CO652.0408 State Supplement

This section contains examples and procedures using materials from this chapter along with other State-approved material.

(a) Calculation of the Leaching Fraction and Total Irrigation Requirement

Salts are added to the soil as irrigation water is applied. If no water leaches below the root zone, salts will accumulate and eventually reduce yields as discussed in Colorado Supplement 3-1. The amount of water required to control salt and maintain root-zone soil salinity low enough to produce an acceptable yield of a specific crop is the leaching requirement. The leaching fraction is dependent upon the salt load of the applied water and the salt tolerance of the crop. Satisfying the leaching requirement is easier on light textured soils than on heavier textured soils.

There are several methods for calculating the leaching requirement for a specific crop and a given water supply. Two methods are presented here. The first was developed by Jim Rhoades[1] at the U.S. Salinity Laboratory in 1974.

$LR = EC_w / (5EC_e - EC_w)$ where

LR = Leaching requirement

EC_w = Salinity of applied water

EC_e = Soil salinity tolerated by the crop

The appropriate units for salinity in this equation are in terms of millimhos per centimeter or decisiemens per meter.

Table CO 3-2 gives soil threshold values for some common crops in Colorado. Links are provided in Colorado Supplement 3-1 to the U.S. Salinity Laboratory which has an extensive database of EC_e values for crops.

An irrigation water analysis and analysis of soil samples from each ¼ of the rooting zone are needed to determine the leaching requirement. The average EC_e value from each ¼ of the root zone should be used. The following example illustrates calculation of the leaching fraction by this method.

Given:

Crop = Alfalfa
$EC_w = 2.0$
$EC_e = 3.4$ (Table CO 3-2, 10% yield reduction)

$LR = EC_w / (5EC_e - EC_w)$
$LR = 2.0 / (5(3.4) – 2.0) = 2.0 / 15.0 = 0.13$ or 13%

This means that 13% of the applied water must percolate below the root zone. The seasonal consumptive use of the crop must be increased by this amount. Rainfall that enters the soil during or after the growing season is equally effective in satisfying a leaching requirement and is part of the leaching fraction.

A second method for determination of the leaching requirement was also developed by Jim Rhoades in 1992. This calculation takes the form of two equations, one for high frequency application of irrigation water such as a sprinkler system, and the other for conventional irrigation such as gated pipe systems. These exponential relations can be calculated as follows:

$LF = 0.1794 / (F_c)^{3.0417}$ (High Frequency)

$LF = 0.3086 / (F_c)^{1.7020}$ (Conventional)

Where: $F_c = EC_{e(ct)} / EC_w$

LF = leaching fraction

$EC_{e(ct)}$ = crop tolerance threshold

EC_w = conductivity of the irrigation water

Table CO 3-2 gives soil threshold values for some common crops in Colorado. Links are provided in Colorado

Supplement 3-1 to the U.S. Salinity Laboratory which has an extensive database of $EC_{e(ct)}$ values for crops.

An irrigation water analysis is still needed to determine the leaching requirement. This method is best used for calculating a leaching fraction for field maintenance during the planning process, does not require soil sampling, and should not be used for fields that show evidence of a salinity problem requiring remediation such as a high Sodium Adsorption Ratio which could potentially require the addition of amendments. The following examples illustrate calculation of the leaching fraction by this method.

Given:

Crop = Alfalfa
Irrigation System = Sprinkler
$EC_w = 2.0$
$EC_{e(ct)} = 3.4$ (Table CO 3-2, 10% yield reduction)

$LF = 0.1794 / (F_c)^{3.0417}$
$F_c = EC_{e(ct)} / EC_w$
$F_c = (3.4 / 2.0) = 1.7$
$LF = 0.1794 / (1.7)^{3.0417} = 0.03$ or 3%

Given:

Crop = Alfalfa
Irrigation System = Sprinkler
$EC_w = 2.0$
$EC_{e(ct)} = 3.4$ (Table CO 3-2, 10% yield reduction)

$LF = 0.3086 / (F_c)^{1.7020}$
$F_c = EC_{e(ct)} / EC_w$
$F_c = (3.4 / 2.0) = 1.7$
$LF = 0.3086 / (1.7)^{1.7020} = .125$ or 12.5%

The amount of water that needs to be applied to meet crop needs and the leaching requirement can be calculated as follows:

$$A_w = ET / (1 – LR) – (SW + EP)$$

where:

Aw = applied water requirement (net)
ET = crop water requirement
LR = leaching requirement
SW = water in root zone at start of growth
EP = effective precipitation after growing season starts

The following example illustrates computation of the applied water requirement.

Given:

ET = 30 inches
LR = 13%
SW = 6 inches
EP = 4 inches

$A_w = ET / (1 – LR) – (SW + EP)$
$A_w = 30 / (1 – .13) – (6 + 4)$
$A_w = 30 / (.87) – 10$
$A_w = 34.5 – 10$
$A_w = 24.5$ inches

(b) Examples

The following is an example of how to calculate a weighted consumptive use

Given: 80 acres of Alfalfa, 40 acres Wheat, and 20 acres Beans
The monthly consumptive use for each of the crops is given in the following table.

Crop	May	June	July	August	September
Alfalfa	3.57	5.17	7.65	6.10	3.26
Wheat	3.41	5.57	4.30	0.03	
Beans	0.48	3.12	7.50	5.29	

Find: The average daily weighted consumptive use for the maximum month.

Solution:

Step 1. Find the maximum monthly water demand.

Crop	May	June	July	August	September
Alfalfa	3.57	5.17	7.65	6.10	3.26
Wheat	3.41	5.57	4.30	0.03	
Beans	0.48	3.12	7.50	5.29	
Totals	7.46	13.86	19.45	11.42	3.26

Maximum month is July at 19.45”

Step 2. Multiply the July consumptive use by the acres for each crop then add the three together.

Alfalfa *80 acres x 7.65in = 612 ac-in*
Wheat *40 acres x 4.30in = 172 ac-in*
Beans *20 acres x 7.50in = 150 ac-in*
Total *934 ac-in*

Then divide by the total number of acres $\frac{934 ac - in}{140 ac} = 6.67 inches$

Step 3. Convert into a daily value by dividing by the number of days in the month.

$\frac{6.67 inches}{31 days} = 0.22 in / day$ This then can be used in future calculations.

It should be noted that this is an average daily consumptive use. In irrigation systems, information on peak period consumptive use is needed for proper design. When selecting a peak consumptive use several factors need to be considered:

1. Soil Water – when the crop evapotranspiration demands are higher than the irrigation system capacity plus rainfall, soil water can be used to provide the difference. This will reduce the peak consumptive use needed for the system. In order to do this a careful accounting of the soil water status is required.
2. Net Irrigation Application – the net irrigation application affects the water readily available to the plants and the wetted surface evaporation. Thus, the smaller net irrigation applications will result in a greater daily use rate for a given period of time. Conversely, higher net irrigation applications will result in a lower use rate.
3. Frequency distribution – the design capacity of an irrigation system for a field depends on the expected crop consumptive use at a given probability level. Many factors must be considered in developing the probability distribution. The probability level selected for design purposes should be based on an economic analysis considering the reduction in crop yield.
4. Time Averaging – an analysis of daily mean consumptive use records for any month at any location will show that the mean consumptive use for the any consecutive 5-day period will be greater than for a consecutive 10-day period. Likewise the 10-day period will be greater than a 15-day period, and so on. So the shorter the period is in days, the greater the consumptive use rate.
5. In the past, the formula

$$U_p = 0.034 * U_m^{1.09} * I^{-0.09}$$

has been used to estimate peak consumptive use. This relationship should only be used for general estimates and where other peak consumptive use methods cannot be applied. For a full discussion on Peak ET_c or consumptive use see National Engineering Handbook Part 623 Chapter 2, pages 2-197 through 2-209.

(c) Reduction of Plant Available Water due to Salinity or Rock Fragments

The effective water holding capacity of a soil can be reduced significantly by the presence of salts or coarse rock fragments in the soil profile, and may require adjustment to the AWC. The reduction of the AWC due to salinity is due to the fact that both the matric and osmotic potential of soil water is always less than zero from the perspective of the plant, and these potentials tend to pull water away from the plant root. As the soil moisture increases, matric potential decreases, and the plant will expend less energy taking up water from the soil. Matric potential approaches zero at saturation. At approximately 1/3 bar, Field Capacity (FC) is reached, and all gravimetric water has been removed from the soil profile. At a soil suction of approximately 15 bars, the plant can no longer extract water from the soil profile, and the Permanent Wilting Point (PWP) is reached. PWP is the soil moisture level at which most crops wilt beyond recovery. Increases in salts affect the soil water potential, resulting in less available matric water for the plant to utilize. Crops can, under some circumstances, show signs of moisture stress even though soil moisture monitoring indicates sufficient soil moisture above the MAD, and a suction of only a few bars. Table CO 4-1 provides a guide to making these adjustments. If rock fragments and salinity are both present, reduce the AWC for the rock fragment component first, then for the salinity component. The National Soil Survey Handbook, Part 618.05 can be used as a source of additional information when making these adjustments.

Table CO 4-1: Guide for Estimating Reduction of AWC from Rock Fragments and/or Salts[1]

% Passing #10 Sieve	EC_e (dS/m)	% Gravel by Volume	Available Water Capacity (AWC) Values (in/in, or cm/cm)											
100		**0**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**
95	2	5	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.14	0.19	0.24	0.29
90/85	4	10	0.03	0.03	0.05	0.05	0.06	0.07	0.08	0.09	0.14	0.18	0.23	0.27
80/75		15	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.13	0.17	0.21	0.26
70	8	20	0.02	0.03	0.04	0.05	0.06	0.06	0.07	0.08	0.12	0.16	0.20	0.24
65/60		25	0.02	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.11	0.15	0.19	0.23
55	12	30	0.02	0.03	0.04	0.04	0.05	0.06	0.06	0.07	0.11	0.14	0.18	0.21
50		35	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.07	0.10	0.13	0.16	0.20
45	16	40	0.02	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.09	0.12	0.15	0.18
40		45	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.06	0.08	0.11	0.14	0.17
35		50	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.08	0.10	0.13	0.15
30		55	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.07	0.09	0.11	0.14
25	20	60	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.06	0.08	0.10	0.12
20		65	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.04	0.05	0.07	0.09	0.11
20		70	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.05	0.06	0.08	0.09
		75	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.04	0.05	0.06	0.08
	25	80	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.04	0.05	0.06
		85	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.05
	30	90	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03
	35	95	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.02
		100	0	0	0	0	0	0	0	0	0	0	0	0

[1] If soil is affected by both coarse fragments and salts, reduce the coarse fragments first and then the salts.
EC_e = Electrical conductivity of saturated paste extract. Units of mmho cm^{-1} and dS m^{-1} are equivalent.
Example: To reduce the AWC by 25% gravel. If AWC is 0.15, then find 0.15 on the top row and drop down to the row that corresponds with 25% gravel, which will give 0.11.
Source: National Soil Survey Handbook 618.05.

(d) Climate Zone and Peak Use Rate

Climate zones have been established within Colorado to assist with generalized estimation of crop consumptive use for planning purposes. A map of the Colorado climate zones is shown in Figure CO 4-1. The formula

$$U_p = 0.034 * U_m^{1.09} * I^{-0.09}$$

has been used to estimate peak consumptive use. This relationship should only be used for general estimates and where other peak consumptive use methods cannot be applied. For a full discussion on Peak ET_c or consumptive use see National Engineering Handbook Part 623 Chapter 2, pages 2-197 through 2-209. Table CO 4-2 utilizes the formula above to estimate the seasonal and monthly consumptive use of crops. Table CO 4-3 gives recommended design use rates for peak consumptive use in inches per day^{-1}.

Table CO 4-2: Peak Period Average daily Consumptive Use Related to Estimated Monthly Use

Net Irrigation Application (Inches)	**Computed Monthly Consumptive Use Rate (U_m) in Inches** (1)														
	4.0	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**	**10.0**	**11.0**	**12.0**
	Average Daily Use Rate (up) in Inches per Day														
1.0	**.15**	**.18**	**.20**	**.22**	**.24**	**.26**	**.28**	**.31**	**.33**	**.35**	**.37**	**.40**	**.42**	**.46**	**.51**
1.5	**.15**	**.17**	**.19**	**.21**	**.23**	**.25**	**.27**	**.29**	**.32**	**.34**	**.36**	**.38**	**.41**	**.45**	**.50**
2.0	**.15**	**.16**	**.18**	**.20**	**.23**	**.25**	**.27**	**.29**	**.31**	**.33**	**.35**	**.37**	**.39**	**.44**	**.48**
2.5	**.14**	**.16**	**.18**	**.20**	**.22**	**.24**	**.26**	**.28**	**.30**	**.32**	**.34**	**.36**	**.39**	**.43**	**.47**
3.0	**.14**	**.16**	**.18**	**.20**	**.22**	**.24**	**.26**	**.28**	**.30**	**.32**	**.34**	**.36**	**.38**	**.42**	**.46**
3.5	**.14**	**.16**	**.18**	**.19**	**.21**	**.23**	**.25**	**.27**	**.29**	**.31**	**.33**	**.35**	**.37**	**.41**	**.46**
4.0	**.14**	**.15**	**.17**	**.19**	**.21**	**.23**	**.25**	**.27**	**.29**	**.31**	**.33**	**.35**	**.37**	**.41**	**.45**
4.5	**.14**	**.15**	**.17**	**.19**	**.21**	**.23**	**.25**	**.27**	**.29**	**.31**	**.33**	**.35**	**.37**	**.41**	**.45**
5.0	**.13**	**.15**	**.17**	**.19**	**.21**	**.23**	**.25**	**.26**	**.28**	**.30**	**.32**	**.34**	**.36**	**.40**	**.44**
5.5	**.13**	**.15**	**.17**	**.19**	**.21**	**.22**	**.24**	**.26**	**.28**	**.30**	**.32**	**.34**	**.36**	**.40**	**.44**
6.0	**.13**	**.15**	**.17**	**.19**	**.20**	**.22**	**.24**	**.26**	**.28**	**.30**	**.32**	**.34**	**.36**	**.40**	**.43**

(1) Based on the formula $U_p = 0.034 * U_m^{1.09} * I^{-0.09}$ where:

U_p = Average peak period consumptive use in inches
U_m = Average consumptive use for the month in inches
I = net irrigation application in inches

Table CO 4-3: Recommended Design use Rates by Climate Zone

Climate Zone 1

Crop	Net Irrigation Application				
	1”	2”	3”	4”	5”
Alfalfa	.37	.35	.34	.33	.32
Sugar Beets	.37	.35	.34	.33	.32
Corn, Grain	.35	.33	.32	.31	.30
Corn, Silage	.33	.31	.30	.29	.28
Grasses, Pasture	.31	.29	.28	.27	.26
Melons & Cantaloupe	.26	.25	.24	.23	.23
Sorghum, Grain	.35	.33	.32	.31	.30
Vegetables, Small	.23	.21	.21	.20	.20
Wheat, Winter	.24	.23	.22	.21	.21

Climate Zone 2

Crop	Net Irrigation Application				
	1”	2”	3”	4”	5”
Alfalfa	.34	.32	.31	.30	.29
Beans, Dry	.32	.30	.28	.28	.27
Sugar Beets	.33	.31	.30	.29	.28
Corn, Grain	.28	.27	.26	.25	.25
Corn, Silage	.27	.26	.25	.24	.24
Grain, Spring	.31	.29	.28	.27	.26
Grasses, Pasture	.28	.27	.26	.25	.25
Orchard w/ Cover	.34	.32	.31	.30	.29
Orchard w/o Cover	.28	.27	.26	.25	.25
Vegetable, Small	.24	.23	.22	.21	.21

Climate Zone 3

Crop	Net Irrigation Application				
	1”	2”	3”	4”	5”
Alfalfa	.31	.29	.28	.27	.26
Beans, Dry	.26	.25	.24	.23	.23
Sugar Beets	.33	.31	.30	.29	.28
Corn, Grain	.28	.27	.26	.25	.25
Corn, Silage	.28	.27	.26	.25	.25
Grain, Spring	.20	.18	.18	.17	.17
Grasses, Pasture	.25	.23	.22	.21	.21
Wheat, Winter	.20	.18	.18	.17	.17

Climate Zone 4

Crop	Net Irrigation Application				
	1”	2”	3”	4”	5”
Alfalfa	.28	.27	.26	.25	.25
Corn, Silage	.24	.23	.22	.21	.21
Grain, Spring	.24	.23	.22	.21	.21
Grasses, Pasture	.23	.21	.21	.20	.20
Wheat, Winter	.25	.23	.22	.21	.21

Climate Zone 5

Crop	Net Irrigation Application				
	1”	2”	3”	4”	5”
Alfalfa	.26	.25	.24	.23	.23
Corn, Silage	.22	.20	.20	.19	.19
Grain, Spring	.22	.20	.20	.19	.19
Grasses, Pasture	.21	.19	.19	.18	.18
Wheat, Winter	.20	.18	.18	.17	.17

Climate Zone 6

Crop	Net Irrigation Application				
	1”	2”	3”	4”	5”
Alfalfa	.24	.23	.22	.21	.21
Corn, Silage	.22	.20	.20	.19	.19
Grain, Spring	.20	.18	.18	.17	.17
Grasses, Pasture	.24	.23	.22	.21	.21
Wheat, Winter	.12	.11	.10	.10	.10

Climate Zone 7

Crop	Net Irrigation Application				
	1”	2”	3”	4”	5”
Alfalfa	.19	.17	.17	.16	.16
Grasses, Pasture	.15	.15	.14	.14	.13

Figure CO 4-1: Map of Colorado Climate Zones

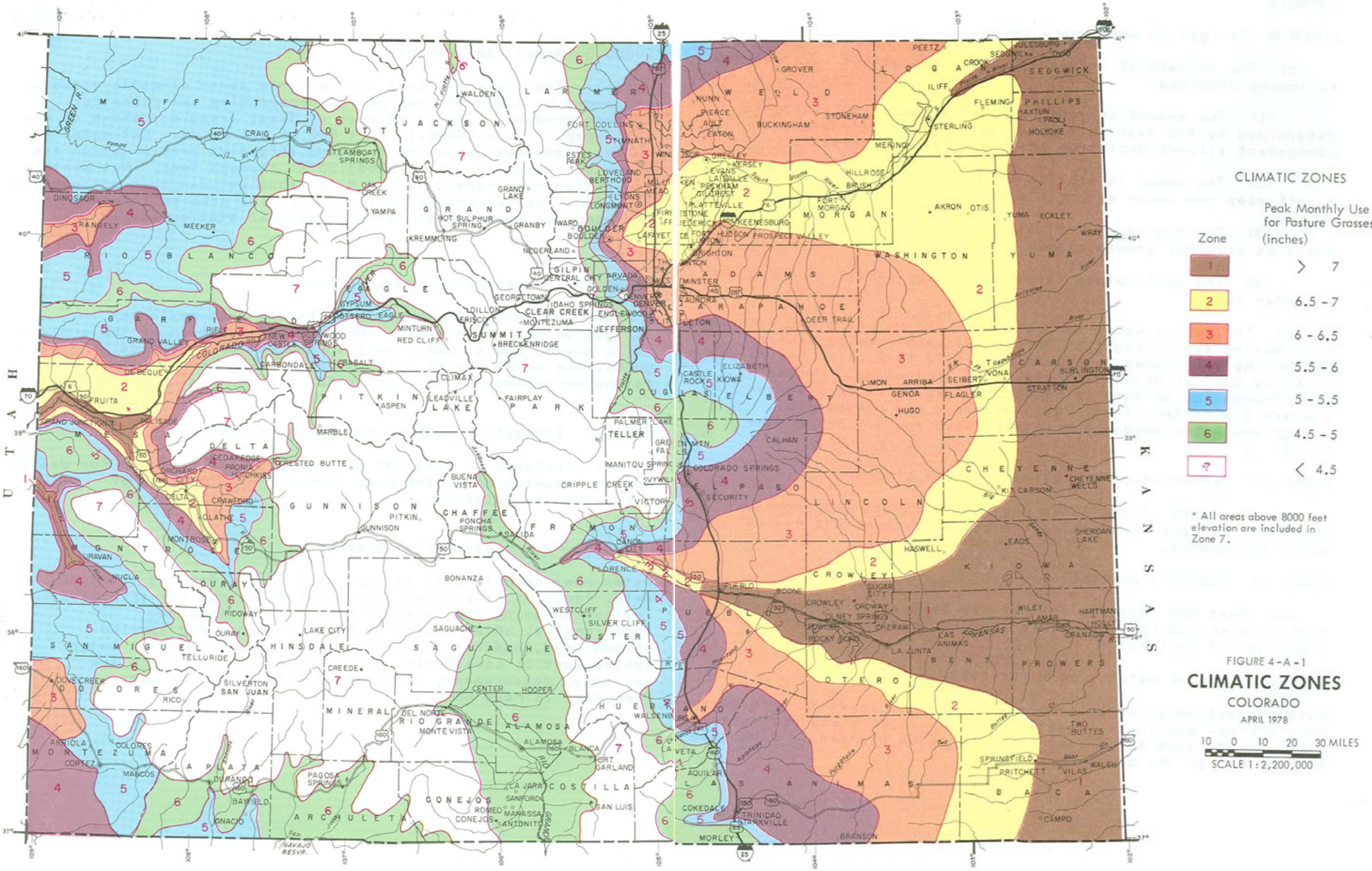

Table CO4-4. Mean crop coefficients, K_{co}, and basal crop coefficients, K_{cbo}, for well-managed crops in a subhumid climate, for use with ET_{os} (following FAO-56*).

Crop	$K_{c\ ini}$ [1]	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
a. Small Vegetables	**0.7**	**1.05**	**0.95**	**0.15**	**0.95**	**0.85**
Broccoli		1.05	0.95		0.95	0.85
Brussels sprouts		1.05	0.95		0.95	0.85
Cabbage		1.05	0.95		0.95	0.85
Carrots		1.05	0.95		0.95	0.85
Cauliflower		1.05	0.95		0.95	0.85
Celery		1.05	1.00		0.95	0.90
Garlic		1.00	0.70		0.90	0.60
Lettuce		1.00	0.95		0.90	0.90
Onions, dry		1.05	0.75		0.95	0.65
green		1.00	1.00		0.90	0.90
seed		1.05	0.80		1.05	0.70
Spinach		1.00	0.95		0.90	0.85
Radish		0.90	0.85		0.85	0.75
b. Vegetables, Solanum Family (*Solanaceae*)	**0.6**	**1.15**	**0.80**	**0.15**	**1.10**	**0.70**
Eggplant		1.05	0.90		1.00	0.80
Sweet peppers (bell)		1.05[2]	0.90		1.00[2]	0.80
Tomato		1.15[2]	0.70-0.90		1.10[2]	0.60-0.80
c. Vegetables, Cucumber Family (*Cucurbitaceae*)	**0.5**	**1.00**	**0.80**	**0.15**	**0.95**	**0.70**
Cantaloupe	0.5	0.85	0.60		0.75	0.50
Cucumber, fresh market	0.6	1.00[2]	0.75		0.95[2]	0.70
machine harvest	0.5	1.00	0.90		0.95	0.80
Pumpkin, winter squash		1.00	0.80		0.95	0.70
Squash, zucchini		0.95	0.75		0.90	0.70
Sweet melons		1.05	0.75		1.00	0.70
Watermelon	0.4	1.00	0.75		0.95	0.70
d. Roots and Tubers	**0.5**	**1.10**	**0.95**	**0.15**	**1.00**	**0.85**
Beets, table		1.05	0.95		0.95	0.85
Cassava, year 1	0.3	0.80[3]	0.30		0.70[3]	0.20
year 2	0.3	1.10	0.50		1.00	0.45
Parsnip	0.5	1.05	0.95		0.95	0.85
Potato		1.15	0.75[4]		1.10	0.65[4]
Sweet potato		1.15	0.65		1.10	0.55
Turnip (and rutabaga)		1.10	0.95		1.00	0.85
Sugar beet	0.35	1.20	0.70[5]		1.15	0.50[5]

* Primary sources of Table 8.2: FAO-56 (Allen et al., 1998), with $K_{c\ ini}$ traceable to Doorenbos and Kassam (1979) and $K_{c\ mid}$ and $K_{c\ end}$ traceable to Doorenbos and Pruitt (1977), Pruitt (1986), Wright (1981, 1982), and Snyder et al. (1989a,b).

[1] These are general values for $K_{c\ ini}$ under typical irrigation management and soil wetting. For frequent wettings such as with high frequency sprinkle irrigation or daily rainfall, these values may increase substantially and may approach 1.0 to 1.2. $K_{c\ ini}$ is a function of wetting interval and potential evaporation rate during the initial and development periods and is more accurately estimated using Figure 8.5 or using the dual $K_{cb\ ini} + K_e$.

[2] Beans, peas, legumes, tomatoes, peppers and cucumbers are sometimes grown on stalks reaching 1.5 to 2 meters in height. In such cases, increased K_c values need to be taken. For green beans, peppers and cucumbers, 1.15 can be taken, and for tomatoes, dry beans and peas, 1.20. Under these conditions h should be increased also.

[3] The midseason values for cassava assume non-stressed conditions during or following the rainy season. The $K_{c\ end}$ and $K_{cb\ end}$ values account for dormancy during the dry season.

[4] The $K_{c\ end}$ and $K_{cb\ end}$ values for potatoes are about 0.40 and 0.35 for long season potatoes with vine kill.

[5] This $K_{c\ end}$ and $K_{cb\ end}$ values are for no irrigation during the last month of the growing season. The $K_{c\ end}$ and $K_{cb\ end}$ values for sugar beets are higher, up to 1.0 and 0.9, when irrigation or significant rain occurs during the last month.

(continued)

Table CO4-4. continued.

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
e. Legumes (*Leguminosae*)	**0.4**	**1.15**	**0.55**	**0.15**	**1.10**	**0.50**
Beans, green	0.5	1.05[2]	0.90		1.00[2]	0.80
Beans, dry, and pulses	0.4	1.15[2]	0.35		1.10[2]	0.25
Chick pea		1.00	0.35		0.95	0.25
Faba bean (broad bean), fresh	0.5	1.15[2]	1.10		1.10[2]	1.05
dry/seed	0.5	1.15[2]	0.30		1.10[2]	0.20
Garbanzo	0.4	1.15	0.35		1.05	0.25
Green gram and cowpeas		1.05	0.60-0.35[6]		1.00	0.55-0.25[6]
Groundnut (peanut)		1.15	0.60		1.10	0.50
Lentil		1.10	0.30		1.05	0.20
Peas, fresh	0.5	1.15[2]	1.10		1.10[2]	1.05
dry/seed		1.15	0.30		1.10	0.20
Soybeans		1.15	0.50		1.10	0.30
f. Perennial Vegetables (with winter dormancy and initially bare or mulched)	**0.5**	**1.00**	**0.80**			
Artichokes	0.5	1.00	0.95	0.15	0.95	0.90
Asparagus	0.5	0.95[7]	0.30	0.15	0.90[7]	0.20
Mint	0.60	1.15	1.10	0.40	1.10	1.05
Strawberries	0.40	0.85	0.75	0.30	0.80	0.70
g. Fiber Crops	**0.35**			**0.15**		
Cotton		1.15-1.20	0.70-0.50		1.10-1.15	0.50-0.40
Flax		1.10	0.25		1.05	0.20
Sisal[8]		0.4-0.7	0.4-0.7		0.4-0.7	0.4-0.7
h. Oil Crops	**0.35**	**1.15**	**0.35**	**0.15**	**1.10**	**0.25**
Castor bean (*Ricinus*)		1.15	0.55		1.10	0.45
Rapeseed, canola		1.0-1.15[9]	0.35		0.95-1.10[9]	0.25
Safflower		1.0-1.15[9]	0.25		0.95-1.10[9]	0.20
Sesame		1.10	0.25		1.05	0.20
Sunflower		1.0-1.15[9]	0.35		0.95-1.10[9]	0.25
i. Cereals	**0.3**	**1.15**	**0.4**	**0.15**	**1.10**	**0.25**
Barley, oats		1.15	0.25		1.10	0.15
Spring wheat		1.15	0.25-0.4[10]		1.10	0.15-0.3[10]
Winter wheat, frozen soils	0.4	1.15	0.25-0.4[10]	0.15-0.5[11]	1.10	0.15-0.3[10]
with non-frozen soils	0.7	1.15	0.25-0.4[10]			
Maize, field (grain corn)[12]		1.20	0.60,0.35	0.15	1.15	0.50,0.15
Maize, sweet (sweet corn)[12]		1.15	1.05[13]		1.10	1.00[13]
Millet		1.00	0.30		0.95	0.20
Sorghum, grain		1.00-1.10	0.55		0.95-1.05	0.35
sweet		1.20	1.05		1.15	1.00
Rice	1.05	1.20	0.90-0.60	1.00	1.15	0.70-0.45

[6] The first $K_{c\ end}$ is for harvested fresh. The second value is for harvested dry.

[7] The K_c for asparagus usually remains at $K_{c\ ini}$ during harvest of the spears, due to sparse ground cover. The $K_{c\ mid}$ value is for following regrowth of plant vegetation following termination of harvest of spears.

[8] K_c for sisal depends on the planting density and water management (e.g., intentional moisture stress).

[9] The lower values are for rainfed crops having less dense plant populations.

[10] The higher value is for hand-harvested crops.

[11] The two $K_{cb\ ini}$ values for winter wheat are for less than 10% ground cover and for during the dormant, winter period, if the vegetation fully covers the ground, but conditions are nonfrozen.

[12] The $K_{c\ mid}$ and $K_{cb\ mid}$ values are for populations > 50,000 plants ha^{-1}. For less dense populations or less uniform growth, $K_{c\ mid}$ and $K_{cb\ mid}$ can be reduced by 0.10 to 0.2. The first $K_{c\ end}$ value is for harvest at high grain moisture. The second $K_{c\ end}$ value is for harvest after complete field drying of the grain (to about 18% moisture, wet mass basis).

[13] If harvested fresh for human consumption. Use $K_{c\ end}$ for field maize if the sweet maize is allowed to mature and dry in the field.

(continued)

Table CO4-4. continued.

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
j. Forages						
Alfalfa hay, ave.cutting effects	0.40	0.95[13]	0.90			
individual cutting periods	0.40[14]	1.20[14]	1.15[14]	0.30[14]	1.15[14]	1.10[14]
for seed	0.40	0.50	0.50	0.30	0.45	0.45
Bermuda hay, ave.cutting effects	0.55	1.00[13]	0.85	0.50	0.95[15]	0.80
spring crop for seed	0.35	0.90	0.65	0.15	0.85	0.60
Clover hay, berseem,						
averaged cutting effects	0.40	0.90[13]	0.85			
individual cutting periods	0.40[14]	1.15[14]	1.10[14]	0.30[14]	1.10[14]	1.05[14]
Ryegrass hay, ave. cuttings	0.95	1.05	1.00	0.85	1.00[15]	0.95
Sudan grass hay (annual),						
averaged cutting effects	0.50	0.90[13]	0.85			
individual cutting periods	0.50[14]	1.15[14]	1.10[14]	0.30[14]	1.10[14]	1.05[14]
Grazing pasture, rotated grazing	0.40	0.85-1.05	0.85	0.30	0.80-1.00	0.80
extensive grazing	0.30	0.75	0.75	0.30	0.70	0.70
Turf grass, cool season[16]	0.90	0.90	0.90	0.80	0.85	0.85
warm season[16]	0.85	0.90	0.90	0.75	0.80	0.80
k. Sugar Cane	0.40	1.25	0.75	0.15	1.20	0.70
l. Tropical Fruits and Trees						
Banana, 1st year	0.50	1.10	1.00	0.15	1.05	0.90
2nd year	1.00	1.20	1.10	0.60	1.10	1.05
Cacao	1.00	1.05	1.05	0.90	1.00	1.00
Coffee, bare ground cover	0.90	0.95	0.95	0.80	0.90	0.90
with weeds	1.05	1.10	1.10	1.00	1.05	1.05
Date palms	0.90	0.95	0.95	0.80	0.85	0.85
Palm trees	0.95	1.00	1.00	0.85	0.90	0.90
Pineapple,[17] bare soil	0.50	0.30	0.30	0.15	0.25	0.25
with grass cover	0.50	0.50	0.50	0.30	0.45	0.45
Rubber trees	0.95	1.00	1.00	0.85	0.90	0.90
Tea, non-shaded	0.95	1.00	1.00	0.90	0.95	0.90
shaded[18]	1.10	1.15	1.15	1.00	1.10	1.05
m. Berries and Hops						
Berries (bushes)	0.30	1.05	0.50	0.20	1.00	0.40
Hops	0.30	1.05	0.85	0.15	1.00	0.80

[13] This $K_{c\ mid}$ for hay crops represents an averaged K_c for before and following cuttings. It is applied to the period following the first development period until the beginning of the last late season period of the growing season.

[14] These K_c coefficients for hay crops represent immediately following cutting; at full cover; and immediately before cutting, respectively. The growing season is described as a series of individual cutting periods (Figure 8.4).

[15] This $K_{cb\ mid}$ for bermuda and ryegrass hay crops represents an averaged $K_{cb\ mid}$ for before and following cuttings. It is applied to the period following the first development period until the beginning of the last late season period.

[16] Cool season grass varieties include dense stands of bluegrass, ryegrass, and fescue. Warm season varieties include bermuda and St. Augustine. Values given are for *potential conditions* representing a 0.06- to 0.08-m mowing height. Turf, especially warm season varieties, can be stressed at moderate levels and still maintain appearance (see Section 8.6 and Table 8.13). Generally a value for the stress coefficient K_s of 0.9 for cool-season and 0.7 for warm-season varieties can be employed where careful water management is practiced and rapid growth is not required. Incorporating these K_s values into an "actual K_c" will yield $K_{c\ act}$ values of about 0.8 for cool-season and 0.65 for warm-season turf.

[17] The pineapple plant has very low transpiration because it closes its stomates during the day and opens them during the night. Therefore, the majority of ET_c from pineapple is evaporation from the soil. The $K_{c\ mid} < K_{c\ ini}$ since $K_{c\ mid}$ occurs during full ground cover so that soil evaporation is less. Values assume that 50% of the ground surface is covered by black plastic mulch and that irrigation is by sprinkler. For drip irrigation beneath the plastic mulch, K_c values given can be reduced by 0.10.

[18] Includes the water requirements of the shade trees.

(continued)

Table CO4-4. continued.

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
n. Fruit Trees and Grapes						
Conifer trees[19]	1.00	1.00	1.00	0.95	0.95	0.95
Kiwi	0.40	1.05	1.05	0.20	1.00	1.00

The following, shaded, section for trees and grapes gives values for $K_{cb\ full}$ used in Eq. 8.85.

	$K_{cb\ full}$[20] initial	$K_{cb\ full}$[20] mid	$K_{cb\ full}$[20] end	$K_{c\ min}$[20]	$K_{cb\ cover}$[20] initial	$K_{cb\ cover}$[20] mid, end
Almonds, no ground cover[21]	0.20	1.00	0.70[22]	0.15		
ground cover	0.20	1.00	0.70[22]	0.15	0.75	0.80
Apples, cherries, pears;						
killing frost[23]	0.30	1.15	0.80[22]	0.15	0.40	0.80
no killing frost[23]	0.30	1.15	0.80[22]	0.15	0.75	0.80
Apricots, peaches, pears, plums, pecans;						
killing frost[24]	0.30	1.20	0.80[22]	0.15	0.40	0.80
no killing frost[25]	0.30	1.20	0.80[22]	0.15	0.70	0.80
Avocado, no grnd cover[26]	0.30	1.00	0.90	0.15		
ground cover	0.30	1.00	0.90	0.15	0.75	0.80
Citrus[27]	0.80	0.80	0.80	0.15	0.75	0.80
Mango, no ground cover[28]	0.25	0.85	0.70	0.15		
Olives[29]	0.60	0.70	0.60	0.15	0.70	0.70
Pistachios	0.30	1.00	0.70	0.15	0.70	0.70
Walnut[30]	0.40	1.10	0.65	0.15	0.75	0.80
Grapes, table or raisin[31]	0.20	1.15	0.90	0.15	0.70	0.70
wine[32]	0.20	0.80	0.60	0.15	0.70	0.70

[19] Conifers exhibit substantial stomatal control due to soil water deficit. The K_c can easily reduce below the values presented, which represent well-watered conditions for large forests.

[20] The first three columns for the orchard crops in the following rows are values for $K_{cb\ full}$ for initial, mid- and end-season periods to be used in Eq. 8.85 along with the $K_{c\ min}$ of column 4 to calculate K_{cb} for the initial, midseason and late-season periods, where the density coefficient, K_d, is calculated from Eq. 8.80 using effective fraction of cover $f_{c\ eff}$ and plant height, h, as noted in the following footnotes. The last two columns are $K_{cb\ cover}$ for initial and for mid- and end-season periods to be used in Eq. 8.85 for when there is active ground cover. Generally the value for $K_{c\ ini}$ is estimated as $0.10 + K_{cb\ ini}$ from Eq. 8.85 and $K_{c\ mid}$ and $K_{c\ end}$ are estimated as $0.05 + K_{cb\ mid}$ or $K_{cb\ end}$ from Eq. 8.85.

[21] Apply Eq. 8.80 with $f_{c\ eff} = 0.4$, $M_L = 1.5$ and h = 4 m for K_d in Eq. 8.85 to derive K_{cb} values similar to FAO-56.

[22] These $K_{c\ end}$ values represent K_c prior to leaf drop. After leaf drop, $K_{c\ end} \approx 0.20$ for bare, dry soil or dead ground cover and $K_{c\ end} \approx 0.50$ to 0.80 for actively growing ground cover.

[23] Apply Eq. 8.80 with $f_{c\ eff} = 0.5$, $M_L = 2$ and h = 3 m for K_d in Eq. 8.85 to derive K_{cb} values similar to FAO-56.

[24] Apply Eq. 8.80 with $f_{c\ eff} = 0.45$, $M_L = 1.5$ and h = 3 m for K_d in Eq. 8.85 to derive K_{cb} values similar to FAO-56.

[25] Apply Eq. 8.80 with $f_{c\ eff} = 0.8$, $M_L = 1.5$ and h = 3 m for K_d in Eq. 8.85 to derive K_c values similar to Johnson et al. (2005), with $f_{c\ eff} = 0.6$, $M_L = 1.5$, h = 3 m for K_c values similar to those derived from Girona et al. (2005), with $f_{c\ eff} = 0.45$, $M_L = 1.5$, h = 3 m for K_{cb} values similar to FAO-56, with $f_{c\ eff} = 0.29$, $M_L = 1.5$, h = 2.5 m for K_c values similar to Paço et al. (2006), and with any $f_{c\ eff} \leq 0.7$, $M_L = 1.5$, h = 3 m to approximate K_c estimates by Ayars et al. (2003).

[26] Apply Eq. 8.80 with $f_{c\ eff} = 0.4$, $M_L = 2$ and h = 4 m for K_d in Eq. 8.85 to derive K_{cb} values similar to FAO-56.

[27] Apply Eq. 8.80 with $f_{c\ eff} = 0.2$, 0.5 and 0.7, $M_L = 1.5$ and h = 2, 2.5 and 3 m for K_d in Eq. 8.85 to derive recommended K_{cb} values that are about 15% higher than the values entered in FAO-56 for these same three levels of $f_{c\ eff}$.

[28] Apply Eq. 8.80 with $f_{c\ eff} = 0.7$ to 0.85, $M_L = 1.5$ and h = 5 m for K_d in Eq. 8.85 for K_{cb} values similar to those derived from de Azevedo et al. (2003).

[29] Apply Eq. 8.80 with $f_{c\ eff} = 0.7$, $M_L = 1.5$ and h = 4 m for K_d in Eq. 8.85 to derive K_{cb} values similar to FAO-56. Apply with $f_{c\ eff} = 0.6$, $M_L = 1.5$, h = 4 m to derive K_c values similar to Pastor and Orgaz (1994), but with $K_{cb\ mid} = 0.45$. Apply with $f_{c\ eff} = 0.3$ to 0.4, $M_L = 1.5$, h = 4 m to derive K_{cb} values similar to Villalobos et al. (2000). Apply with $f_{c\ eff} = 0.05$ and 0.25, $M_L = 1.5$, h = 2 and 3 m to derive K_c values similar to Testi et al. (2004).

[30] Apply Eq. 8.80 with $f_{c\ eff} = 0.7$, $M_L = 1.5$ and h = 5 m for K_d in Eq. 8.85 to derive K_{cb} values similar to FAO-56.

[31] Apply Eq. 8.80 with $f_{c\ eff} = 0.65$, $M_L = 1.5$ and h = 2 m for K_d in Eq. 8.85 to derive K_c values similar to Johnson.et al. (2005). Apply with $f_{c\ eff} = 0.45$, $M_L = 1.5$, h = 2 m for K_{cb} values similar to FAO-56.

[32] Apply Eq. 8.80 with $f_{c\ eff} = 0.5$, $M_L = 1.5$ and h = 2 m for K_d in Eq. 8.85 to derive K_{cb} values similar to FAO-56.

(continued)

Table CO4-4. continued.

Crop	$K_{c\ ini}$ [1]	$K_{c\ mid}$	$K_{c\ end}$
o. Wetlands, Temperate Climate			
Cattails, bulrushes, killing frost	0.30	1.20	0.30
Cattails, bulrushes, no frost	0.60	1.20	0.60
Short veg., no frost	1.05	1.10	1.10
Reed swamp, standing water	1.00	1.20	1.00
Reed swamp, moist soil	0.90	1.20	0.70
p. Special			
Open water, < 2 m depth or in subhumid climates or tropics		1.05	1.05
Open water, > 5 m depth, clear of turbidity, temperate climate		0.65[33]	1.25[33]

[33] These K_c values are for deep water in temperate latitudes where large temperature changes in the water body occur during the year, and initial and peak period evaporation is low as radiation energy is absorbed into the deep water body. During fall and winter periods ($K_{c\ end}$), heat is released from the water body that increases the evaporation above that for grass. Therefore, $K_{c\ mid}$ corresponds to the period when the water body is gaining thermal energy and $K_{c\ end}$ when releasing thermal energy. These K_c values should be used with caution.

The start of maturity and beginning of decline in K_c is often signaled by the beginning of aging, yellowing or senescence of leaves, leaf drop, or the browning of fruit so that ET_c is reduced relative to ET_o. Calculations for K_c and ET_c are sometimes presumed to end when the crop is harvested, dries out naturally, reaches full senescence, or experiences leaf drop. For some perennial vegetation in frost-free climates, crops may grow year round so that the date of termination is the same as the date of "planting." The length of the late season period may be relatively short (less than 10 days) for vegetation killed by frost (for example, maize at high elevations in latitudes > 40°N) or for agricultural crops that are harvested fresh (for example, table beets and small vegetables). The value for $K_{c\ end}$ should reflect the condition of the soil surface (average water content and any mulch cover) and the condition of the vegetation following harvest or after full senescence. K_c during nongrowing periods having little or no green ground cover can be estimated using the equation for $K_{c\ ini}$ as described later.

FAO-56 provides general lengths of growth (development) stages for a wide variety of crops under different climates and locations. This information is reproduced in Table 8.3. The lengths in Table 8.3 serve only to indicate typical proportions of growing season lengths under a variety of climates. In all applications, local observations of the specific plant stage development should be made to account for local effects of plant variety, climate, and cultural practices. Local information can be obtained by interviewing farmers, ranchers, agricultural extension agents, and local researchers, by conducting local surveys, or by remote sensing (Neale et al., 1989; Tasumi et al., 2005).