

DROUGHT TIP

Drought Management for California Almonds

Impacts of Stress on Almond Growth and Yield

Almond trees are tolerant to drought conditions and respond to water availability with increasing yields. Research has shown that trees are able to survive on as little as 7.6 inches of water (Shackel et al. 2011), but they produce maximally with 54 to 58 inches in many areas of California (Sanden 2007). Minimizing water stress increases growth and yield due to increased rates of photosynthesis and respiration.

Water and carbon dioxide are required by plants for photosynthesis. Water is provided through the root system of the tree, while stomata, or “windows,” on the lower leaf surface are responsible for allowing carbon dioxide to enter the leaf and oxygen to leave. As this gas exchange occurs, substantial amounts of water vapor is also lost through the stoma via transpiration. When the water loss potential from transpiration exceeds the amount of soil-water the roots can easily absorb, the plant will begin to appear stressed. If water applications through either irrigation or rainfall are not adequate to alleviate this stress, stomatal closure will be initiated, reducing gas exchange, rate of photosynthesis, and production of carbohydrates. This limits the amount of energy available for the many processes, negatively impacting vegetative growth and potentially fruit and kernel development.

The severity of stress determines its effect on the tree. Low to moderate levels of plant stress often occur within orchards and may be beneficial. Research has shown that an application of moderate stress at the onset of hull split helps to reduce the fungal disease hull rot and synchronize hull split (Teviotdale et al. 2001). Mild to moderate stress levels, if monitored, are useful for irrigation scheduling, as plant stress levels indicate the current soil-water status (Fulton et al.

DAVID DOLL, University of California Cooperative Extension Farm Advisor, Merced County
KENNETH SHACKEL, Professor, Department of Plant Science, University of California, Davis



2014). Severe plant stress, however, should be avoided when possible, as it impacts plant growth. Responses to severe water stress depend on when the stress is imposed. Impacts on vegetative growth, fruit and kernel development, and floral bud development are outlined below.

Impacts on Vegetative Growth

The period after leaf out is a time of rapid vegetative growth that is necessary to establish fruiting positions and carbohydrate reserves for future yields. Water use in the spring is low at the beginning but increases as leaves fully expand and the canopy develops. Typically, the relatively cool temperatures, short day length, and high relative humidity during this period mean that trees require less water, and the water demand may be met by the soil-water stored in the root zone from winter rains. In these cases, trees may grow relatively stress-free with minimal irrigation until full leaf expansion around 4 to 5 weeks after bloom.

Vegetative growth is reduced by moderate to severe water stress after full leaf expansion (or at any point in the growing season for a long enough period). Research has shown that nut load is directly related to canopy growth and size (Prichard et al. 1996; Lampinen et al. 2007). Therefore, lack of canopy growth due to irrigation deficits after full canopy expansion until harvest leads to a reduction of fruiting spurs and future yield potential. One year of reduced spur production will not necessarily lead to a dramatic decrease in next year's yield, but the effect can be cumulative if consecutive years of deficit irrigation occur and the number of fruiting spurs decrease. If the viable spur pool is already reduced due to a year of deficit irrigation, future yields will decline more if deficit irrigation is extended due to drought or other circumstances that may limit water availability. This phenomenon has been observed in trials in Spain and California, where fruit loads were unaffected by applied water stress in the first 2 years of the 4-year trial but were reduced in the final 2 years.

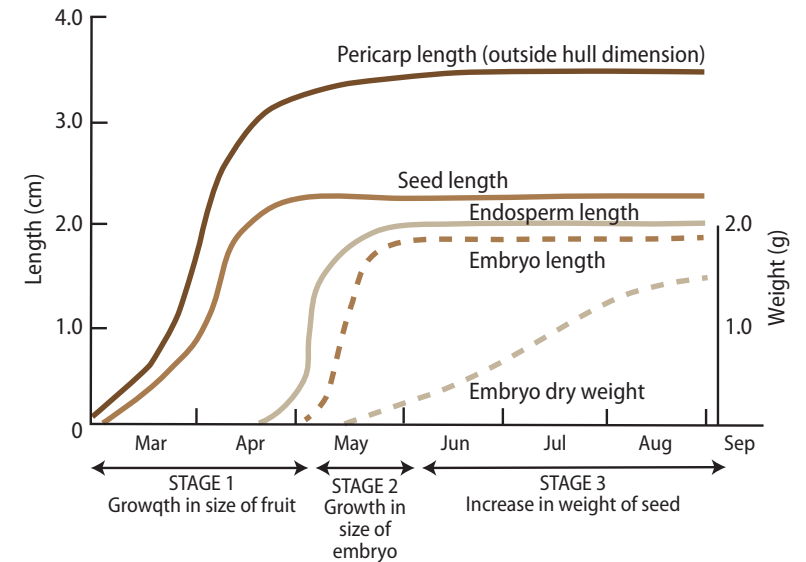


Figure 1: The three stages of almond fruit development and the typical length and weight of the fruit at each stage.

Impacts on In-Season Kernel Development

Fruit and kernel development follow a three-stage process (Kester et al. 1996) (fig. 1). During stage I, rapid growth of the hull, shell, and integuments occurs. The kernel begins to form as a white structure with a translucent jelly. Stage I ends once the maximum external dimensions of the hull, shell, and kernel have been reached, which is about 2 months after bloom. Severe tree water stress rarely occurs during stage I fruit growth (petal fall through late April and May) due to stored soil moisture, shorter days, and cooler temperatures; but if it does, it is thought that increased nut drop, smaller fruit, and kernel size will be observed because of reduced photosynthate directed toward cell division and expansion.

Stage II is a period of rapid fruit expansion. The hull and shell reach maximum size about 2 months after pollination. This is followed by shell hardening and kernel expansion (or hardening of

the shell and expansion of the kernel), with a corresponding increase in the dry weight of the kernel. This period, which is typically in late May or early June in California, has a high seasonal irrigation demand during which almonds are very sensitive to water deficits.

The final period of fruit growth is the preharvest period of stage III. At this point, hull, shell, and kernel differentiation are complete and the kernel begins to accumulate solids at a continuous rate until harvest (maturity). Harvest is signaled by two events: the onset of hull split and the formation of an abscission layer between the peduncle and nut. Both of these events are impacted by irrigation practices. Too much water can increase the duration of the hull split period and thus delay the onset of harvest. In contrast, too little water can decrease kernel weight and result in poor nut removal due to an increase in the number of nuts with dried hulls adhering tightly to the shell (i.e., “hull tights”).

Determining the timing and potential impact of water stress during stage III of kernel development is complicated. A severe stress imposed after kernel fill through harvest reduces kernel dry weights and produces textured or shriveled almond kernels. If a moderate, regulated stress level of 14 to 18 bars stem water potential (SWP, discussed below) is imposed from kernel fill through hull split, however, the impacts on kernel weight and size are minimized, while the synchrony of hull split is improved. In a 4-year study, this regulated deficit did not impact kernel yields over the experiment’s duration, but it did reduce kernel weight by 2 to 3% compared with the full irrigation treatment (Stewart et al. 2011). This reduction of applied water saved 10 to 15% of the total season’s water budget.

It is critical to maintain irrigation through the post-hull-split/preharvest period, as the too-high water stress level reduces kernel weight and quality. A study conducted in Kern County determined that there is an indirect relationship between the length of preharvest irrigation cutoff and kernel quality (Goldhamer and Viveros 2000). In this study, preharvest irrigation cutoffs occurred from as late as 8 days to as early as 57 days prior to shaking. Kernel quality was negatively impacted when preharvest cutoffs extended beyond 15 days. This cutoff period, however, varies among soil types and irrigation management strategies. Monitoring should be done on an

orchard basis. If needed, water should be applied to minimize the stress during the preharvest timing (after hull split to harvest). This prevents the negative impacts on kernel weight and quality.

Impacts on Development of Fruit Buds

Severe stress from deprivation of postharvest irrigation has been found to decrease the next year’s crop yield more than does a preharvest water deficit. Studies have shown that very severe postharvest stress (–40 bars predawn leaf water potential) caused a 52% reduction in ‘Nonpareil’ bloom density and a 94% reduction in fruit set, resulting in a 73.6% reduction in the following year’s yield (Goldhamer and Viveros 2000). Furthermore, yield loss was observed in all treatments across this trial that withheld postharvest irrigations, regardless of the preharvest cutoff. This reduction was attributed to stress impacts on floral bud development that occur late in the season.

In contrast, a study near Manteca was successful in reducing postharvest irrigations without any negative crop impacts (Prichard et al. 1996). In this study, water was applied based on tree stress and reduced based on low observed tree stress level. This reduction was thought to be possible due to adequate soil-water reserves in the root zone from irrigation and fall rainfall that may occur in some almond-growing regions of California. Tree stress levels should be monitored into the postharvest season to determine the need for postharvest irrigation.

The timing of bud development varies by cultivar and geographic region and can occur before and after harvest for late- and early-harvested varieties, respectively (Lamp et al. 2001). Since multiple varieties are typically planted within an orchard, it is important to minimize stress during the period between hull split and harvest in order to maximize the following year’s production. If possible, water demands should be met through the end of September. Care should be taken during this period when using low-volume or micro-irrigation systems because the lower application rates do not allow for quick recovery of severely depleted soil moisture.

Understanding Deficit Irrigation (DI)

Water deficits occur when a tree's water demand exceeds the amount of water available in the soil. These deficits increase water tension within the plant, and when this stress is high enough it will negatively affect many plant processes. As described above, almond trees have a varying tolerance of stress throughout the season. Ideally, growers would achieve the most efficient use of irrigation water (i.e., the most “crop per drop”) when they irrigate just before water stress is low enough to cause a significant reduction in yield. This method of applying water during critical almond development periods and limiting water application during less-critical periods is called strategic deficit irrigation (SDI).

Plant water stress is commonly evaluated by measuring midday stem water potential (SWP) using a pressure chamber or equivalent device. SWP is a direct measure of water tension (negative pressure) within plant and is given in metric units of pressure, such as bars (1 bar is about 1 atmosphere of pressure) or megapascals (MPa; 1 MPa equals 10 bars or about 145 psi). Even under fully irrigated conditions, the July SWP in almond trees at midday can be as much as -1 MPa simply because this much tension is required to pull water out of the soil and through the tree. Technically, SWP should always be shown as a negative value (e.g., -1 MPa), but in conversation we often omit mentioning “negative” before the value. More information about the operation of the pressure chamber can be found in *Using the Pressure Chamber for Irrigation Management in Walnut, Almond, and Prune* (ANR Publication 8503; Fulton et al. 2014).

Through the use of a pressure chamber, plant stress can be readily monitored. Water applications can be made once specified levels of stress are reached, reducing stress extremes and damage to the current crop and future yields. Further, SDI may be used to extend watering intervals and save water. The downside of this approach, however, is the challenge of managing the minimal soil moisture reserves required to achieve SDI while preventing too much stress with micro-irrigation systems that are designed to “just meet” peak crop water demand.

Putting It into Practice: Drought Management Irrigation Strategies

As a consequence of the drought and diminishing ground water supplies, water availability will be limited in many major production areas. Growers will need to decide when to apply water to reduce the impacts of stress on trees. The best place to start is to know how much water has typically been applied annually to the orchard. Once this estimate is known, it is possible to compare this amount with what is considered a “fully irrigated” orchard. This distinction is suggested because experience has shown that many commercial almond orchards are under-irrigated. A mature, fully irrigated almond orchard that shades about 80% of the ground area at noon in midsummer can use approximately 49 to 58 acre inches of water, depending on location (Goldhamer and Girona 2012; unpublished data). This calculation is based on the 30-year averaged reference crop evapotranspiration data for the respective area, as determined by the statewide California Irrigation Management Information System (CIMIS), and may vary slightly from year to year. This point of comparison is needed since a further reduction of applied water in a traditionally under-irrigated orchard can lead to severely stressed trees and unintended outcomes. Keep in mind that rainfall and soil moisture depletion are considered water applied to an orchard and may reduce total required irrigation. For more information on scheduling irrigation, see *Scheduling Irrigations: When and How Much Water to Apply*, UC ANR Publication 3396 (Hanson et al. 1999).

Two irrigation strategies exist for drought management of almond: hull split SDI and proportional deficit irrigation (e.g., 80% of normal crop ET_c .) The appropriate strategy depends on water availability and use of a pressure chamber.

Hull Split SDI

Hull split SDI maintains full irrigation until the completion of kernel fill. After kernel fill and until 90% hull split, irrigation is applied only when trees reach SWP values of -14 to -18 bars (Shackel et al. 2004). Field research has shown that this technique decreases water use by as much as 34% during this period,

Table 1. Thirty-year average evapotranspiration rates for unstressed pasture (ET_o)¹ and almonds (ET_c)² in inches for several CIMIS zones within almond-producing areas of California

Month	K _c ³	Zone 12 ⁴		Zone 14 ⁵		Zone 15 ⁶		Zone 16 ⁷	
		ET _o	ET _c	ET _o	ET _c	ET _o	ET _c	ET _o	ET _c
Jan	0.40	1.24	0.50	1.55	0.62	1.24	0.50	1.55	0.62
Feb	0.41	1.96	0.81	2.24	0.92	2.24	0.92	2.52	1.04
Mar	0.62	3.41	2.11	3.72	2.30	3.72	2.30	4.03	2.49
Apr	0.80	5.10	4.09	5.10	4.09	5.70	4.57	5.70	4.57
May	0.94	6.82	6.44	6.82	6.44	7.44	7.02	7.75	7.31
Jun	1.05	7.80	8.20	7.80	8.20	8.10	8.51	8.70	9.14
Jul	1.11	8.06	8.93	8.68	9.61	8.68	9.61	9.30	10.30
Aug	1.11	7.13	7.90	7.75	8.59	7.75	8.59	8.37	9.28
Sep	1.06	5.40	5.73	5.70	6.05	5.70	6.05	6.30	6.68
Oct	0.92	3.72	3.41	4.03	3.69	4.03	3.69	4.34	3.97
Nov	0.69	1.80	1.23	2.10	1.44	2.10	1.44	2.40	1.64
Dec	0.43	0.93	0.40	1.55	0.66	1.24	0.53	1.55	0.66
Total (in)			49.73		52.61		53.73		57.72

Notes:

¹Normal year evapotranspiration of unstressed grass (reference crop, ET_o) 30-year CIMIS average for the respective zone.

See cimis.water.ca.gov/App_Themes/images/etozonemap.jpg.

²Evapotranspiration rates for almonds were calculated by multiplying ET_o by the crop coefficient (K_c).

³Referenced crop coefficient (K_c) (unpublished data)

⁴Zone 12 ET_o rates from Chico, Fresno, Madera, Merced, Modesto, and Visalia.

⁵Zone 14 ET_o rates from Newman, Red Bluff, and Woodland.

⁶Zone 15 ET_o rates from Bakersfield and Los Banos.

⁷Zone 16 ET_o rates from Coalinga and Hanford.

reducing total seasonal water use by about 15% while having minimal impacts on the current and next season's crop (Stewart et al. 2011). In practice, it can be difficult to fine-tune the irrigation schedule to this SWP threshold. Many growers initially reduce water applications by 50% around mid-June and adjust the amount of subsequent irrigations once stress levels increase and soil moisture depletion occurs. Water should be applied prior to harvest to improve hull split and reduce hull tights (Prichard et al. 1994). This strategy is a particularly effective method for reducing hull rot (Tetviotdale et al. 2001), if that is a problem, but it also improves harvestability by reducing the force and time required for shaking, which can benefit the long-term health of the orchard.

Proportional Deficit Irrigation

If a pressure chamber is unavailable or the anticipated seasonal water deficit is greater than 15% for the seasonal ET_c, reduced water

applications can be made by applying a fixed proportion of ET_c. In this method, the amount of water available for the season should be calculated as a percentage of full ET_c. This percentage should be applied to spread the deficit evenly across the season. In other words, if it is determined that enough water is available to supply only 55% of ET_c for the whole season, each irrigation would match 55% of the determined ET_c for that irrigation period. An example is given in table 2. Current-season and future yield loss should be expected when using this strategy, but research has shown this to be the most effective strategy in minimizing losses for large irrigation deficits (Goldhamer et al. 2006).

Imposing whole-season SDI or applying water as a percentage of ET_c will help preserve kernel quality and future yields as much as possible. Nevertheless, the current season's yield will begin to drop, and further declines in production can be anticipated in subsequent years if a drought continues. By employing whole-

Table 2. Comparison of an irrigation plan for an orchard near Merced during May 2014 for a fully irrigated and a 55% water-deficit-irrigated orchard

Date (May 2014)	Merced ET _o (CIMIS Station 148) ¹	Almond K _c for the month of May ²	ET _c ³ required to fully irrigate orchard for the week	Water applied in order to achieve a 55% proportional seasonal deficit ⁴
1–3	0.74	0.94	0.70	0.38
4–10	1.47	0.94	1.38	0.76
11–17	1.95	0.94	1.83	1.01
18–24	1.67	0.94	1.57	0.86
25–31	2.11	0.94	1.98	1.09
Total	7.94		7.46	4.10

Notes:

¹Evapotranspiration of the reference crop (ET_o) is sourced from CIMIS. Real time data for the current week/year can be found at <http://www.cimis.water.ca.gov/>.

²Referenced crop coefficient (K_c) (unpublished data)

³Evapotranspiration rates for almonds were calculated by multiplying ET_o by the crop coefficient (K_c).

⁴Proportional deficits are calculated by multiplying the target deficit by the fully irrigated ET_c.

season SDI, stress imposed during stage I will reduce fruit load and size. This leads to a reduced amount of photosynthate required to fill the nuts during stage II, producing more complete kernel fill and higher quality. This contrasts to the erroneous “feast then famine” strategy of fully irrigating the almonds through stage I, then deficit-irrigating in stage II. This latter strategy results in increased fruit set or nut load but may reduce kernel fill and increase shriveling. Both strategies lead to similar field kernel yield per acre, but quality and marketability, and thus kernel price, will be reduced in the feast then famine strategy. Future yield reduction depend on the severity of stress applied during the postharvest period and the overall seasonal impact on vegetative growth.

Managing Severe, Persistent Drought

Although a rarely used option, SDI can be implemented under conditions of severe, persistent shortages of irrigation water supplies. While not yet well researched or documented, reports of past drought-stricken seasons suggest that trees can be kept alive with as little as 6 to 8 inches of water (including stored soil moisture). In severe cases, irrigation from leafout to the end of May should occur when midday SWP values reach –16 bars. From June 1 until the end of the season, irrigation should be delayed until the stress level reaches –25 bars. When SWP indicates that an application of water is warranted, the amount applied should follow the above-outlined proportional deficit irrigation strategy. In

general, an effort should be made to maintain the canopy on the tree. Research shows that the major consequences of severe drought are the carry-over effects on next year’s crop, but these can be mitigated by modest amounts of irrigation during the drought year. Recovery to normal yields should occur after 2 years of a full irrigation schedule (Prichard et al. 1994).

Managing Drought for Young, Developing Orchards

Maximal water use for young trees is much less than that of trees in a mature, canopied orchard, so reducing irrigation is not usually done for 1- to 3-year-old blocks. Reducing water applications on young, nonbearing trees leads to reduced growth and a longer time to maximal harvest. When deficit-irrigating young almonds, the impacts on kernel quality are not of concern; available water should be applied evenly across the season as a percentage of ET_c. In the year preceding the first harvest, reduce water stress as much as possible during the floral bud development stage (described above).

With developing orchards, it is easy to over-apply water due to the lack of rooting depth and lateral root growth. After an irrigation, water movement should be checked and compared with the tree’s rooting pattern. Water applied outside of the root zone may be lost to deep percolation. Irrigation system designs should incorporate the flexibility to directly apply the water to the developing root zone. If the water exceeds the depth of the root system, the duration of irrigation should be reduced.

Factors and Considerations in Water Use Reduction

Age of Orchard Block

Due to the negative impacts of severe drought, it may be beneficial from an operational standpoint to redirect water from older orchards to younger or higher-producing blocks, with the intent of removing the older block. Block age, productivity, operational costs, and orchard removal timeframe should be factored into the decision, as it will take 2 years of full irrigation to bring the orchard back to normal production. In a more severe situation in which minimal winter rains have not provided adequate soil moisture, water diversion should also be considered to provide the minimum 6 to 8 inches of water to keep an orchard alive.

Effects of Crop Load and Harvest

Research in peaches suggests that crop removal has little, if any, impact on water use (Goldhamer and Holtz 2009). Although equivalent research has not yet been done, almond crop water use is thought to be similar to that of peaches. Speculation by almond researchers in California and Spain suggests that the crop can account for up to 10% of water usage. In periods of severe drought, however, artificially reducing crop load to save water is not recommended due to the redirection of resources into vegetative growth, which could require more water. Crop load will thin naturally, especially if stress is applied prior to the nut drop period in May.

Negative Effects of Canopy Reduction

Severe pruning (“stumping” or “dehorning”) is not recommended as it increases new growth, potentially leading to higher transpiration rates. Furthermore, a study on severe drought has found that pruning trees often removes more wood than would be killed by severe water stress. For instance, in a 1-year drought experiment that withheld all irrigation water from drip-irrigated almond trees on a shallow soil, the most severely stressed trees that reached a SWP of -5 MPa (-50 bars) in July showed only about 15% canopy dieback after 2 years. This is in contrast to trees in which scaffolds were cut back to reduce the canopy by 50% during the drought treatment (Shackel et al. 2011).

Increasing Soil Salinity from Reduced Water Quantity or Quality

Reduction of water application or reliance on low-quality groundwater may increase soil salinity, leading to a reduction in yield (Grattan 2002; Hanson et al. 1993). Soil salinity should be monitored through annual sampling, especially when using low-quality water, deficit irrigation, or when winter rainfall is low. Under drought conditions, a leaching program is best implemented in the dormant period to reduce root zone salinity levels. Leaching during the dormant season will be more efficient when ET_c is lower and there is less potential to leach nitrate and other nutrients from the root zone since they will have been applied and taken up by the trees relatively early in the growing season. Leaching salinity with additional water during the growing season is difficult due to the higher water demand of the trees and, in many cases, the slow infiltration rate of orchard soils. The use of fertilizers or soil amendments containing chlorides should be minimized in periods of drought.

Variety Influences on Water Requirements

Although different almond varieties may exhibit different stress levels growing in the same soil-water condition (e.g., Monterey begins to wilt at -18 SWP, while Nonpareil begins to wilt at -22 SWP), research has shown that the thresholds and types of impacts of water stress on physiological processes were similar among varieties (Shackel and Doll 2012). These findings indicate that the differences in the field are not due to a variety being more sensitive to stress but rather that in-field differences among varieties are due to different growth habits that may influence water uptake (e.g., root system depth, lateral length, or architecture) or increase water consumption (canopy architecture or leaf count), or both. Hence, different varieties reach thresholds for implementing SDI at different rates and times. This highlights the importance of properly delivering water to all of the trees within the orchard to prevent the onset of severe water stress.

Other factors that impact the effect of water stress on almond varieties include the timing of maturation and harvest. Later-harvested varieties undergo floral bud differentiation prior to harvest. Thus, preharvest cutoffs for these varieties may negatively

impact fruiting bud differentiation (Lamp et al. 2001). Timing to induce SDI, as well as the time required for harvest dry-down (depletion of stored soil moisture), also varies among varieties and soil types (an ideal setup would have an irrigation system that could irrigate different varieties differently). Early-harvesting and late-harvesting varieties require more water in the postharvest and preharvest period, respectively. Some researchers, however, believe these differences are minor in practice because water use is more directly dictated by canopy coverage. Thus, trees should be fully irrigated if full water allocation is available prior to harvest and through postharvest.

Micro-irrigation Systems and Timing of Water Applications

Micro-irrigation systems can maximize distribution of water by minimizing losses to evaporation. These systems can apply smaller amounts of water and irrigate more frequently than flood or furrow irrigation. The systems should be fully maintained to ensure uniformity of water distribution, and water application rates should not exceed soil intake rates (Schwankl et al. 2007). Reduced application of water is usually not possible with flood or furrow irrigation because they require a minimal amount to advance the water across the field. The only option with these systems is to wait longer between irrigations.

Reduction of Water Losses to Evaporation

The run time for micro-sprinkler systems may need to be shortened to reduce water application. If the run time is reduced too much, however, water will not infiltrate deep enough into the soil, eventually leading to a higher percentage of water lost to evaporation. Therefore, run times should be no less than 6 hours; longer run times lose less water to evaporation. Run times, however, should not exceed soil intake rates or water-holding capacity. Minimum run time is not as much of an issue with drip systems due to a reduced wetted area on the soil surface (L. Schwankl, personal communication).

Timing of irrigation should take into account higher evaporative losses due to increasing temperatures and wind speeds. Therefore, the evaporative losses will be greater during the day, and

irrigation sets should be started in the evening and completed before late morning.

Removal of Cover Crop

Vegetation cover on the orchard floor should be either removed or managed carefully to eliminate water loss through transpiration. Depending on the coverage, cover crops or residual vegetation can increase orchard water use by as much as 30% (Prichard et al. 1989). In water-short years, cover crop removal should occur prior to leafout but no earlier than mid-January. This allows the cover crop to reduce runoff from winter rains but eliminates water use after February.

Minimal Impacts of Anti-transpirants

University of California research has not been able to document water savings or reduction of plant stress with the application of anti-transpirants, or “plant coolants,” and thus they are not recommended (Shackel et al. 2011). Many new products, however, enter the market annually, and there is always the possibility that some may prove to be of benefit. When applying these products, it is important to leave several untreated areas in the field in order to determine product’s effectiveness.

Reduction of Nitrogen Applications

Nitrogen applications should be reduced during periods of drought. The reduction rate should be proportional to the expected reduction in yield from deficit irrigation. Nitrogen rates in the spring should be reduced to prevent growth, as excessive vegetative growth increases tree water demand. Most data suggest that long-term yield reductions generally follow a 1:1 relationship with long-term water reductions, meaning that a 30% reduction in relative applied water leads to a 30% reduction in relative yield.

Insect Management

Periods of drought influence insect pest populations. Mites flare on stressed trees (Youngman and Barnes 1986), and increased miticide applications may be needed. Stressors include water stress and dust, both which are common in periods of little rainfall. Navel orangeworm populations are impacted by drought as well (D. Goldhamer, unpublished). Reduced winter rains can make it difficult to remove

mummies with winter shaking, leading to an increase in the overwintering population. Warmer temperatures common during drought years lead to faster insect development. Furthermore, hull split is generally accelerated in drought years, which changes the timing to apply a hull split navel orangeworm spray.

Bibliography

- Fulton, A., J. Grant, R. Buchner, and J. Connell. 2014. Using the pressure chamber for irrigation management in walnut, almond, and prune. Oakland: University of California Division of Agriculture and Natural Resources Publication 8503. UC ANR website, anrcatalog.ucdavis.edu/Details.aspx?itemNo=8503.
- Goldhamer, D., and J. Girona. 2012. Almond. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., *Crop yield response to water*. FAO Irrigation and Drainage Paper 66:358–373. FAO website, www.fao.org/nr/water/docs/irrigationdrainage66.pdf.
- Goldhamer, D., and B. Holtz. 2009. Rational early season drought planning for almond growers. *The Pomology Post* (UC Cooperative Extension Madera County) 59 (March 2009). UC ANR website, ucanr.edu/files/47998.pdf.
- Goldhamer, D., and M. Viveros. 2000. Effects of preharvest irrigation cutoff durations and postharvest water deprivation on almond tree performance. *Irrigation Science* 19:125–131. Irrigation Science website, link.springer.com/article/10.1007%2Fs002710000013.
- Goldhamer, D., M. Viveros, and M. Salinas. 2006. Regulated deficit irrigation in almonds: Effects of variations in applied water stress timing on yield and yield components. *Irrigation Science* 24:101–114. Irrigation science website, link.springer.com/article/10.1007/s00271-005-0014-8.
- Grattan, S. 2002. *Irrigation water salinity and crop production*. Oakland: University of California Division of Agriculture and Natural Resources Publication 8066. UC ANR website, anrcatalog.ucdavis.edu/Details.aspx?itemNo=8066.
- Hanson, B., S. Grattan, and A. Fulton. 1993. *Agricultural salinity and drainage*. Oakland: University of California Division of Agriculture and Natural Resources Publication 3375.
- Hanson, B., L. Schwankl, and A. Fulton. 1999. *Scheduling irrigations: When and how much water to apply*. Oakland: University of California Division of Agriculture and Natural Resources Publication 3396.
- Kester, D., G. Martin, and J. Labavitch. 1996. Growth and development. In W. Micke, ed., *Almond Production Manual*. Oakland: University of California Division of Agriculture and Natural Resources Publication 3364.
- Lamp, T., J. Connell, R. Duncan, M. Viveros, and V. Polito. 2001. Almond flower development: Floral initiation and organogenesis. *Journal of the American Society for Horticultural Science* 126(6): 689–696. JASHS website, journal.ashspublications.org/content/126/6/689.full.pdf+html.
- Lampinen, B., T. Dejong, S. Weinbaum, S. Metcalf, C. Negron, M. Viveros, J. McIlvane, N. Ravid, and B. Baker. 2007. *Spur dynamics and almond productivity*. Modesto: 2007–2008 Annual Research Report to the Almond Board of California. UC Drought Management website, ucmanagedrought.ucdavis.edu/PDF/Lampinen%20et%20al%202007.pdf.
- Prichard, T., W. Sillis, W. Asai, L. Hendreicks, and C. Elmore. 1989. Orchard water use and soil characteristics. *California Agriculture* 43(4): 23–25.
- Prichard, T., W. Asai, P. Verdegaal, W. Micke, and B. Teviotdale. 1994. *Effects of water supply and irrigation strategies on almonds*. Modesto: Almond Board of California. Comprehensive project report 1993–94.
- Prichard, T., P. Verdegaal, W. Asai, and W. Micke. 1996. *Residual effects of water deficits and irrigation strategies on almond*. Modesto: Almond Board of California. Comprehensive project report 1995–96.

- Sanden, B. 2007. Fall irrigation management in a drought year for almonds. Bakersfield, CA: University of California Cooperative Extension Kern Soil and Water, (Sept. 2007). UC Drought Management website, ucmanagedrought.ucdavis.edu/PDF/Sanden%202007.pdf.
- Schwankl, L., T. Prichard, and B. Hanson. 2007. Soil intake rates and application rates in sprinkler-irrigated orchards. Oakland, CA. University of California Division of Agriculture and Natural Resources Publication 8216. UC ANR website, anrcatalog.ucdavis.edu/Details.aspx?itemNo=8216.
- Shackel, K., and D. Doll. 2012. Plant-based measures of water stress for irrigation management in multiple almond varieties. Modesto: 2012–2013 Annual Research Report to the Almond Board of California.
- Shackel, K., R. Buchner, J. Connell, J. Edstrom, A. Fulton, B. Holtz, B. Lampinen, W. Reil, and M. Viveros. 2004. Final Report: Deficit Irrigation Management During Hull Split. Modesto: Final Report to The Almond Board of California.
- Shackel, K., J. Edstrom, A. Fulton, B. Lampinen, and L. Schwankl. 2011. Drought survival strategies for established almond orchards on shallow soil. Modesto: 2011–2012 Annual Report to The Almond Board of California.
- Stewart, W., A. Fulton, W. Krueger, B. Lampinen, and K. Shackel. 2011. Regulated deficit irrigation reduces water use of almonds without affecting yield. *California Agriculture* 65(2): 90–95.
- Teviotdale, B, D. Goldhamer, and M. Viveros. 2001. The effects of deficit irrigation on hull rot of almond trees caused by *Monilinia fructicola* and *Rhizopus stolonifer*. *Plant Disease* 85(4): 399–403. ASP Journals website, <http://apsjournals.apsnet.org/doi/abs/10.1094/PDIS.2001.85.4.399>.
- Youngman, R., and M. Barnes. 1986. Interaction of spider mites (Acari: Tetranychidae) and water stress on gas exchange rates and water potential of almond leaves. *Environmental Entomology* 15:594–600.

For More Information

To order or obtain ANR publications and other products, visit the ANR Communication Services online catalog at anrcatalog.ucanr.edu/ or phone 1-800-994-8849. You can also place orders by mail or FAX, or request a printed catalog of our products from

University of California
Agriculture and Natural Resources
Communication Services
1301 S. 46th Street
Building 478 – MC 3580, Richmond, CA 94804-4600
Telephone 1-800-994-8849 • 510-665-2195 • FAX 510-665-3427
E-mail: anrcatalog@ucanr.edu

©2015 The Regents of the University of California. This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. To view a copy of this license, visit creativecommons.org/licenses/by-nc-nd/4.0/ or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.

Publication 8515

ISBN-13: 978-1-60107-898-8

The University of California Division of Agriculture & Natural Resources (ANR) prohibits discrimination against or harassment of any person participating in any of ANR's programs or activities on the basis of race, color, national origin, religion, sex, gender identity, pregnancy (which includes pregnancy, childbirth, and medical conditions related to pregnancy or childbirth), physical or mental disability, medical condition (cancer-related or genetic characteristics), genetic information (including family medical history), ancestry, marital status, age, sexual orientation, citizenship, or service in the uniformed services (as defined by the Uniformed Services Employment and Reemployment Rights Act of 1994: service in the uniformed services includes membership, application for membership, performance of service, application for service, or obligation for service in the uniformed services) or any person in any of its programs or activities.

University policy also prohibits retaliation against any employee or person participating in any of ANR's programs or activities for bringing a complaint of discrimination or harassment pursuant to this policy. This policy is intended to be consistent with the provisions of applicable State and Federal laws.

Inquiries regarding the University's equal employment opportunity policies may be directed to Linda Marie Manton, Affirmative Action Contact, University of California, Davis, Agriculture and Natural Resources, 2801 Second Street, Davis, CA 95618-7779, 530-750-1318. For information about ordering this publication, telephone 1-800-994-8849.

An electronic copy of this publication can be found at the ANR Communication Services catalog website, anrcatalog.ucanr.edu/.



This publication has been anonymously peer reviewed for technical accuracy by University of California scientists and other qualified professionals. This review process was managed by ANR Associate Editor for Pomology, Viticulture, and Subtropical Horticulture Larry J. Bettiga.

rev-9/15-SB/CR