drought tips

Number 92-34

Citrus Irrigation Scheduling During a Drought

Knowing when to irrigate a crop and how much water to apply is especially important during a drought. Irrigation timing depends on the irrigation method, soil water intake characteristics, and the difference between water content at field capacity (when the soil is essentially full of water) and the actual soil water content at a given time.

The difference between field capacity and the actual soil water content is called the "soil water depletion." Irrigation timing and the amount of water to be applied are determined by monitoring or estimating soil water depletion and applying water when the depletion reaches a pre-selected level, called the management allowable depletion (MAD). The management allowable depletion is set at a level that will prevent yield-reducing water stress and also be compatible with the irrigation method.

For surface (flood or furrow) irrigation, MAD is usually set at a level that will maximize the distribution uniformity of the water infiltrated into the soil. If the tree roots are shallow or the soil has low water-holding capacity, a lower MAD may be needed to avoid water stress, although this may reduce application efficiency.

For low-volume (drip or micro-sprinkler) systems, the MAD is often selected based on how much water can be applied in a 24-hour period or, if necessary, at a level that will avoid water stress.

Schedules for both surface and low-volume-irrigated citrus can be determined using a water balance procedure that budgets for losses and additions of water to the soil. Water losses occur through evapotranspiration, runoff, and deep percolation. Water additions can come from irrigation applications, rainfall, fog interception, and water tables.

Crop Evapotranspiration (ETc)

Citrus ETc is calculated by multiplying reference evapotranspiration (ETo) by a crop coefficient (Kc): ETc = ETo x Kc. Average ETo data are given by zones of similar evaporative demand in UC Drought Tip 92-54. In the Central Valley of California, a constant Kc = 0.65 provides a good estimate of potential citrus ETc. Using a Kc = 0.60 has given good yield results in the Southern California desert. In humid, coastal locations, a Kc = 0.70 may be prudent. Using these Kc values and ETo values by evaporative demand zone (Figure 1), Table 1 provides the running total (cumulative) ETc data for citrus on every tenth day of the year. These data can be plotted as in Figure 2 for the San Joaquin Valley to estimate cumulative ETc on any day of the year. Citrus grown in sites more directly exposed to sunlight and wind may have higher ETc, while citrus grown in protected areas may have lower ETc.

Corrections for Immature Trees

Immature trees use less water than mature trees. Figure 3 shows the water use of an immature crop relative to that of a mature crop. The percent of ground shading is determined by subtracting from 100 percent the percentage of surface area showing bare ground when the orchard is viewed from above. Citrus that shades more than 70 percent of the ground is considered to be mature. To determine ETc for an immature crop, multiply the mature crop ETc by the percent of ETc selected from Figure 3. For example, given mature trees with ETc = 0.20 inches, the ETc for the immature citrus at 15 percent ground shading is 60 percent of mature ETc (from Figure 3) and the ETc equals 0.12 inches (= 0.20 x 0.60). Similar adjustments may be needed for mature lemons with less than 70 percent ground shading.

Rainfall and Fog.

Since rainfall contributes to crop water needs, rainy weather requires adjustments to ETc. Any rainfall that coats the plants or is stored in the root zone where the crop can use it for evapotranspiration is "effective" rainfall. Therefore, rainfall in excess of the soil water depletion before the rainfall passes below the root zone and is not effective. Water that flows out of the orchard as surface runoff is also not effective rainfall. Effective rainfall is difficult to measure or estimate. Generally, most rainfall up to the preceding soil water depletion is effective unless the rainfall is heavy, there is a steep slope, or the soil has a slow intake rate.

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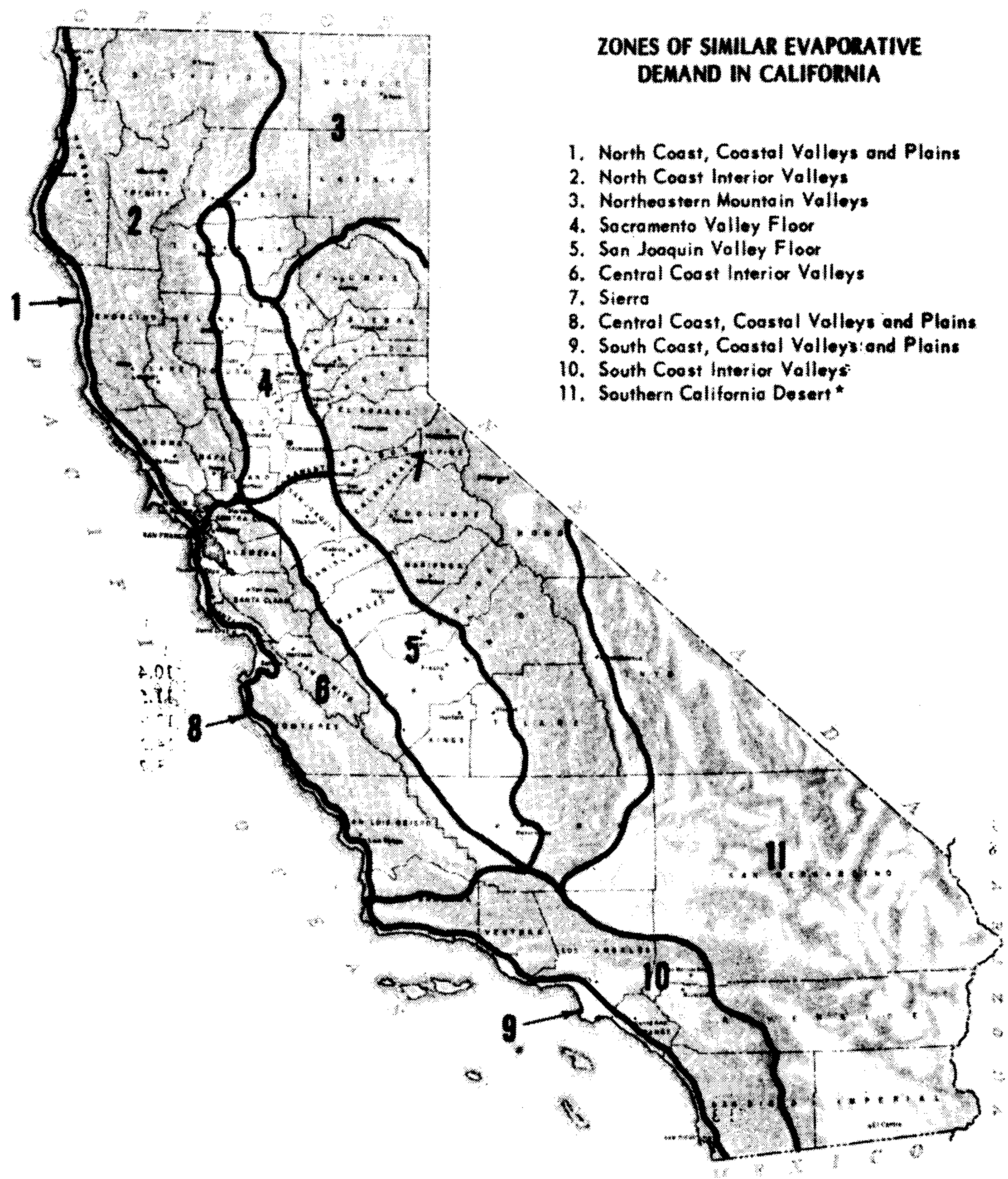

Figure 1. Evaporative demand zones.

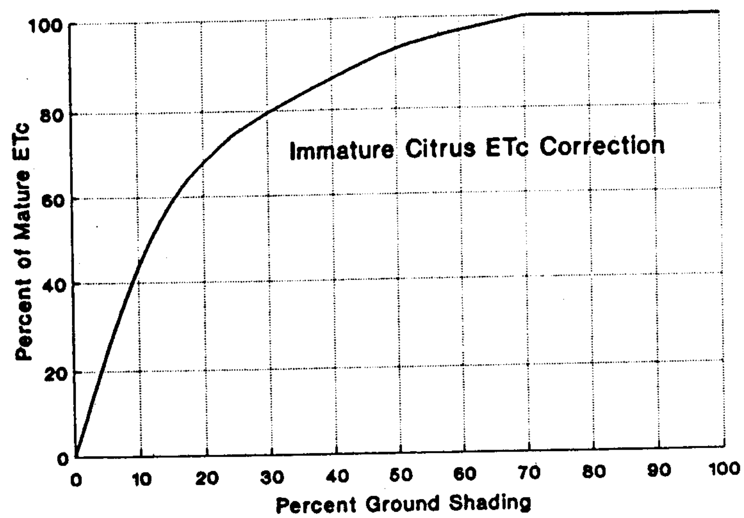

Figure 2. Cumulative citrus ETc for the San Joaquin Valley and net application amounts for surface irrigated citrus using MAD = 3.0 inches.

Date	Evaporative Demand Zone 4	5	6	8	9	10	11
	inches per day						
J 10	0.2	0.1	0.3	0.4	0.4	0.4	0.5
J 20	0.5	0.3	0.7	0.8	0.8	0.7	1.0
J 30	0.7	0.6	1.0	1.2	1.2	1.1	1.6
F 9	1.0	0.8	1.4	1.7	1.8	1.7	2.2
F 19	1.4	1.2	1.9	2.2	2.4	2.2	3.0
M 1	2.0	1.8	2.5	2.8	3.0	2.9	3.9
M 11	2.5	2.3	3.1	3.4	3.6	3.6	4.9
M 21	3.1	3.0	3.8	4.1	4.3	4.3	6.1
M 31	3.8	3.8	4.6	4.9	5.1	5.2	7.3
A 10	4.7	4.6	5.4	5.7	5.9	6.1	8.7
A 20	5.7	5.6	6.3	6.6	6.9	7.1	10.2
A 30	6.7	6.7	7.3	7.6	7.8	8.1	11.9
M 10	7.8	7.9	8.5	8.7	8.8	9.2	13.7
M 20	9.0	9.3	9.7	9.7	9.7	10.4	15.7
M 30	10.3	10.8	10.9	10.8	10.8	11.5	17.7
J 9	11.8	12.4	12.2	11.9	12.0	12.9	19.9
J 19	13.4	14.0	13.6	13.1	13.2	14.3	22.2
J 29	15.0	15.6	15.0	14.2	14.4	15.7	24.5
J 9	16.7	17.3	16.4	15.4	15.6	17.3	26.9
J 19	18.4	19.0	17.7	16.7	16.9	18.8	29.2
J 29	20.0	20.5	19.2	17.8	18.1	20.4	31.3
A 8	21.6	22.1	20.5	19.0	19.3	22.0	33.3
A 18	23.0	23.5	21.8	20.1	20.6	23.5	35.2
A 28	24.3	24.8	23.0	21.1	21.8	25.0	37.0
S 7	25.5	26.0	24.1	22.1	23.0	26.3	38.8
S 17	26.7	27.0	25.2	23.0	24.1	27.6	40.5
S 27	27.8	28.0	26.2	23.9	25.1	28.7	42.1
O 7	28.7	28.9	27.1	24.6	26.0	29.7	43.6
O 17	29.4	29.6	28.0	25.4	26.7	30.7	44.9
O 27	30.1	30.2	28.7	26.0	27.4	31.4	46.0
N 6	30.6	30.7	29.3	26.7	28.1	32.1	46.9
N 16	30.9	31.1	29.8	27.2	28.7	32.7	47.7
N 26	31.2	31.3	30.3	27.7	29.3	33.1	48.3
D 6	31.5	31.5	30.6	28.1	29.9	33.6	48.7
D 16	31.7	31.7	30.9	28.4	30.4	34.0	49.1
D 26	31.9	31.8	31.3	28.7	30.9	34.4	49.4
Kc =	0.65	0.65	0.65	0.70	0.70	0.70	0.60

Actual ETc values are variable within each zone and can be adjusted upward or downward depending on the local climate relative to average for the zone. A monthly ETc more than 10 percent above or below the values listed would be unusual. The zones were developed by the California Department of Water Resources (DWR). Sources for ET data include DWR Bulletin 113-3 and Pruitt et al. (1987).

Table 1. Cumulative citrus ETc every tenth day by evaporative demand zone

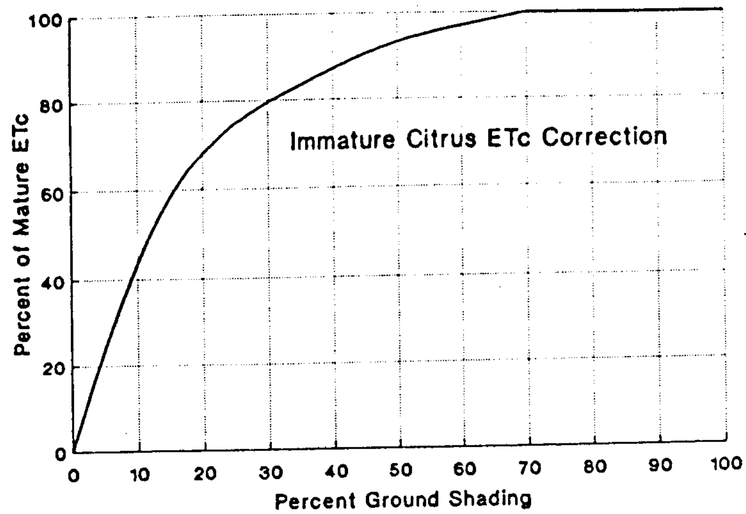

Figure 3. Percentage of mature ETc for immature citrus as a function of percent ground shading by the trees.

Date	Evaporative Demand Zone						
	4	5	6	8	9	10	11
				inches per day			
J 10	0.021	0.016	0.032	0.039	0.039	0.036	0.049
J 20	0.023	0.019	0.034	0.041	0.039	0.037	0.054
J 30	0.029	0.025	0.038	0.045	0.046	0.046	0.061
F 9	0.038	0.034	0.045	0.050	0.057	0.057	0.071
F 19	0.046	0.044	0.052	0.055	0.064	0.064	0.082
M 1	0.051	0.053	0.058	0.060	0.066	0.068	0.095
M 11	0.058	0.062	0.066	0.066	0.067	0.071	0.108
M 21	0.067	0.072	0.073	0.074	0.071	0.077	0.121
M 31	0.079	0.081	0.080	0.081	0.078	0.085	0.133
A 10	0.091	0.090	0.088	0.088	0.086	0.095	0.145
A 20	0.100	0.102	0.097	0.094	0.092	0.101	0.158
A 30	0.107	0.116	0.107	0.099	0.095	0.106	0.172
M 10	0.114	0.129	0.116	0.104	0.098	0.111	0.188
M 20	0.125	0.142	0.123	0.108	0.103	0.117	0.202
M 30	0.138	0.152	0.128	0.111	0.110	0.126	0.214
J 9	0.153	0.160	0.132	0.113	0.117	0.135	0.224
J 19	0.163	0.165	0.136	0.115	0.121	0.144	0.232
J 29	0.168	0.168	0.139	0.118	0.123	0.150	0.234
J 9	0.169	0.167	0.142	0.120	0.123	0.155	0.232
J 19	0.166	0.163	0.141	0.120	0.125	0.158	0.224
J 29	0.158	0.157	0.137	0.118	0.125	0.158	0.209
A 8	0.148	0.147	0.131	0.113	0.127	0.157	0.192
A 18	0.138	0.137	0.125	0.108	0.125	0.151	0.181
A 28	0.130	0.125	0.118	0.101	0.120	0.143	0.178
S 7	0.122	0.114	0.111	0.094	0.113	0.132	0.178
S 17	0.112	0.102	0.103	0.088	0.104	0.120	0.171
S 27	0.099	0.091	0.096	0.082	0.094	0.108	0.158
O 7	0.084	0.080	0.088	0.078	0.083	0.097	0.139
O 17	0.070	0.068	0.079	0.072	0.075	0.085	0.119
O 27	0.056	0.056	0.070	0.066	0.069	0.073	0.102
N 6	0.043	0.042	0.058	0.059	0.064	0.062	0.085
N 16	0.033	0.031	0.049	0.051	0.060	0.053	0.069
N 26	0.026	0.022	0.040	0.043	0.057	0.046	0.053
D 6	0.022	0.016	0.033	0.035	0.053	0.042	0.040
D 16	0.020	0.013	0.030	0.032	0.050	0.040	0.035
D 26	0.021	0.014	0.031	0.034	0.047	0.039	0.039
Kc =	0.65	0.65	0.65	0.70	0.70	0.70	0.60

Actual ETc values are variable within each zone and can be adjusted upward or downward depending on the local climate relative to average for the zone. A monthly ETc more than 10 percent above or below the values listed would be unusual. The zones were developed by the California Department of Water Resources (DWR). Sources for ET data include DWR Bulletin 113-3 and Pruitt et al. (1987).

Table 2. Citrus daily ETc rates on every tenth day by evaporative demand zone.

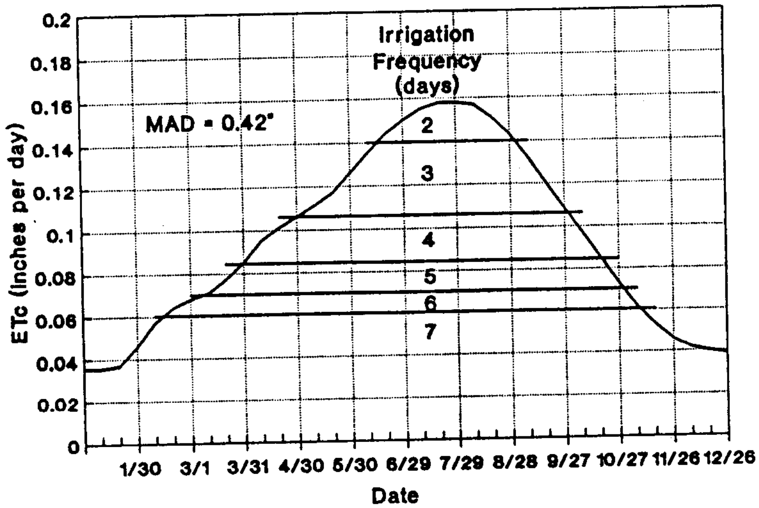

Figure 4. Daily ETc rates for South Coast Interior Valleys and irrigation frequencies for low-volume irrigated citrus using a MAD = 0.42 inches.

During foggy periods, contributions to ETc by intercepted fog reduce soil water losses. When fog interception occurs, cumulative ETc overestimates actual soil water depletion. A correction for fog interception is made by noting the time at which fog dries off the trees and estimating the contribution as a fraction of daily ETc. See Drought Tip 92-40 for guidelines on how to correct for fog interception.

Irrigation Scheduling

Surface Irrigation. Use the cumulative ETc data (Table 1) to determine the soil water depletion between irrigations and to design an irrigation schedule. When there is no contribution from rainfall, fog, or a water table, the total ETc from the last irrigation provides an estimate of soil water depletion. Contributions from rainfall, fog, and water tables reduce the soil water depletion relative to cumulative ETc and lengthen the time between irrigations.

To illustrate how cumulative ETc data are used for scheduling, consider the following example. If the best application efficiency (75 percent) is achieved when the applied water is 4 inches, an irrigation of 4.0 inches depth is required on each date that 3.0 inches is depleted from the soil. The cumulative ETc data can be plotted as in Figure 2 to estimate soil water depletion. An irrigation is needed whenever 3.0 inches of soil water depletion occurs. Effective rainfall, fog interception, and water tables may supply some water needs and delay the next irrigation.

Low-Volume Irrigation. Daily ETc rates are used for irrigation scheduling of low volume irrigation systems. Table 2 provides daily ETc rates for citrus by zones of similar evaporative demand (Figure 1). The set time (ST) for an irrigation is calculated as:

$$ST = (AD + AE) + AR \qquad (1)$$

where AD is the actual soil water depletion since the last irrigation, AE is the application efficiency expressed as a fraction, and AR is the application rate in inches per hour. AD is calculated as the cumulative ETc minus rainfall, fog interception, and water table contributions since the last irrigation. The system's distribution uniformity provides an estimate of application efficiency if the net application amount at each irrigation is approximately equal to the mean depth of water infiltrated into the quarter of the orchard receiving the least water. Application rate is determined from the pump flow rate and the acreage being irrigated.

Given: a 40-acre orange grove with a pump output of 400 gallons per minute and an application rate of 10 gallons per minute per acre. Dividing by 450, the application rate is equivalent to: 10 + 450 = 0.022 inches per hour. For a maximum set time of 24 hours, the applied water is: 24 x 0.022 = 0.53 inches. If the distribution uniformity is 80 percent , the MAD equals 0.53 x 0.80 = 0.42 inches. Therefore, an irrigation should be applied before 0.42 inches of water is depleted from the soil.

Data from Table 2 are plotted in Figure 4 to determine irrigation frequency for a low-volume system. In our example, an irrigation is needed before the total ETc from the last irrigation date exceeds 0.42 inches. If the mean daily ETc rate exceeds 0.21 inches (= 0.42 + 2), daily (one-day frequency) applications are needed. Similarly, if the mean daily ETc rate exceeds 0.14 inches (= 0.42 + 3), applications are needed every other day (two-day frequency). A three-day frequency is needed when mean daily ETc exceeds 0.105 inches (= 0.42 + 4). In Figure 4, irrigation frequencies are separated by horizontal lines and the appropriate frequencies (in days) are indicated. To identify appropriate irrigation frequencies, a figure similar to Figure 4 should be plotted using local ETc information (Table 2) and MAD based on the irrigation system used.

Deficit Irrigation

The amount of water to apply during an irrigation is typically calculated by dividing the soil water depletion by the system application efficiency to ensure that the mean depth infiltrated into the low quarter (the 25 percent of the orchard receiving the least water) is equal to the soil water depletion. This forces 87.5 percent of the orchard to infiltrate a depth greater than the soil water depletion before irrigation. In deficit irrigation, the depth infiltrating the low quarter is less than the soil water depletion before irrigation, and the percentage of the orchard being refilled decreases. Parts of the orchard that are refilled with water may not exhibit water stress or yield reduction, whereas areas that are not refilled can have reduced ETc and yield.

Recent research in the San Joaquin Valley has shown that oranges irrigated with a low-volume irrigation system can experience moderate deficit irrigation (80 percent of estimated 100 percent ETc) with little loss in marketable yield. However, yield losses may be greater for citrus grown in shallower soils with different water-holding characteristics. Stress timing and irrigation method are additional factors that may influence yield response to deficit irrigation.

Several years of research on the response of citrus to high frequency (low-volume) deficit irrigation in Spain showed that ETc was reduced by between 5 and 21 percent and yield was reduced by 5 percent and 15 percent when water applied was 80 percent and 60 percent of estimated 100 percent ETc. The annual 100 percent cumulative ETc was approximately 33 inches, which is comparable to many of California's citrus growing region. Fruit number was not affected by deficit irrigation, but average fruit weight decreased. Soluble solids and acid content of the fruit increased. Full irrigation all year -- except during flowering and fruit set when 60 percent of full irrigation was applied-- decreased yield by 4 percent. This treatment also decreased juice acid content and peel thickness. When the orchard was fully irrigated all season -- except during fruit maturation, when 60 percent of fall irrigation was employed -- lower quality fruit with thicker peels and more acid was produced.

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