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Irrigation Scheduling for Walnut Orchards

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In most areas of California, a mature walnut orchard has the potential to use about 42 acre-inches of water per acre. This equates to about 290 gallons of water for each pound of nuts produced in a 2-ton orchard. Inadequate irrigation of walnut trees can result in reduced nut size; sunburn; increased mite pressure; and increased disease, especially deep bark canker. Recent research suggests that the impact of water stress on yield and quality depends on the degree of stress, the part of the season in which it is imposed, and the duration of the stress. Depriving trees of adequate water during critical development periods leads to production loss.

Since most California walnuts are produced in regions that receive less effective rainfall than the trees' potential water use, the vast majority of California growers irrigate their orchards. Effective management calls for maintaining an adequate supply of soil moisture throughout the season. Irrigation based on past experience has been the traditional water management method, but increasing water costs; the fact that the municipal, industrial, and environmental sectors are competing for water; and the potential to improve orchard production and profits all call for scientific irrigation scheduling based on sound horticultural principles.

Scientific irrigation scheduling techniques determine when to irrigate and how much water to apply. There are two fundamentally different approaches to scientific irrigation scheduling: (1) estimating the amount of water the orchard is using and (2) monitoring soil moisture levels by hand or with various instruments. Other scheduling techniques, now mainly in the research phase, use plant-water status or canopy temperature measurements made with specialized equipment to signal when irrigation is needed. More research is needed to determine whether these techniques can be used successfully to irrigate walnut trees.

The first currently used approach is known as the water budget method. It involves knowledge of the soil, plant, and climate. This chapter focuses on this approach; soil moisture–monitoring techniques are covered in chapter 21. A single approach cannot be universally recommended. Many growers use the water budget method as their primary technique. A comprehensive program includes one of the soil moisture–monitoring techniques to check the accuracy of the water budget method.

THE WATER BUDGET METHOD

The orchard water budget balances water additions and losses from the orchard. The irrigation requirement is the difference between water losses and effective rainfall. In other words:

$$\text{Irrigation requirement} = ET_c - \text{effective rainfall} + \text{system losses}$$

where ET_c is crop evapotranspiration (the sum of transpiration from leaves and evaporation from the soil). Effective rainfall is the rainfall amount stored in the root zone. Although this is difficult to estimate, it can meet a significant part of the seasonal needs in many growing regions. Therefore, effective rainfall should not be ignored. The amount of rainfall stored in the soil depends on rainfall intensity and duration and usually ranges from 50 to 70 percent of total winter rainfall. Rather than using empirical approaches to estimate effective rainfall, measuring the depth of wetted soil at the beginning of the season is usually more practical. As for losses other than ET_c, deep percolation (the movement of water to the area below the root zone) and surface runoff can occur even with the best irrigation management. Surface systems that apply large amounts of water infrequently are potentially subject to the greatest system losses. Waste can be minimized, but it is not usually economically feasible to eliminate it entirely.

Since localized irrigation systems (drip systems, microsprinklers, foggers, and the like) that are operated frequently do not rely heavily on the soil to act as a reservoir for water, soil moisture-holding capacity is of far less importance with their use. With traditional systems, irrigations can be timed and application amounts can be determined once the size of the reservoir and the ET_c are estimated. Figure 20.1 illustrates this. Realize, however, that storing soil-water is not as simple as holding water in a reservoir. Replenishing the root zone profile and the ability of trees to extract stored water involve processes that are complex as well as variable in the field. Knowledge of soil moisture replenishment and extraction is important for understanding irrigation scheduling, so this chapter discusses them in some detail.

Water Movement and Storage

The soil is a complex matrix of solid particles, voids, and small amounts of organic matter. Its water-holding capacity depends on the relative volume of void space (porosity) and the size of the pores (pore size distribution). There is a direct relationship between soil particle size (texture) and pore space. Coarse-textured soils (sands) contain a relatively small percentage of total pore space; fine-textured soils (clays and clay loams) contain a relatively high percentage. Even though clays have a larger porosity, their average pore size is small when compared to the pore size in sands. Because the rate of water flow depends primarily on pore size, water does not move as readily in clay soils as it moves in sandy soils.

Water applied to a field infiltrates quickly into the soil at first; it slows as irrigation continues. With surface irrigation methods, the soil infiltration rate controls the amount of water that infiltrates. Thus, the soil infiltration rate usually dictates the irrigation, or set, time. With sprinklers or localized irrigation, the system application rate determines the amount of water infiltration, assuming the minimum soil intake rate is not exceeded. Because the goal of efficient irrigation is to get a specific quantity of water into the soil for storage, the infiltration rate is of primary importance with surface methods. The infiltration rate is highest early in the season and usually decreases with successive irrigations. The reasons for this are not well understood, but they seem to be associated with changes in soil surface chemistry and structure.

When water is applied to a field, the pore space in the upper level of the soil profile is nearly filled. As irrigation continues, the depth of the nearly saturated soil zone increases. If the soil profile has been dry, a distinct boundary exists between wet and dry soil. When irrigation stops, some water moves out of the wetted zone and partially wets the dry soil below it. If the subsoil is already moist, the water may move out of the root zone, making it unavailable for tree uptake. This wastes water and will be discussed later, in the section on irrigation efficiency.

After irrigation, water drains rapidly at first. But, as the large pores empty, the soil conducts water much less readily. After 2 or 3 days, the rate of water movement slows to the point that it becomes negligible; the remainder of the soil-water is considered stored. At this point, the water content of the soil is called its field capacity (FC). FC is the upper limit of water storage. A practical lower limit of soil-water content, below which crop growth is severely reduced by water stress, is defined as the permanent wilting point (PWP). Walnut trees usually show visible leaf wilting when soil in the bulk of the root zone approaches the PWP.

The difference between FC and PWP is termed available water content (AWC). Table 20.1 shows the range and average AWC of various soil types. The table states AWC in terms of inches of water per foot of soil. (Several terms are used to express soil-water content, but inches of water per foot of soil is a practical unit that can be visualized as the depth of water obtained if all available water were extracted from a 1-foot depth

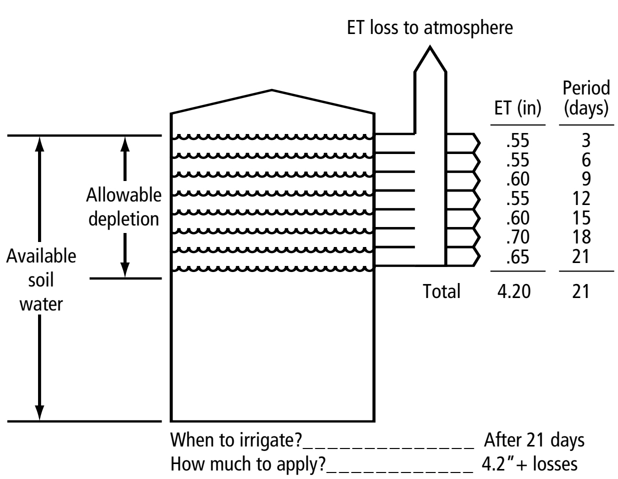

Figure 20.1 A conceptual illustration of the water budget method of estimating irrigation needs.

Table 20.1 Estimates of available water content for different soil types.

Soil type	Available water content	
	Range (in/ft)	Average (in/ft)
Coarse-textured sand	0.5–1.25	0.90
Sandy loams	1.25–1.75	1.50
Silty clay loams	1.50–2.30	1.90
Clay	1.60–2.50	2.10

of soil.) As table 20.1 shows, sands, with their relatively small total pore space, do not store large amounts of water. However, what little water is held is easily removed by plant roots—this will be discussed in the next section, which explains allowable depletion. A clay soil, because of its high porosity, has a large AWC. However, the small water-filled pores of clays exert attracting forces that tend to resist water extraction by plants. Intermediate-textured soils, the loams, have good water-holding properties and, because of their wide range of particle sizes, are able to readily release water for tree use. Once you know the AWC, you can easily determine the total water-holding capacity of a profile: Multiply the AWC by the root zone depth.

The wide range of AWC for each soil type demonstrates the uncertainty of estimates and indicates that factors other than particle size affect water-holding capacity. The University of California (UC) and U.S. Department of Agriculture's Soil Conservation Service have developed specific AWC information for most soils in agricultural regions of California. Precise determinations of AWC are not usually necessary for irrigation scheduling. Indeed, the expressions FC, PWP, and AWC are actually concepts. Do not think of them as absolute, fixed amounts; they are practical estimates used to represent the continually changing water content of the soil profile.

Allowable Depletion

Although comparing soil-water storage to storage in a reservoir can be useful, it is not entirely accurate. As soil-water content decreases, it becomes more difficult for roots to extract the remaining water even though moisture content remains well above the PWP. This is because, after the large soil pores give up their water, the smaller pores must assume two important functions: They must store water and conduct water that is moving from the soil to plant roots. Small pores hold water tightly (a relatively large amount of energy is required for extraction) and water travels quite slowly through them. These factors combine to limit water uptake as soils dry out. Thus, crop growth decreases before the entire root zone reaches the PWP. For this reason, you should usually irrigate before the root zone water content reaches a level that restricts growth.

Unfortunately, no single soil-water depletion level can be recommended for all situations. The safe amount of depletion—called allowable depletion (AD), or yield threshold depletion (YTD)—is usually referred to as a percentage of the total available water in the root zone. AD depends on numerous factors, including rooting depth, soil texture, and the weather. The impact of these factors on the safe level of AD are interrelated and complex. Figure 20.2 illustrates the relationship between depletion and plant growth for two extreme situations. One example refers to a shallow-rooted crop on a clay soil grown under hot, windy conditions. Here, a depletion of 30 to 40 percent of available root zone moisture may affect crop growth. Conversely, a deeply rooted crop grown on a sandy soil under mild weather conditions may be able to tolerate an AD of 70 to 80 percent before the growth rate drops. AD is difficult to determine, but precise determinations are not required. An AD of 50 percent has been used successfully to plan irrigation in California walnut orchards and is considered reasonable for most situations.

Remember: The objective of irrigation is to keep adequate moisture in the soil. Estimates of AD allow use of the maximum amount of soil-water (consistent with optimal tree performance) between irrigations. This means you irrigate the fewest number of times possible. Because there are fixed costs associated with each irrigation, irrigation based on AD is usually the most economical. For example, if trees can remove 50 percent of total AWC between irrigations, then irrigating when only 25 percent of available water in the root zone has been depleted requires twice as many irrigations. The YTD concept is important only when using surface irrigation and sprinklers; localized irrigation systems can be operated economically regardless of how frequently they are used, because labor costs associated with each irrigation are minimal.

Orchard Water Use

The water budget procedure can be used successfully only if the ET_c is known. ET_c depends on climate, plant, soil, and orchard management.

Weather conditions. The weather is the primary determinant of ET_c. Because evaporation from the soil sur-

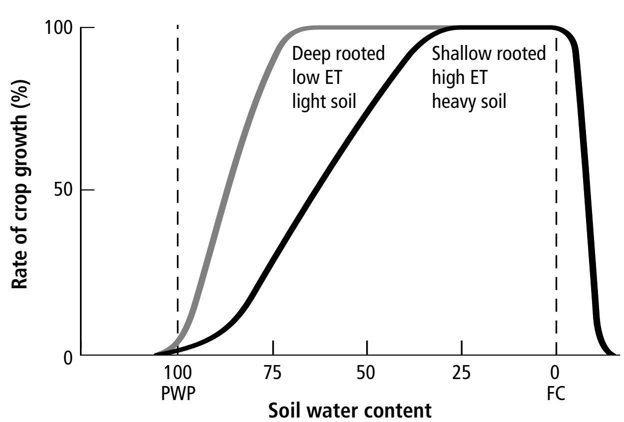

Figure 20.2 Two situations showing the relationship between allowable depletion and plant growth.

face and leaf transpiration involve vaporizing water, the energy status of the atmosphere is of major consequence. The main component of the energy balance in an orchard is solar radiation (sunlight intensity), although temperature, humidity, and wind speed also affect it. Additionally, if an orchard is bordered upwind by bare ground, advective energy transfer can cause ET_c to drastically increase.

Surface evaporation. This component of ET_c is important only when the soil surface is wet. After an irrigation, wet soil exposed to the sun can evaporate water at the same rate that trees transpire. As the soil surface dries out, surface evaporation decreases rapidly. The total amount of water evaporated depends on the orchard floor area that is wetted and the number of irrigations. Because both evaporation and transpiration require energy, excessive evaporation somewhat reduces available energy and crop transpiration. However, increased evaporation does not reduce transpiration by a like amount.

Plant factors. The most significant plant factor affecting ET_c is the total leaf area intercepting solar radiation. This depends on the size of the tree canopy, planting density, and stage of leaf development during the season. Rather than trying to measure leaf area, research indicates that the degree of plant cover (shade) over the orchard floor correlates well with sunlit leaf area. Research with developing almond trees indicates that, as a young orchard matures, ET_c reaches its maximum when 55 to 60 percent of the ground is shaded by tree canopies at midday. Figure 20.3 shows the relationship between percentage of ground cover and ET_c for almond. Note that the relationship between percentage of shade and ET_c is far from being a 1:1 correlation. Presumably, the orchard floor area receiving direct sunlight transfers advective energy to the tree canopies, thereby increasing ET_c. Even though walnut trees have a somewhat different canopy architecture than almond, tree experts believe the relationship shown in figure 20.3 can be used in regard to walnut.

Orchard management. Although most factors affecting ET_c are not subject to a grower's control, orchard management can influence water usage. As noted, frequency of irrigation and size of the wetted surface area influence evaporation. Effective management controls both factors and limits evaporation loss. With furrow irrigation of young trees, the manager can use one furrow on either side of the tree row rather than wet multiple furrows completely. Studies show that localized irrigation can significantly decrease evaporation and thus save water in young orchards. With mature trees, localized irrigation achieves little reduction of surface evaporation.

Although cover crops can be beneficial, planting them has an undesirable consequence: They use considerable amounts of water. Cover crops or actively growing weeds can increase seasonal ET_c by 30 to 40 percent in mature deciduous orchards and even more in young orchards. Thus, take into account the cost and availability of water when considering cover crops.

Evaporative Demand Estimates

Because climatic conditions have the greatest influence on ET_c, many mathematical formulas have been developed to estimate ET_c based on meteorological measurements. So-called reference crop evapotranspiration (ET_o) values are derived from these empirical equations; ET_o values approximate evapotranspiration from a close-cut grass crop. Another index of evaporative demand is evaporation from a free water surface (E_{pan}). E_{pan} is strictly a physical mechanism (for example, it occurs even at night) and transpiration is light dependent and biologically controlled by the leaf stomata. Therefore, tests have shown that daily ET_c usually correlates better with ET_o than with E_{pan}. Long-term, historical average daily ET_o rates have been compiled for locations throughout California and appear in UC DANR Publ. 21454, *Irrigation Scheduling: A Guide for Efficient On-farm Water Management.*

The crop coefficient. The relationship between ET_c and ET_o, when expressed as the ratio ET_c/ET_o, is called the

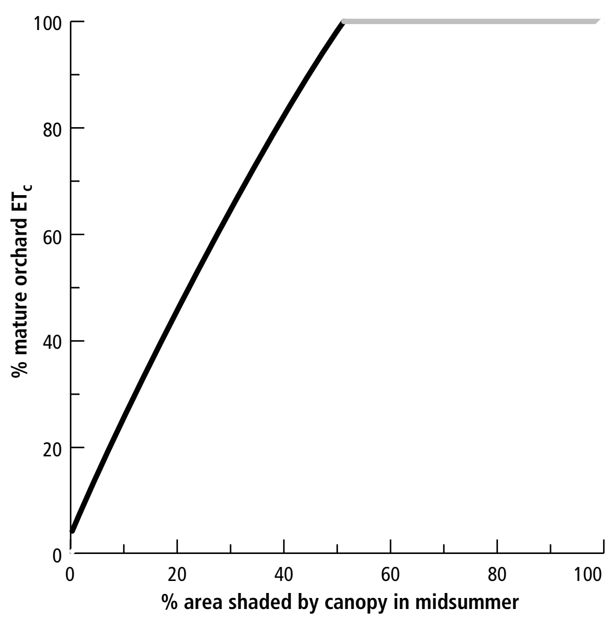

Figure 20.3 The relationship between percentage of ground cover and almond ET_c (from Fereres et al. 1982). Note that it is not 1 to 1.

crop coefficient (K_c). The K_c varies with the crop and its stage of growth, but it is assumed to be independent of location for the interior valleys of California. Thus, a single set of walnut tree K_c values can be used throughout most of the state, with the exception of the coastal areas. Research on Chico at the Kearney Agricultural Center, San Joaquin Valley, was used to develop seasonal K_c values for walnut (table 20.2). Leafout for this cultivar is about March 15. Early in the season, as the tree canopies are developing, the K_c is relatively low. It reaches a maximum of 1.14 by early July. The K_c remains at this maximum value until leaf senescence begins, about mid-September for this cultivar.

Some adjustment of K_c is required for earlier- or later-season cultivars. Research has not yet established precise guidelines for this. Work with other crops suggests that, to arrive at an approximation, the K_c list shown in table 20.2 can be shifted based on leafout date. For example, a cultivar with a March 1 leafout would be expected to have a K_c of 0.12 for March 1 through 15 and 0.53 for March 16 through 31. On the other hand, for a later-season cultivar with a leafout of April 1, the cited K_c values would apply to the periods April 1 through 15 and April 16 through 30. This approach for adjusting K_c assumes that early-harvest cultivars also have earlier leaf senescence and vice versa.

Estimating ET_c. Table 20.2 gives bimonthly ET_c estimates for walnut trees grown in the San Joaquin Valley under clean cultivation during a normal weather year. Although the table cites long-term average ET_o values, the bimonthly K_c values can also be used with current (real-time) ET_o data. Information in this table applies to mature orchards (orchards with 55–60% or more shaded area) where irrigation is not less than every 2 weeks. There is very little difference between seasonal cumulative ET_c for the San Joaquin Valley and that for the Sacramento Valley. Again, a cover crop increases the ET_c rate, especially during the spring, when cover crops provide for near-complete interception of solar radiation.

Long-term average ET_c data can be used successfully for irrigation scheduling even though a "normal" year seldom occurs. Use common sense to modify irrigation schedules based on long-term averages if the season has drastically higher or lower than normal temperatures or winds. To be more accurate, use real-time ET_o estimates available from the California Irrigation Management Information System (CIMIS) network of automated weather stations, which is operated by the State of California Department of Water Resources. Also, several newspapers and radio stations in California report reference crop data. Be careful to recognize whether the data are estimates of ET_o, E_{pan}, or some other reference value. Each represents a different measurement, and you must use the appropriate crop coefficients to avoid error.

Irrigation Efficiency

When water is applied to an orchard, some losses are unavoidable, and they must be considered in calculating the actual amount of water to be applied. The type of irrigation system used, soil and climatic conditions, and water management practices largely determine irrigation efficiency.

Water applied to a field can be lost in the form of runoff; percolation below the root zone; and, with

Table 20.2 Long-term, historical average ET_c for mature Chico walnut under clean cultivation in the San Joaquin Valley.

Date	ET_o (in/day)	K_c	ET_c (in/day)	Cumulative ET_c (in)	ET_c (gal/tree/day)*
Mar.16–31	0.103	0.12	0.01	0.2	3.6
Apr. 1–15	0.157	0.53	0.08	1.4	28.7
Apr. 16–30	0.157	0.68	0.11	3.0	39.4
May 1–15	0.197	0.79	0.16	5.4	57.3
May 16–31	0.197	0.86	0.17	8.1	60.9
June 1–15	0.256	0.93	0.24	11.7	86.0
June 16 –30	0.256	1.00	0.26	15.6	93.2
July 1–15	0.275	1.14	0.31	20.3	111.1
July 16 –31	0.275	1.14	0.31	25.2	111.1
Aug. 1–15	0.236	1.14	0.27	29.3	96.7
Aug. 16–31	0.236	1.14	0.27	33.6	96.7
Sept. 1–15	0.177	1.08	0.19	36.5	68.1
Sept. 16–30	0.177	0.97	0.17	39.0	60.9
Oct. 1–15	0.110	0.88	0.10	40.5	35.8
Oct. 16–31	0.110	0.51	0.06	41.5	21.5
Nov. 1–15	0.047	0.28	0.01	41.6	3.6

*Based on 24-by-24-foot spacing. The following equation can be used to calculate individual tree water use for other spacings:
gal/tree/day = ET (in/day) × (ft^2) × 0.622 (gal/in-ft^2).

sprinklers, spray evaporation and drift. One of the goals of farm water management is to minimize losses while keeping the trees supplied with adequate water. For instance, runoff can be minimized by using an irrigation system design that prevents or reuses collected tailwater. Application efficiency (E_a) is a term commonly used to describe how well growers irrigate. It is defined as the percentage of applied water stored in the root zone.

$$E_a = \frac{\text{water stored}}{\text{water applied}}$$

Generally, Ea is directly related to how uniformly water can be applied over the surface.

Irrigation methods used in California walnut orchards include surface systems (basin, furrow, and border strip), sprinklers, drip systems, and microsprinklers. Each method differs in how uniformly it can apply water. With surface irrigation, the intake properties of the soil and the rate of application dictate the rate that water moves over the field; thus, these factors control the uniformity of infiltration. The faster the water moves to the bottom of the basin or run, the smaller is the difference in the opportunity time for infiltration between the top and the bottom of the field. This results in more uniform infiltration of water. Distribution of water by sprinkler irrigation depends mostly on system design, including spacing, nozzle type and size, riser height, and operating pressure. In addition to system design and operation, maintenance and adequate filtration determine the efficiency of drip or microsprinkler irrigation. Sprinkler, drip, or microsprinkler systems can usually be operated with higher efficiencies than can surface methods, since runoff and deep percolation can be minimized.

Because application efficiencies vary, each situation must be evaluated for E_a. Your local Cooperative Extension and the Soil Conservation Service offer assistance in evaluating systems. Table 20.3 shows gross estimates of E_a associated with different irrigation methods.

IRRIGATION SCHEDULE DEVELOPMENT

Each component of the water budget has been discussed; it is a simple procedure to determine an actual irrigation schedule. For surface-irrigated orchards, this means the water loss through ET_c is totaled until it exceeds the predetermined AD percentage of the total available water in the tree root zone. At that time, irrigate; the amount should equal the amount lost through ET_c plus the unavoidable losses due to runoff, deep percolation, and spray evaporation. The examples in figure 20.4 show actual development of an irrigation schedule for a mature, clean-cultivated walnut orchard, first for surface irrigation and then for a drip or microsprinkler system.

The water budget procedure is based on sound agronomic principles. However, even if you use the most accurate information and most appropriate techniques, be sure to check the soil periodically—either by hand, with a soil probe or auger, or with the monitoring instruments described in chapter 21. Monitoring is necessary because of uncertainties associated with (1) the amount of water applied and the depth of penetration, (2) estimates of AWC and YTD, which are affected by spatial variability of soils, and (3) estimates of (E_a).

Limiting Factors

The operational obstacles that sometimes hinder the development of surface irrigation schedules include slow infiltration rates; fixed deliveries of irrigation district water; and various cultural practices, including harvesting. If anticipated, these problems can be dealt with easily.

Walnut trees, particularly young ones, are susceptible to crown and root rots common in excessively wet soil. Many growers do not want irrigation water standing in the orchard for more than 24 hours. Because the intake rate dictates the quantity of water entering the soil in surface irrigation, the amount that infiltrates in 24 hours becomes the maximum application for each irrigation. On low infiltration–rate soils, this may be less than the irrigation requirement calculated by the water budget method. For the example presented earlier, assume that the infiltration rate averages 0.10 inch per hour. Thus, about 2.40 inches of water infiltrate at each irrigation. This value, not 4.20 inches, becomes the amount of depletion allowed (4.20 inches was based on AWC, YTD, and rooting depth). A lower infiltration rate means the grower must irrigate more frequently than originally scheduled but with less water per application.

Similarly, the irrigation schedule can be adjusted if water deliveries from the irrigation district occur on a fixed schedule. For example, if water is received every 2

Table 20.3 Gross estimates of irrigation efficiency (E_a) according to irrigation method.

System	Ea (%)
Basin	70–80
Border strip	70–80
Furrow	65–75
Sprinkler	75–85
Drip or microsprinkler	85–95

weeks, the irrigator simply determines crop water usage over the previous 2 weeks and applies that amount plus losses due to system inefficiency. So, rather than applying the same amount of water per irrigation, the quantity applied changes throughout the season.

Decline and Recovery from Deficit Irrigation

Decline. In a southern San Joaquin Valley study, mature hedgerow Chico walnuts were irrigated at 33, 66, and 100 percent ET_c for 3 years. This corresponded to seasonal ET_c amounts of 14, 28, and 42 acre-inches of water per acre. Following this deficit irrigation, the trees were returned to 100 percent ET_c for the next two seasons. Figures 20.6, 20.7, and 20.8 show the relative influences of the water stress and reintroduction of full irrigation on individual nut size, nut load (number per tree), and yield.

After one stress year, there were only minor reductions in nut yields for the two deficit irrigation regimes (fig. 20.6). Even with 33 percent ET_c, yields were lower by only about 10 percent. However, nut yields decreased much more rapidly in the second and third stress years. After year three, yields were reduced by about 35 and 50 percent in the 66 and 33 percent ET_c regimes, respectively. Yield reductions were due to a combination of both lower nut loads and smaller, lighter nuts.

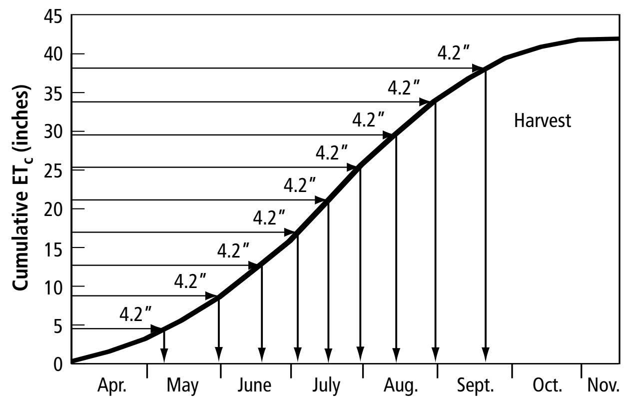

Figure 20.5 Determining irrigation dates in the southern San Joaquin Valley with the water budget approach.

GENERAL INFORMATION

Location: southern San Joaquin Valley
Soil: sandy loam
Rooting depth: 6 ft
Available water content (AWC): 1.4 in/ft
Allowable depletion (AD): 50% of total AWC

Example 1.
SURFACE IRRIGATION

Assume application efficiency (E_a): 75%

A. TOTAL AVAILABLE STORED WATER

AWC × Rooting depth

1.4 in/ft × 6 ft = 8.4 in

B. YTD AMOUNT

Total available stored water × AD

8.4 in/ft × 0.50 = 4.2 in (net irrigation requirement)

C. GROSS IRRIGATION REQUIREMENT

Net irrigation requirement/E_a

4.2 in/0.75 = 5.6 in

D. WATER USE RATE

Historical ET_c data from table 20.2 for a clean-cultivated orchard are plotted as cumulative ET_c versus time in Figure 20.5. Note: More accurate accounting is possible using current ET_c values.

E. DATES OF IRRIGATION

Simply draw horizontal lines for every 4.2 in. of cumulative ET_c (amount of depletion allowed). The date of irrigation is determined by drawing a vertical line to the date line where the horizontal line intersects the ET_c curves. Note: The final irrigation date and application amount have been adjusted to allow for storage of winter rains. Also, this procedure assumes that the root zone profile is fully wet at the start of the season, either by winter rains or postharvest irrigation. If this is not the case, the initial soil-water level can be estimated or determined by soil probing and the first irrigation set accordingly.

Example 2.
DRIP OR MICROSPRINKLER IRRIGATION

Assume application efficiency (E_a): 90%

Tree spacing: 24 × 24 ft

A. WATER USE (ET_c) RATE FOR JULY 16 TO 31 IS 0.28 IN/DAY.

Individual tree ET_c = ET_c (Depth/Time) × Tree spacing × Constant

= 0.28 in/day × (24 × 24 ft) × 0.622 gal/in-ft^2

= 111 gal/tree/day

B. IRRIGATION REQUIREMENT

ET_c/E_a (111 gal/tree/day)/0.90 = 123 gal/tree/day

Figure 20.4 Worksheet examples for developing irrigation schedules.

The relationship between nut load, deficit irrigation level, and time is shown in figure 20.7. While nut loads were lower in the second stress season, the decrease accelerated in the third stress year. Reduced crop loads were due to the fact that reduced shoot (fruit wood) growth lowered the number of fruiting positions for the following seasons. Since vegetative growth was severely limited by the water stress (data not shown), the bearing areas of the trees were simply smaller. This illustrates the impact of growth on eventual yields. Also, since vegetative growth in walnuts occurs over much of the season (there is no separation between the shoot and nut growth periods), there is no apparent time when water stress is not detrimental to tree performance, with the possible exception of postharvest.

Individual nut weight decreased only modestly after one year of deficit irrigation (fig. 20.8). However, the reduction in nut weight accelerated in the second stress season; nut weight in the 33 percent ET_c regime was about 21 percent less than the unstressed nuts. By stress year three, individual nut weight actually recovered in both stress regimes, because of the compensating effect of a much lower nut load on individual nut weight. This indicates that nut size alone is not a good indication of water stress.

Recovery. Upon returning the trees to full irrigation, tree growth, and water relations immediately recovered (data not shown), but the yields from that season's full irrigation were little changed from the last stress year (fig. 20.6). The slight yield increases were due to some increase in individual nut weight. However, yields completely recovered after 2 years of full irrigation. This was due primarily to a steep increase in nut load (fig. 20.7). Again, rapid shoot growth in the first year of full irrigation produced the fruiting positions necessary to return the trees to full production. This indicates that hedgerow walnuts have the potential for rapid recovery from lengthy periods of water deficits. This fast production recovery from severe water stress was also possible because of the absence of stress-induced disease or insect pressures. It must be emphasized that this absence of secondary stress pressures is cultivar and site dependent. Chico is more tolerant of heat and water stress-related problems than other cultivars. Trunk diseases, such as deep bark canker, that occur in many water-stressed orchards, were not evident in this study.

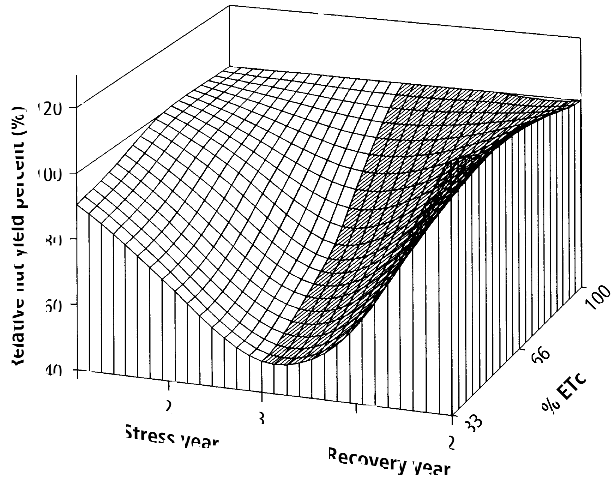

Figure 20.6 Relationship between relative yield (dry in-shell), time, and irrigation level.

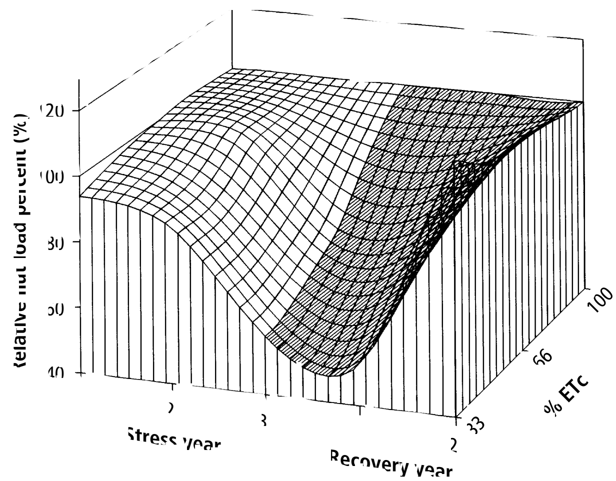

Figure 20.7 Relationship between relative tree nut load (number per tree), time, and irrigation level.

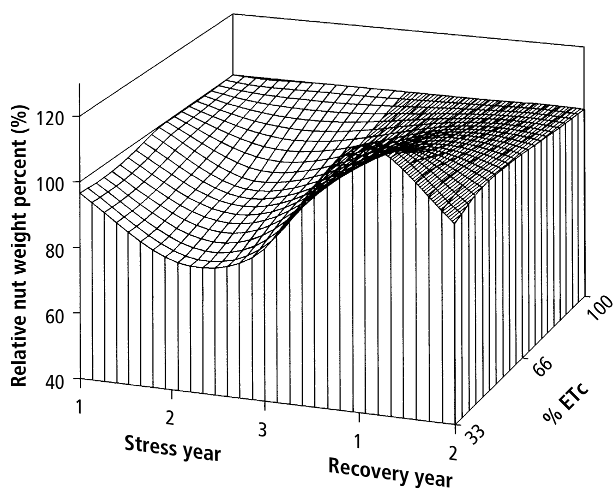

Figure 20.8 Relationship between relative individual nut weight, time, and irrigation level.