Effects of Regulated Deficit Irrigation on Walnut (Juglans regia) Grafted on Northern California Black (Juglans hindsii) or Paradox Rootstock

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Abstract

Chandler walnut (*Juglans regia* cv Chandler) on Northern California Black (*Juglans hindsii*) and Paradox (*Juglans hindsii* x *Juglans regia*) rootstocks were irrigated to achieve two levels of regulated deficit irrigation (RDI) in 2002 thru 2005. The RDI strategy was to maintain high midday stem water potential (MSWP) early in the growing season to favor shoot growth and nut size then gradually decrease MSWP toward harvest. For the low water stress control (fully irrigated), MSWP was maintained at –0.3 to –0.6 MPa throughout the growing season. For the mild RDI treatment, trees were maintained at –0.3 MPa to –0.6 MPa early in the season and MSWP was gradually decreased to –0.7 to –0.9 MPa by harvest. Moderate stress RDI treatments were the same as mild except MSWP was gradually decreased to –0.9 to –1.1 MPa by harvest. Stem Water Potential was measured midday (12-4 pm) by placing leaves inside foil bags. Leaves remained bagged for at least ten minutes to achieve equilibrium. Bagged leaves were removed, placed inside a pressure chamber and stem water potential was measured.

Experimental design was a randomized complete block with three treatments and four replicates. The experiment was located inside a commercial Chandler orchard planted in 1994 to a 5.5m x 9.1m north south hedgerow configuration at a density of 197 trees/ha. Water application used one Nelson R-5 mini sprinkler per tree with an application rate ranging from 0.76 to 1.27 mm/hr. Applied water was manipulated using timers to open and close valves. Each of the twelve plots consisted of three tree rows with 13 trees per row. Six trees in the center of each plot were used for data collection and the remaining trees were used as guards. The six data trees alternated

every other tree grafted on Northern California Black (NCB) or Paradox rootstock. This alternate pattern created the opportunity to evaluate rootstock response to RDI strategy. Occasionally, tree mortality resulted in a plot with two trees on NCB and four trees on Paradox. Applied water, soil moisture content, MSWP, shoot growth, nut size, yield, crop load, crop quality and economics were evaluated.

Yield, crop load, edible yield, % large sound and crop value were affected by rootstock and irrigation treatment. In general, Paradox out performed NCB for all irrigation treatments. Fully irrigated Paradox yielded 5355-7041 kg/ha compared to 3507-5140 kg/ha for fully irrigated NCB trees. Starting in 2003, RDI treatments showed a much greater effect on yield components. Nut load was most severely affected with losses in the 30% range. Reductions in nut load translated into losses in yield and total value. RDI significantly reduced kernel quality (darker kernels) in 2003 due to unusually warm weather during the growing season. Yields for moderate stress Paradox were not significantly different from yields on low stress NCB suggesting yield advantages of the hybrid Paradox rootstock can be reduced by water management.

INTRODUCTION

A mature walnut orchard transpires an enormous amount of water. Although conditions vary, in the Central Valley of California most walnut orchards have the potential to evaporate about 10.65 ML/ha of water (Goldhammer et.al.,1998). Since there is little if any effective rainfall during the growing season, almost all California walnut acreage is irrigated. In fact, on-farm water management is the most critical cultural practice in the production system. Production economics and competition for California's limited developed water resources have focused a great deal of attention on irrigated agriculture.

Water managers have two potential techniques to conserve or save water. Managers can improve irrigation efficiency at the field, farm or water district level and/or explore the use of regulated deficit irrigation (RDI). Water saving under RDI should result from the decreases in transpiration that occur when the crop is under water stress. RDI imposes water stress by withholding water at a stage of crop growth that responds favorably to stress or at least tolerates it. A deficit irrigation strategy is not likely to be adopted at the farm level if it results in decreased yield or quality particularly if income is consistently reduced. RDI has been studied in many crops, however, it is not clear if walnut is a good candidate for RDI or tolerant of moisture stress at all.

Ramos et.al. (1978) compared frequently irrigated Serr walnut trees to non irrigated trees on a deep Panoche clay loam soil. Moisture stress decreased nut size and reduced kernel quality. Fully irrigated walnut trees resulted in 43% higher returns compared to non-irrigated trees. Although tree water status was not reported, it is likely tree stress exceeded the mild or moderate stress levels that might be reasonable to implement in a RDI regime.

Research conducted in California (Goldhammer et.al., 1988) on a hedgerow planting of Chico walnuts (*Juglans regia* cv chico), indicated that bearing walnuts are not good candidates for RDI strategies. After three consecutive years of deficit irrigation, cumulative dry in-shell yield was reduced. Walnut quality parameters such as size and off-grade were also negatively affected. The deficit treatment applied 33% less water than the fully irrigated treatments.

To be successful, an RDI strategy would need to identify specific stages of walnut growth and production where moisture stress could be safely applied. Walnut development occurs in two distinct stages (Pinney et.al., 1998). Following pollination, nut size and weight increase rapidly. About 8-10 weeks after pollination, nut sizing slows as shells begin to lignify and harden. Nuts attain ultimate size at that time. Following shell hardening, kernel growth and development become the primary process as kernels mature and accumulate oil. Nuts attain maximum total weight about 18 weeks following pollination. Nuts remain on the tree until the outer husks dehisce and walnuts are ready to harvest.

RDI is not a new water management concept. Some of the earliest research with RDI was initiated in Australia and New Zealand over 30 years ago. However, the use of midday stem water potential (MSWP, McCutchan 1992 and Fulton et.al., 2001) to categorize tree moisture stress is fairly new in California. In this experiment we were able to use MSWP to manage applied water to create a gradually increasing water stress regime approaching harvest. This scenario avoided significant moisture stress early in the season when nut sizing and the majority of shoot growth occurs.

MATERIALS AND METHODS

This experiment was positioned within a well-managed commercial, vigorous growing Chandler walnut orchard in the Upper Sacramento Valley of Northern California. Trees were planted in 1994 to a hedgerow configuration (197 trees/ha). Rootstock alternated between Paradox hybrid and Northern California Black (NCB).

The orchard soil is described as a Maywood loam (Gowans 1967). Maywood is a well-drained medium textured soil formed in alluvium from sedimentary rock described as a fine sandy loam to a nearly sandy clay loam. The subsoil contains slightly more clay than the surface soil. Drainage is good, runoff slow and permeability and fertility are moderate. Walnut root distribution is primarily in the upper meter of soil.

In Northern California, Chandler walnuts break dormancy and leaf out in early April. Spring rainfall is adequate to meet early season evapotranspiration. The irrigation season typically begins about mid May. Climate in the Upper Sacramento Valley is hot and dry during the growing season.

Except for water application, test trees were managed the same as the main orchard. Nutrition, weed control, pest management, etc. followed standard orchard practice. Pruning was done mechanically using a hedging machine. Each tree side was hedged every other year. Hedging saws were set at a fixed cutting depth as they traveled down a row. A vigorously growing, large spreading tree would experience more pruning wood removal compared to a small upright tree. This might favor yield on a small, less pruned tree.

Water application was by one Nelson R-5 mini sprinkler per tree connected to above ground polyethylene supply hose. Test trees were irrigated on the same schedule as the entire commercial orchard. The typical in-season irrigation schedule was twenty-four hours every three days. Differential application rates in the test plot were achieved by renozzling existing sprinklers to increase or decrease application rate. Water application rates for the low, mild and moderate treatments were 1.27, 1.02 and 0.76 mm/hr, respectively. In addition, automated ball valves were installed into the mild and moderate treatment supply lines so system run time could be reduced to decrease applied water. Flow meters were installed to measure actual applied water in each of the twelve experimental plots.

Experimental design was a randomized complete block with three treatments and four replicates (twelve plots). Each plot consisted of three rows of trees. Each row had twelve or thirteen trees per row. The middle row of each plot was designated as the test row and the outside two were guard rows. The test row and guard rows received the same irrigation regime. The middle six trees of the test row were then used as the data trees. In total, data was collected from 72 individual trees (12 plots x 6 data trees per plot). The orchard was planted with alternating Paradox and NCB rootstocks.

Three irrigation treatments/strategies were evaluated for four consecutive years (2002-2005). Stem water potential measurements guided applied water decisions, making it possible to reproduce target stress levels for subsequent years. The three treatments were labeled, "low, mild, and moderate."

1) Low water stress: MSWP maintained at –0.3 to –0.6 MPa
2) Mild water stress: MSWP gradually increased from –0.3 to –0.9 MPa
3) Moderate water stress: MSWP gradually increased from –0.3 to –1.2 MPa

Soil moisture was monitored using a Campbell Pacific neutron probe and Irrometer Watermark soil sensors. One PVC access tube was installed in each plot and measurements were made weekly at 30.5 cm increments for 1.5 meters. On-site calibration converted counts to volumetric water content. Watermark sensors attached to data loggers were installed in one replicate in each irrigation regime at 45.7 cm and 91.4 cm depths. Sensors were logged at 30-minute intervals.

In 2002 and 2003, shoot elongation and nut size were measured. For nut growth, ten walnuts per tree, reachable from the ground were tagged. Selected nuts were randomized throughout the lower canopy on the unpruned side of the tree. Only spurs with a single walnut were tagged. If necessary, developing nuts were removed to make a single nut spur. The goal was to evaluate nut growth as equally as possible between treatments. Nuts were tagged after any unpollinated nuts dropped (15-20 mm diameter). Nut diameter was expressed as the average of two digital caliper measurements. After the first diameter was measured, the caliper was rotated 90 degrees for a second measurement. Measurements were made every 7 to 10 days until growth stopped. Nut growth per tree is the average of the ten tagged walnuts.

Current season shoot growth was measured with a tape from shoot attachment to the terminal growth point. Early in the season, four shoots per tree were selected and tagged. Only single shoots were selected to reduce competition and standardize shoot selection. Shoots were selected on the pruned sides of test trees. Mechanical pruning towers were used so mid to upper canopy shoots could be measured. Measurements were made every 7-10 days starting in April/May and continuing into August.

MSWP (McCutchan and Shackel, 1992) was measured weekly using a pressure chamber (Soil Moisture Equip. Corp., Santa Barbara, California). Measurements were made between 12:00h and 16:00h by selecting and bagging one terminal leaflet per tree within ground reach that was close to the trunk or main scaffold. Commercial mylar bags were used to stop transpiration, eliminate light and allow the leaflet water potential to equilibrate with the stem. After a minimum of 10 minutes (Fulton et al., 2001), bagged leaflets were removed, recut and placed into the pressure chamber. A skilled operator could measure a leaflet in less than one minute. MSWP values were averaged to represent the treatment and used to manage applied water to achieve the three treatment stress levels. Average MSWP is reported for each irrigation regime and is the mean of 24 MSWP measurements from individual trees on a given day.

Dry in-shell yield and walnut quality was measured on the six individual data trees per plot. Plot harvest began by hand raking any windfall nuts back to their respective tree. After windfall separation, the first tree in the row was mechanically shaken. After nut removal, all those walnuts were hand raked and piled adjacent to the harvested tree. The mechanical shaker advanced to the next tree and the process was repeated until all data trees were individually shaken and raked. Following shaking, nuts were shoveled into a small portable field harvester, tumbled, cleaned and sacked. Sack weights provided total wet field weight per tree. As the nuts were weighed, random subsamples were collected for quality analysis and moisture content conversion to dry in-shell weight. Subsamples averaged about 2.7 kilograms (8-10 percent of total). Sub samples were air dried until no additional water loss was measured. Subsample wet to dry ratio was multiplied by the whole tree wet weight to calculate in-shell dry weight for each tree.

Diamond Walnut evaluated the dry in-shell nut quality and value from each of the data trees using standard commercial procedures. A sample weighing from 1000 to 1005 grams of dry in-shell nuts was used for quality determinations. Parameters measured included assessments of number of nuts per sample, nut weight, nut size, kernel color, edible kernel, off-grade, shell stain, mold, kernel shrivel, and insect damage. The number of nuts counted in each of these samples was used as a conversion to calculate the number of nuts per tree.

Irrigation management can affect harvest timing. In 2002 all three treatments were harvested on 10/15/02. For 2003 moderate stress treatments were harvested on 10/27/03 and low to mild treatments harvested one week later. 2004 treatments were all harvested on 10/7/04 and the 2005 harvest occurred on 10/19/05.

RESULTS AND DISCUSSION

Table 1 illustrates the seasonal pattern of MSWP and applied water for the three irrigation regimes. Neutron probe measurements indicated stored moisture contributions of only .74 ML/ha to .92 ML/ha; so applied water was the major component in seasonal evapotranspiration. After stored soil moisture depletion, MSWP was very responsive to applied water. A 24-hour delay in irrigation could cause a reduction in MSWP of as much as –0.3 MPa. Since the test plot was part of the larger orchard irrigation system it was challenging to hit specific MSWP targets. A clear separation in MSWP was apparent for the low stress regime, however, it was more difficult to achieve consistent separation between the mild and moderate treatments.

Shoot growth and nut diameter were measured for each treatment and rootstock, however, for brevity the data are not presented. Cumulative shoot growth showed no differences by rootstock. Cumulative shoot growth was affected by irrigation treatment with significantly less shoot growth for the moderate stress treatments compared to the low and mild treatments. Less shoot growth may be a factor in the yields and values for the moderate stress treatment. Green immature nut diameter was not significantly different for rootstock or irrigation treatment. Presumably nut sizing was complete before substantial water stress occurred. RDI treatments reduced trunk cross sectional area for both Paradox and NCB.

Major impacts of the RDI treatments were on yield and kernel quality. Specifically: percent large in-shell walnuts, edible yield, and most importantly nut load.

For the first three years of the experiment, there were no dramatic differences in % large sound in-shell walnuts by rootstock or irrigation practice (Table 2). In 2002 moderate stress reduced % large for both rootstocks. Differences were less clear in 2003 and there were no significant differences in 2004. There appears to be a trend toward less percent large for the low stress Paradox trees (92%, 82%, 72% and 73% for 2002-05 respectively). In 2005, % large sound was significantly lower for the low stress Paradox. 73% for the low stress Paradox compared to 80-85% for the remaining treatments. The size reduction may be due to crop load. In 2005 crop load (Table 4) for the low stress Paradox treatment was high at 3073 nuts/tree.

For 2002, irrigation treatment did not affect edible yield for either rootstock (Table 3). However, edible yields were higher for Paradox compared to NCB. In 2003 treatment effects became more apparent. Rootstock had no effect and irrigation treatment significantly reduced edible yield. 53%, 51% and 49% for the low, mild and moderate Paradox and 52%, 50% and 49% for the low, mild and moderate NCB treatments. In 2004 there was no statistical separation. In 2005 Paradox edible yield was unaffected by irrigation treatment while moderate stress reduced edible yield for the NCB rootstock. Kernel filling occurred before water stress was imposed; as a result edible yield may not be impaired every year. Weather conditions in 2003 may also explain those data.

The major yield component affected by moisture stress was crop load (Table 4). In 2002 Paradox had significantly more walnuts per tree compared to NCB and no effects from irrigation treatment were observed. That might be expected because fruit bud development occurs in the previous year so it would be reasonable to see no treatment differences in the first year of the experiment. For 2003, 2004 and 2005 nut load was dramatically decreased by water stress. In 2005, moderate stress significantly reduced nut load for both rootstocks. Low stress Paradox trees averaged 3073 nuts/tree compared to 2033 nuts/tree for moderate stress treatments. NCB showed the same trend and again Paradox out yielded NCB. Notice that for 2003 and 2005 (Table 4) crop load for moderate stress Paradox are not statistically different from low stress NCB and in 2004, moderate stress Paradox significantly under yielded low stress NCB. Perhaps the horticultural yield advantage of hybrid Paradox rootstock can be compromised by water stress.

Reasons for nut load decrease were investigated by Little et.al. 2006 (unpublished masters thesis). Water stress reduced nut load by decreasing the percentage of dormant buds that opened. The buds that did open were more vegetative and floral buds that did break had a lower percentage of flowers.

Yield data (Table 5) shows the same trends as the nut load data. As before, Paradox out yielded NCB, water stress decreased yield and for 2003, 2004 and 2005 yields for moderate stress Paradox were not statistically different from low stress NCB rootstocks. Moderate Paradox yielded 5539, 3436 and 4088 kg/ha compared to 5140, 4048 and 3347 kg/ha for low stress NCB respectively for 2003, 2004 and 2005. Four-year total yield favors the low stress Paradox yield at 24,089 kg/ha. Horticulturally, NCB rootstock grows a smaller, less vigorous tree compared to Paradox. Since the planting alternated Paradox and NCB, Paradox could potentially out compete NCB and influence yield comparisons. Since low stress NCB yields (3507, 5140, 4048, 3347 kg/ha respectively for 2002-2005) did not gradually decline over the course of the experiment (Table 5) tree competition may not be a major factor in the yield data. Research yields are most accurate for demonstrating treatment effects and may not translate into accurate commercial yields.

CONCLUSIONS

Chandler walnuts do not appear to be good candidates for RDI for either rootstock evaluated. Moisture stress affected many tree and crop characteristics, the most critical being reduced nut load and in some cases reduced kernel quality. Both are very important in the gross financial return to the farmer. In this experiment, Paradox out-yielded NCB. When Paradox was moderately stressed, yields were reduced, compromising its yield advantage compared to NCB.

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Tables

Monthly Average	2002 Season			2003 Season			2004 Season			2005 Season		
	Low	Mild	Mod	Low	Mild	Mod	Low	Mild	Mod	Low	Mild	Mod
May	-.42	-.45	-.54	-.38	-.42	-.44	-.26	-.27	-.28	-.46	-.41	-.42
June	-.40	-.48	-.65	-.25	-.40	-.51	-.48	-.58	-.69	-.54	-.44	-.41
July	-.34	-.60	-.78	-.28	-.65	-.75	-.50	-.76	-.89	-.61	-.65	-.60
Aug	-.33	-.66	-.77	-.32	-.79	-.89	-.32	-.64	-.85	-.56	-.82	-.80
Sept	-.28	-.89	-.96	-.34	-.85	-1.02	-.28	-.60	-.81	-.61	-.73	-.98
Season Avg.	-.35	-.62	-.74	-.31	-.62	-.72	-.37	-.57	-.70	-.56	-.61	-.64
Applied Water (ML/ha)	11.08	7.88	6.48	11.27	6.58	5.48	10.88	6.68	5.88	9.68	7.38	6.58

Table 1. Summary of monthly average MSWP (MPa), applied water (ML/ha) and the three different irrigation strategies imposed on Chandler walnut, 2002-2005.

Rootstock	Irrigation Treatment	% Large Sound In-shell Walnuts 2002	2003	2004	2005
Paradox	Low	92.05 a	82.38 a	72.66	73.04 c
Paradox	Mild	92.12 a	84.97 a	81.05	80.78 b
Paradox	Moderate	85.41 bc	85.08 a	78.55	82.69 ab
NCB	Low	91.17 a	81.85 ab	75.02	80.70 b
NCB	Mild	89.99 a	75.39 b	80.45	83.22 ab
NCB	Moderate	84.08 c	78.71 ab	78.49	85.91 a
P value		p<0.01	p<0.05	p=0.32	p<0.01
LSD (0.05)		5.26	6.80	NS	4.96

Table 2. Percent Large Sound In-shell Walnuts for each year by irrigation treatment and rootstock. Subsample analysis by Diamond Walnut of California.

Rootstock	Irrigation Treatment	Edible Yield (%) 2002	2003	2004	2005
Paradox	Low	49.31 ab	53.72 a	47.30	46.20 a
Paradox	Mild	48.97 ab	51.35 bc	48.35	46.32 a
Paradox	Moderate	49.76 a	49.40 d	47.82	46.32 ab
NCB	Low	48.42 bc	52.47 ab	48.84	45.36 ab
NCB	Mild	47.81 c	50.66 cd	48.51	44.24 bc
NCB	Moderate	47.90 c	49.58 d	48.85	42.88 c
P value		p<0.01	p<0.01	p=0.13	p<0.01
LSD (0.05)		0.92	1.28	NS	1.62

Table 3. Edible Yield for each year by irrigation treatment and rootstock. Subsample analysis by Diamond Walnut of California.

Rootstock	Irrigation Treatment	Nut Load (nuts/tree) 2002	2003	2004	2005
Paradox	Low	2312 a	3955 a	2652 a	3073 a
Paradox	Mild	2245 a	3557 ab	1915 b	2401 b
Paradox	Moderate	2195 a	3119 bc	1576 c	2033 bc
NCB	Low	1543 b	2727 c	1947 b	1671 cd
NCB	Mild	1493 b	1948 d	1323 cd	1288 de
NCB	Moderate	1583 b	1840 d	1058 d	1019 e
P value		p<0.01	p<0.01	p<0.01	p<0.01
LSD (0.05)		312	546	301	498

Table 4. Total number of walnuts per tree for each year of irrigation treatment and rootstock. Nut load is the product of individual tree dry in-shell weight and count per kilogram.

Rootstock	Irrigation Treatment	Yield (kg/ha) 2002	2003	2004	2005	4 Year Total Yield
Paradox	Low	5355 a	7041 a	5652 a	6041 a	24,089 a
Paradox	Mild	4936 ab	6215 ab	4222 b	4861 b	20,234 b
Paradox	Moderate	4562 b	5539 bc	3436 cd	4088 bc	17,625 c
NCB	Low	3507 c	5140 c	4048 bc	3347 cd	16,042 c
NCB	Mild	3311 c	3748 d	2896 de	2643 de	12,598 d
NCB	Moderate	3323 c	3461 d	2289 e	2135 e	11,208 d
P value		p<0.01	p<0.01	p<0.01	p<0.01	p<0.01
LSD (0.05)		674	1006	672	977	2587

Table 5. Yield and four year total yield by irrigation treatment and rootstock. Yields were taken on individual trees (yield conversion to hectare using 197 trees/ha).