Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Trees and Vines

Introduction

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.

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.

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Division of Agriculture and Natural Resources
Leaflet 21428

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. 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 assumed to be constant from year to year. Daily changes in ETo, in response to variation in evaporative demand, affect the estimated ETc which is calculated as:

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

This leaflet provides a method to determine daily Kc values to use corresponding to the growth and development of tree and vine crops grown in California.

General Crop Coefficient Curves

The Kc value on any given day is equal to the ratio of ETc to ETo on that day. Figure 1 shows average ETo and ETc curves for almonds grown near Bakersfield in the San Joaquin Valley. The ETc curve was determined using crop coefficients from table 1 assuming no ground cover and a leafout date of March 1. Figure 2 shows the Kc curve for the almond example calculated as the ratio of ETc to ETo on each day. Most deciduous tree and vine crops have similarly shaped Kc trends during a growing season. If the crop has a ground cover during the spring and fall, the early and late season Kc values are higher and there would be less change in Kc values over the season.

The method used to estimate Kc values involves separating the cropping season into the following growth and development periods.

Rapid growth is the period from leafout to when the leaves grow to near their maximum size and vegetative growth has slowed. Some sample dates for the end of rapid growth are given by crop and leafout date in table 1.

Midseason is the period from the end of rapid growth to when the crop transpiration begins to decrease due to aging. The end of midseason growth is difficult to visually identify, but the ratio of number of days from leafout until the end of midseason to the number of days from leafout until the time when transpiration ceases is nearly constant for a 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 transpiration begins to decline due to aging until crop transpiration ceases or leaf drop occurs.

Daily Kc Estimation

The letters B, C, D, and E represent the dates preceding rapid growth, midseason, late season, and at the end of late season, respectively. Table 1 gives crop coefficients and typical growth and development dates for many California crops and locations. It is not possible to list Kc values for all crops and varieties, so those given in table 1 should be used only as a guide for choosing the correct information.

The following sections will discuss daily Kc estimation during each growth period using almonds grown near Bakersfield in the San Joaquin Valley as an example. Growth dates B, C, and E are March 1, May 28, and October 31, respectively, from table 1. The percentage of the season from leafout to date D is P = 78, which is listed as the last two digits of the code in table 1. The Kc values on the selected dates B, C, and E are 0.52, 0.87, and 0.65, respectively, for almonds without a cover crop. If a cover crop was grown in the spring and fall, the Kc1 and Kc3 values would need to be adjusted upward according to the table 1 footnote to 0.82 and 0.85, respectively. However, no cover crop is assumed in this example.

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 as shown in figure 2. The values 0.52 and 0.87 were selected for Kc1 and Kc2 from table 1. To estimate the Kc value on an intermediate date, locate the date on the bottom scale and follow a line up to the Kc line. Then follow a line horizontally to the left-hand scale and read the Kc for that day. For example, the Kc value on March 31 is approximately 0.64.

Crop coefficients during rapid growth can also be estimated mathematically by determining the slope (b1) of the Kc line as:

$$b1 = (Kc2 - Kc1) \div BC \qquad (2)$$

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:

$$Kc = Kc1 + (b1 \times d1) \qquad (3)$$

Midseason from date C to D

The Kc during midseason is set equal to Kc2 (figure 2). The end of midseason (date D) is determined as:

$$D = (P \div 100) \times AE \qquad (4)$$

where P is the percentage of the growing season from date B to date D, given as the last two digits of the code in table 1 and AE is the number of days during the growing season. For the almond example, late season begins at P = 78 percent of the season and the season is 244 days long, so date D occurs at: (78 ÷ 100) x 244 = 190 days after leafout, or on September 7.

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. Late season Kc values can be determined graphically using figure 2. A date during late season is located on the bottom scale and a line is followed upward to the Kc line. Then a line is horizontally followed from the intersection with the Kc line to the left-hand scale. For example, the Kc on September 30 is approximately 0.78.

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

$$b2 = (Kc3 - Kc2) \div DE \qquad (5)$$

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:

$$Kc = Kc2 + (b2 \times d2) \qquad (6)$$

Cover Crops

Cover crops in orchards and vineyards increase the evapotranspiration from a crop during rapid growth and late season because the cover crop will transpire more water than would evaporate from a bare soil surface. Note that Kc values for deciduous trees in table 1 are for orchards with no cover crop and they should be adjusted upward if a cover crop is grown. Guidelines on the adjustment are given in the footnotes for table 1.

Correction for immature deciduous trees

Evapotranspiration rates depend on the percentage of ground shaded by a crop, and immature crops use less water. Ground shading is determined by subjectively estimating the percentage of ground surface area shaded by the crop canopy at midday during midseason. Cover crop shading is not included in estimates of shading by the orchard or vineyard. Figure 3 can be used to adjust estimated ETc for a mature crop to that of an immature crop. Find the percentage ground shading by the crop at midseason on the bottom scale; go upward to the curve and then to the left-hand scale to read what percentage of mature ETc will be used by the crop. The percentage of mature ETc can also be determined using equation 7 for percent ground shading up to 61%,

$$PER = 3.050 + 2.558\ G - 0.016\ G^2 \qquad (7)$$

where PER is the percentage of mature ETc and G is the percent ground shading. Note that this correction is based on studies of drip-irrigated deciduous trees and corrections for other crops and irrigation systems might be different.

Citrus

The Kc values for citrus are treated differently from those for deciduous trees and vines. A reasonably accurate estimate of citrus ETc can be made assuming a constant Kc of 0.65 or 0.56 for the entire year in the Central Valley or southern California desert, respectively. No definitive information is available on the water use of immature citrus. However, a correction similar to that for deciduous trees might be reasonable if updated as the trees grow during the season.

Conclusions

The information provided here can be used to estimate daily crop coefficients for tree and vine crops. These Kc values can be multiplied by normal or real-time daily ETo values to obtain estimates of crop evapotranspiration (ETc).

Averaging daily Kc values over a period of time and multiplying by accumulated ETo will give estimates of accumulated ETc. However, accuracy decreases as length of time period increases during rapid growth or late season.

Crop coefficient information given 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.

Evapotranspiration estimates only provide information on how much water was depleted from the soil by a crop. 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 efficiency, and (2) 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.

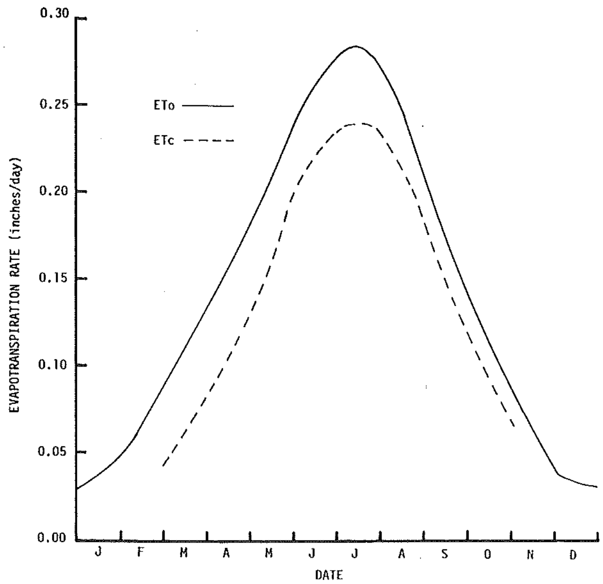

Fig. 1. Normal reference evapotranspiration (ETo) and crop evapotranspiration (ETc) for almonds with no cover crop grown near Bakersfield, California.

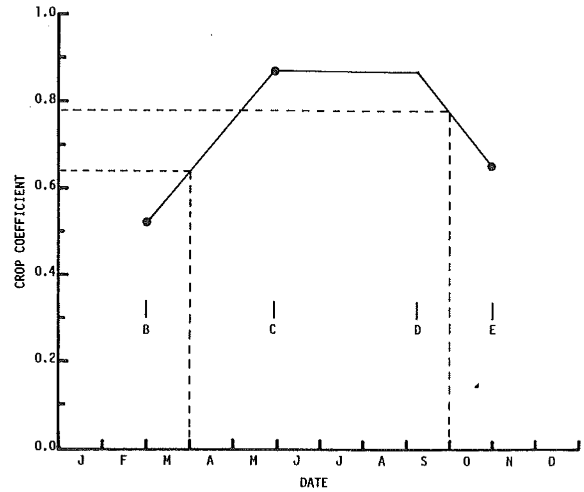

Fig. 2. Crop coefficient (Kc) curve for almonds grown with no cover crop in the San Joaquin Valley with leafout (date B) on March 1, 60 percent ground shading (date C) on May 28, and leafdrop (date E) on October 31.

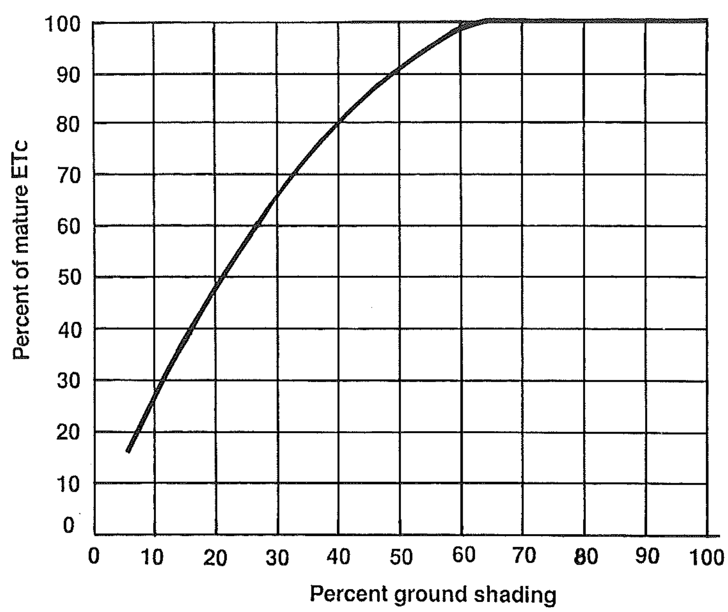

Fig. 3. Relationship between the percent ground area shaded by tree canopy in midsummer and ETc of drip-irrigated young trees as a percent of ETc of mature orchards (estimated from figure 8 in UC Leaflet 21259).

Table 1. Tree and vine coefficients[a] for date B (Kc1), date C (Kc2), and date E (Kc3) with approximate growth dates. Crop coefficients given for deciduous trees are for **no cover crop**. See the footnotes to correct Kc values for cover crops. Choose the crop coefficients and growth dates corresponding most closely to leafout date (B) for your crop to obtain a first estimate of the Kc values and dates to use for calculating ETc.

		Crop Coefficient			Growth dates			
Region	Crop	Kc1	Kc2	Kc3	B	C	E	Code[b]
Imperial Valley	Citrus	0.56	0.56	0.56	01/01	05/01	12/31	375
	Deciduous orchard	0.55	0.95	0.70	02/28	06/24	10/31	186
	Guayule	0.28	0.72	0.50	01/01	07/24	12/31	166
Central Valley	Deciduous[c] orchard	0.50	0.91	0.48	02/12	05/30	11/03	175
		0.55	0.92	0.52	02/26	06/24	11/10	174
		0.52	0.87	0.65	03/01	05/28	10/31	178
		0.50	0.86	0.75	03/16	06/09	11/15	180
	Deciduous[d] orchard	0.50	1.01	0.53	02/12	05/30	11/03	175
		0.55	1.02	0.57	02/26	06/24	11/10	174
		0.52	0.93	0.88	04/15	06/10	11/10	190
		0.52	0.97	0.85	03/01	05/28	10/31	178
		0.50	0.96	0.80	03/16	06/09	11/15	180
		0.50	0.85	0.80	04/01	06/02	11/30	190
	Grapes	0.35	0.81	0.27	03/12	05/30	09/22	172
		0.25	0.80	0.27	03/26	05/25	10/06	171
		0.27	0.82	0.32	04/30	07/06	11/10	169
		0.06	0.78	0.20	03/01	05/10	09/30	173
		0.07	0.80	0.30	03/16	05/30	10/15	164
		0.07	0.76	0.12	04/16	06/24	11/15	175
	Kiwifruit	0.31	1.05	1.05	04/15	06/01	10/31	175
	Citrus	0.65	0.65	0.65	01/01	05/01	12/31	375
	Olives	0.58	0.80	0.80	03/31	06/19	10/31	175
	Pistachio	0.04	1.12	0.33	03/31	06/04	08/07	161
Statewide	Evergreen shrubbery	1.15	1.15	1.15	01/01	05/01	12/31	375
	trees	1.20	1.20	1.20	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), Goldhamer, et al. (1985), Pruitt and Snyder (1984), and Buchner, Shaw and Schulbach (1985).

[b]The first digit of the code identifies the crop type (1 = deciduous; 3 = constant year-round Kc). For deciduous crops, the last two digits are the percentage of the season from leafout (date B) to date D when the Kc begins to decline due to aging. When the crop type is equal to 3, the Kc values do not decline and the last two digits of the code set equal to 99.

[c]Includes peaches, apricots, pears, plums, almonds and pecans without a cover crop. Add 0.30 to Kc1, 0.25 to Kc2, and 0.20 to Kc3 for orchards with an active cover crop.

[d]Includes apples, cherries, and walnuts without a cover crop. Add 0.40 to Kc1, 0.30 to Kc2, and 0.30 to Kc3 for orchards with an active cover crop.

References

Buchner, R. P., D. A. Shaw, and H. Schulbach. 1985. Kiwi irrigation scheduling. Soil and Water Newsletter, No. 62. University of California Cooperative Extension. pp. 1-6.

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. (ed.). 1981. Drip irrigation management. UC Leaflet 21259.

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.

Goldhamer, D. A., R. K. Kjelgren, R. Beede, L. Williams, J. M. Moore, J. Lane, G. Weinberger, and J. Menezes, Jr. 1985. Water use requirements of pistachio trees and response to water stress. Annual report to the California Pistachio Industry. pp. 85-92.

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.

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.

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Acknowledgments

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.

3m-rep-2/89-HS/FB