Current Understanding of Regulated Deficit Irrigation in Walnut

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RDI Concept

Regulated deficit irrigation (RDI) is a management strategy that purposely imposes water stress on a crop with the expectation of benefits. A principle underlying RDI is that it imposes water stress by withholding water at a stage of crop growth that responds favorably or at least tolerates stress. A deficit irrigation strategy is not likely to be adopted at the farm level if it results in decreased crop yield or quality to the extent that crop income is consistently reduced.

RDI and Water Use Efficiency

About 30 years ago when some of the earliest research with RDI was initiated in Australia and New Zealand on peaches and pears, the motivation was to develop deficit irrigation strategies that resulted in horticultural benefits such as less pruning, less incidence of disease, and improved fruit quality and value while sustaining or improving yield. This was also the impetus for RDI research that followed in California. At that time, water savings from RDI was considered a secondary benefit primarily for use during periods of drought.

Today, due to competition for California's developed water resources, RDI has been included in a long term, integrated approach to managing California's water resources. Water savings from RDI is the result of using crop stress to reduce crop water consumption (transpiration) and is different from water savings from improved irrigation efficiency at either a field, farm, or water district level. Some major components of the integrated approach to managing the state's water resources include conjunctive management of existing surface and groundwater resources, water transfer or marketing programs, and possibly new off-stream surface storage.

RDI has been proposed as having the potential to realize substantial water savings that might be linked to water transfer programs, if implemented in nine permanent crops representing 1.75 million bearing acres in California. Nearly, 200,000 acres of bearing walnuts were identified among this acreage. However, uncertainty about effective strategies for implementing RDI in walnut has been acknowledged.

RDI Strategies in Walnut

Research conducted in the late 1980's at the Kearney Agriculture Center on a hedgerow planting of the variety Chico indicated that bearing walnut orchards are not good candidates for realizing horticultural benefits while saving water by using RDI strategies. After three consecutive years of RDI, at a level of about 13 inches of annual water deficit (33 percent less than historic ETc for walnut), cumulative dry in-shell yield was reduced by 20 percent or 4300 lbs per acre. Walnut quality parameters such as size and off-grade were also negatively affected. Unlike wine grape, pistachio, and other permanent crops, a specific stage of crop growth and development that responded positively or tolerated water stress was not identifiable.

In recent years, the question of whether RDI is applicable to bearing walnut orchards has re-surfaced partly because no information is available on new, predominant commercial varieties such as Chandler walnut. Also, a practical, plant-based irrigation scheduling technique referred to as midday stem water potential (SWP) measured with a pressure chamber was not available for use in the earlier walnut research. Some scientists suggest that RDI in walnut is more feasible since this new technique is available to evaluate real-time orchard water status and to guide deficit irrigation in walnut.

Midday Stem Water Potential (SWP) Measurement in Walnut

Midday Stem Water Potential (SWP) is measured with a pressure chamber during mid afternoon when evaporative demand is high and more stable. In walnut, a terminal leaflet that is still connected to the tree is selected and covered with a water resistant, light reflecting foil bag for a minimum of ten minutes to prevent transpiration through the leaf and to allow the water potential inside the leaflet to equilibrate with the stem and larger canopy. After equilibration, the leaf (still in bag) is excised from the tree and placed inside an air-tight chamber, but a small part of the leaf stem (the petiole) is exposed to the outside of the chamber through a seal. The pressure chamber operator pressurizes the chamber and observes when water just begins to appear at the cut end of the petiole and records the pressure indicated on the gage.

The pressure chamber can be thought of as a device for measuring the suction force as water evaporates from the leaves. Water within the plant mainly moves through very small interconnected cells, collectively called xylem, which are essentially a network of pipes carrying water from the roots to the leaves. The current model of how this works is that the water in the xylem is under tension, and as the soil dries, or for some other reason the roots become unable to keep pace with evaporation from the leaves, then the tension increases. A high value of pressure means high tension and a high degree of water stress. The unit of pressure most commonly used is the Bar (1 Bar = 14.5 pounds per square inch). Because tension is measured, values are reported as negative numbers.

New Investigations with RDI in Walnut

The California Walnut Research and Marketing Board sponsored two experiments focusing on irrigation management in bearing walnuts beginning in the 2002 season and continuing through the 2004 season. One experiment was located in Tehama County and the second experiment was located in San Joaquin County. Similar Randomized Complete Block experimental designs (3 irrigation treatments and 4 replicates) and experimental methods were used at each location. Objectives were to develop management strategies for walnut using a combination of evapotranspiration, soil, and plant-based indicators of water status; and to understand the relationship between SWP and walnut productivity.

The Tehama County orchard was grown on the Maywood sandy loam soil series, consisting of stratified, shallow soils. The orchard was planted in the spring of 1994 using a 30 by 18 foot-spacing (81 trees/ac). Nine acres were involved in the experiment. Two-thirds of the trees were Chandler on paradox rootstock and 1/3 were Chandler on Northern California Black rootstock. Crop growth and development, yield, and walnut quality were measured during the 2002, 2003, and 2004 seasons representing the 9^{th}, 10^{th}, and 11^{th} growing seasons, respectively. Hedgerow pruning occurred during the experiment. The orchard was irrigated using microsprinklers.

The San Joaquin County Orchard was grown on the Cogna loam soil series, a deep well-drained alluvial soil. The orchard is approximately 20 to 25 years old with Chandler on Paradox rootstock and planted in a 32 by 32 foot equilateral triangle arrangement. The orchard has been historically hand pruned at a relatively low frequency and intensity and pruning was minimal during 2002-2004 when the experiment was conducted. The orchard was irrigated using microsprinklers.

This paper primarily presents experimental results from the Tehama County experiment and briefly discusses important contrasts in results between the Tehama and San Joaquin County experiments. More detailed results from both the San Joaquin County and Tehama County experiments will be provided in other venues.

RDI Strategies Evaluated

The cumulative effects of three different irrigation strategies on Chandler walnut were evaluated over three growing seasons. The three strategies were termed low, mild, and moderate stress, respectively. SWP measured one or two times per week was used as the primary tool to differentiate and guide the irrigation strategies. A water balance approach using water meters, soil water content, and soil matric potential monitoring was also used to describe and confirm the application of each strategy. Table 1 summarizes the irrigation strategies for each season at the Tehama County experiment.

Table 1. Summary of monthly average and season average SWP (bars) for the three different irrigation strategies evaluated in Chandler walnut at the Tehama County irrigation experiment, 2002 –2004. Seasonal applied irrigation water (inches/acre) is provided.

Month	**2002 Season**			**2003 Season**			**2004 Season**		
	Low	**Mild**	**Mod**	**Low**	**Mild**	**Mod**	**Low**	**Mild**	**Mod**
May	-4.2	-4.5	-5.4	-3.8	-4.2	-4.4	-2.6	-2.7	-2.8
June	-4.0	-4.8	-6.5	-2.5	-4.0	-5.1	-4.8	-5.8	-6.9
July	-3.4	-6.0	-7.8	-2.8	-6.5	-7.5	-5.0	-7.6	-8.9
Aug	-3.3	-6.6	-7.7	-3.2	-7.9	-8.9	-3.2	-6.4	-8.5
Sept	-2.8	-8.9	-9.6	-3.4	-8.5	-10.2	-2.8	-6.0	-8.1
Season Avg	-3.6	-6.2	-7.4	-3.1	-6.2	-7.2	-3.7	-5.7	-7.0
Applied Water (inches)	43.8	31.2	25.8	44.5	26.2	21.7	42.9	26.6	23.3

For Tehama, in the low stress strategy, irrigation water was applied at rates about 10 percent above real-time estimates of crop evapotranspiration (ETc) for walnut. Seasonal SWP averaged between –3.1 and –3.6 bars. Soil-water deficits were commonly between 10 to 30 percent depletion of the available soil water until late in the season at which time they increased to near 50 percent depletion. Gradually increasing water stress was imposed in the mild and moderate stress irrigation strategies. The idea was to impose mild stress in May and June when shoot growth and nut sizing is occurring and then impose more stress by withholding irrigation water from July through September during kernel development. Rates of applied irrigation water ranged from 20 to 40 percent below real-time estimates of ETc for walnut. Soil-water deficits were routinely between 30 and 70 percent depletion of the available soil-water.

Effect of Deficit Irrigation on Walnut Productivity

At the Tehama County experiment, the three-year cumulative dry, in-shell walnut yield for trees irrigated using mild and moderate stress deficit irrigation strategies was reduced by an average of 2,432 and 3,714 lbs/ac, respectively, below the low stress irrigation strategy. Figure 1 illustrates the annual effects of water stress, using SWP as an indicator, on dry in-shell walnut yield. In 2002, a downward trend in yield was apparent. The extent of the reduction was less than 17 percent and in some cases there was no reduction in yield or an increase in yield. Regression statistical analysis suggested that about 36 percent of the yield variability could be associated with crop stress caused by deficit irrigation. Statistical tests for significance indicate this trend in yield reduction may occur at a 95 percent probability level. The downward yield trend continued in 2003, Yield reductions were slightly more pronounced but less than 20 percent. Regression analysis suggested that about 42 percent of the yield variability was attributable to deficit irrigation and the probability of the trend occurring was about 98 percent. In 2004, the downward trend in yield was more pronounced. The slope of the trend line increased from 4.35 and 4.03 in 2002 and 2003, respectively, to 10.2 in 2004. Yield reductions approached 50 percent during the third crop and suggested that the effects of deficit irrigation on walnut yield may accrue over multiple seasons in walnuts orchards similar to the one in Tehama County.

Yield results are not shown for the San Joaquin County experiment. The cumulative yield for the 2002 and 2003 seasons averaged 9 to 11 percent less under the mild and moderate stress deficit irrigation strategies, respectively, in the San Joaquin experiment. The 2004 yield results have not yet been analyzed. Yield reductions associated with deficit irrigation in the San Joaquin County orchard were not nearly as pronounced as in the Tehama County experiment nor were yield reductions statistically different among the irrigation strategies indicating the reductions are not necessarily related to water stress.

Figure 2 illustrates the annual effects of water stress, using SWP as an indicator, on walnut value for the Tehama County experiment. Walnut value is influenced by numerous walnut quality parameters such as nut size, kernel color, and edible yield. In 2002, a slight downward trend was apparent in quality from crop stress imposed by withholding irrigation. The reduction was less than 5 percent and in some cases there was no reduction in crop value. Regression analysis suggested that about 32 percent of the variability in crop value could be associated with crop stress caused by deficit irrigation. Statistical tests for significance indicate this trend in reduced crop value may occur at a 94 percent probability level. The downward trend in walnut value was much more pronounced in 2003. Reductions in 2003 crop value approached 15 percent. Regression analysis suggested a strong correlation between crop value, as influenced by walnut quality, and deficit irrigation. About 84 percent of the variability in crop value was attributable to deficit irrigation and the probability of the trend occurring exceeded 99 percent. Reduction in nut size and darker kernels were important walnut quality parameters affected by deficit irrigation in 2003. Deficit irrigation did not affect walnut quality or crop value at all in 2004. These findings show that undesirable effects of deficit irrigation on walnut quality and crop value can occur and that they can be significant. However, other environmental conditions must coincide with the deficit irrigation for nut quality to be negatively impacted.

Reports for the San Joaquin experiment in 2002 and 2003 indicate that deficit irrigation did not affect walnut quality or related crop value in either year. A report for 2004 is pending.

Gross revenue from walnut production is dependent upon both walnut yield and is based on walnut quality and related crop value. Figure 3 shows the annual effects of water stress, using SWP as an indicator, on crop revenue for the Tehama County orchard. In 2002, a downward trend was apparent. The reduction was less than 20 percent and in some cases there was no reduction in crop revenue. Regression analysis suggested that about 36 percent of the variability in crop revenue could be associated with deficit irrigation. Statistical tests for significance indicate this trend in reduced crop revenue may occur at a 96 percent probability level. The downward trend in crop revenue was slightly more pronounced in 2003. Reductions in 2003 crop revenue approached 30 percent. Regression analysis suggested a correlation between crop revenue and deficit irrigation. About 71 percent of the variability in crop revenue was attributable to deficit irrigation and the probability of the trend occurring exceeded 99 percent. Deficit irrigation continued to reduce crop revenue in 2004. The slope of the trend line increased from 4.98 and 6.49 in 2002 and 2003, respectively, to 10.2 in 2004. Reductions in crop revenue approached 50 percent during the third crop depending upon the extent of crop stress imposed by withholding water and suggests that the effects of deficit irrigation on walnut yield may accrue over multiple seasons in walnuts orchards similar to the one in Tehama County.

Effects of deficit irrigation strategies on crop revenue have not been completed at the San Joaquin experiment. Preliminary reports for the 2002 and 2003 seasons suggest the effects of deficit irrigation strategies on walnut yield and quality, thus, crop revenue are not nearly as pronounced as those experienced at the Tehama County experiment.

Summary

These recent experiments in Chandler walnut indicate that one irrigation strategy may not necessarily fit all walnut orchards and growing environments. One of these experiments provides some evidence that RDI strategies can be detrimental to walnut in some production settings. The Tehama experiment agrees with earlier investigations in the 1980's suggesting that walnut may not be an ideal candidate for implementing RDI strategies. A stage of walnut growth or development that benefits from RDI while saving water was not identifiable. In contrast, the preliminary results from the San Joaquin experiment indicates some opportunity may still exist to implement RDI strategies in some walnut orchards and growing environments. Further experimentation is needed to understand the interactions between RDI strategies and orchard design, orchard age, pruning practices, and variable environmental conditions.

These experiences do indicate that use of the pressure chamber and SWP can be a reliable indicator of orchard water status and crop response. SWP can be a valuable irrigation management tool to guide site-specific irrigation management decisions.

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Figure 1. Effect of water stress as indicated by SWP on annual dry in-shell walnut yield of Chandler walnut grown on Paradox rootstock, Tehama County experiment, 2002-2004.

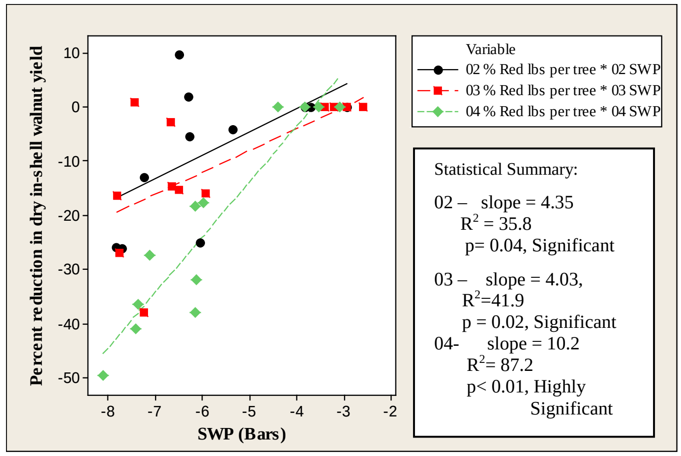

Figure 2. Effect of water stress as indicated by SWP on annual walnut value (based upon walnut quality) of Chandler walnut grown on Paradox rootstock, Tehama County experiment, 2002-2004.

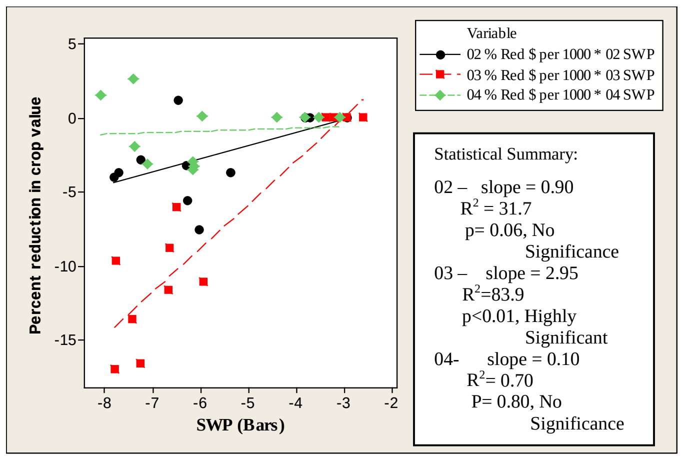

Figure 3. Effect of water stress as indicated by SWP on annual, gross crop revenue (based upon walnut yield and quality) of Chandler walnut grown on Paradox rootstock, Tehama County experiment, 2002-2004.