Crop Coefficients Developed at Bushland, Texas for Corn, Wheat, Sorghum, Soybean, Cotton, and Alfalfa

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Abstract

Crop coefficients derived from evapotranspiration measured with large, precise weighing lysimeters at Bushland, TX are presented for the major regional irrigated crops – corn, wheat, sorghum, soybean, cotton, and alfalfa. The ASCE/EWRI standardized reference evapotranspiration equation for daily weather data for short (ET_{os}, grass) and tall (ET_{rs}, alfalfa) crops was used as the base. Crop coefficients for both ET_{os} and ET_{rs} were summarized. They were generally in agreement with K_{cb} values from Davis, CA; Kimberly, ID; and from FAO-56.

Introduction

Crop coefficients are widely used to estimate crop water use and to schedule irrigations. They are defined as

$$K_c = \frac{ET_c}{ET_*} \qquad [1]$$

where ET_c is the crop water use usually expressed in mm d^{-1} and ET_* represents a reference crop water use expressed in the same units (Doorenbos and Pruitt, 1977; Jensen et al., 1990; Allen et al., 1998). Wright (1982) expressed the K_c as a basal crop coefficient (K_{cb}) for a dry soil surface but with a soil profile adequately irrigated or supplied with water to fully meet the crop water uptake from the soil. Essentially, the K_{cb} is defined as follows:

$$K_{cb} = \left(\frac{K_c - K_s}{K_a} \right) \qquad [2]$$

where K_s is the adjustment for increased evaporation from a wet soil surface (dimensionless) and K_a is the "water stress" or evaporation (*ET*) reduction fraction dependent on soil water depletion (Jensen et al., 1990). For a crop in a "basal condition", K_s is defined as 0 and K_a is defined as 1.0. The "basal crop *ET*" has been proposed as basically a characterization of the crop transpiration (Allen et al., 1998).

The reference crop *ET* (ET_*) has been standardized for grass or alfalfa (Jensen et al., 1990); for a hypothetical short crop (Allen et al., 1998); and more recently developed for both a short crop (ET_{os}) or a taller crop (ET_{rs}) (Allen et al., 2005) for both daily or hourly time periods. One central intent of the ASCE/EWRI standardized *ET* equations (Allen et al., 2005) is to utilize similar reproducible ET_* values with routine weather data. These standardized equations for ET_{os} and ET_{rs} are based on the Penman-Monteith equation from ASCE Manual 70 (Jensen et al., 1990); and they build upon the simplifications from FAO-56 (Allen et al., 1998).

The purpose of this paper is to present and briefly discuss and describe the K_c values measured at Bushland, TX with precision weighing lysimeters (Marek et al., 1988; Howell et al., 1995a) since 1988. The crops were produced in large fields that were sprinkler irrigated frequently to maintain adequate soil water for the "well-watered" crop *ET*.

Procedures

These studies were conducted at the USDA-ARS Laboratory at Bushland, TX (35º 11' N lat.; 102º 06' W long.; 1,170 m elev. above MSL). Crop *ET* was measured with one or two weighing lysimeters (Marek et al., 1988) each located in the center of 4.4-ha 210 m E-W by 210 m N-S fields (four fields arranged in a square pattern). The soil at this site is classified as Pullman clay loam (fine, mixed, superactive thermic Torrertic Paleustoll) (Unger and Pringle, 1981; Taylor et al., 1963) which is described as slowly permeable because of a dense B22 horizon about 0.3 to 0.5 m below the surface. The plant available water holding capacity within the top 2.0 m of the profile is approximately 240 mm (Tolk and Howell, 2001) ~200 mm to 1.5-m) depth). A calcareous layer at about the 1.4 m depth limits significant rooting and water extraction below this depth. Variations of this soil series are common to more than 1.2 million ha of land in this region and about 1/3 of the sprinkler-irrigated area in the Texas High Plains (Musick et al., 1988). Weighing lysimeters offer one of the most accurate means to measure *ET* (Hatfield, 1990). Predominate wind direction is SW to SSW, and the unobstructed fetch (fallow fields or dryland cropped areas) in this direction exceeds 1 km. The field slope is less than 0.3 percent. More descriptive information is provided in Howell et al. (1995b), Howell et al. (1997), Howell et al. (2004), and Evett et al. (2000).

Lysimeter mass was determined using a Campbell Scientific[1] CR-7X data logger to measure and record the lysimeter load cell (Interface SM-50) signal at 0.5-Hz (2 s) frequency. The load cell signal was averaged for 5 min and composited to 30-min means (reported on the mid point of the 30 min, i.e. data were averaged from 0-30 minutes and reported at 15 min). The lysimeter mass resolution was 0.01 mm, and its accuracy exceeded 0.05 mm (Howell et al., 1995a). Daily ET was determined as the difference between lysimeter mass losses (from evaporation and transpiration) and lysimeter mass gains (from irrigation, precipitation, or dew) divided by the lysimeter area (9 m^2). A pump regulated to -10 kPa provided vacuum drainage, and the drainage effluent was held in two tanks suspended from the lysimeter (their mass was part of the total lysimeter mass) and independently weighed by load cells (drainage rate data are not reported here). ET for each 24-h period was divided by 1.02 to adjust the lysimeter area to the mid point between the two walls (10 mm air gap; 9.5 mm wall thickness; 9.18-m^2 area instead of 9.00-m^2 area). This correction would be applicable for full-cover crops, but it would not be necessary for bare soil conditions. Nevertheless, it was applied to all data uniformly. Lysimeter data were screened to remove only days with snow or maintenance. Lysimeter *ET* data included days with irrigations and rainfall although the lysimeter water balance on these days may be less precise.

Solar irradiance, wind speed, air temperature, dew point temperature, relative humidity, precipitation, and barometric pressure were measured at an adjacent weather station (Howell et al., 1995b) placed over an irrigated grass surface (cool-season lawn mixture containing bluegrass, perennial rye-grass, etc.). Reference *ET* (ET_{os} and ET_{rs}) was computed with the ASCE/EWRI standardized equations (Allen et al., 2005) using REF-ET© v2 (Allen, 2001). Crop coefficients were computed by equation [1], and presented and discussed qualitatively, here, only on a time scale. They will be reported in more detail with appropriate statistical analyses in future papers in both time and growing degree formats.

Bushland Crop Coefficients

Fully irrigated crops were produced for near maximum commercial yields with prevailing agronomic practices. Table 1 summarizes the crops produced, the specific variety or hybrid used, and the year of production. It also presents information on the maximum leaf area index (*LAI*), crop height, and when available the crop yields (when available) from the lysimeter(s) themselves and the surrounding field(s). The lysimeter crop was maintained nearly identical to the surrounding field in appearance, soil water status, and growth and development.

[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

Corn

The corn hybrids were all classified as full-season hybrids and adapted to this environment. The 1989 crop received substantial hail damage soon after emergence, but the growing point was still below ground at that time and it developed well

Table 1. Summary of Bushland irrigated weighing lysimeter crops.

Crop	Year	Var./Hybrid	LAI_{max}	$Height_{max}$	Lys. Yield	Field Yield	Field Dry Matter
			m^2 m^{-2}	m	g m^{-2}	g m^{-2}	kg m^{-2}
Alfalfa	1996	PIO[1] 5454	6.94	0.72	na	same	1650
	1997		4.54	0.73		as	1640
	1998		5.28	0.70		Field	2060
	1999		3.85	0.59		DM[2]	1520
Corn	1989	PIO 3321	4.91	2.56	1216	1171	2098
	1990	PIO 3124	5.46	2.77	1061	941	na
	1994	PIO 3245	5.71	2.24	1322	1430	2638
Cotton	2000	PM 2145RR®	1.94	0.66	150.0	131.6	na
	2001	PM 2145RR®	4.01	0.96	111.9	102.1	na
	2002	PM 2145RR®	3.97	1.03	120.5	60.1	na
Grain Sorg.	1988	DK 41Y	4.45	1.05	726.0	754.0	1545
	1993	DK 56	5.30	1.48	908.7	982.0	1980
	2005	DK 39Y	2.35	1.00	711.5	678.0	1357
Soybean	1995	PIO 9461	5.22	0.88	407.7	460.5	994
	2003	PIO 94B73RR®	4.21	0.73	474.3	496.7	874
	2004	PIO 94B73RR®	5.40	1.05	315.2	424.5	873
Winter Wheat	1989-90	TAM 200	3.65	na	460.3	421.4	1316
	1991-92	TAM 107	7.07	1.12	325.7	688.9	2200
	1992-93	Mesa (AgriPro)	4.10	0.96	516.4	642.2	1848

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[2] Dry Matter.

although set back about 7-10 days from its typical development. The 1989 and 1990 seasons used two weighing lysimeters. The data were averaged together. The 1994 season used two lysimeters, but one was used to produce a short-season hybrid (Howell et al., 1998) (data not used herein) and only the full-season hybrid data are presented here. Figure 1 illustrates the Bushland corn K_c values for both the ET_o (short crop) and ET_r (taller crop) ASCE standardized references. The generalized FAO-56 crop calendar and typical K_{cb} values for corn (Allen et al., 1998) generally fit the median in these data. The K_c for the ET_r reference agreed relatively well with the

K_{cb} peak value near 1.0 from Wright (1982) for Kimberly, ID and the 1.17 peak K_{cb} for the ET_o reference from Pruitt for Davis, CA (Jensen et al., 1990).

Winter Wheat

The 1989-90 crop did not develop a significant fall growth and was subsequently slower in developing (Figure 2). More specific information is in Howell et al. (1995b). The lower initial K_{cb} (0.15) suggested from FAO-56 fit the 1989-90 fall and winter while the larger initial K_{cb} from FAO-56 (0.5) appeared to fit the 1991-92 and 1992-93 crops better during fall and winter. The FAO-56 crop calendar did not match the winter wheat development. The K_c for the ET_r reference was nearer to 0.95 than 1.0 for the peak K_{cb} from Wright (1982) for Kimberly, ID and nearer to a peak K_{cb} of 1.3 for for the ET_o reference for barley from Pruitt for Davis, CA (Jensen et al., 1990). Interestingly, winter wheat has peak water use rates nearly rates as great as alfalfa or corn.

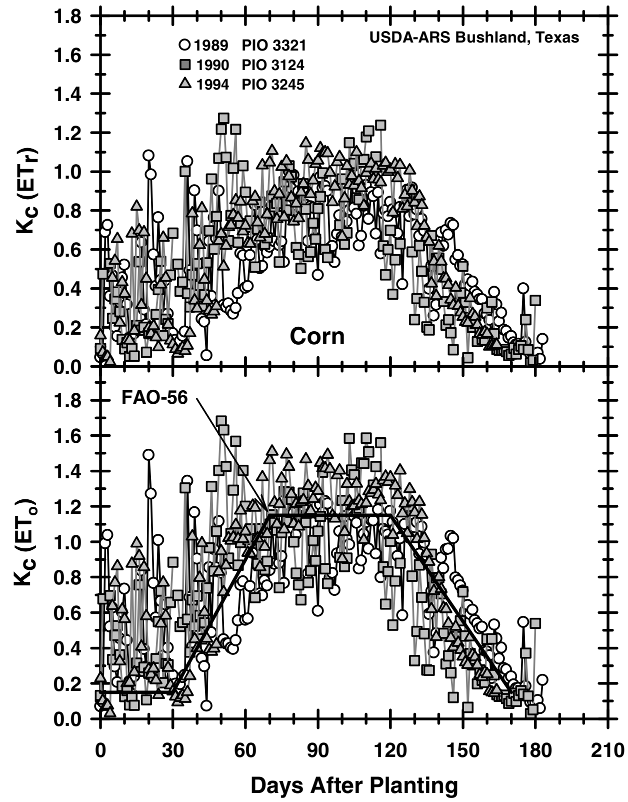

Figure 1. Bushland corn crop coefficients.

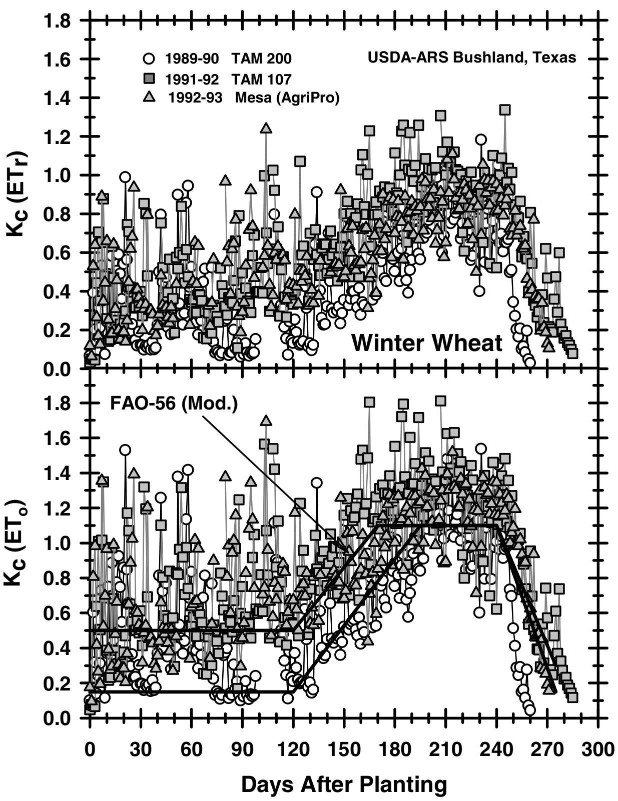

Figure 2. Bushland winter wheat crop coefficients.

Grain Sorghum

The sorghum hybrids were varied from a medium-full (DK 56) to a medium early (DK-41Y) to a short-season hybrid (DK 39Y). The FAO-56 crop calendar and K_{cb} values fit the full-season hybrid well in the 1993 season (Figure 3). The shorter maturity hybrids had lower peak K_c values. The peak K_c values for the full-season hybrid agreed with the peak of 1.08 from Davis, CA (Jensen et al., 1990) for the ET_o reference ET.

Soybean

The FAO-56 crop calendar and K_{cb} values fit the soybean variety (Group IV) rather well (Figure 4). The K_c for the ET_r reference was nearer a peak K_{cb} value of 0.85 in 2003 & 2004 closer in agreement with the peak value of 0.95 for K_{cb} for beans in Idaho from Wright (1982) and near to the 1.12 peak K_{cb} for the ET_o reference for beans in Davis, CA (Jensen et al., 1990). Neither source reported soybean K_{cb} data, but FAO-56 (Allen et al., 1998) reported K_{cb} data for soybean.

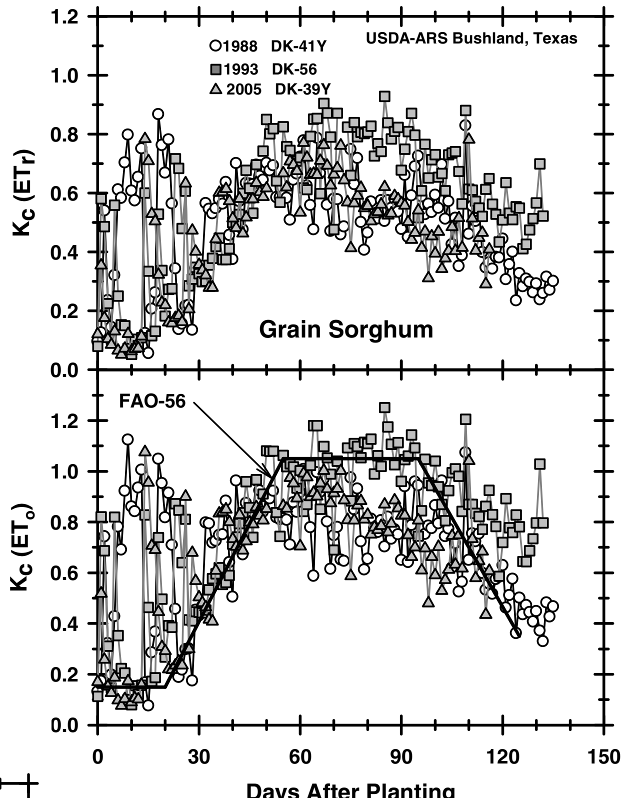

Figure 3. Bushland grain sorghum crop coefficients.

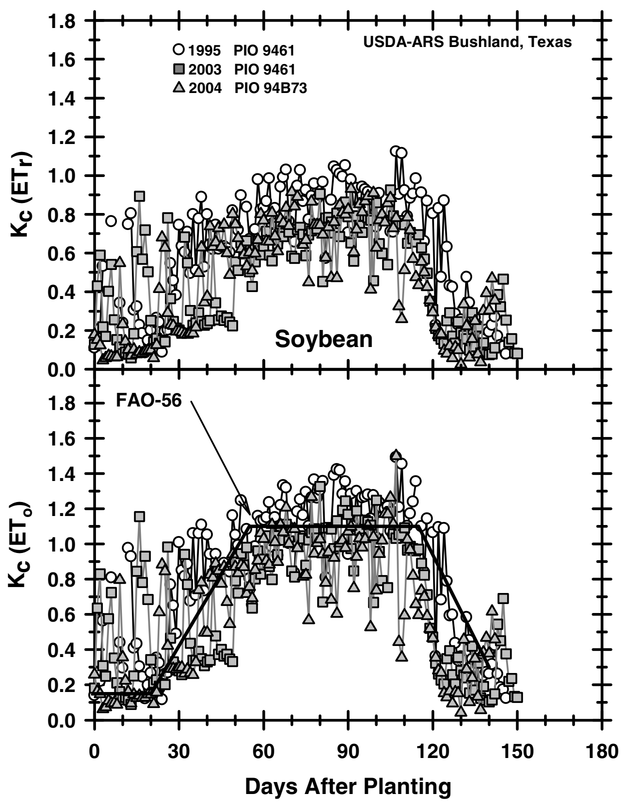

Figure 4. Bushland soybean crop coefficients.

Cotton

The FAO-56 "Texas" cotton crop calendar did not fit the Bushland K_c time pattern. The peak K_{cb} values (Figure 5), however, agreed well (Allen et al., 1998; Howell et al., 2004) with the modified crop calendar. The Bushland environment is marginal for the heat unit requirement for cotton. Despite this limitation, cotton production has spread into the Northern Texas High Plains and into southwestern and south central Kansas as an alternate crop for corn with a lower irrigation requirement.

Alfalfa

The K_c values (Figure 6) for

alfalfa were near 1.0 for the ET_r reference equation in agreement with values from Wright (1982) at Kimberly, ID, but not constant at 1.0 throughout the year. Of course alfalfa K_c values are cyclic with cuttings and re-growth. In most seasons we obtained four hay cuttings, except in 1998 (a drought year) when we obtained five cuttings and the greatest season yield (2060 g m^{-2} dry). Evett et al. (2000) provides other discussions on the alfalfa ET. The peak ET_o/ET_r ratio exhibited by the K_c (ET_o) graph illustrates the typical advective effects on crops at Bushland, TX.

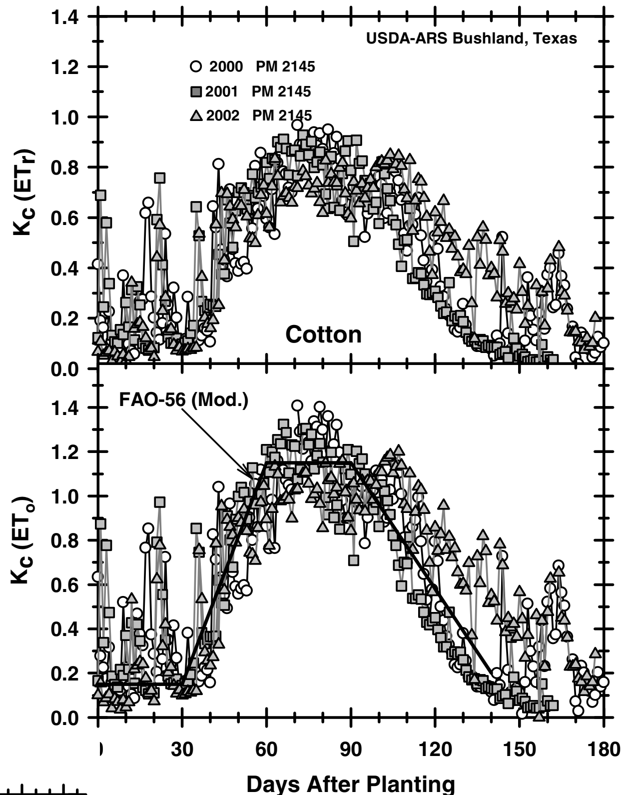

Figure 5. Bushland cotton crop coefficients.

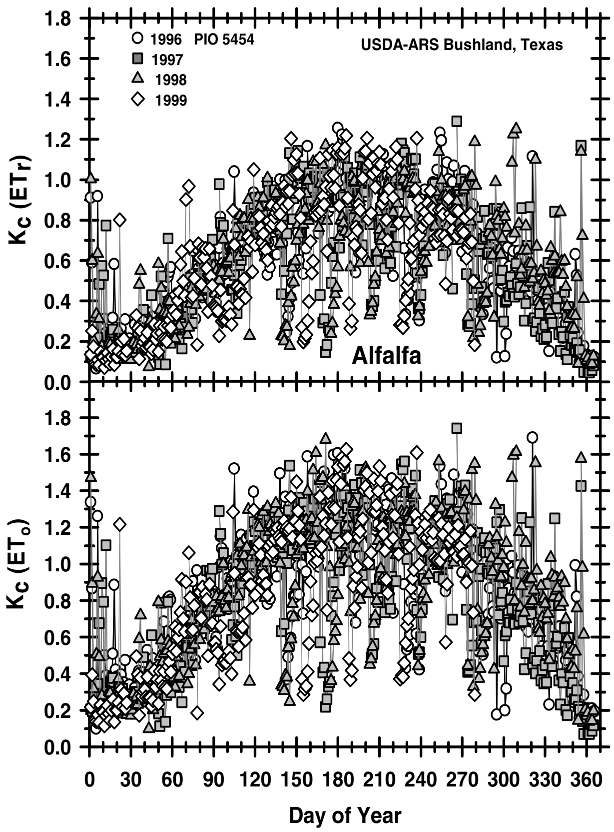

Figure 6. Bushland alfalfa crop coefficients.

Summary

This family of crop coefficients (K_c) from Bushland, TX is largely in agreement with those from Davis, CA; Kimberly, ID; and from FAO-56. Differences can be attributed to varietal and climatic differences. They can permit accuracy in estimating crop water use and improved water resource utilization from the Ogallala aquifer through better irrigation scheduling.

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