Drought Irrigation Strategies for Deciduous Orchards

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role stomata perform in regulating the water economy of trees and their influence on eventual plant productivity cannot be overstated, and deserves some discussion.

Stomata go through a daily cycle of opening and closing, primarily in response to light, assuming nonlimiting soil water levels. Since stomata open in the presence of direct sunlight, high transpiration rates occur during the day. Water loss is negligible at night. Even under nonlimiting soil water levels, however, the rate of transpiration may begin to exceed that of water uptake by the roots. Without some type of regulation, water loss from the leaves would result in excessive dehydration, which in turn would damage critical leaf tissues and eventually cause leaf death. Stomatal aperture is quite sensitive to the internal water status of leaves and as the severity of the water deficit increases, stomata begin to close. The rate, degree, and duration of closure depends on the severity of the leaf water deficiency, which in turn depends largely on the availability of the soil water. Stomatal closure restricts the loss of water vapor, thereby allowing the water status of the leaf (and other parts of the plant) to stabilize, and in some cases partially to recover. Without stomatal control of water loss, deciduous trees could not maintain a favorable water balance under even mild drought conditions.

Leaf stomata act both as the exit points for water vapor loss and as the entry conduits for carbon dioxide. Carbon dioxide diffuses from the atmosphere through the stomata and into the leaf where photosynthesis converts it into sugars, the building blocks necessary for plant growth and the fuel that powers important plant processes. The rate of carbon dioxide assimilation depends directly on stomatal behavior. Carbon uptake (photosynthesis) is inextricably tied to plant water use (transpiration). In effect, the plant trades water for carbon. Since carbon is ultimately converted into the various organs of the plant (leaves, shoots, branches, and fruit), the direct relationship between tree productivity and water use is clear. This is not to say that the other plant-based factors influenced by water supply, such as plant water status, are not important considerations in plant performance. On the contrary, one of the primary objectives of this leaflet is to provide information on how best to manipulate orchard irrigation so water stress is limited to the least-sensitive plant developmental periods. Although plant water use, and therefore carbon assimilation, will be reduced when water supplies are restricted, you can moderate the effect on productivity if you control the timing, duration, and magnitude of the water deficit through irrigation management.

The potential to minimize negative impacts on the crop by manipulating irrigation is much greater with trees than with field and row crops. This is due mostly to the tree crops' generally greater separation between the vegetative and reproductive growth periods, the importance of stored carbohydrates in vegetative sinks of woody plants that can be mobilized when photosynthesis is reduced by water deficits, and the dependence of productivity on both the current and previous seasons stress history—especially the water status during shoot growth and bud differentiation and development. The number of fruiting positions per plant, one of the major yield components, is established during the previous season(s) in most deciduous tree species. Carry-over effects of water stress on future tree productivity must be considered as you optimize drought-year irrigation strategies.

Water Stress and Plant Development

Identifying stress-sensitive periods

Many researchers have studied the effects of water deprivation on crop plants. Much of their work has focused on how biochemical processes, such as photosynthesis and respiration, are influenced. Another focus area has been the effect on plant processes, such as vegetative and reproductive growth. Less work has been done to study the interrelationships of physiological responses and real-world plant performance—to evaluate and predict the effect of water deprivation on plant development, and on crop yield and quality. Field and row crops have been the focus of most research to date, which is not surprising in view of their economic and social importance worldwide. However, knowledge gained with herbaceous plants has limited relevance to developing drought irrigation strategies for trees. Recent studies involving tree water requirements and tree responses to water supplies have substantially increased our knowledge, but the amount of information varies with species. While much more work is needed to equal the level of knowledge that currently exists with regard to herbaceous crops, it seems clear that certain stages of tree crop development are more sensitive to water stress than others in terms of impact on productivity. Figure 1 shows a typical annual pattern of tree growth and development. For the purposes of the following discussion, we have divided the season into three parts: (1) bud break through fruit set, (2) fruit growth and development, and (3) postharvest.

Bud break through fruit set. Bud break, followed rapidly by bloom and flowering, occurs in the spring when evaporative demand is normally low. Shoot growth also begins at this time, and usually continues at a rapid pace during this period. As with herbaceous plants, deciduous trees' expansive growth processes (e.g., shoot growth) are very sensitive to water deficits. Even mild water deficits early in the season reduce shoot elongation, which results in smaller tree canopies and fewer fruiting positions the following year in most species. A recent study showed that in addition to shoot elongation, shoot initiation was extremely sensitive to even mild water deficits, again indicating the need for adequate early season soil water. In young trees, maximum rates of canopy development hasten orchard maturity, so preventing water deficits during vegetative growth stages is a high priority.

Based on the need for adequate shoot initiation, shoot growth, and bud initiation for the following year's crop, it seems prudent to avoid even mild water stress during the early part of the season. A recent study found that it is during this period that photosynthesis is hard pressed to meet the carbohydrate demands of the tree, so any reduction in carbon

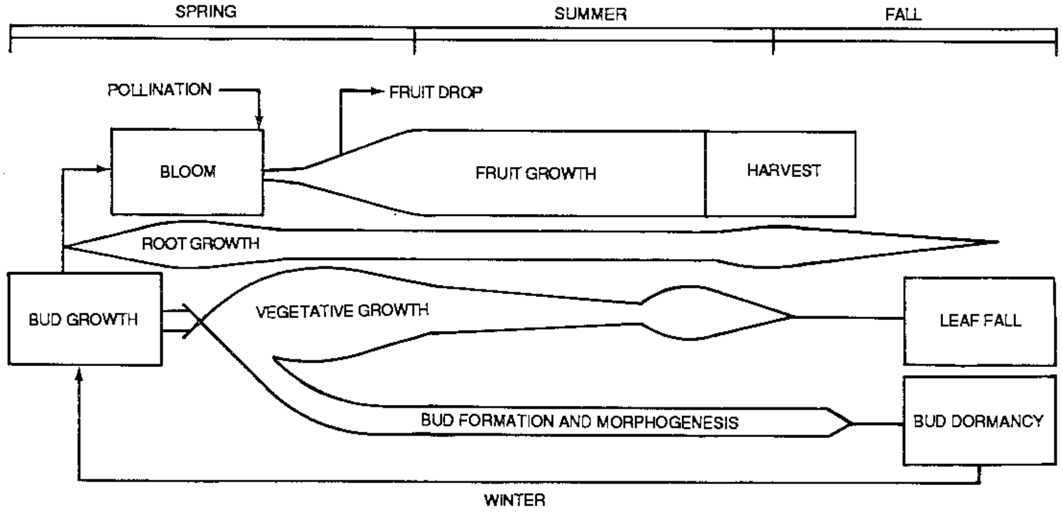


Fig. 1. A generalized representation of the tree growth and development processes in deciduous fruit and nut trees over time.

dioxide assimilation due to water stress should be avoided. Additionally, it's been shown in apples that the development of water stress immediately after petal fall can substantially reduce fruit set. Even under conditions that make water precious—low rainfall and restricted water supplies—the water needs of the plant in early to mid-spring should be fully satisfied, especially since the low evaporative demand during this period results in relatively low water use rates in the orchard.

Fruit growth and development. Fruit growth stages and when they occur relative to shoot growth are prime factors in determining the production-related sensitivity of preharvest growth stages to water stress. For example, the shoot growth required to establish the following year's crop of late-harvest peaches is virtually complete by the time initial expansion of the fruit (stage I of fruit development) slows, roughly 4 weeks after fruit set. Pit hardening is another biofix that occurs near the end of stage I. Additional shoot growth thereafter is of little benefit to the plant. Indeed, reducing shoot growth during the lag period of fruit growth (stage II) by allowing moderate water deficits to develop may actually increase carbohydrate reserves for later use by the fruit. Moreover, the presence of mild to moderate plant water stress during stage II should have a relatively small influence on fruit development for two reasons: (1) the fruit expansion rate is slow (it's the "plateau" of the double-sigmoid development curve), and (2) compensatory fruit growth is possible during the final third of the fruit development period (stage III) if the water deficits are alleviated. Water deficits during this final rapid growth period can seriously reduce fruit size, which is the primary quality component for fresh market fruit varieties. Work in Australia indicates that the controlled regime of plant water stress outlined above can reduce unneeded vegetation growth and tree water use by 33 percent without affecting yield, fruit size, or the following year's crop.

While fruit trees such as peach with double-sigmoid fruit development patterns have some stress tolerance during part of the fruit development period, you must observe extreme caution when considering stress for other deciduous trees during this time. Their responses are highly species-dependent. This relates, in part, to the relative timing of shoot and fruit growth.

In walnut, for example, the shoot extension and rapid fruit expansion periods overlap considerably. As such, water stress during early to mid fruit development would hurt both yields and the following season's crop load. Apple also has an extended overlap of shoot and fruit growth periods, resulting in high sensitivity to water deficits during at least the first half of the fruit development period.

Walnut also presents the problem of sunburn damage to the nuts; the extent depends on the cultivar. With cultivars that tolerate heat-related injury (dark kernel color), moderate to severe plant water deficits in the time just before harvest are of little concern. However, high nut temperatures must be prevented in heat-sensitive cultivars through irrigation management to maintain good kernel quality.

Other important production aspects that can be affected by water stress during this time are kernel filling of nuts, fruit drop, and harvestability of mechanically shaken trees. The sensitivity of kernel filling to water stress seems to depend on the species. Almond, for example, is particularly sensitive. In contrast, several studies have shown that the kernels of other nut trees are extremely strong sinks for photosynthate, and that the filling process takes priority over other carbohydrate-requiring processes during this time. Thus, nut filling in general is considered tolerant of water deficits. The same appears true for preharvest fruit drop in, for example, prunes. Although the amount of fruit dropped can be considerable, it doesn't appear to be significantly related to irrigation. The ease of harvest of mechanically shaken fruit trees also does not appear to be influenced by plant water deficits. However, moderate to severe water stress can result in "stick-tights" in nut crops, particularly almond and pistachio. These stress levels can also delay hull split in almonds and increase the occurrence of unsplit nuts in pistachio.

Not all consequences of water deficits are negative—mild water stress has been shown to enhance the eating quality of many pome and stone fruits, probably because the proportion of soluble solids increases as fruit water content decreases. In apple, mild water deficits can improve color and reduce titratable acidity.

Conversely, physiological disorders such as bitter pit in apple and cracking in prunes have been attributed to moderate to severe water stress during the fruit development period. The occurrence of "split pit" in peaches (especially clings) increases when trees are moderately to severely stressed late in stage I or early in stage II of fruit development, and then immediately and heavily irrigated.

Postharvest. In general, the period after harvest is least sensitive to water deficits. Indeed, orchardists around the world commonly reduce irrigation after harvest. In California, many almond growers in the southern Central Valley practice deficit irrigation after harvest with little apparent effect on subsequent seasons' productivity. However, the quantitative impacts of this practice have not been adequately established—additional irrigation might or might not improve yields. Research results indicate that postharvest irrigation in pistachio is relatively unimportant; cutting off irrigation after 75 percent of the potential seasonal water needs had been applied (2 to 3 weeks prior to harvest) affected neither current nor subsequent years' marketable yields.

Most fruit trees appear to be particularly tolerant of postharvest water stress. A recent 3-year study found that applying only one irrigation after an early June harvest did not affect subsequent fruit loads of early maturing peaches, even though the water stress imposed in this study was severe—soil water levels throughout the root zone approached the permanent wilting point for much of the postharvest period. Return bloom actually increased, but this has little practical significance since the fruit is manually thinned in the spring. However, undesirable fruit "doubling" (two joined fruit per stem) was appreciably higher in the postharvest-stressed trees, possibly as a result of excessive heat buildup in the developing buds during the fall. Cherry and plum are other fruit trees that are subject to the formation of doubles and "spur fruit" (one developed and one aborted fruit that are joined) because of high flower bud temperatures that result from postharvest water deficits.

While reducing postharvest irrigation appears to have a relatively minor effect on the yields and quality of most deciduous fruit and nut trees, general recommendations must be made with caution. Species response varies considerably. For example, flower bud formation and retention in apricot appear to be quite sensitive to moderate water deficits that result from the lack of postharvest irrigation. In many deciduous tree species, severe plant water deficits can induce premature leaf fall (defoliation), which, if followed by heavy irrigation or by early rains, can promote regrowth and flowering in the fall. This circumstance will result in reduced flowering the next spring.

As noted earlier, much more work is needed in fruit and nut trees to understand the relationships between plant water stress and tree performance. Although there are gaps in current information, we have compiled a summary of the knowledge available on the sensitivity of major deciduous fruit and nut trees grown in California to water deficits at different phenological growth stages (fig. 2). Crop development periods are characterized as having high, moderate, or low sensitivity to water stress based on the effect of stress on current and subsequent seasons' yields and quality. Figure 2 contains the best information currently available, and is subject to revision with time.

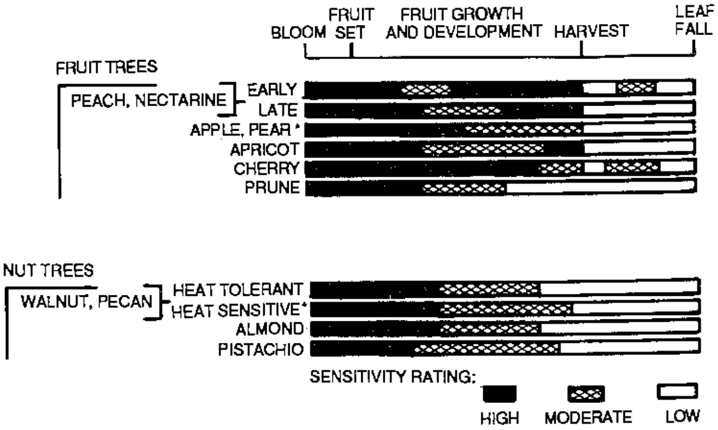
Tree adaptation to drought conditions

All crop plants, including deciduous trees, have evolved from ancestors that grew in natural ecosystems. Herbaceous plants have been bred extensively by crop scientists whose primary objective has been to increase yield per unit of land area. Fruit and nut trees, however, are much closer to their natural ancestors, and must be considered as more primitive. As such, they possess traits that allowed their predecessors to compete and to endure the process of natural selection. Adaptations that were useful in this process may not favor the production of edible products of good quality, but they may be extremely useful in allowing the trees to survive periods of drought.

Through these drought adaptations, deciduous trees can at best suffer only modest decreases in productivity from a mild drought, and at worst, survive. Two adaptations deserve mention: (1) osmotic adjustment and (2) water extraction from deep soil zones.

Osmotic adjustment is the buildup of solutes within plant cells, resulting in a favorable cell water status as soil water availability decreases, which may in turn delay the onset of stomatal closure. Also referred to as osmoregulation, this phenomenon has been observed in apple, almond, pistachio, peach, and pear trees, and probably occurs in most other deciduous species.

Water extraction from deep in the profile has been measured in a number of deciduous tree species, particularly in the absence of adequate irrigation. This clearly has adaptive value under drought conditions. Deep-profile water extraction is minor under normal irrigation conditions, since trees usually extract water preferentially from the upper layers in



* Sunburn of fruit may increase as a result of water deficits preceeding harvest due to higher fruit temperatures and more sun exposure. Application of "whitewash" may reduce damage.

Fig. 2. Sensitivity of plant development periods to water deficits. "Sensitivity" is defined as the negative effects that water deficits have on current and subsequent seasons' crop yields and quality. Species are characterized individually based on the sensitivity of their developmental periods to water deprivation over the season. Valid comparisons cannot be made between species. This figure is based on the hest information currently available, and is subject to revision.

Table 1. The effects of deficit irrigation at various percentages of full ET_c sustained over the season on mature pistachio

Irrigation regime	**Stress year**	**Radial trunk growth**	**Blank nut production**	**Unsplit nut production**	**Harvest-ability of filled nuts**	**Marketable yield**
% ET_c		*in*	*——% of tree nut load——*			*lb dry in-shell nuts/tree*
Dryland	1	0.03	29.8	56.6	52.3	2.5
	2	0.03	37.8	16.7	82.7	4.1
	3	0.01	43.1	23.3	65.9	3.4
25	1	0.04	18.3	36.8	77.5	11.9
	2	0.05	36.7	14.3	58.1	4.3
	3	0.01	37.9	25.2	69.4	6.4
50	1	0.07	17.8	8.8	92.5	19.5
	2	0.06	23.8	7.7	80.7	10.5
	3	0.04	30.4	19.5	79.2	11.6
75	1	0.13	18.2	7.0	98.2	25.6
	2	0.17	21.5	11.2	90.1	15.9
	3	0.08	31.1	11.7	95.0	25.7
100	1	0.14	11.2	10.9	98.4	30.1
	2	0.21	15.9	9.0	90.5	14.4
	3	0.12	15.1	19.0	94.6	31.3

the soil profile. Only after the upper zone is largely depleted does extraction begins from deeper layers. In one study of peach trees grown on a deep soil rich in stored water, the trees maintained near-maximum rates of photosynthesis when irrigated at less than the evapotranspiration (ET) rate throughout the season. Researchers attributed this to the trees' extraction of deep soil moisture. Interestingly, the same study showed that a dry-land orchard (no irrigation) depleted less deep-soil moisture, apparently because of the trees' less-expansive or less-active root system.

Other tree adaptations to drought include leaf rolling (boating) and defoliation; both decrease leaf exposure to solar radiation. Plant water stress severe enough to induce defoliation should be avoided if possible. If it occurs, you must take care in post-defoliation water management, as previously noted.

Impact of water stress on tree performance

The timing, magnitude, and duration of water deficits all clearly influence tree performance. Thus, the seasonal amount of underirrigation to an orchard crop may only indirectly indicate the effects of deficit irrigation on productivity, in contrast to many herbaceous crops for which a linear relationship can exist between seasonal water use and crop yield. Much of the production-related research on deficit irrigation of deciduous trees to date has consisted of irrigating at various fractions of full potential water use over an entire season. While this type of work identifies the relative impact of water stress on plant processes, it doesn't allow accurate prediction of the impact of controlled deficit irrigation programs on tree productivity. Nevertheless, these studies' results provide useful examples of the potentially harmful effects of plant water deficits. Table 1 presents growth and yield component information from a 3-year sustained deficit irrigation study on pistachio. The data show the increasing damage to productivity from year one through year three, with the severity of the response depending on the degree of water deprivation. The crop yield reflects the cumulative effect of water stress on all the individual factors that determine productivity (the yield components). These factors vary from species to species both in their importance and in their sensitivity to plant water stress.

Irrigation Management

The goal of good irrigation management is to supply the plant with the correct amount of water at the proper time. This goal remains unchanged in a time of drought, although decisions are complicated by the constraint of water supply. The same information on plant, soil, atmospheric, and irrigation system factors that you need in order to schedule irrigations during a normal year is even more important in a drought year.

Two fundamentally different approaches are used to scientifically schedule irrigations. The first is the *water budget* approach, by which you apply irrigation to satisfy the estimated water use requirements of the orchard. The second approach involves irrigating based on measurements of soil or plant water status. A number of publications available from University of California Agricultural Publications discuss both of these approaches under normal water conditions. These publications include

- Irrigation Scheduling. Publication 21454
- The Water Budget Method—Irrigation Scheduling for Southern San Joaquin Valley Deciduous Orchards. Leaflet 21419
- Drip Irrigation Management. Leaflet 21259
- Basic Irrigation Scheduling. Leaflet 21199
- Irrigating Deciduous Orchards. Leaflet 21212

Since crop water use is a primary factor in developing drought irrigation strategies (indeed, the severity of a drought is often expressed as the percentage of a normal year's available water), and water-use information is integral to the water budget approach, we will focus on this scheduling technique. The publications listed above provide information on soil- and plant-based scheduling techniques as well as more detail on the water budget approach.

The water budget approach

Irrigation management with normal water supplies takes into account the *evapotranspiration* (ET) losses from the orchard—the sum of *evaporation* (E) from the soil surface and *transpiration* (T) from the plants. Orchard transpiration depends on the tree species, the size of the tree canopy, and the presence or absence of a cover crop or actively growing weeds. Soil evaporation loss is a function of the frequency and amount of soil surface wetting at each irrigation. While irrigation frequency and distribution are dictated by grower decisions, management of orchard vegetation offers the greatest potential for influencing orchard water use rates. An actively growing cover crop or weeds can add an additional 18 inches of water use per season. While cover crops aid in infiltration and help to moderate air temperatures, the cost of these benefits in terms of water use may be too high under drought conditions. During droughts, orchards should be clean-cultivated, either by physical or chemical methods, especially during the summer months. Frequent cultivations expose moist soil and increase surface evaporation, so avoid them in favor of chemical weed control.

Information on the ET of individual deciduous tree species is limited. Until recently, it was assumed that transpiration rates of different species varied only slightly under California conditions. New research results indicate that considerable differences exist between species, and possibly even between cultivars. To date, specific ET data has been developed for almond, pistachio, and walnut. Research is underway on the ET of peach. Reports indicate that in the absence of specific ET information, almond ET values should be used as a first approximation for other deciduous trees.

Since crop evapotranspiration (ET_c) correlates with evaporative demand, irrigation scientists have found it useful to relate ET_c to the standardized indices of ET of a grass reference crop (ET_o) or pan evaporation (E_{pan}). While E_{pan} has successfully indexed evaporative demand for many years, ET_o is the new standard for use in irrigation scheduling in California. Researchers have developed specific crop factors, hereafter referred to as crop coefficients (K_c), that relate ET_c to ET_o.

Bimonthly K_cs for almond, pistachio, and walnut are shown in table 2. The relatively high values for pistachio and walnut merit some explanation. The height of a mature walnut tree (and of other related species, such as pecan) is greater than those of other deciduous trees, and this may increase the canopy-zone wind speed. With more air passing over each leaf, transpiration increases. The high peak demand K_c for pistachio probably relates to two aspects of stomatal behavior that distinguish pistachio from other species: (1) maximum leaf conductance values are high, and (2) little or no stomatal closure normally occurs at midday.

To estimate water use rates of mature orchards, multiply the K_c by the ET_o value. The ET_o is usually determined from meteorological data collected at weather stations in appropriate (irrigated grass or pasture) environments. A recently completed University of California research project established a network of approximately 50 weather stations throughout the state. Known as CIMIS (California Irrigation Management Information System), this network is now operated by the California State Department of Water Resources (DWR), which monitors the stations daily. The weather and calculated ET_o data are stored in a computer that can be accessed by phone modem. This information is available free of charge if you contact the DWR Office of Water Conservation, P.O. Box 388, Sacramento, CA 94236-0001. Long-term historical values of ET_o throughout the state have also been determined and are available in Leaflet 21426 (*Determining Daily Reference Evapotranspiration* [*ET_o*]). For example, average ET_o figures for Parlier are shown in table 2. Historical averages provide a good first estimate of current season ET, although rates vary from year to year. The current (real-time) ET information is most crucial to growers using high-frequency irrigation systems with known application efficiencies. Many orchards under drip and low-volume sprinklers fit this description.

Besides orchard ET estimates, the water budget method usually requires a knowledge of the root zone depth, soil water storage capacity, the yield-threshold soil water depletion, and the irrigation system's application efficiency.

System Management and Modification

With restricted water supplies, you must minimize nonbeneficial losses of applied water. In other words, your goal is to

Table 2. Long-term historical grass reference crop (ET_o) values for Parlier, California, and crop coefficient (K_c) values for mature almond, pistachio, and walnut, grown under clean cultivated conditions

Date	Average ET_o	Crop coefficient (K_c)		
		Almond	Pistachio	Walnut
	in/day			
March 16–31	0.13	0.54	—	0.12
April 1–15	0.16	0.60	0.07	0.53
April 16–30	0.18	0.66	0.43	0.68
May 1–15	0.21	0.73	0.68	0.79
May 16–31	0.24	0.79	0.93	0.86
June 1–15	0.25	0.84	1.09	0.93
June 16–30	0.26	0.86	1.17	1.00
July 1–15	0.27	0.93	1.19	1.14
July 16–31	0.26	0.94	1.19	1.14
August 1–15	0.24	0.94	1.19	1.14
August 16–31	0.22	0.94	1.12	1.14
September 1–15	0.19	0.94	0.99	1.08
September 16–30	0.16	0.91	0.87	0.97
October 1–15	0.12	0.85	0.67	0.88
October 16–31	0.09	0.79	0.50	0.51
November 1–15	0.06	0.70	0.35	0.28
Average seasonal water use (in/ac)	45.9	38.7	40.7	41.8

maximize *application efficiency;* the percentage of applied water that's stored in the root zone and available for plant uptake. High efficiency requires both good water-management decisions (e.g., when to irrigate, how much water to apply) and irrigation systems designed and maintained to achieve high *uniformity* of applied water. Of the key factors here—management decisions and uniformity of application—growers directly control the former and highly influence the latter. As such, the magnitude of applied water losses depends primarily on the skill of the irrigator and the value he or she places on efficient water use.

For the most part, irrigation losses result from the deep percolation of water below the root zone and the runoff of excess water from the end of the field, although sprinkler systems also involve spray evaporation and wind drift losses. Obviously, field runoff must be collected and reused when water supplies are limited. Deep percolation occurs because irrigation water cannot be applied with complete uniformity to a field, regardless of the method used. Some areas of the field receive more water than others, and when the infiltrated amount exceeds the water-holding capacity of the root zone, water travels beyond the depth where it can be extracted by the plant. The extent of deep percolation depends on the irrigator's ability to apply water uniformly, the amount of water applied, and the storage capacity of the root zone.

Achievable uniformity depends on the irrigation methods used—pressurized (sprinkler or drip) or surface (furrow, border, or basin) systems. Properly designed and maintained pressurized systems allow greater control of infiltrated amounts and uniformity, since the native spatial variability of soil infiltration properties has minor importance. With surface systems, even the most uniform soil has intake rates that vary over the field and limit distribution uniformity. However, the uniformity of water application with surface systems can be maximized by changing cultural and irrigation management practices. Table 3 presents estimated ranges of distribution uniformity attainable for the irrigation methods used in California's orchards.

Surface systems

The uniformity of infiltrated water in surface irrigated orchards depends on the rate at which water advances across the field and the spatial variability of soil intake rates. The opportunity time for infiltration is usually highest at the inflow end of the field, decreasing with distance down the run. An exception is when water is allowed to pond at the end of the field. Infiltration opportunity time differences can be reduced most easily by increasing the inflow rate at the top of the field. Most growers do not have the option of increasing the water delivery rate to the field, but they can achieve higher inflow rates by reducing the amount of land (number of tree rows) irrigated at one time. This may involve changing the arrangement of levees or

Table 3. Estimated attainable irrigation uniformities and application efficiencies under various irrigation practices for a normal water year, assuming nondeficit irrigation (deficit irrigation regimes have greater application efficiencies)

System	Distribution uniformity	Application efficiency
	%	%
Surface		
Furrow	70–80[*]	75–85[†]
Border	70–85[*]	65–80[†]
Basin	85–90[*]	75–90
Sprinklers (solid-set)	85–90	85–90
Drip and low-volume sprinklers	80–90	75–85

[*] Does not include nonuniformity because of the spatial variability of soil

[†] Higher values for systems with tailwater recovery systems or cutback

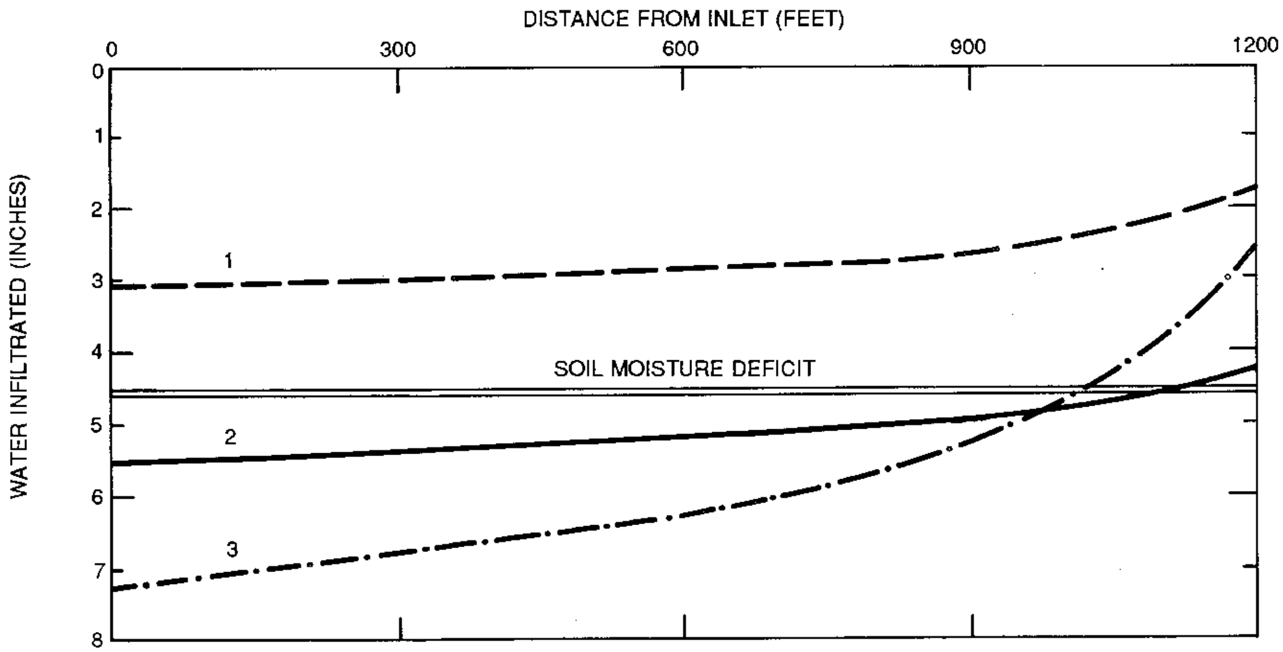


Fig. 3. Distribution of infiltrated water for a surface-irrigated orchard under three management regimes: (1) systematic deficit irrigation (SDI), root zone not refilled; (2) high inflow rate (fast advance) and proper set time, root zone refilled; and (3) low inflow rate (slow advance). The areas between the curves and below the soil moisture deficit line for the last two regimes represent water lost to deep percolation.

checks. Growers must recognize that while higher inflow rates result in full advance in less elapsed time, excessive runoff and overirrigation can occur unless the set times are reduced. Figure 3 illustrates how an increased inflow rate can improve the uniformity of infiltrated water.

A relatively new surface irrigation technique that has been shown to reduce differences in intake opportunity time is surge irrigation, the application of water as a series of pulses rather than as a continuous flow. Intermittent application reduces the soil intake rate, which increases the rate of water advance. Studies on furrow-irrigated fields have shown that the water required for full advance can be reduced by 20 to 50 percent with surge irrigation relative to continuous flow. The greatest improvement occurred on soils with relatively high intake rates. One limitation to surge irrigation in orchards is that the commercially available systems all use gated pipe, not normally a component of orchard irrigation systems. However, the technique appears viable if existing orchard systems can be adapted for its use.

While minimizing the differences in intake opportunity time improves uniformity, the upper limit of uniformity depends on spatial variability of infiltration over the field. Growers can do little to influence spatial variability, except that which results from orchard traffic. Studies show that even in a single furrow of what's considered uniform soil, the *distribution uniformity* (ratio of the amount infiltrated at the lowest quarter of the field to the average amount infiltrated) with equal opportunity times was only about 80 percent as a result of the native spatial variability of intake properties.

With normal water availability conditions in California, growers usually strive to irrigate as infrequently as possible since the number of irrigations determines the labor costs, which are relatively high for surface systems. Thus, the objective of each irrigation is to refill the plant root zone, recognizing that losses to deep percolation are unavoidable with this strategy. While this is an acceptable strategy in normal water years, priorities are different during a drought. The goal of minimizing nonbeneficial water losses justifies practices that are not normally considered, including *systematic deficit irrigating* (SDI), a practice that applies less water than normal per irrigation and increases the number of irrigations during the season. Refilling the profile is not the objective of SDI. Instead, water is applied in a regime that only partially wets the root zone, even in areas of the field that have the greatest intake opportunity times. This results in application efficiencies approaching 100 percent. Figure 3 illustrates the distribution of infiltrated water under SDI. This higher-frequency, lower-volume approach to surface irrigation is appropriate only when water is precious and when the benefits of minimal deep percolation losses outweigh the effects of plant water stress that are likely to develop.

To implement SDI, you must adjust not only the timing and amount of each irrigation but probably the physical layout of the system as well. Even using the highest nonerrosive inflow rates for the fastest possible advance, deep percolation at the top of the field is likely under full-coverage irrigation (flood, border, or basin) with all but the lowest soil infiltration rates. An alternative is to run furrows on either side of the tree row rather than wet the entire orchard floor. This would encourage the lateral movement of water in the soil and lessen the possibility that downward water flow would result in deep percolation. To a degree, partially wetting the soil surface will reduce the extent of surface evaporation. However, this savings of water will probably be balanced by additional surface evaporation that results from the more frequent irrigations. One trade-off with SDI is that the flat soil surface required for harvest of many tree crops is temporarily destroyed, so the soil must be reworked at harvest time.

Another useful technique for SDI is to irrigate alternate furrows or drive rows. Again, only a fraction of the available surface area is irrigated at any one time, thereby refilling only a fraction of the plant's root zone and necessitating more frequent irrigations during the season. Is it more efficient to irrigate the same furrow or middle throughout the season or to switch patterns? There is no universal answer to this. It depends primarily on how the infiltration rate changes with time over the season as a result of the irrigation and orchard traffic.

In most California soils, infiltration decreases with time over the season—not due just to traffic, but also to poorly understood factors involving the physical and chemical properties of the soil. Table 4 shows data on infiltration behavior monitored on a Wasco sandy loam that was irrigated frequently during one season. The basic infiltration rate decreased by an order of magnitude (0.32 to 0.03 inches per hour) during the 10 irrigations from early February to late August. Amounts infiltrated over a 24-hour period decreased similarly (13.8 to 1.3 inches). Note that this occurred in furrows that had no wheel traffic. While this may represent an extreme example, the same phenomenon has been observed frequently. The possibility of deep percolation decreases with time as the same soil is irrigated. This normally is considered a problem, since refilling the soil profile becomes difficult, but with SDI, it may be beneficial. Clearly, no one would want to switch at midseason from a low-intake situation such as that found in previously irrigated furrows to the high-infiltration situation associated with unirrigated soil if minimizing deep percolation were a priority. Indeed, using alternate furrow irrigation and switching midway through the season to previously unirrigated furrows is a common practice in normal years to increase infiltrated amounts on slowly permeable soils. Note that, even though a furrow or border may remain unirrigated, orchard traffic through the season may result in subsequent intake rates that are lower than anticipated.

Sprinkler systems

Whereas most of the lack of uniformity in surface systems is due to variable soil intake rates and infiltration opportunity times, a properly designed sprinkler system applies water at less than the infiltration rate, rendering soil intake properties of minor importance. As such, sprinklers (and all pressurized systems) are more controllable and amenable to management.

The uniformity of sprinkler-applied water depends on hydraulic design, system maintenance, and wind conditions during operation. Systems are usually designed so that hydraulic pressures throughout the system vary by no more than 20 percent. This results in discharge rates that should differ by less than 10 percent. In addition to variations in discharge rates, other factors that affect distribution are the spacing and height of risers, sprinkler and nozzle type, system pressure, and wind velocity. Particularly important in orchards is preventing the interception of spray patterns by the tree canopies due to high sprinkler angles. This not only diminishes uniformity but often results in runoff. Poor maintenance can lead to excessively worn nozzles and sprinklers, mixed nozzle sizes and types, and leaky pipe joints. Operating the system at suboptimal pressures can also reduce distribution uniformity.

Table 4. Infiltration characteristics measured over a season in a Wasco sandy loam, furrow-irrigated field (data are for nontraffic furrows)

Date	**Steady-state intake rate**	**Water infiltrated in 24 hours**
	in/hr	*in*
2/6	0.32	13.8
6/15	0.17	4.9
7/7	0.11	3.1
7/19	0.09	4.0
7/28	0.08	2.4
8/3	0.05	2.2
8/9	0.08	2.2
8/16	0.03	1.1
8/24	0.04	1.1
8/31	0.03	1.3

One way to decrease sprinkler losses is to irrigate as much as possible during nighttime hours. This should decrease both spray evaporation losses (estimated to be from 5 to 15 percent of applied water during the day) and wind drift, since wind velocities are usually lower at night. The SDI approach discussed for surface systems to improve application efficiency requires caution when used with sprinklers. While it's desirable to refrain from completely refilling the root zone (to prevent deep-percolation losses), excessively frequent, full-coverage irrigations can significantly increase surface evaporation, especially in young orchards.

Low-volume (drip, microsprinkler) systems

These systems are the latest in the developmental pathway of irrigation methods. When properly designed, maintained, and managed, they offer the highest possible uniformity and least possible irrigation losses. However, like any irrigation system, poor design, maintenance, and management can result in wasted water. Indeed, more than a third of the drip irrigation systems evaluated in a recent San Joaquin Valley survey had distribution uniformities less than 70 percent. This was ascribed primarily to filtration and water quality problems that caused emitter plugging. Potentially achievable uniformities of low-volume systems approach 90 percent. Moreover, they offer irrigators the greatest control possible in the frequency and durations of irrigations. As such, they are ideally suited for use in drought irrigation strategies that limit water deficit periods to least sensitive plant growth stages.

Determining an Irrigation Schedule

You need to make a number of decisions in order to determine the timing and amount for water applications under drought conditions. A step-by-step procedure follows, with sample calculations. For examples of irrigation scheduling under normal water supply conditions, refer to Leaflet 21419 (*The Water Budget Method—Irrigation Scheduling for Southern San Joaquin Valley Deciduous Orchards*). The following examples assume that the seasonal water supply will be reduced by approximately 33 percent of normal. Sample calculations are presented for two irrigation methods—border strip and low-volume sprinkler. We have made assumptions to simplify the development of our sample strategies. Innovative, creative deficit irrigation regimes will probably involve tactics that are site-specific, especially when utilizing SDI with surface irrigation methods where soil infiltration plays an important role.

Crop:	Late-harvest (mid-August) peach trees grown under clean-cultivated conditions
Tree spacing:	12 x 6 ft
Soil:	Fine sandy loam uniform with depth
Location:	Parlier, California
Root zone depth:	6 ft

For border irrigation

Step 1: Estimate the available moisture in root zone. Generalized estimates of *available water* (AW) contents for different soil types are given in table 5. To determine total AW, multiply the appropriate AW value by the rooting depth. Note that if the soil texture varies substantially with depth, AWs must be determined for each textural layer and then summed to obtain the entire root zone AW.

Example:

available water (AW) =1.5 inches of water per foot of soil
total AW = AW x rooting depth in feet
= 1.5 inches/foot x 6 feet
= 9 inches

Step 2: Estimate the normal orchard water use. To calculate the normal orchard water use, you must know the ET_o and K_c, available in table 2. We have no specific K_c data for peach, so we will assume that it is approximately that of almond. Daily ET_o multiplied by the appropriate K_c gives daily orchard ET. Based on the data in table 2, cumulative ET_c under normal water conditions is plotted in figure 4. Remember that the ET_o values in table 2 are long-term averages, and that real-time values are more precise.

Table 5. Estimated available water per foot of soil for soils of various textures

Soil type	Available water
	in water/ft soil
Sand	0.5–0.7
Fine sand	0.7–0.9
Loamy sand	0.7–1.1
Sandy loam	0.8–1.4
Fine sandy loam	0.9–1.6
Loam	1.0–1.8
Silt loam	1.2–1.8
Clay loam	1.3–2.1
Silty clay loam	1.4–2.5

Step 3: Decide when to irrigate. With normal water supplies, irrigation timing depends largely on how much of the AW can be extracted without hurting tree performance. This fraction of the AW, the *yield threshold depletion* (YTD), depends on soil, plant, and atmospheric factors and is normally assumed to be approximately 50 percent for the conditions in this example. Thus, our YTD is 4.5 inches (0.50 x 9.0 inches). Assuming that in normal years the soil water profile begins the season full from the combination of winter rainfall and winter irrigations, deciding when to irrigate with unrestricted water is simply a matter of periodically determining when the cumulative ET_c equals (but does not exceed) the YTD. This procedure is illustrated in figure 4, and results in a total of eight irrigations in a normal year, beginning on May 1, then May 26, and so on. The example orchard has been irrigated at ET_c increments of 4.5 inches.

When determining the timing of irrigations in a drought year, deciding when the tree performance is most sensitive to

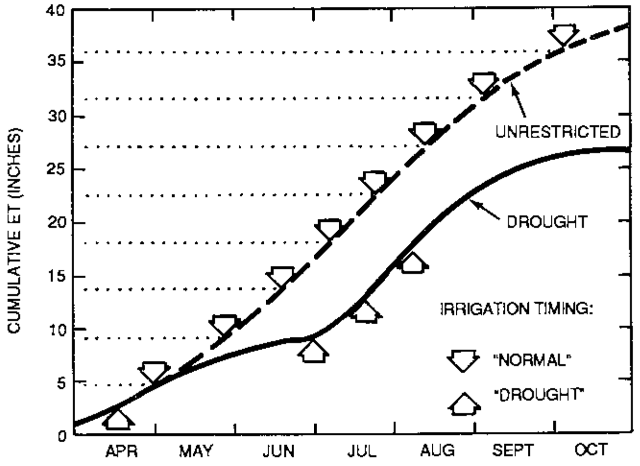


Fig. 4. Comparison of cumulative crop water use (ET_c) over time in normal (unrestricted) and drought years for a border-strip-irrigated peach orchard. The drought-year ET_c is based on a deficit irrigation regime (developed in the text) that assumes two-thirds of the normal water supply is available.

water deficits is of critical importance, since we know that the tree is going to be stressed for water at certain times during the year (remember, we have water sufficient to meet only two-thirds of a normal year's orchard water use). The information in figure 2 on plant water stress tolerance can be used as a guide for timing irrigations in a drought.

In this example, we assume that we start the drought season with only 5 inches of AW, again resulting from rainfall (albeit subnormal), soil water carry over from the previous season, and winter irrigation. Even though the profile is not full, winter irrigation may be undesirable, since high infiltration rates may result in poor application efficiency. However, since the bloom and fruit set periods are sensitive to water deficits, we want to meet the tree's full water needs early in the season. In view of a YTD of 50 percent and the initial total AW, the first irrigation occurs after 2.5 inches of water use (0.50 x 5.0 inches), on April 15. This strategy results in the onset of plant water deficits and consequent reduction in transpiration in early May, as shown in figure 4. This coincides with the moderately stress-tolerant phenological development period of stage II fruit growth, the *lag phase*. Between April 15 and July 1, the moderate stress tolerance period in this example, normal-year ET_c totals 13.6 inches. But by withholding irrigation until July 1, water use will be reduced to 7.0 inches (the sum of the 2.5 inches of total AW remaining in the profile prior to April 15 and an effective irrigation amount of 4.5 inches).

July 1 through harvest is the period of rapid fruit growth, when productivity again becomes highly sensitive to water stress (fig. 2), so irrigation timing returns to normal intervals (every 4.5 inches of cumulative ET_c). This results in irrigations on July 1, July 19, and August 8. After harvest, no irrigations are planned, based on the high tree tolerance to water deficits at that time.

Step 4: Calculate the irrigation amount. As discussed earlier, normal irrigation practices result in some losses during application, primarily to deep percolation. Besides nonuniformity of applied water, the major factor determining these losses is the storage capacity of the soil water reservoir (i.e., the amount of AW left in the root zone at each irrigation). Application efficiencies may improve with drought irrigation regimes, since the profile will generally be drier than normal at each irrigation.

Application efficiencies for well-designed, well-managed irrigation systems are shown in table 3. They should be considered rough estimates. Verify their accuracy by checking orchards for the depth of water penetration after each irrigation. If the penetration is less than expected, the efficiency was overestimated—and vice versa—assuming that the amount of water applied was measured accurately.

Under normal water supply conditions, application amounts are determined by dividing the amount of water depleted since the previous irrigation (which is normally the cumulative ET_c) by the application efficiency.

Example:

Cumulative ET_c (from step 3) = 4.5 inches

Assume border-strip efficiency = 75 percent

$$\text{Amount of water to apply} = \frac{\text{cumulative } ET_c \text{ (inches)}}{\text{application efficiency}}$$

$$= \frac{4.5 \text{ inches}}{0.75}$$

$$= 6 \text{ inches per acre}$$

$$= 162{,}924 \text{ gallons per acre}$$

When a tree experiences water deficits, determining the cumulative ET_c is virtually impossible because transpiration depends largely on stomatal behavior, which is difficult to predict. Decisions on irrigation amounts after periods of plant stress should be based on the remaining AW capacity of the root zone, and the sensitivity of the subsequent phenological development period to water deficits.

Consider the April 15 irrigation first. Although only 2.5 inches remain of total AW at this point, we want to keep from fully recharging the profile, if possible, for two reasons: (1) deep percolation may be appreciable, and (2) the onset of water stress would be delayed, and less water would therefore be saved during a relatively safe period for plant water stress. In other words, water used to fully recharge the profile could be put to better use later in the season. An SDI that will partially replenish the root zone is desirable, and adding 4.5 inches to the soil water reservoir seems reasonable. Since the application efficiency would be higher (assume 90 percent), the application amount would be 5 inches (4.5 inches ÷ 0.90).

Due to the extended period of stress between the first and second irrigations, we assume that nearly all of the AW in the 6-foot root zone will be exhausted. Additionally, the risk-reward ratio at the second irrigation favors refilling the entire root zone in view of the extreme sensitivity of the fruit to water stress from this point to harvest, even though the application efficiency would be less. Therefore, the July 1 irrigation amount would be 12 inches (9 inches ÷ 0.75).

The last two irrigations would require 6 inches of water, as under normal conditions (4.5 inches ÷ 0.75). Thus, the seasonal drought strategy applies 29 inches of water, compared with 48 inches when water availability is unrestricted.

Step 5: Calculate the set time. The irrigation set time depends on the amount of water to be applied (Step 4) and the rate of water application. Inflow measurement is critically important with surface irrigation. With pumps, you measure inflow with in-line meters or estimate it based on pump test information. With canal or ditch water, inflow estimates can be made with various devices, such as flumes, or calculated on the basis of hydraulic heads in syphons and discharge pipes. Local farm advisors can supply information on using these techniques.

Example:

Amount to apply = 162,924 gallons/acre (from Step 4)

Discharge rate to field = 1,000 gallons/minute

= 60,000 gallons/hour

$$\text{Set time} = \frac{\text{amount of water to be applied}}{\text{inflow rate}}$$

$$= \frac{162{,}924 \text{ gallons/acre}}{60{,}000 \text{ gallons/hour}}$$

$$\approx 2.7 \text{ hours/acre}$$

This example illustrates the problems that growers face in designing deficit irrigation programs with surface irrigation. Dictating when plant stress will occur is difficult with deep soils and extensive root systems, since after any irrigation the trees return to full or near-full ET_c rates. While the onset of transpiration-reducing stress depends on several factors, the amount of water applied is the most important. Growers have only limited control over applied water under most conventional surface irrigation systems, consistent with achieving full advance over the field. A minimum amount of water is required, and this amount is often in excess of what is desirable for precise management of stress conditions in the orchard. This example is based on the conventional management of a surface-irrigated orchard. Additional SDI techniques will allow growers more flexibility in deficit irrigation management.

Low-volume sprinklers

Much of the difficulty in managing surface irrigation systems when water supplies are limited stems from the lack of control over the distribution of infiltrated water and the amount of water that must be applied during each irrigation. High-frequency, low-volume application systems such as drip and low-volume sprinklers allow growers to overcome these control problems, permitting more creative and flexible irrigation scheduling regimes. Many aspects of the border strip irrigation example contrast markedly with localized irrigation. The following example highlights these differences. The new example uses the same cropping and site assumptions listed previously, except that low-volume sprinkler irrigation is used.

Step 1: Estimate the unrestricted orchard water use. The ET_o and K_c information found in table 2 will help you estimate the orchard's unrestricted rate of water use. However, it is more convenient to list water use rates as gallons per tree per day than as inches per day with localized irrigation. Use the following equation for this conversion:

ET (gallons/tree/day) = ET (inches/day)
x tree spacing (square feet)
x 0.622 (gallons/square foot-inch)

Using the data in table 2, we calculated the bimonthly ET_c data for peach in gallons per tree per day (table 6).

Step 2: Determine the irrigation frequency. How often you irrigate depends on three factors: (1) system design, (2) ET_c requirements, and (3) grower preference. Most drip systems are designed to operate daily and to deliver just enough water to satisfy peak daily water use demands. This design approach allows you to use the smallest possible pipe sizes, pumps, and the like, and thus the least initial expense. With such a design, you have little choice but to irrigate daily in order to meet the ET_c.

When water availability is restricted, the irrigator applies less water, whether by decreasing the irrigation frequency or the duration of each application. Less-frequent irrigation may reduce surface evaporation somewhat, since the surface will be wetted less often. However, a precise determination of water savings is impossible, since the dynamics of surface evaporation are extremely complex, involving evaporative demand, soil type, wetted area, and shading. Decreasing the frequency from daily to every other day probably would have little influence on surface evaporation. More severe reductions in frequency can save some water, but you must take care not to induce excessive tree stress. Remember that with localized irrigation, water is being absorbed from only a fraction of the soil profile. For this reason, water deficits develop quite rapidly, especially in sandy soils.

The range of irrigation frequencies possible with low-volume sprinklers is usually much greater than with drip, since application rates and wetted surface areas are greater. This results in greater flexibility in irrigation timing. For example, system design may allow you to reduce irrigations from three per week to one per week, which would certainly reduce seasonal surface evaporation. On the other hand, the relatively large application required under the less-frequent operation would increase the trees' water-use rates immediately after the irrigation. This would be followed by the onset of plant water stress that would become most severe just before the next irrigation, relative to high-frequency deficit irrigation. In other words, the trees would be subjected to greater periodic fluctuations in plant water status under lower frequency operation. Research in this area is limited; we simply don't have enough information to determine whether the reduced surface evaporation offsets the possible detrimental effects of greater plant water status fluctuations. In this example, we will irrigate once every 4 days.

Step 3: Calculate the irrigation amount. Water application amounts depend on the ET_c rates, the irrigation frequency, and the application efficiency. In order to save approximately one-third of normal water use, we will manipulate ET_c by controlled stress management during the periods of high and moderate plant stress tolerance. Again using the phenological growth stage sensitivity information shown in figure 2, it seems prudent to irrigate at 45 percent of full ET_c during the moderately sensitive stage II of fruit growth and at 25 percent of full ET_c postharvest. These percentages or *drought strategy*

Table 6. Drought irrigation schedule for a late-harvest (mid-August) high-density peach orchard (12-x-6-foot tree spacing), assuming low-volume sprinklers are used and only two-thirds of normal water supply is available

	Normal year			
Date	**ET_c**	**Applied water***	**Drought strategy factor**	**Drought strategy applied water†**
	gal/tree/day	*gal/tree/day*	*%*	*gal/tree/day*
March 16–31	3.1	3.4	100	3.4
April 1–15	4.3	4.8	100	4.8
April 16–30	5.3	5.9	100	5.9
May 1–15	6.9	7.7	45	3.1
May 16–31	8.5	9.4	45	3.8
June 1–15	9.4	10.4	45	4.2
June 16–30	10.0	11.1	45	4.5
July 1–15	11.2	12.4	100	12.4
July 16–31	10.9	12.1	100	12.1
August 1–15	10.1	11.2	100	11.2
August 16–31	9.3	10.3	25	2.3
September 1–15	8.0	8.9	25	2.0
September 16–30	6.5	7.2	25	1.6
October 1–15	4.6	5.1	25	1.2
October 16–31	3.2	3.6	25	0.8
November 1–15	1.9	2.1	25	0.5
Total seasonal applied water	—	1,934 gal/tree (43.2 in/ac)	—	1,134 gal/tree (25.3 in/ac)

[*] Assumes that full ET_c is met by irrigation, and that application efficiency is 90 percent.

[†] Assumes that application efficiency is 90 percent when full ET_c is met, and 100 percent under deficit irrigation.

factors depend primarily on how severely the normal water supplies are reduced.

While the application efficiency of a localized irrigation system depends on design, maintenance, and management, it is enhanced by SDI. Take this into account when you determine how much water to apply. Using the above drought strategy factors and estimates of application efficiency, we developed an irrigation schedule (table 6).

Example (stress-tolerant period):

First week of June
Irrigating at 45 percent of full ET_c
Application efficiency 100 percent
Irrigation every 4 days

$$\text{Daily water need} = \frac{ET_c}{\text{application efficiency}}$$

$$= \frac{0.45 \times 9.4 \text{ gallons/tree/day}}{1.0} \text{(from table 6)}$$

$$= 4.2 \text{ gallons/tree/day}$$

$$\text{Amount to apply} = 4.2 \text{ gallons/tree/day} \times 4 \text{ days}$$

$$= 16.8 \text{ gallons}$$

Example (stress-sensitive period):

Third week of July
Irrigating at full ET_c rates
Application efficiency 90 percent
Irrigation every 4 days

$$\text{Daily water need} = \frac{ET_c}{\text{application efficiency}}$$

$$= \frac{10.9 \text{ gallons/tree/day}}{0.90} \text{ (from table 6)}$$

$$= 12.1 \text{ gallons/tree/day}$$

$$\text{Amount to apply} = 12.1 \text{ gallons/tree/day} \times 4 \text{ days}$$

$$= 48.4 \text{ gallons}$$

Step 4: Calculate the set time. Set time (the duration of water application) depends on the amount of water applied (from

Step 4) and the irrigation system application rate. You can determine application rates by using a water meter or calculate them based on measured or published emitter-discharge rates. The set time is simply the amount of water to be applied divided by the application rate.

Example:

Third week of July
One low-volume sprinkler per tree
Each emitter delivers 8 gallons per hour
Irrigation every 4 days

$$\text{Set time} = \frac{\text{water volume to be applied}}{\text{application rate}} = \frac{48.4 \text{ gallons}}{8 \text{ gallons/hour}} \approx 6.1 \text{ hours}$$

It should be noted that irrigating at the onset of stress-sensitive periods to relieve the plant stress as quickly as possible will require water application in excess of 100 percent ET_c until the bulk of the root zone is wetted. Much of the water initially applied to a dry profile is held tightly in small soil pores and the large soil pores (where most root extraction occurs) are the last to be refilled.

Additional Considerations

Young trees

Since maximizing vegetative growth is the primary objective in the early years of an orchard, and shoot extension is quite sensitive to water deficits, inadequate irrigation will delay orchard maturity. Thus, meeting the water needs of the trees is particularly important, and may influence decisions on allocating water supplies to mature or young blocks on the same farm.

Estimating the water requirements of immature deciduous trees is difficult for two reasons. First, researchers have developed little information in this area. One study on young almond trees established that young orchard ET_c, when expressed as a percentage of mature orchard ET_c, is approximately twice the shaded area of the orchard floor measured at midday. For example, an immature orchard that shades 20 percent of the orchard floor would use approximately 40 percent as much water as a mature orchard. This rule of thumb assumes that surface irrigation is applied at 2-week intervals. Note that the evaporation component accounts for a much larger percentage of ET in young orchards that in mature orchards. This is because young trees have relatively low transpiration rates, and a partial canopy cover allows exposure of wet soil to direct sunlight. Evaporation depends on the area of the orchard floor that is wetted and the frequency of irrigation.

Determining the water requirements in first- or second-year trees is also difficult, since the application efficiency of the irrigation system cannot be measured easily. This is because of the small size and uncertain location of the root zone. Since irrigation systems are usually designed to perform optimally in a mature orchard, a significant amount of water can be lost to deep percolation in young orchards just because water is applied outside of the root zone. Even low-volume systems that have high distribution uniformities and high application efficiencies in mature orchards have much lower application efficiencies in new plantings (values of 30 to 50 percent are typical in first-year trees). Application efficiencies improve as the root zones develop.

Growers can maximize the application efficiency in young orchards by managing their irrigation systems to limit the amount of water applied outside the root zone. With a low-volume system, you can place the emitters close to the trunk, recognizing that they will be moved as the trees mature. As another alternative, you can operate low-volume sprinklers at reduced pressures to decrease the area wetted, although you should check the system to make sure it maintains a high uniformity of application. With surface systems, small furrows on either side of the tree can improve application efficiency.

Pruning

Since orchard ET is influenced by the size of the tree canopy, pruning can affect tree water requirements. However, appreciably reducing orchard ET requires severe pruning. Only consider this if the survival of the trees is at stake, as may be the case if little or no irrigation water is available. Research on apples shows that removing a large portion of the canopy will decrease transpiration enough to allow the trees to survive. Productivity, however, will be drastically reduced. This practice is not recommended for drought-tolerant trees such as pistachio that can survive without excessive pruning for several years with only 2 or 3 inches of water.

Thinning

Research also shows that transpiration rates can be influenced by the presence of fruit. The rapid growth of fruit apparently results in somewhat higher carbon dioxide assimilation and tree water use rates, but the magnitudes of these increases are relatively small. Thinning to reduce orchard water requirements should not be considered as a viable practice. Assuming that water deprivation will decrease the amount of photosynthate available for fruit production, heavier than normal thinning may be necessary to produce fruit of an acceptable size.

Fertilization

Although both water and nutrients are important requirements for optimal tree growth, adding additional fertilizer during periods of drought will not compensate for reduced irrigation.

In general, fertilizer practices should be maintained or, if anything, modestly reduced if you anticipate less vegetative growth.

Fixed delivery dates

During drought irrigation periods, the timing of irrigation is extremely important in managing plant water deficits. If the irrigation district's delivery dates are on a fixed schedule (e.g., once every 3 weeks), you have little flexibility in timing your irrigations. Cooperation between growers and districts to best coordinate delivery schedules is more important during droughts than under normal conditions.

Salinity

Under normal irrigated agriculture conditions, a certain amount of deep percolation is necessary to leach salts from the root zone. These salts are delivered in the irrigation water and then left behind when the roots extract "pure" water from the soil, and can give cause for concern if they build up to high levels. History shows that entire civilizations have been dislocated because they failed to control soil salinity. However, this occurred over decades. With the usually good quality of California's surface water, the increase in salinity that results from 1 or 2 years of deficit irrigation is unlikely to result in crop damage. Only growers who use high-salinity well water need to be concerned with the short-term buildup of salinity in California.

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