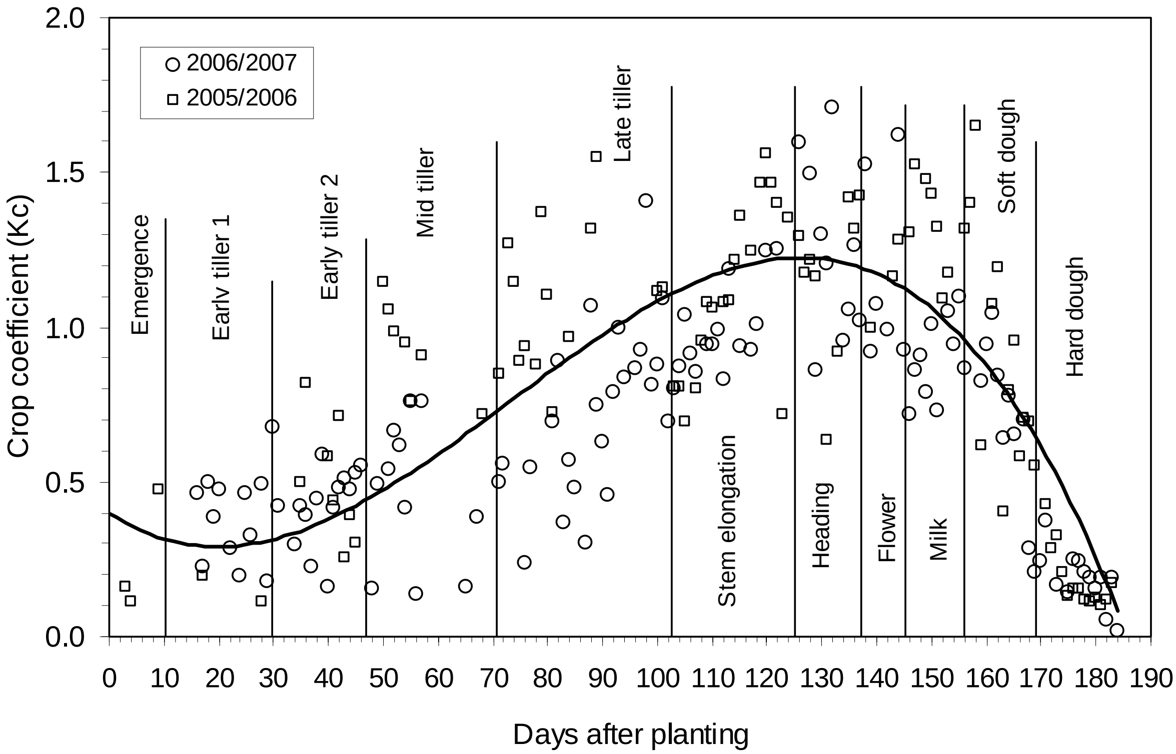

Figure 5. Crop coefficients of wheat as a function of days after planting in 2005/2006 and 2006/2007 at Uvalde, TX. Vertical lines represent a yr-average growth stages.

Table 6. Wheat crop coefficients determined at Uvalde, Texas in comparison to those from Bushland, Texas and from FAO.

Texas

Growth Stage	Uvalde	Bushland
Emergence	0.53	0.50
Early tiller 1	0.40	0.50
Early tiller 2	0.43	0.45
Mid tiller	0.63	0.90
Late tiller	0.93	1.00
Stem elongation	1.18	1.25
Heading	1.23	1.35
Flower	1.18	1.30
Milk	1.08	1.10
Soft dough	0.85	0.90
Hard dough	0.35	0.70

FAO

Growth stage	K_C
K_C ini	0.70
K_C mid	1.15
K_C end	0.25

DISCUSSION

Research has repeatedly shown that proper irrigation management is key to achieving profitable yields. PET networks and crop simulation models have proven to be reliable, inexpensive, and effective tools for estimating crop water needs in research settings. Recently, networks of weather stations have been established in many part of Texas for the purpose of supporting predictions of crop ET. It is estimated that, in the northern Texas panhandle, yearly fuel cost savings would exceed 18 million dollars if all irrigators used the PET network data. However to support predictions of crop evapotranspiration, generic crop coefficients will not fulfill the need for precise irrigation applications.

The need for regionalized crop coefficients (K_C) is demonstrated by the comparison between the K_C developed in Bushland and those developed in Uvalde. For example, corn crop coefficients from Uvalde are significantly lower than those from Bushland. This difference probably is due to elevated air temperatures that impede the plant to transpire at its full potential. In the Wintergarden region, the use of K_C developed in other regions will result in over-watering and consequently increased production costs and reduced profits.

In summary the development of regionally based K_C helps tremendously in irrigation management and furthermore provides precise water applications in those areas where high irrigation efficiencies are achieved by center pivot with LEPA (low energy precision application) systems or subsurface drip irrigation.

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