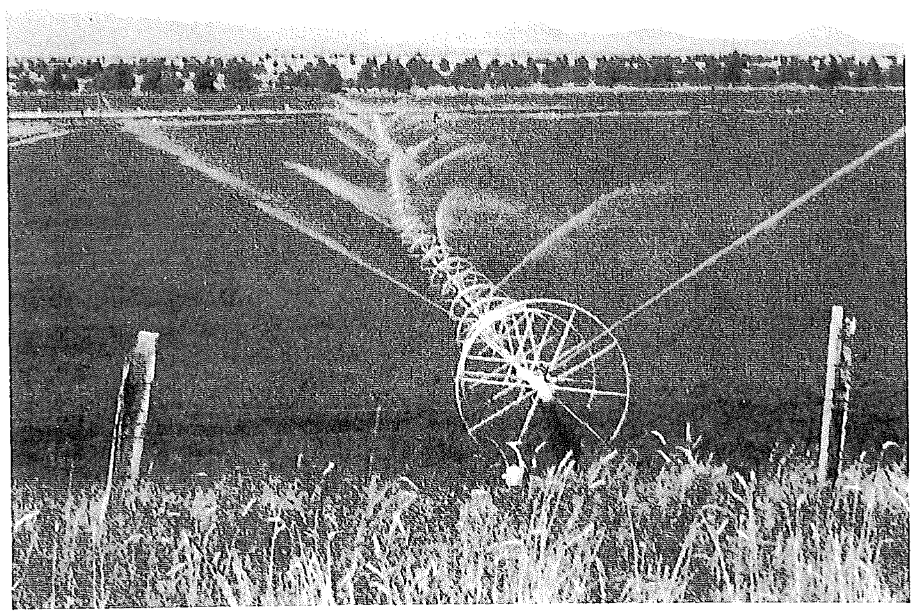
Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Agronomic Crops, Grasses, and Vegetable Crops



Reference evapotranspiration (ETo) information is now available in many agricultural areas of California through the California Irrigation Management Information System (CIMIS). Direct access to real-time (daily) weather and ETo information through a computer dialup service can be obtained by writing:

California Department of Water Resources
Office of Water Conservation
P.O. Box 942836
Sacramento, CA 94236-0001

These daily real-time ETo estimates are used by growers to determine a refined irrigation schedule that can optimize profits relative to the use of water.

Cooperative Extension **University of California**
Division of Agriculture and Natural Resources
Leaflet 21427

Historical average or "normal" ETo values are useful in determining an average or normal irrigation schedule for your crop that will give good results in most years. Daily normal ETo for many locations within California can be determined using the method and average monthly ETo accumulations given in Determining Daily Reference Evapotranspiration, UC Leaflet 21426. For locations not listed in Leaflet 21426, mean monthly ETo in mm/day can be obtained for any location in the state by interpolation using ETo isoline maps provided in Reference Evapotranspiration (ETo) for California, UC Bulletin 1922.

The real-time and normal ETo estimates approximate the evapotranspiration (ET) of a 4- to 7-inch tall, cool-season grass (an uncut pasture) that is not water stressed. The information can be used to estimate the ET of a crop (ETc) by multiplying the ETo values by factors (crop coefficients or Kc values) that account for the difference in ET between the crop and ETo. Daily changes in ETo, in response to variation in evaporative demand, affect the estimated ETc which is calculated as:

$$ETc = ETo \times Kc \qquad (1)$$

Although crop coefficients vary from day to day, depending on many factors, they are mainly a function of crop growth and development. The rate of crop growth and development will change from year to year, but the crop coefficient corresponding to a particular growth and development stage is fixed from year to year. This leaflet provides a method to determine daily Kc values to use corresponding to the growth and development of many agronomic crops, grasses, and vegetable crops grown in California.

General Crop Coefficient Curves

The Kc value on any given day is equal to the ratio of the ETc to the ETo on that day. Figure 1 shows measured values of ETo (ET grass) and ETc for beans from research done at the University of California at Davis. The ETo values vary from day to day but they are reasonably constant during the summer months shown. The ETc of beans start at a low value, increase to slightly higher than ETo during midseason, and then decrease to a low value at maturity when transpiration ceases. Most agronomic and vegetable crops have Kc trends similar to the beans.

> Ground shading is subjectively estimated as the percentage of the ground surface area shaded by a crop at midday.

The method used to determine Kc values involves separating the cropping season into specific growth and development periods consisting of the following:

Initial growth is the period from planting to about 10 percent ground shading by the crop. For alfalfa hay, it is from greenup or cutting to 10 percent ground shading.

Rapid growth is the period from approximately 10 percent to peak or 75 percent ground shading, whichever occurs first.

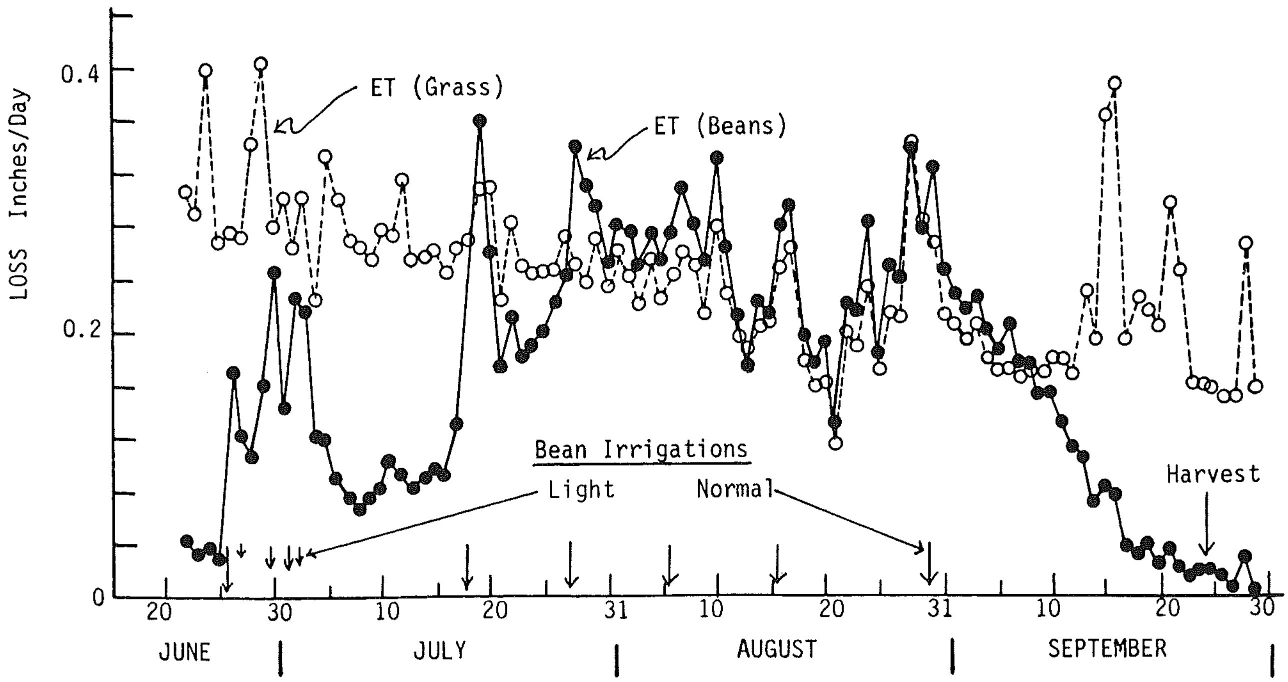


Fig. 1. Daily ET data for beans and grass measured using two lysimeters 20 feet in diameter, Davis, California, 1968. Unpublished data from W. O. Pruitt.

Midseason is the period from peak or 75 percent ground shading to when the crop transpiration begins to decrease due to aging. The end of midseason growth is difficult to identify visually but the ratio of days from planting until the end of midseason to days from planting until maturity is similar for a selected crop, regardless of where it is grown. Ratios for California crops are given as a percentage in the last two digits of the code in table 1.

Late season is the period from when the crop coefficient begins to decline due to crop aging until harvest or when transpiration ceases. For alfalfa, the Kc does not decline during late season unless it is being grown for seed.

Daily Kc Estimation

The letters A, B, C, D, and E represent the dates preceding initial growth (planting), rapid growth, midseason, late season, and at the end of late season, respectively. Table 1 gives crop coefficients that are expected on dates B, C, and E for many California crops and locations. These Kc values and the corresponding growth and development dates are used to determine Kc values on any date during the season.

The following sections will discuss Kc determination during each growth period. Beans planted on April 1 near Modesto in the San Joaquin Valley will serve as an example. The dates A, B, C, and E are April 1, April 30, May 25, and July 31, respectively, and the percentage of the growing season to date D is P = 74, which is listed as the last two digits of the code in table 1. The Kc values on dates B, C, and E are 0.14, 1.15, and 0.30, respectively.

Initial growth from date A to B

An estimate of the crop coefficient (Kc1) to use during initial growth is given in the Kc1 column of table 1 by crop and location in California. The corresponding planting dates are given in column A under growth dates. The Kc1 value for beans planted on April 1 in the San Joaquin Valley is 0.14, and it is plotted as the Kc during initial growth of dry beans in figure 2.

The Kc1 values provided in table 1 are typical for the region specified, but the value during initial growth can be affected by the frequency of rainfall or sprinkler irrigation. When the soil surface is exposed to sunlight and wet, the surface evaporation rate is greater and the Kc is higher. To adjust for these factors, figure 3 is used to estimate Kc1 based on the interval between irrigations or rainfall and on the average ETo during initial growth. For example, if the average ETo during the period is 0.15 inch per day and the recurrence interval is 10 days then Kc1 is 0.38. Equation 2 can also be used to calculate Kc1, where the recurrence interval in days is substituted for R and the average ETo is substituted for E in the equation.

$$Kc1 = 1.28 - 0.07515R + 0.001848R^2 + (-0.0493 - 0.01091R + 0.0004684R^2)(25.4E) + (0.0015 + 0.00075R - 0.0000302R^2)(25.4E)^2 \quad (2)$$

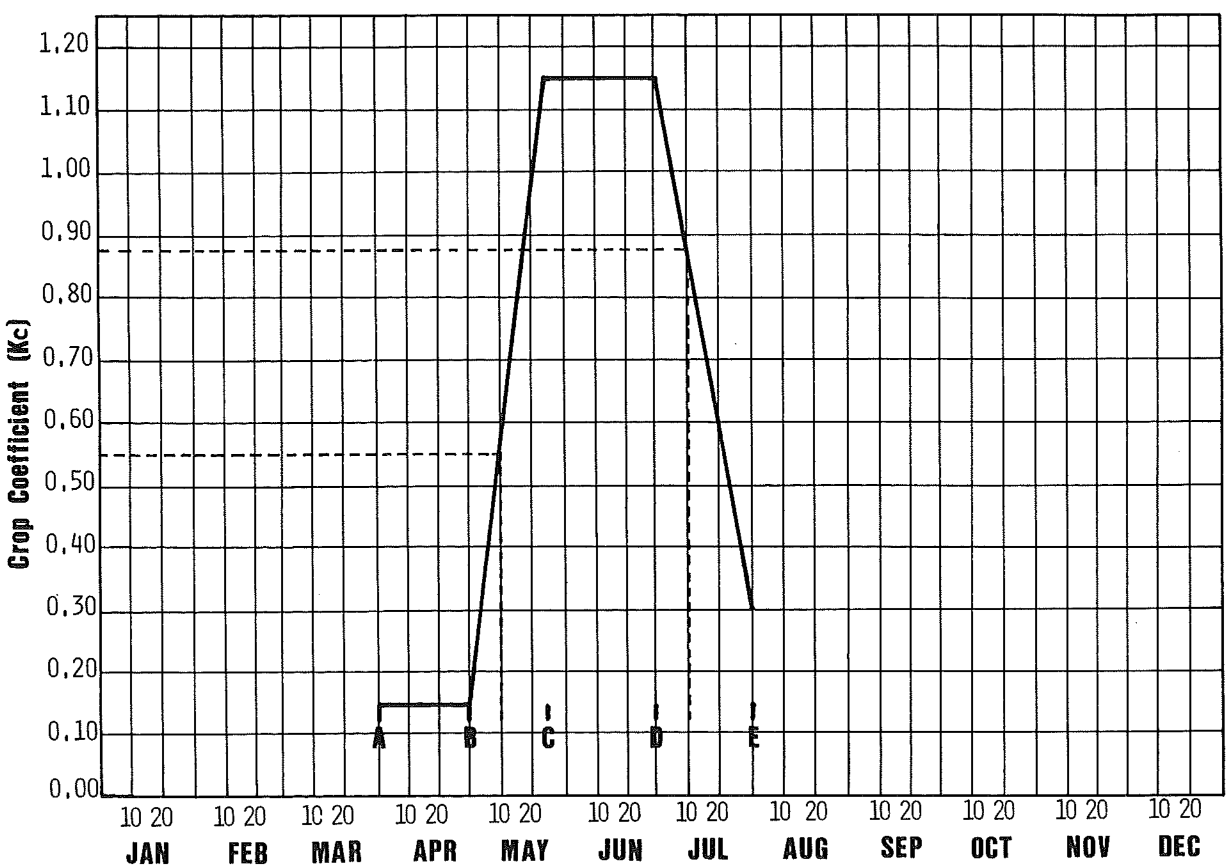


Fig. 2. Crop coefficient (Kc) curve for beans grown in the San Joaquin Valley with planting on April 1, 10 percent ground shading on April 30, 75 percent ground shading on May 25, and maturity on July 31.

If the average ETo exceeds 0.4 inch/day or the recurrence interval exceeds 20 days, values obtained from equation 2 will be inaccurate due to the limits of the equation. Under these conditions, use extrapolations of figure 3 to estimate Kc1 or use the Kc1 values in table 1.

Rapid growth from date B to C

Crop coefficients on each day during rapid growth are estimated by assuming the Kc changes linearly from Kc1 on date B to Kc2 on date C. A value for Kc1 is selected from table 1 or it is estimated using equation 2 or figure 2. For your crop and location, Kc2 is chosen from table 1. A line is drawn from Kc1 to Kc2 between dates B and C on a graph as shown in figure 3 for dry beans. To estimate the Kc value on a given date during rapid growth, locate the date on the bottom scale and move vertically up to the Kc line. Then follow a horizontal line to the left-hand scale and read the Kc for that day. For example, the Kc value on May 10 is 0.55.

Crop coefficients during rapid growth can also be estimated mathematically by determining the slope (b) of the Kc line as:

$$b1 = (Kc2 - Kc1) \div BC \qquad (3)$$

where BC is the number of days from date B to date C. Then the Kc on a date that is d1 days after date B during rapid growth is calculated as:

$$Kc = Kc1 + (b1 \times d1) \qquad (4)$$

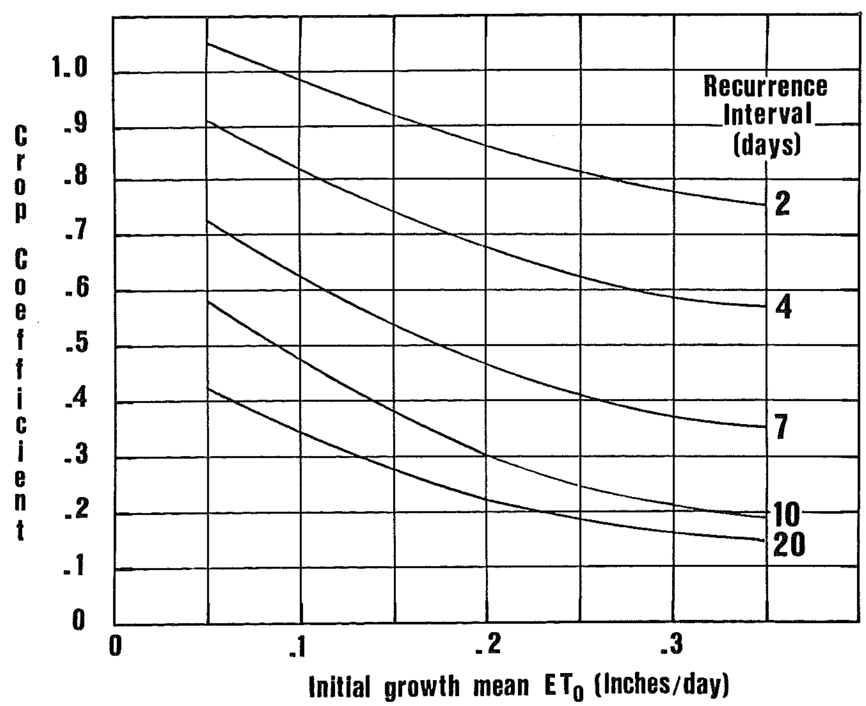


Fig. 3. Crop coefficients during initial growth of annual crops as a function of mean ETo during the period and recurrence interval of sprinkler irrigation or rainfall.
(Adapted from Doorenbos and Pruitt, 1977)

Midseason from date C to D

The Kc during midseason is set equal to Kc2. During this time, the crop ET rate is at its maximum in relation to ETo, and the Kc value is assumed to be constant. The end of midseason (date D) is determined as:

$$D = (P \div 100) \times AE \qquad (5)$$

where P is the percentage of the season from date A to D extracted from the last two digits of the code in table 1 and AE is the number of days in the growing season. For the beans example, late season begins at P = 74 percent of the season and the season is 121 days long so date D occurs (74 ÷ 100) x 121 = 90 days after planting or on June 30. A similar procedure would be used for other crops and locations.

Late season from date D to E

Crop coefficients during late season are assumed to change linearly from Kc2 on date D to Kc3 on date E. Kc2 and Kc3 are both estimated from table 1 for your crop and location. Late season Kc values are estimated graphically as shown in figure 3. A date during late season is located on the bottom scale and a line is followed upward to the Kc line. Then a horizontal line is followed from the intersection with the Kc line to the left-hand scale. For example, the Kc on July 10 is 0.88.

Crop coefficients during late season can also be determined mathematically by estimating the slope (b2) as:

$$b2 = (Kc3 - Kc2) \div DE \qquad (6)$$

where DE is the number of days from date D to date E. Then the Kc on a date d2 days after date D during late season is calculated as:

$$Kc = Kc2 + (b2 \times d2) \qquad (7)$$

Many combinations of crop coefficient and growth and development dates are given in table 1, but not every possibility is included. Use the information only as a guide to select subjectively the Kc values and growth and development dates.

Alfalfa and grass Kc estimates

Alfalfa growth stages were estimated, assuming that the cumulative ETc during a cutting cycle will equal the cumulative ETo during the same time period. After cutting on date A and at the beginning of midcycle, the Kc values were set to 0.4 and 1.2, respectively. The beginning of midcycle (date C) was fixed half way between cuttings and date B was varied until the cumulative ETc equaled cumulative ETo during the cycle. Usually, date B (10 percent ground shading) was one day after date A (cutting), or it was a few days after greenup. The Kc remains at 1.2 during late season, so selection of any P less than 100 percent or greater than 50 percent will not affect ETc estimation. Several agencies and researchers have recommended using ETo directly as a method to estimate alfalfa ETc. Using the growth dates and Kc values suggested in this leaflet, however, should improve accuracy.

Irrigated pasture that is 4 to 6 inches (10 to 15 cm) tall should use water at the ETo rate. Hence, ETc equals ETo and the Kc is equal to 1.0. Taller or shorter pasture grass will likely use slightly more or less than ETo and the Kc should be adjusted accordingly.

Turfgrasses are shorter than an irrigated pasture and use less water. A Kc of 0.80 will provide reasonably accurate estimates of ETc for a cool-season species. Warm-season turfgrasses use less water and a Kc of 0.60 will give good estimates of ETc. Often turfgrasses are a mixture of cool-season and warm-season species and a Kc of 0.7 may be sufficient for estimating ETc.

Conclusions

This information can be used to estimate daily crop coefficients for agronomic crops, grasses, and vegetable crops. These Kc values can be multiplied by normal or real-time (current) ETo values to obtain estimates of crop evapotranspiration.

Crop coefficient information provided here is based on measurements or estimates of crop water use and reference evapotranspiration. Crop ET can vary depending on irrigation method, crop variety, and irrigation management. Some trial and error is required to refine the information for a particular crop, location, and management.

It is important to note that evapotranspiration only provides information on how much water was depleted from the soil through the evapotranspiration process. Knowing how much water to apply also depends on uniformity of application, infiltration rates, runoff, water movement below the root zone, and contributions from other sources, such as water tables, dew, and precipitation. It is recommended that (1) the irrigation method or system be tested for application rate and efficiency and (2) the soil water or plant water status be monitored as a check against the evapotranspiration scheduling method.

Using ETc to estimate water use on fields with high water tables will often lead to overestimation of soil water depletion because water tables contribute an unknown quantity of water towards crop water use. The irrigation requirement is usually less than indicated by ETc in cropped fields with high water tables. Thus, an estimate of the water table contribution or a site-specific calibration of soil water depletions relative to ETc is required in these situations.

Table 1. Agronomic crop, vegetable crop, and miscellaneous coefficients for date B (Kc1), date C (Kc2), and date E (Kc3) with approximate growth dates. Growth dates are A = planting, B = 10 percent ground shading, C = 75 percent ground shading, and E = transpiration ceases or harvest. Select the data corresponding closely with your planting date for a first estimate of Kc and growth data for estimating ETc. Adjust the data as needed.

Region	Crop	Crop Coefficient[a]			Growth dates				Code[b]
		Kc1	Kc2	Kc3	A	B	C	E	
Imperial Valley	Alfalfa	0.40	1.20	1.20	11/15	11/19	12/09	01/15	275
		0.40	1.20	1.20	01/15	01/20	02/17	03/15	275
		0.40	1.20	1.20	03/15	03/16	04/04	04/14	275
		0.40	1.20	1.20	04/15	04/16	05/20	05/15	275
		0.40	1.20	1.20	05/15	05/16	06/01	06/15	275
		0.40	1.20	1.20	06/15	06/16	07/01	07/15	275
		0.40	1.20	1.20	07/15	07/16	07/31	08/15	275
		0.40	1.20	1.20	08/15	08/16	08/31	09/15	275
		0.40	1.20	1.20	09/15	09/16	10/09	11/15	275
	Asparagus	0.25	0.95	0.25	01/01	03/30	05/01	12/31	286
	Barley	0.23	1.04	0.10	11/30	12/16	02/02	05/31	261
		0.30	1.11	0.10	12/31	01/02	03/06	05/31	273
	Cantaloupe	0.42	0.96	0.90	01/31	03/01	04/15	05/31	291
		0.15	0.97	0.30	07/31	08/08	10/02	11/30	272
	Carrots	0.43	1.06	0.75	09/30	10/27	12/21	04/30	269
	Cotton	0.40	0.86	0.40	03/31	04/30	08/28	10/31	282
	Lettuce	0.17	1.02	0.45	08/31	09/20	10/31	12/31	271
		0.30	0.83	0.45	10/31	11/20	01/15	03/31	264
	Onions	0.75	1.03	0.20	12/31	02/15	04/01	05/31	265
	Sorghum (forage-cut 1)	0.14	1.01	0.15	03/31	04/25	05/21	08/31	256
	Sorghum (forage-cut 2)	0.57	1.20	0.30	07/30	08/11	09/07	11/30	243
	Sorghum (grain)	0.10	1.15	0.10	02/28	03/15	04/02	07/31	233
	Sorghum (grain)	0.09	1.19	0.10	05/31	06/12	07/06	10/31	237
	Squash	0.19	0.85	0.80	08/31	09/15	10/27	12/31	296
		0.45	1.30	0.05	12/31	01/21	02/21	04/30	246
	Sugarbeets	0.18	1.14	0.70	06/30	07/15	09/27	04/30	262
		0.28	1.10	0.75	09/30	10/17	12/06	06/30	283

Continued

Table 1. Continued

Region	Crop	Crop Coefficient[a] Kc1	Kc2	Kc3	Growth dates A	B	C	E	Code[b]
Imperial Valley (cont'd)	Tomatoes (processing)	0.41	1.20	0.60	01/31	03/07	04/18	06/30	279
	Tomatoes (marketing)	0.45	1.12	0.30	12/31	02/15	04/15	05/31	270
	Wheat	0.38	1.07	0.15	12/31	01/15	02/13	05/31	279
Northern Mountain Valleys	Alfalfa (4 cuttings)	0.40	1.20	1.20	04/01	04/07	04/30	05/25	275
		0.40	1.20	1.20	05/25	05/26	06/16	07/05	275
		0.40	1.20	1.20	07/05	07/06	07/26	08/15	275
		0.40	1.20	1.20	08/15	08/16	08/28	09/10	275
	Alfalfa (3 cuttings)	0.40	1.20	1.20	04/01	04/07	05/01	05/31	275
		0.40	1.20	1.20	05/31	06/01	06/26	07/15	275
		0.40	1.20	1.20	07/15	07/16	08/06	08/31	275
	Barley	0.27	1.15	0.10	04/30	05/10	06/14	08/31	269
	Potatoes	0.08	1.20	0.70	04/30	06/10	08/20	09/30	282
Sacramento Valley	Alfalfa	0.40	1.20	1.20	02/12	02/23	03/03	03/31	275
		0.40	1.20	1.20	04/01	04/03	04/18	05/15	275
		0.40	1.20	1.20	05/06	05/07	05/20	06/04	275
		0.40	1.20	1.20	06/05	06/06	06/18	07/02	275
		0.40	1.20	1.20	07/03	07/05	07/16	07/31	275
		0.40	1.20	1.20	08/01	08/02	08/16	08/31	275
		0.40	1.20	1.20	09/01	09/02	09/16	10/04	275
	Beans (pinto)	0.15	1.09	0.22	04/30	05/23	06/06	08/18	275
		0.08	1.08	0.30	06/03	06/11	07/14	09/22	276
	Corn	0.20	1.15	0.50	04/02	04/25	06/18	08/25	278
		0.20	1.15	0.48	04/30	05/24	07/07	09/08	273
		0.18	1.15	0.55	06/17	07/04	08/05	10/20	274
	Rice	0.95	1.24	1.00	05/13	06/12	07/17	10/31	280
	Small grains	0.20	1.23	0.10	10/14	11/06	01/10	06/02	273
		0.31	1.23	0.10	11/15	12/16	02/18	07/04	270
		0.25	1.20	0.15	12/16	01/12	03/30	08/04	271
	Sorghum (grain)	0.14	1.10	0.73	05/13	06/15	07/14	09/29	266
		0.13	1.12	0.43	06/17	07/13	08/05	10/27	262
		0.14	1.13	0.62	07/01	07/27	08/21	10/31	268
	Sugarbeets	0.25	1.10	1.00	01/29	03/19	05/15	08/25	292
		0.20	1.12	0.95	03/01	04/01	05/24	11/01	286
		0.11	1.14	0.83	04/02	04/15	06/29	12/31	287

Continued

Table 1. Continued

Region	Crop	Crop Coefficient[a]			Growth dates				Code[b]
		Kc1	Kc2	Kc3	A	B	C	E	
Sacramento Valley (cont'd.)	Tomatoes	0.26	1.11	0.73	02/26	04/22	06/11	08/11	282
		0.25	1.10	0.63	04/02	05/15	06/24	09/08	277
		0.25	1.14	0.90	04/30	05/25	07/07	09/22	272
		0.20	1.14	0.80	06/03	06/18	07/31	09/29	275
San Joaquin Valley	Alfalfa	0.40	1.20	1.20	02/12	02/22	03/07	03/21	275
		0.40	1.20	1.20	04/01	04/03	04/18	04/30	275
		0.40	1.20	1.20	05/06	05/07	05/20	06/04	275
		0.40	1.20	1.20	06/05	06/06	06/18	07/02	275
		0.40	1.20	1.20	07/03	07/04	07/15	07/31	275
		0.40	1.20	1.20	08/01	08/02	08/14	08/31	275
	Beans	0.14	1.15	0.30	04/01	04/30	05/25	07/31	274
		0.14	1.12	0.35	05/01	05/18	06/08	08/15	268
		0.14	1.07	0.20	06/16	07/01	07/26	09/30	274
	Corn	0.19	1.17	0.40	03/16	04/12	05/27	08/15	272
		0.19	1.17	0.40	04/01	04/25	06/14	08/31	268
		0.18	1.10	0.45	04/16	05/07	06/28	09/15	274
		0.19	1.06	0.55	05/16	06/07	07/16	09/30	277
		0.26	1.07	0.30	06/16	06/21	07/25	10/15	269
	Cotton	0.12	1.20	0.30	04/01	05/03	07/01	09/30	279
		0.16	1.18	0.40	04/16	05/18	07/06	10/15	269
		0.19	1.15	0.30	05/01	05/24	07/07	10/31	268
	Melons	0.14	1.10	0.10	02/15	03/31	04/30	06/30	279
		0.18	1.11	0.08	03/16	04/17	05/23	07/31	275
		0.18	1.10	0.10	04/16	05/09	06/22	08/15	278
	Onions	0.30	1.14	0.63	03/01	04/11	05/24	08/31	263
		0.18	1.15	0.78	09/16	10/06	01/01	05/31	272
		0.27	1.11	0.55	11/16	12/12	02/01	07/31	284
	Potatoes	0.51	1.15	0.75	12/01	02/24	03/26	05/15	287
		0.43	1.18	0.40	02/01	02/29	04/12	06/15	275
		0.55	1.21	0.40	03/01	03/21	04/26	06/30	269
	Rice	0.95	1.25	0.95	04/01	04/26	05/28	08/31	259
	Small grains	0.25	1.20	0.40	11/01	12/14	01/25	05/15	274
		0.22	1.17	0.38	12/01	12/24	03/02	05/31	275
		0.23	1.18	0.18	12/16	01/20	03/16	06/30	274
		0.30	1.17	0.20	01/01	02/01	03/22	06/30	272

Continued

Table 1. Continued

Region	Crop	Crop Coefficient[a] Kc1	Kc2	Kc3	Growth dates A	B	C	E	Code[b]
San Joaquin Valley (cont'd.)	Sorghum (grain)	0.16	1.05	0.45	05/01	06/04	07/04	09/30	265
		0.14	1.08	0.30	06/16	07/12	08/10	10/31	263
		0.13	1.06	0.30	07/01	07/29	08/22	11/15	268
	Sugarbeets	0.24	1.13	0.90	02/01	03/27	05/13	08/31	270
		0.15	1.11	0.95	03/16	04/10	06/07	09/15	263
		0.20	1.07	1.00	05/01	05/20	07/13	12/15	289
		0.23	1.10	0.95	06/16	07/06	08/13	03/15	284
	Tomatoes	0.25	1.16	0.70	03/01	04/28	06/10	08/15	272
		0.24	1.12	0.70	04/01	05/08	06/28	08/31	271
		0.25	1.12	0.68	05/01	05/22	07/18	09/15	269
	Tomatoes	0.20	1.00	0.80	03/23	04/23	05/30	08/02	275
Statewide	Open water surfaces	1.10	1.10	1.10	-	01/01	05/01	12/31	375
	Wet light soil	1.05	1.05	1.05	-	01/01	05/01	12/31	375
	Wet dark soil	1.10	1.10	1.10	-	01/01	05/01	12/31	375
	Grazed pasture	0.90	0.90	0.90	-	01/01	05/01	12/31	375
	Grass-clover	1.05	1.05	1.05	-	01/01	05/01	12/31	375

[a]Crop coefficients were estimated from Fereres et al. (1981), Doorenbos and Pruitt (1977), Letey and Vaux (1984), CDWR (1986), Phene et al. (1985), and Pruitt and Snyder (1984).

[b]The first digit of the code identifies the crop type (2 = annual crop or alfalfa; 3 = constant year-round Kc). The last two digits are the percentage of the growing season from date A and to date D. Date D is the date when the Kc values begin to decline due to crop aging. When the crop type is equal to 3, the precentage to date D is set to 99.

References

CDWR. 1986. Crop Water Use in California. Bulletin 113-4, California Department of Water Resources.

Doorenbos, J., and W. O. Pruitt. 1977. Crop water requirements. 2nd edition, Irrigation and Drainage Paper No. 24, FAO, Rome. 144 pp.

Fereres, E., P. M. Kitlas, W. O. Pruitt, and R. M. Hagan. 1980. Development of irrigation management programs. Report prepared for the California Department of Water Resources. Agreement No. B53142.

Letey, J., and H. J. Vaux, Jr. 1984. Water duties for California agriculture. Report prepared for the California Water Resources Control Board, Sacramento, Calif. Agreement No. 2-043-300-0.

Phene, C., D. W. Meek, K. R. Davis, R. L. McCormick, and R. B. Hutmacher. 1985. Real-time crop evapotranspiration and determination of crop coefficients. Proceedings ASAE Publication 14-85. pp. 122-128.

Pruitt, W. O., E. Fereres, K. Kaita and R. L. Snyder. 1987. Reference evapotranspiration (ETo) for California. UC Bulletin 1922. 14pp + 12 plates.

Pruitt, W. O., and R. L. Snyder. 1984. Crop water use. Chapter 5 in G. S. Pettygrove and T. Asano (eds.), Irrigation with Reclaimed Municipal Wastewater--A Guidance Manual. California Water Resources Control Board. Report No. 84-1 Wr. pp. 5-7.

Snyder, R. L., W. O. Pruitt, and D. A. Shaw. 1987. Determining daily reference evapotranspiration (ETo). UC Leaflet 21426. 12 pp.

The Authors

The authors are Richard L. Snyder, Biometeorologist, Cooperative Extension, Davis; Brenda J. Lanini, former Staff Research Associate, Cooperative Extension, Davis; David A. Shaw, Postgraduate Researcher, Cooperative Extension, Davis, and William O. Pruitt, Irrigation Engineer, Department of Land, Air and Water Resources, Davis.

Acknowledgements

The authors wish to thank Ed Craddock, Tom Hawkins, and Richard Wagner of the California Department of Water Resources for their contributions to this leaflet.

Partial funding for development of this leaflet was provided by the **California Department of Water Resources, Office of Water Conservation.**

1m-rep-9/94-HS/FB

Printed on recycled paper.