Effects of Regulated Deficit Irrigation on Walnut Grafted on 'Northern California Black' or 'Paradox' Rootstock

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Abstract

'Chandler' walnut (*Juglans regia*) 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 through 2005. The RDI strategy was to maintain high midday stem water potential (MSWP) early in the season (to favor shoot growth and nut size) and then gradually lower it until harvest. In a fully irrigated control, MSWP was maintained at -0.3 to -0.6 MPa throughout the growing season. In mild and moderate RDI treatments, MSWP was maintained at -0.3 MPa to -0.6 MPa early in the season and later lowered to -0.7 to -0.9 MPa or -0.9 to -1.1 MPa, respectively, by harvest. Nut load, total and edible yield, and the percentage of large, sound nuts were significantly affected by rootstock and irrigation treatment. In general, trees on 'Paradox' outperformed trees on 'Northern California Black' in all irrigation treatments, producing 2.0, 1.9, and 1.6 tonne more nuts per hectare, on average, under control and mild and moderate RDI conditions, respectively. On average, nut load on 'Paradox' was reduced by 19 and 30%, respectively, under mild and moderate water RDI conditions, while nut load on 'Northern California Black' was reduced by 28 and 38%, respectively.

INTRODUCTION

Mature walnut orchards transpire enormous amounts of water using ≈10.65 ML/ha of water per year in central California (Goldhamer et.al., 1998). One potential method to reduce water use is by implementing regulated deficit irrigation (RDI). When using RDI, irrigation is purposely withheld during certain periods when water stress is tolerable or possibly favorable to production. Regulated deficit irrigation has been studied in many crops, however, not all crops respond favorably to RDI.

The objective of the present study was to examine the potential of RDI for reducing water use and improving production in walnut. Walnuts develop in two distinct stages (Pinney et.al., 1998). First, nuts increase rapidly in both size and weight after pollination. Then, at 8-10 weeks after pollination, the shell hardens and kernel growth becomes the primary process. Oils accumulate as the kernel matures. Maximum total nut weight is attained at approximately 18 weeks after pollination. Nuts are finally harvested once the outer husks dehisce. To test RDI, trees on two different rootstocks were gradually exposed to water stress during the second stage of nut development.

MATERIALS AND METHODS

The study was conducted in a well-managed, commercial orchard of 'Chandler' walnut trees planted in 1994 in the upper Sacramento Valley of northern California. Trees were grafted on either 'Paradox' or 'Northern California Black' ('NCB') rootstock (in alternating rows) and spaced 5.5m x 9.1m. Orchard soil is Maywood loam (Gowans, 1967) with slightly more clay in the subsoil than in the surface soil. Drainage is good, runoff is slow, and permeability and fertility are moderate. Roots were distributed primarily in the upper meter of soil. Pruning was done mechanically using a hedging machine. Trees were hedged on one side or the other each year. Nutrition, weed control, and pest management were done following standard commercial practices.

Three irrigation treatments were evaluated from 2002 to 2005. Treatments included: 1) low water stress, where trees were well-watered and stem water potential was maintained at -0.3 to -0.6 MPa; 2) mild water stress (i.e., RDI), where irrigation was withheld at 8-10 weeks after pollination until stem water potential reached -0.9 MPa; and moderate water stress, where irrigation was withheld at 8-10 weeks after pollination until stem water potential reached -1.2 MPa. Treatments were arranged in a randomized complete block design with four replicates per treatment. Each plot consisted of three rows of 12-13 trees and measurements were taken on the center six trees only. Stem water potential was measured weekly using a pressure chamber (Soil Moisture Equip. Corp., Santa Barbara, California) between 12:00 and 16:00h, following procedures outlined in McCutchan and Shackel (1992). For each measurement, one terminal leaflet per tree was selected within ground reach near the trunk or main scaffold. The leaflet was covered at least 10 min with a foil-laminated plastic bag before it was removed, re-cut and placed into the pressure chamber. Irrigation was applied using one Nelson R-5 mini sprinkler per tree. Sprinklers were run 24 h every 3 d. Water was applied (using different nozzles) at 1.27, 1.02, and 0.76 mm/hr in the low, mild, and moderate treatments, respectively. Water applications were further reduced in mild and moderate treatments using automated ball valves installed in the supply line. Flow meters were used to monitor actual water applied to each treatment.

Shoot elongation and nut size were measured in 2002 and 2003. Current-season shoot growth was measured from the base of the shoot to the terminal growth point. Four shoots per tree were selected early in the season and tagged. Only single shoots were selected on the pruned side of the trees. Shoots were located in the mid to upper canopy. Each shoot was measured every 7-10 d from April/May to August. For nut growth, 10 walnuts per tree, reachable from the ground, were tagged. Tagging was done after the unpollinated nuts had dropped from the trees. Selected nuts were randomized throughout the lower canopy on the unpruned side of the tree. Only spurs with a single walnut were tagged. Nuts were removed to make a single nut spur when necessary. Nut diameter was measured at two locations (90 degrees apart) using a digital caliper. Nut diameter was measured every 7-10 d until growth stopped.

Dry in-shell yield and nut quality were measured on six trees per plot. Each plot was harvested by first hand raking any windfall nuts back under the respective trees. Then, the first tree in the row was mechanically shaken and nuts were hand raked and piled beneath the tree. The mechanical shaker then 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 ≈2.7 kg (8-10% of total). Subsamples were air dried until no additional water loss was measured. Subsample wet to dry weight ratios were multiplied by whole tree wet weights to calculate in-shell dry weight for each tree. Dry in-shell nut quality was evaluated commercially on 1000 to 1005 g samples. Quality measurements included 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. Nuts were harvested on 15 Oct. in 2002, 27 Oct. (moderate stress) or 3 Nov. (low and mild stress) in 2003, Oct. 7 in 2004, and Oct. 19 in 2005.

RESULTS AND DISCUSSION

Table 1 illustrates the seasonal changes in midday stem water potential and the total amount of water applied to each irrigation treatment each season. Stem water potentials differed among water stress treatments by as early as June in some years and as late as August in others. However, target water potentials were not necessarily reached each year in the mild water stress treatment (i.e., -0.9 MPa) and were never reached in the moderate water stress treatment (i.e., -1.2 MPa). Seasonal stem water potentials were similar to those reported by Fulton et al. (2001).

Shoot growth was similar between rootstocks, but was significantly reduced by moderate water stress (data not shown). Diameter of green, immature nuts was also similar between rootstocks as well as among irrigation treatments. Presumably nut sizing was complete before substantial water stress occurred.

Water stress mostly affected yield and nut quality. In both rootstocks, the percentage of large, sound, in-shell nuts was significantly reduced by moderate water stress in 2002 (Table 2). By 2005 moisture stress increased the percentage of large, sound, in-shell nuts but reduced crop load or number of walnuts per tree (Table 5). RDI resulted in smaller crops of larger walnuts. The percentage of edible nuts was sometimes reduced (Table 3) and nut load and yield were often reduced at both moderate and mild water stress (Tables 4 and 5). Moisture stress also decreased nut size and reduced kernel quality in ‘Serr’ walnut trees (Ramos et.al., 1978). Little (2006) found that water stress reduced nut load by decreasing the percentage of dormant buds that opened, increasing the ratio of vegetative to floral buds, and reducing the number of flowers. Since nut load and yield were not affected the first season, it is likely that water stress mostly affected fruit bud development in our study as well.

Between rootstocks, trees on ‘Paradox’ generally had higher yields than those on ‘Northern California Black’, though the impact of water stress on each appeared similar (Table 5). Ramos et.al. (1978) compared frequently irrigated ‘Serr’ walnut trees to non-irrigated trees on a deep Panoche clay loam soil. Similar to our results, 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.

CONCLUSIONS

‘Chandler’ walnuts do not appear to be good RDI candidates for either rootstock evaluated. Goldhamer et.al. (1988) reached a similar conclusion in a RDI study done on ‘Chico’ walnuts. Moisture stress affected many tree and crop characteristics in our study, 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 fully irrigated ‘NCB’.

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Tables

Table 1. Midday stem water potentials of 'Chandler' walnut trees irrigated at low, mild, and moderate levels of water stress in 2002-2005. The total amount of water applied to each treatment each season is also shown.

	Midday stem water potential (MPa)											
Monthly average	2002			2003			2004			2005		
	Low	Mild	Mod	Low	Mild	Mod	Low	Mild	Mod	Low	Mild	Mod
May	-0.42	-0.45	-0.54	-0.38	-0.42	-0.44	-0.26	-0.27	-0.28	-0.46	-0.41	-0.42
June	-0.40	-0.48	-0.65	-0.25	-0.40	-0.51	-0.48	-0.58	-0.69	-0.54	-0.44	-0.41
July	-0.34	-0.60	-0.78	-0.28	-0.65	-0.75	-0.50	-0.76	-0.89	-0.61	-0.65	-0.60
Aug	-0.33	-0.66	-0.77	-0.32	-0.79	-0.89	-0.32	-0.64	-0.85	-0.56	-0.82	-0.80
Sept	-0.28	-0.89	-0.96	-0.34	-0.85	-1.02	-0.28	-0.60	-0.81	-0.61	-0.73	-0.98
Seasonal average	-0.35	-0.62	-0.74	-0.31	-0.62	-0.72	-0.37	-0.57	-0.70	-0.56	-0.61	-0.64
Water applied (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 2. Percentage of large, sound, in-shell nuts from 'Chandler' walnut trees on 'Paradox hybrid' or 'Northern California Black' (NCB) rootstock irrigated at low, mild, and moderate levels of water stress in 2002-2005.

Rootstock	Irrigation treatment	Large, sound walnuts (%) 2002	2003	2004	2005
Paradox	Low	92.0 a	82.4 a	72.7	73.0 c
Paradox	Mild	92.1 a	85.0 a	81.0	80.8 b
Paradox	Moderate	85.4 bc	85.1 a	78.6	82.7 ab
NCB	Low	91.2 a	81.8 ab	75.0	80.7 b
NCB	Mild	90.0 a	75.4 b	80.4	83.2 ab
NCB	Moderate	84.1 c	78.7 ab	78.5	85.9 a
P value		<0.01	<0.05	0.32	<0.01
LSD (0.05)		5.26	6.80	NS	4.96

Table 3. Percentage of edible nuts from 'Chandler' walnut trees on 'Paradox hybrid' or 'Northern California Black' (NCB) rootstock irrigated at low, mild, and moderate levels of water stress in 2002-2005.

Rootstock	Irrigation treatment	Edible walnuts (%) 2002	2003	2004	2005
Paradox	Low	49.3 ab	53.7 a	47.3	46.2 a
Paradox	Mild	49.0 ab	51.3 bc	48.3	46.3 a
Paradox	Moderate	49.8 a	49.4 d	47.8	46.3 ab
NCB	Low	48.4 bc	52.5 ab	48.8	45.4 ab
NCB	Mild	47.8 c	50.7 cd	48.5	44.2 bc
NCB	Moderate	47.9 c	49.6 d	48.8	42.8 c
P value		<0.01	<0.01	0.13	<0.01
LSD (0.05)		0.92	1.28	NS	1.62

Table 4. Nut load on 'Chandler' walnut trees on 'Paradox hybrid' or 'Northern California Black' (NCB) rootstock irrigated at low, mild, and moderate levels of water stress in 2002-2005.

Rootstock	Irrigation treatment	Nut load (walnuts/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		<0.01	<0.01	<0.01	<0.01
LSD (0.05)		312	546	301	498

Table 5. Yield of 'Chandler' walnut trees on 'Paradox hybrid' or 'Northern California Black' (NCB) rootstock irrigated at low, mild, and moderate levels of water stress in 2002-2005.

Rootstock	Irrigation treatment	Yield (kg/ha) 2002	2003	2004	2005	Four-year total
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		<0.01	<0.01	<0.01	<0.01	<0.01
LSD (0.05)		674	1006	672	977	2587