IRRIGATION MANAGEMENT IN WALNUT USING EVAPOTRANSPIRATION, SOIL AND PLANT BASED DATA

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ABSTRACT

The study was conducted on the Chandler variety at two sites, one in San Joaquin County and one in Tehama County. In the second year of the study, it was again difficult to maintain target levels of midday stem water potential at both sites. Part of the reason for this was the gradual loss of lower profile soil moisture over the season in both deficit treatments at both sites. This likely resulted in the trees being largely dependent on the top 18" or so of soil for their water supply by the end of the season. By the second year, both deficit treatments had a significant impact on canopy development as measured by midday canopy light interception at the Tehama, but not at the San Joaquin site. This was likely due to more vigorous shoot growth occurring at the Tehama site which is younger and also was mechanically hedged, as compared to the older, minimally pruned San Joaquin site. Although there were no significant treatment impacts on yield at the San Joaquin site in 2003, there was a slight tendency towards lower yields in the deficit treatments. At the Tehama site, both deficit treatments resulted in decreased dry weight yields and the effect appeared to be due to more than simply less canopy development. Treatment impacts on nut quality have been largely insignificant in the first two years of the study. The lack of treatment effects on quality and yield at the San Joaquin site which averaged significantly more negative midday stem water potentials in all three treatments compared to the Tehama site suggests that water stress of the magnitude of the deficit treatments in this study, may not be the major factor impacting nut quality. In fact, the level of kernel shrivel and mold was higher at the wetter Tehama site in 2003 as compared to the drier San Joaquin site suggesting, that wet conditions may have negative impacts on quality. The effects of tree water status on kernel color are also unclear after two years of this study. These preliminary results suggest that impacts of deficit irrigation treatments may vary widely depending on orchard age, soil differences etc.

INTRODUCTION

Irrigation management has been implicated as a major factor in numerous walnut problems including *Phythophthora* root rot (Mircetich et.al, 1998), walnut decline (Blanchard, 1939; Schreader, 1972) and deep bark canker (Brown, 1976; Teviotdale et. al., 1977).

Recent irrigation related problems encountered have included too much water causing *Phytophthora* related orchard damage, dieback (not linked to any diseases) caused by improper irrigation (usually excessive water early in the season), and later season water deficits combined with hot, dry weather causing extensive blackening of hulls and nuts in Chandler walnuts. Many farm advisors spend a large proportion of their farm call time going out to look at problems that turn out to be irrigation related.

A common perception among growers is that walnut trees need to be kept very wet to get good production. However, as described above, irrigating in excess of plant needs can lead to a number of problems. Also, because nut sizing is largely completed by June, moderate stress later in the season may not impact crop load significantly if it is not severe enough to impede nut filling. Measurements done on a variety of walnut orchards in the Sacramento and San Joaquin Valleys in 2001 suggest that substantial stress occurs in many productive walnut orchards as the summer proceeds. In most cases, the growers were unaware that the trees were under stress since visible symptoms were not obvious. In other cases, the midday leaf water potential data suggested that the orchards might well have been over-irrigated based on the fact that the values stayed on or above the baseline all season.

The pressure chamber can be an effective tool for irrigation management. By regular measurement of midday stem water potential and withholding irrigation until a reasonable falloff from the baseline occurs, over-irrigation and resulting root damage can be avoided. Likewise, avoiding an excessive falloff from the baseline can avoid undesirable stress from deficit irrigation associated with shallow and deep bark canker and other orchard health problems. By combining the pressure chamber with use of crop evapotranspiration information or monitoring of deep moisture with Watermark sensors and/or tensiometers, a soil water balance can be maintained that allows sufficient drying between irrigation cycles to prevent over-irrigation that can lead to *Phytophthora* and dieback, while preventing deficit irrigation of a level sufficient to impact shoot growth and nut load, nut sizing or other quality characteristics.

The advantage of the pressure chamber compared to soil moisture monitoring or applying evapotranspiration estimates alone is that the pressure chamber provides a measure of crop stress that integrates root health and volume, soil-water availability, non-uniform irrigation and weather conditions. With soil moisture monitoring a very limited volume of soil around the sensor is used to indicate soil-water status in the root zone, and there is no way of knowing with certainty that the sensors have been accurately placed to represent the soil-water status of the root zone. Furthermore, if loss of root function has occurred, Goldhamer et.al. (1987) showed that the measurement of soil moisture status may not indicate a problem even though the trees are under stress. In these situations, the use of a pressure chamber is essential for irrigation management.

Despite all the irrigation related problems that occur regularly in walnut, there have been relatively few resources devoted to understanding the fundamentals of walnut water relations as they relate to tree longevity, disease and productivity. Good water management is essential for growers. Orchards that are adequately irrigated without over irrigating will provide the best returns overall. Orchards that are over irrigated are prone to many problems include *Phytophthora* root rot, decline etc. Orchards that go into a state of decline lead to increased costs since they need to be removed and replanted, but as the trees mature following replanting, they often go through the same cycle of decline once again if management practices have not been altered. An additional benefit of better water management might be a balance between enough shoot growth to sustain crop bearing wood and resulting nut load and less vegetative growth. In a mature orchard where the trees have filled in their allotted space, this could provide an effective management strategy. Finally, there is some preliminary evidence that moderately stressed walnut trees can potentially show a reduction in codling moth susceptibility (Mills et. al. 2001) and mold problems (Prichard et. al, 2001).

OBJECTIVES

1) Develop water management strategies for walnut using a combination of evapotranspiration, soil and plant based measurements.

2) Develop basic data on the relationship between midday stem water potential and walnut productivity.

The data that comes out of this project should give growers the tools to effectively manage water to maximize productivity while minimizing excessive vegetative growth and potential environmental problems.

PLANS AND PROCEDURES

Experimental design

All experimental design and procedures are duplicated at two sites, one in San Joaquin County and one in Tehama County.

San Joaquin County Site- The San Joaquin County site is a 'Chandler' orchard planted on Paradox rootstock at a 32' by 32' equilateral triangle arrangement (49 trees/acre). The soil is a Cogna loam which is a deep well drained alluvial derived soil. The orchard is irrigated with one Nelson R10 sprinkler per tree. Variation in irrigation treatments was achieved using different size nozzles with the high, medium and low irrigation treatments applying 0.066, 0.056, 0.047 inches per hour. There are four replications of each irrigation treatment with 3 rows per replication. A replication consists of 18 trees receiving the same irrigation treatment.

Tehama County Site- The orchard was planted in 1994 on a 30' by 18' spacing (81 trees/acre). The soil is a Maywood sandy loam series, consisting of stratified soils. Sandy loam textures are predominant from about 0 to 30 inches, gravelly sandy loam soils are common from about 30-54 inches, and loams and clay loams are found below 54 inches. The variety is 'Chandler' alternating on Northern California Black and Paradox rootstocks. Replants have been on Paradox rootstock. The orchard is irrigated with one Nelson R-5 micro-sprinkler per tree. Variation in irrigation treatments was achieved using different size nozzles with the high, medium and low irrigation treatments applying 0.055, 0.046, 0.038 inches per hour. The water application in the mild and moderate stress treatments represents a 16 and 30 percent reduction in the hourly water application rate, respectively. The surrounding orchard outside of the experimental plots was irrigated at the same frequency as the low stress experimental treatment. Typically during the summer, the low stress irrigation treatment was irrigated every third day for 18 hours. Manual shutoff valves were placed on each irrigation line in order to allow turning the water on and off to these plots as needed to achieve target stress levels. There are four replications of each of the three irrigation treatments with 3 rows per replication and 12-13 trees per row as well as guard rows between plots. Flow meters were installed in-line for each row of trees where crop response data were taken to provide an accurate record of applied water.

Soil moisture monitoring

Soil moisture was monitored with neutron probes as well as Watermark soil resistance blocks. At the San Joaquin location, a neutron probe was placed in one replication in each treatment. In addition, Watermark sensors attached to small dataloggers were placed at 18" and 36" in one replication in each treatment. At the Tehama County site, a neutron probe access tube was placed in each replication of all treatments to a minimum depth of five feet. Watermark sensors, attached to small dataloggers, were placed at 18' and 36" in one replication for each treatment. Watermark sensors were set to continuously log at 30 minute intervals. Neutron probe measurements were taken every 3 or 4 days beginning in mid-May through mid September on the same days that midday stem water potential measurements were taken.

Midday stem water potential monitoring

The goal of this project is to maintain target water potentials for the three different irrigation regimes at each site throughout the season (Fig. 1).

San Joaquin County Site- The middle four trees in each plot were used for detailed water potential, nut and shoot growth measurements. Midday stem water potential was measured approximately every 7-10 days (generally near the end of an irrigation cycle) on 4 trees per plot (a total of 12 trees per treatment). Leaves in low, shaded positions near the base of the tree were bagged at least 15 minutes before sampling and placed immediately in the pressure chamber (still enclosed in the bag). Any needed adjustments to the sprinkler head sizing or turning on/off irrigation treatments will be done promptly to assure meeting treatment target midday stem water potentials.

Tehama County Site- Due to the high frequency and low volume irrigation, midday stem water potential was measured approximately every 3-4 days on 6 trees per plot (total of 24 trees per treatment) using methods similar to those described above for the San Joaquin County site. Midday stem water potential was measured just prior to irrigation to the extent possible. Although rootstocks originally alternated between Northern California Black and Paradox rootstocks, replanting was done with Paradox. This study ended up with a total of 14 Paradox and 10 Northern California Black rooted trees being monitored for midday stem water potential in each treatment.

Canopy light interception measurements

Canopy light interception was measured approximately every three weeks using a Decagon Ceptometer (80 cm bar with light sensors mounted on it). Measurements were taken within 1 hour of the time the sun is directly overhead by making 100 measurements in a grid pattern covering a consistent area in each replication. Small differences in light penetration can be difficult to detect with this method. Therefore, an additional 30 measurements were taken directly underneath the tree canopy in each replication to look for potential differences in canopy light penetration within the tree canopy.

Shoot and nut growth measurements

San Joaquin County site- Nut diameter was measured approximately every three weeks with a digital micrometer on 10 nuts per tree on the same 12 trees per treatment on which stem water potential was measured. Shoot growth was measured on 3 shoots per tree for a total of 36 shoots per treatment on the same trees as nuts were measured. Because little growth was occurring, selected shoots were hand pruned and shoot growth was measured on the re-growth on these shoots in 2002. In 2003, only unpruned shoots were measured.

Tehama County site- Nut growth measurements were made every 7-10 days on 10 nuts per tree on the same 24 trees per treatment on which stem water potential was measured. Shoot growth was measured on unpruned and pruned shoots on each of the same trees in 2002 and on pruned shoots in 2003.

Harvest
Yields were monitored by harvesting the individual monitored trees at both sites. After each individual tree was shaken, the nuts were swept into windrows and harvested with a small manually pulled cup-type harvester at the Tehama County site and the growers' harvester at the San Joaquin County site. Sub-samples were taken for drying, size and quality analysis.

RESULTS

Soil moisture monitoring- San Joaquin County site- Watermark sensor data indicated that the soil moisture tension in the control treatment was high in the winter (0-10 cbars) and remained in the 0-70 cbar range throughout most of the summer (Fig. 1). By contrast, in the mild and moderate stress treatments, although the soil moisture was high in the winter, as the season progressed the soil moisture gradually dried down to very low levels by early Fall (Fig. 1).

Tehama County site- At the Tehama County site, results for the Watermark sensor data was generally similar to that at the San Joaquin County site (Fig. 1). Soil moisture was high in all treatments during winter and gradually dried down in the mild and moderate stress treatments through the summer (Fig. 1).

Applied water
Tehama County- Cumulative applied water for the control, mild and moderate stress irrigation treatments at the Tehama County site in 2002 averaged 43.8, 31.2 and 25.8 inches, respectively. Cumulative real time crop evapotranspiration for walnut at the site was estimated to be 41.7 inches. This represents total applied water exceeding total crop evapotranspiration by 5 percent in the control treatment and a deficit of 25 and 38 percent for the mild and moderate stress treatments, respectively. In 2003, applied water averaged 44.5, 26.2 and 21.7 inches for the control, mild and moderate stress treatments respectively (Fig. 2). In 2003, this resulted in respective applications of 134, 79 and 68% of crop evapotranspiration which totaled 37.5 inches (Fig. 2).

San Joaquin County- - Cumulative applied water for the control, mild and moderate stress irrigation treatments at the San Joaquin County site in 2003 averaged 31.2, 26.6 and 22.2 inches, respectively. This site provides a significant soil water resource averaging 7.1 inches across treatments. In season effective rainfall also added 3.0 inches to meet consumptive use. Total water consumed, including in-season rainfall and soil moisture for the control, mild and moderate stress treatments averaged 40.0, 37.4, and 33.0 inches respectively. Estimated evapotranspiration for the crop was 41.0 inches. In 2003, this resulted in respective applications of 98, 91 and 80% of crop evapotranspiration.

Soil water depletion

San Joaquin County- Average soil-water depletion in the 0 to 9-foot range determined by neutron probe measurements is illustrated for the San Joaquin County site in Fig. 3. . Soil moisture declined similarly in all treatments until the June 24 soil moisture reading. At that time the irrigation volume was increased in all treatments resulting in an increase in soil moisture in the control and mild stress treatments over the moderate stress treatment.

All treatments ended the season at leaf drop with nearly the same soil moisture content which was on the average 1.25 inches less than in 2002

Tehama County- Average soil water stored in the root zone was highest in the control treatment during the summer (Fig. 4). Levels for the mild and moderate stress treatments were somewhat lower than the control but similar to each other (Fig. 4).

Midday stem water potential

San Joaquin County- There was again some difficulty in maintaining the target midday stem water potentials (MSWP) at both sites in 2003. In interpreting these data, it is important to realize that the MSWP measurements at the San Joaquin Valley site were generally done near the end of the 14 day irrigation cycle so they represent the most stressed conditions that the trees experienced. The treatment average MSWP would have been somewhat less negative. This is showed by comparing the first set of readings taken in August 2003 (right before irrigation) to the second set of readings (right after an irrigation). The recovery varied from approximately 1-2 bars after irrigation. This is not much of a factor at the Tehama County site where irrigation generally occurred about twice per week.

The MSWP for the treatments tended to be generally below the target levels for all treatments from late June through early August (Fig. 5). Through August and September, treatment water potentials were near the targets (Fig. 5).

Tehama County- In 2003, at the Tehama County site, there was also considerable variation of the MSWP around the target values but the fluctuations tended to be over a shorter time period (Fig. 6). This may have been due to the frequent low volume irrigation combined with limited root development below three feet in the stratified soils. The MSWP for the control treatment ran above the fully watered baseline for most of the season again in 2003 (Fig. 6) suggesting the baseline may need to be revised. The mild and moderate stress treatments tended to run somewhat above the baseline most of the season at the Tehama County site (Fig. 6).

Canopy light interception

San Joaquin site- In 2003, there were no significant difference in the midday canopy light interception for any of the treatments after the first reading of the season (Fig. 7c). The significantly higher midday canopy light interception for the mild stress treatment seen in 2002 (Fig. 7a) was no longer significantly different than the control by the end of the 2003 season (Fig. 7c). Midday canopy light interception was above 80% for all three treatments (Fig. 7c).

Light interception measured at the San Joaquin site beneath the tree canopy was generally at the mid ninety percent level and there were no significant treatment effects at any time during the season although there was a tendency towards higher light interception for the control treatment compared to both deficit treatments in 2003 (Fig. 7d) as compared to in 2002 (Fig. 7b).

Tehama County site- In 2003, the control treatment had significantly higher midday canopy light interception compared to the moderate stress for the last 3 sampling dates and compared to the mild stress for the last sampling date (Fig. 8c). The end of season midday canopy light interception for the control, mild and moderate stress treatments was 14, 18 and 18% higher respectively, for the San Joaquin site compared to Tehama site. There were no significant treatment differences in light interception beneath the tree canopy at the Tehama County site in 2002 (Fig. 8b) or 2003 (Fig. 8d).

Shoot growth- San Joaquin County site- Only unpruned shoots were measured at the San Joaquin County site in 2003. There was very little shoot growth on any of the treatments in 2003 and there were no significant treatment effects at any time during the season (Fig. 9).

These data agree with the lack of significance in the midday canopy light interception data (Fig. 7c).

Tehama County site- There were no significant effects of treatment on shoot growth on the Northern California Black rooted trees (Fig. 12). For the Paradox rooted trees, the moderate stress treatment had significantly less shoot growth at the last three measurement dates in 2003 (Fig. 12).

Nut growth- San Joaquin site- In 2003, the moderate stress treatment had significantly smaller hull diameters compared to the control when readings of nut diameter began in early mid-June (Fig. 11). However, by the last measurement date in mid-August, the differences were no longer significant (Fig. 11). However, when shell diameters were measured after hulling, the moderate stress treatment nuts were significantly smaller than the control (inset table in Fig. 11).

Tehama County site- There were no significant treatment differences in hull diameter at any time during the season for either the trees on Northern California Black or Paradox rootstocks (Fig. 12). The nuts on the Paradox rooted trees were significantly smaller than the nuts on Northern California Black rooted trees, but this was most likely a crop load related effect (see Table 3).

Harvest- San Joaquin County site- As was the case in 2002, once again in 2003 there were no significant treatment impacts on overall yield (Table 1). When the treatment yield were adjusted to similar midday canopy light interception as the control (to account for treatment differences in canopy development, the yields of the two deficit treatments were closer to those of the control (still not significantly different). However, as mentioned earlier, the nut size was significantly smaller in the moderate stress treatment compared to the control and this difference showed up in the Diamond quality grading data as well (Table 4). There were no significant treatment impacts on mold, insect damage, shrivel, or adhering hulls at the San Joaquin site in the Diamond quality data (Table 4). There were significantly less black nuts (adhering hull) at harvest in the moderate stress treatment compared to the control or mild stress treatments at the San Joaquin site in 2003.

Neither of the deficit treatments had significantly different color (as measured by RLI) than the control in 2003 (Table 4).

Tehama County site- Although there were no significant treatment related impacts on dry weight yield at the Tehama site in 2002, in 2003, both the mild and moderate stress treatments had significantly less dry weight yield than the control (Table 2). When these differences were converted to a similar midday light interception (to control for treatment differences in canopy development, the mild stress treatment yield was not significantly different than the control while the moderate treatment yield still was less (Table 2, last column). When the treatment yields are separated out by rootstock, it is clear that in all deficit treatments, the Paradox rooted trees produced significantly more dry weight yield than the Northern California rooted trees (Table 3). The impact of the deficit treatments was more severe on the Northern California Black as compared to the Paradox rooted trees as evidenced by the significant effect of the moderate treatment on decreasing yield in the mild stress treatment on the Northern California Black rooted trees but not on the Paradox rooted trees (Table 3).

There were no significant treatment effects on nut percent large nuts, mold, or kernel shrivel at the Tehama site in 2003 (Table 5). There were significantly less adhering hulls in the Diamond quality sample for the control treatment compared to the moderate stress treatment (Table 5) as well as in the black nuts determined at harvest (Table 6). However, this difference may have been related to a higher retention of the adhering hull nuts in the stressed trees since at an earlier measurement date in September, there were significantly more black nuts that fell on the fully watered trees as compared to the stressed trees (Fig. 13). There was also a significant treatment impact on kernel color (as measured by RLI – larger number means lighter color; Table 5). This effect was not seen in 2002 at the Tehama site (Table 5) or in either year at the San Joaquin site (Table 4). In fact, if RLI is plotted versus seasonal average midday stem water potential (last two columns of Table 4 and Table 5), it appears that the season to season effect is much greater than the within season effect (Fig. 14), perhaps due to temperature and/or timeliness of harvest related issues.

DISCUSSION

2002- The first year results suggested that the range of target water potentials that were selected for the treatments was reasonable. The difference in shoot versus nut growth in the mild and moderate stress treatments compared to the more intensively irrigated control suggested that there may be level of mild water deficit that can have a beneficial impact on minimizing shoot growth without impacting nut growth in walnut while utilizing water efficiently. The fact that neither deficit treatment had a significant impact on dry yield in the first years was expected since this is the first season that stress was imposed in these orchards.

2003- In the second year of the study, it was again difficult to maintain target levels of midday stem water potential. Part of the reason for this was the gradual loss of lower profile soil moisture over the season in both deficit treatments at both sites (Fig. 1). This likely resulted in the trees being largely dependent on the top 18” or so of soil for their water supply by the end of the season. By the second year, both deficit treatments had a significant impact on canopy development as measured by midday canopy light interception at the Tehama (Fig. 8), but not at the San Joaquin site (Fig. 7). This was likely due to more vigorous shoot growth occurring at the Tehama site (Fig.10) which is younger and also was mechanically hedged, as compared to the older, largely unpruned San Joaquin site (Fig. 9). Although there were no significant treatment impacts on yield at the San Joaquin site in 2003, there was a slight tendency towards lower yields in the deficit treatments (Table 1). At the Tehama site, both deficit treatments resulted in decreased dry weight yields and the effect appeared to be due to more than simply less canopy development (Table 2). Treatment impacts on nut quality have been largely insignificant in the first two years of the study (Table 4, 5). The lack of treatment effects on quality and yield at the San Joaquin site which averaged significantly more negative midday stem water potentials in all three treatments compared to the Tehama site suggests that water stress of the magnitude of the deficit treatments in this study, may not be a major factor impacting nut quality. In fact, the level of kernel shrivel and mold was higher at the wetter Tehama site in 2003 as compared to the drier San Joaquin site suggesting, that wet conditions may have negative impacts on quality (Table 4, 5). The number of black nuts (adhering hulls) at harvest was significantly higher in the moderate stress treatment compared to the control at the Tehama site in 2003 while the opposite effect was seen at the San Joaquin trial (Table 6). The effects of tree water status on kernel color are also unclear after two years of this study (Fig. 14). These preliminary results suggest that impacts of deficit irrigation treatments may vary widely depending on orchard age, soil differences etc.

TABLES

Table 1. Fresh weight yield by treatment for the San Joaquin site as measured in the field and dry weight adjusted yield based on adjusting fresh weight based on a dry sub-sample. Different letters indicate significant difference at 5% level.

San Joaquin yield by treatment

	2002		2003	
Treatment	**Dry weight yield (tons/acre)**	**Dry weight yield adjusted to control light interception**	**Dry weight yield (tons/acre)**	**Dry weight yield adjusted to control light interception**
Control	3.55 a	3.55 a	4.43 a	4.43 a
Mild stress	3.26 a	3.13 a	3.94 a	4.01 a
Moderate stress	3.29 a	3.42 a	3.80 a	4.06 a
LSD	0.68		0.87	

Table 2. Fresh weight yield by treatment for the Tehama site as measured in the field and dry weight adjusted yield based on adjusting fresh weight based on a dry sub-sample. Different letters indicate significant difference at 5% level.

Tehama yield by treatment

	2002		2003	
Treatment	**Dry weight yield (tons/acre)**	**Dry weight yield adjusted to control light interception**	**Dry weight yield (tons/acre)**	**Dry weight yield adjusted to control light interception**
Control	1.98 a	1.98 a	2.82 a	2.82 a
Mild stress	1.84 a	1.86 a	2.33 b	2.53 a
Moderate stress	1.74 a	1.82 a	2.07 b	2.37 b
LSD	0.35		0.33	

Table 3. Dry weight yields for 'Chandler' on Northern California Black and Paradox rootstocks by treatment for the Tehama site. Different letters indicate significant difference at 5% level (reading across table). LSD indicates level for significant difference by rootstock (reading down table).

Tehama yield by rootstock and treatment

Rootstock	2002 Dry weight yield (tons/acre)			2003 Dry weight yield (tons/acre)		
	Control	Mild Stress	Moderate Stress	Control	Mild Stress	Moderate Stress
NCB	1.62 a	1.50 a	1.37 a	2.34 a	1.70 b	1.94 ab
Paradox	2.24 a	2.08 a	1.99 a	3.16 a	2.79 a	2.16 b
LSD	0.45	0.52	0.39	0.37	0.46	0.70

Table 4. Quality data for the San Joaquin County site from Diamond Walnut. Harvest samples were obtained from each individual tree that was monitored for water potential. Different letters indicate significant difference at 5% level.

San Joaquin Diamond Quality data 2002

Treatm	%large	%mold	%insect	%shrivel	%adhering hull	RLI	Seasonal average MSWP
Control	88.3 a	2.62 a	0.31 a	0.75 a	0.12 a	52.2 ab	-5.7 a
Mild stress	88.8 a	3.37 a	0.12 a	0.94 a	0.25 a	50.6 b	-7.3 b
Mod. stress	77.3 b	2.87 a	0.50 a	1.12 a	0.37 a	52.9 a	-9.1 c
LSD	6.8	1.35	0.44	0.72	0.40	1.87	0.6

San Joaquin Diamond Quality data 2003

Treatm	%large	%mold	%insect	%shrivel	%adhering hull	RLI	Seasonal average MSWP
Control	63.5 a	1.00 a	0.00 b	0.99 b	0.75 a	54.9 b	-7.1 a
Mild stress	63.3 a	0.75 ab	0.25a	2.00 a	1.00 a	54.4 c	-8.7 a
Mod. stress	64.2 a	0.50 b	0.00 b	1.00 b	0.75 a	55.6 a	-9.8 b
LSD	2.8	1.35	0.18	0.67	0.78	0.4	0.6

Table 5. Quality data for the Tehama County site from Diamond Walnut. Harvest samples were obtained from each individual tree that was monitored for water potential. Different letters indicate significant difference at 5% level.

Tehama Diamond Quality data 2002

Treatm	%large	%mold	%insect	%shrivel	%adhering hull	RLI	Seasonal average MSWP
Control	96.0 a	0.83 b	0.00 a	1.04 b	1.25 a	51.5 a	-3.8 a
Mild stress	94.5 a	2.62 a	0.12 a	2.29 a	0.83 ab	51.3 a	-5.7 b
Mod. stress	85.7 b	2.29 a	0.17 a	2.71 a	0.42 b	52.2 a	-7.1 c
LSD	3.0	0.84	0.17	0.93	0.67	1.6	0.5

Tehama Diamond Quality data 2003

Treatm	%large	%mold	%insect	%shrivel	%adhering hull	RLI	Seasonal average MSWP
Control	79.4 a	2.21 a	0.12 a	3.71 a	0.12 b	56.1 a	-3.2 a
Mild stress	77.6 a	2.46 a	0.08 a	3.67 a	0.54 ab	54.2 b	-6.2 b
Mod. stress	78.7 a	3.22 a	0.22 a	4.13 a	0.61 a	53.8 c	-7.3 c
LSD	4.7	1.20	0.20	1.42	1.00	0.46	0.3

Table 6. Black nuts in harvest sample, 2003.

San Joaquin County

Treatment	Percent black nuts (adhering hulls)	Percent sunburned nuts
Control	4.41 a	0 a
Mild stress	5.44 a	0.40 a
Mod. stress	1.79 b	0.55 a
LSD	1.61	0.68

Tehama County

Treatment	Percent black nuts (adhering hulls)	Percent sunburned nuts
Control	2.45 b	0 a
Mild stress	3.77 ab	0 a
Mod. stress	4.75 a	0 a
LSD	1.60	n/a

Figure 1. Soil moisture at the Tehama and San Joaquin County sites as measured with Watermark soil moisture sensors at two and four foot depths through season on control, mild stress and moderate stress plots.

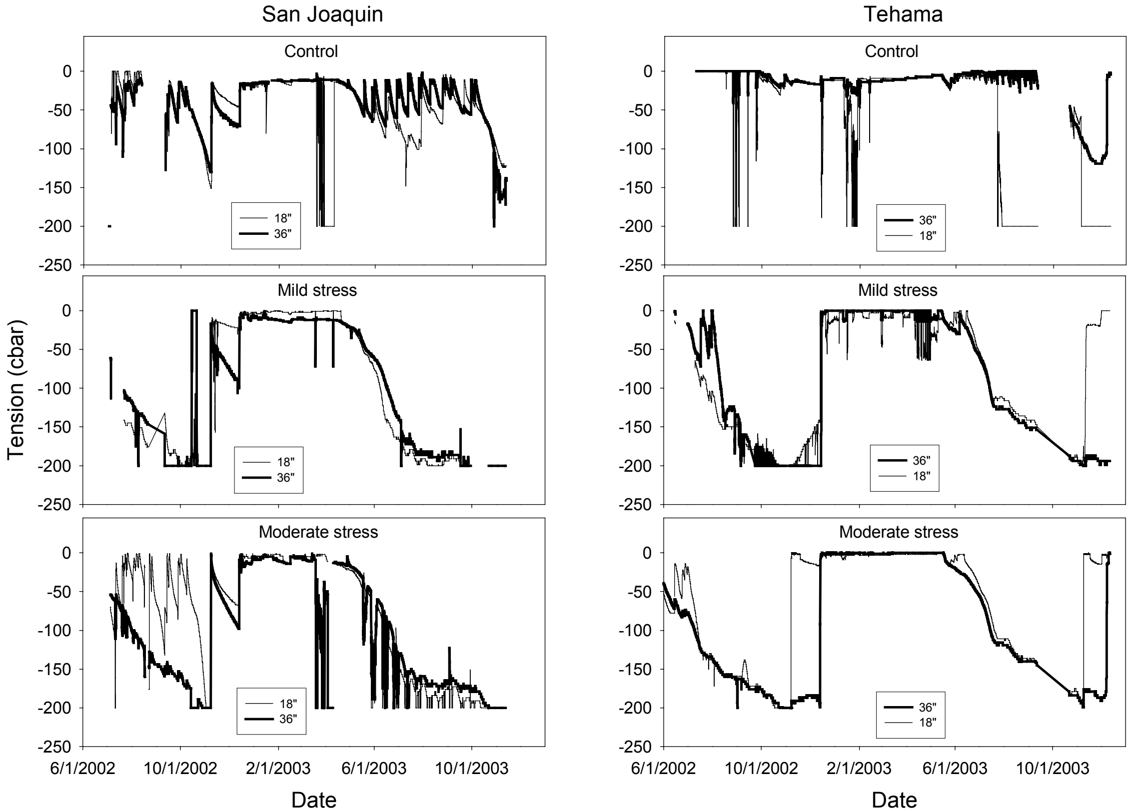


Figure 2. Average applied plus stored water and walnut evapotranspiration (ET) over 2003 season for Tehama County site.

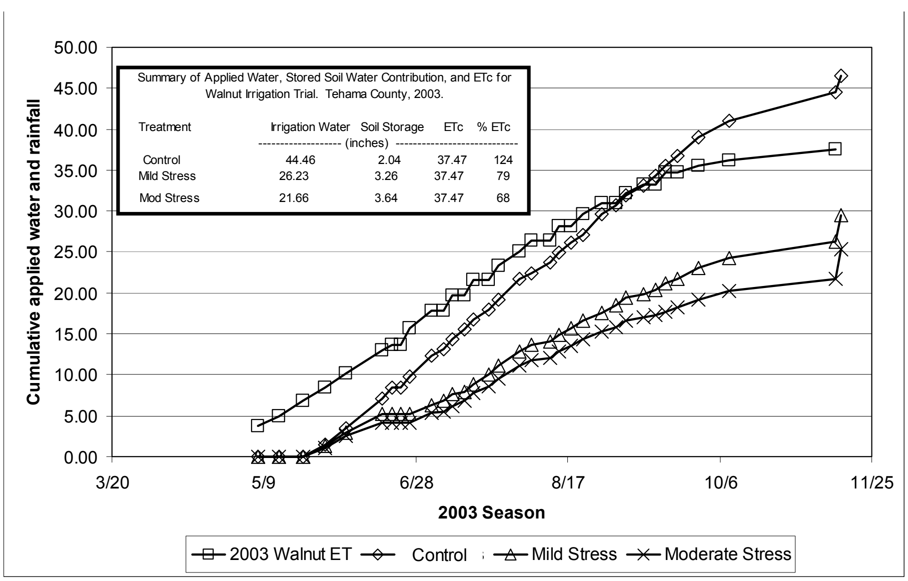


Figure 3. Average profile available moisture, as measured with a neutron probe, for Chandler walnuts at the San Joaquin County Site, 2003.

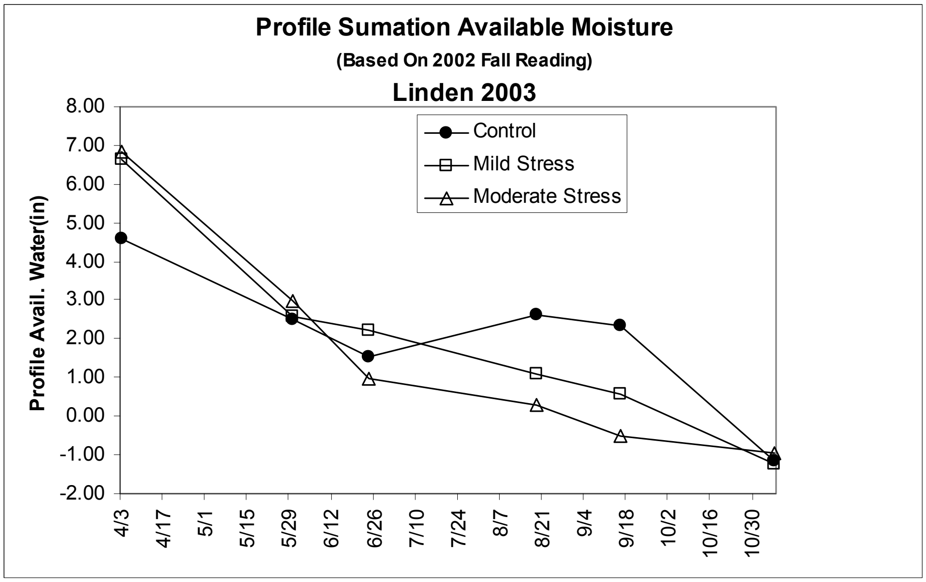


Figure 4. Average soil water content in five-foot root zone, as measured by neutron probe, for Chandler walnuts at Tehama County Site, 2003.

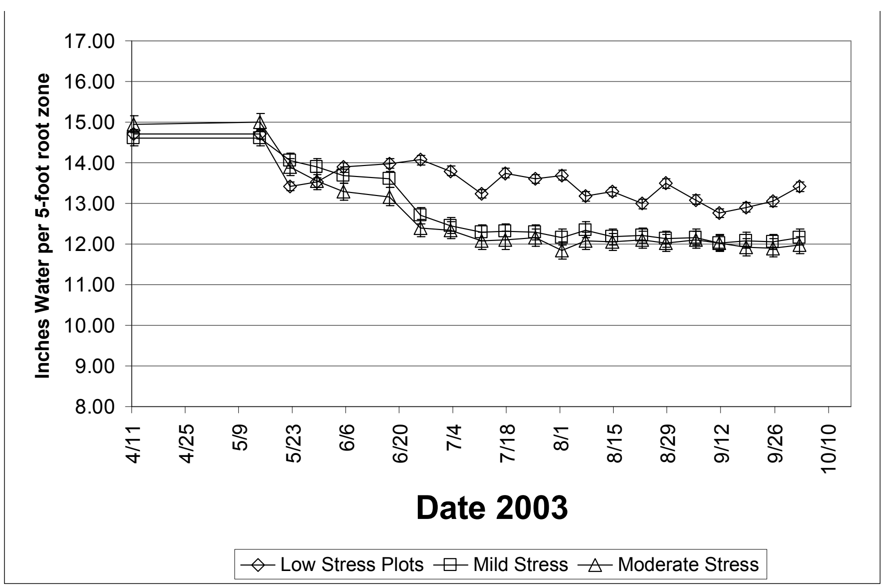


Figure 5. Midday stem water potential by irrigation treatment for San Joaquin County site for 2002 and 2003 seasons. The control, mild and moderate stress are marked with solid circles, open squares and open triangles respectively Error bars indicate plus or minus two standard errors.

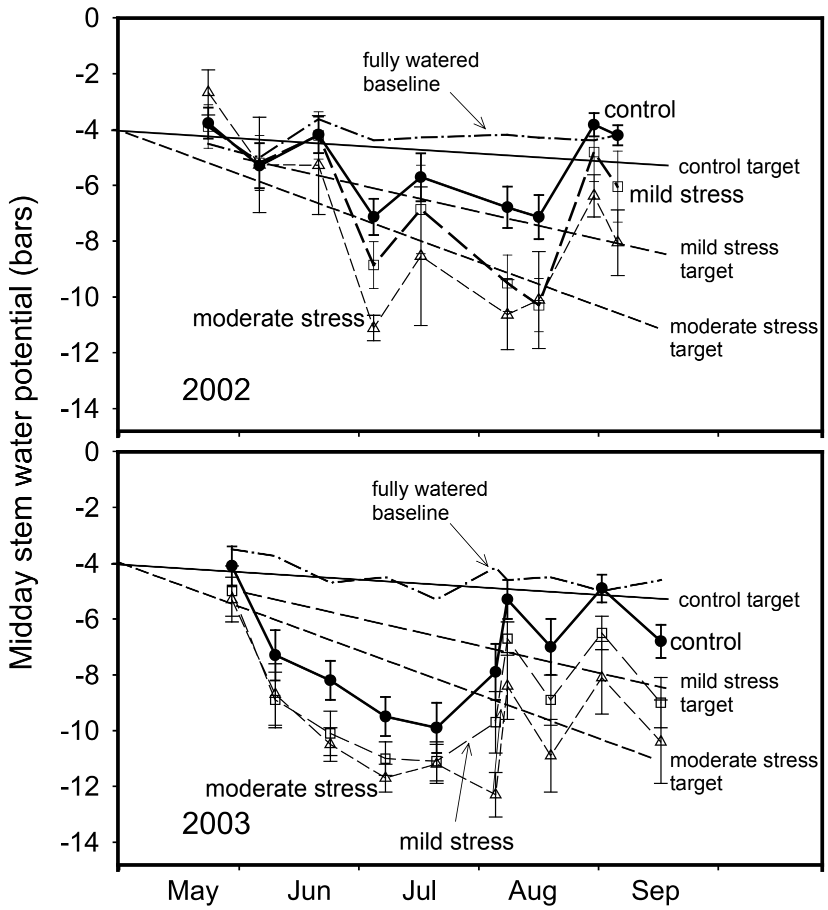


Figure 6. Midday stem water potential for Tehama County site for 2002 and 2003 seasons. The control, mild and moderate stress are marked with solid circles, open squares and open triangles respectively. Error bars indicate plus or minus two standard errors.

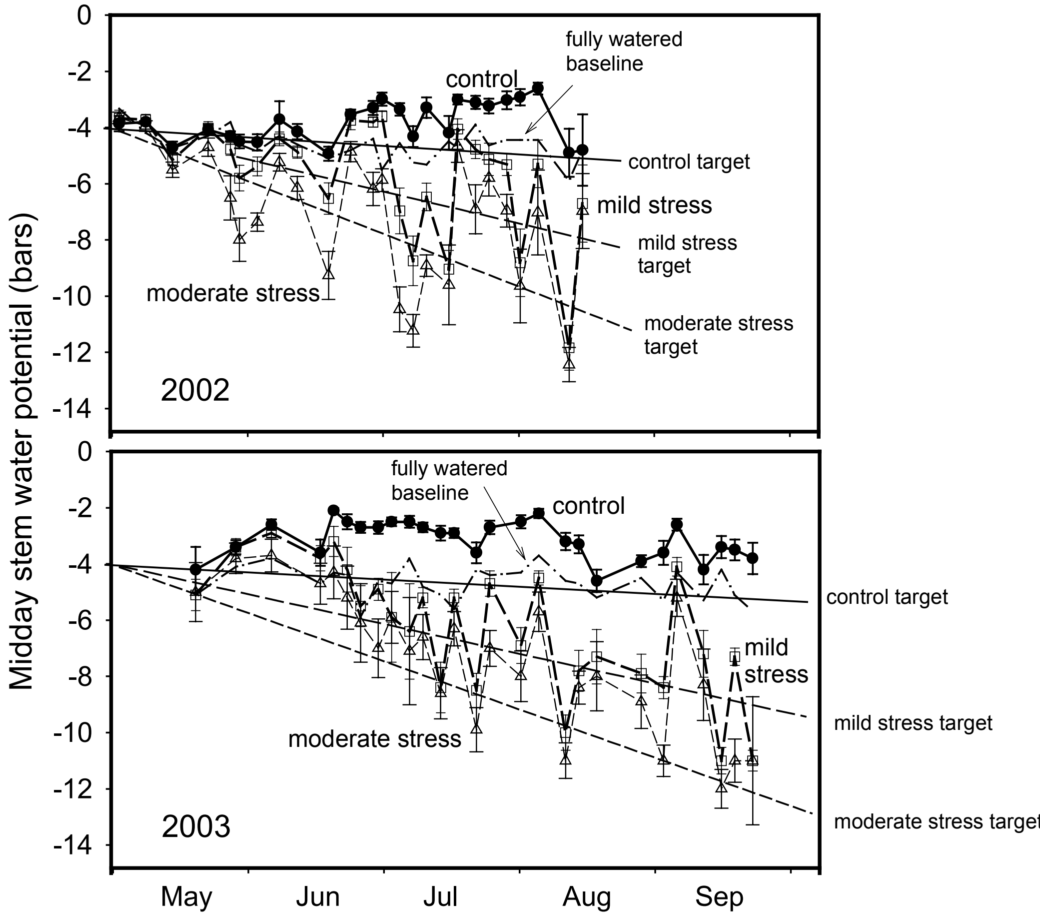


Figure 7. Canopy light interception for the 2002 and 2003 seasons at the San Joaquin County site as measured underneath (a,c) entire orchard and (b,d) underneath tree canopy only. Asterisk indicates significant difference from control. There were no significant treatment differences in canopy light interception under tree canopy.

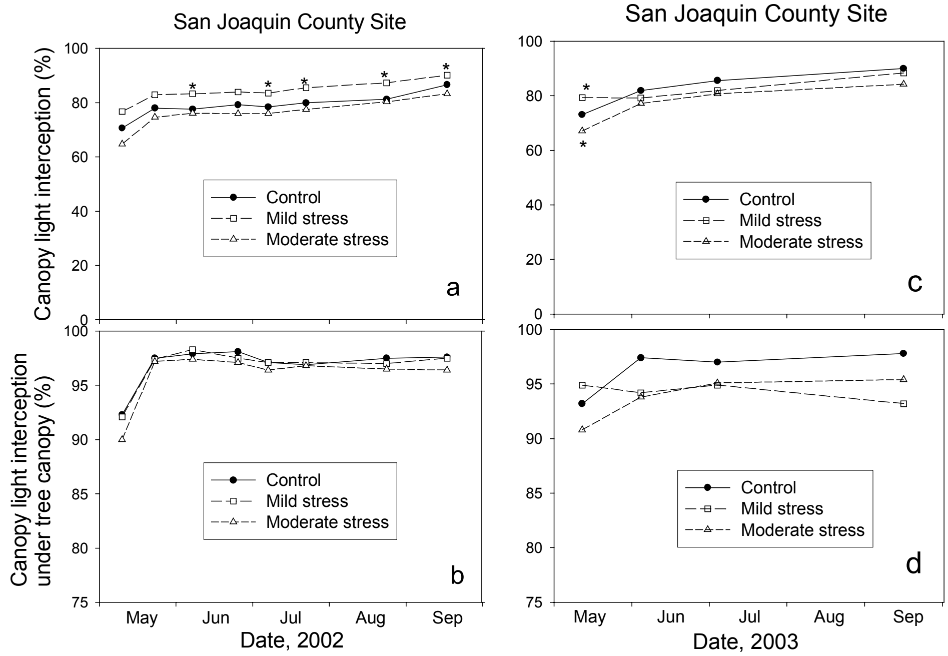


Figure 8. Canopy light interception for the 2002 and 2003 seasons at the Tehama County site as measured for (a,c) entire orchard and (b,d) underneath tree canopy only. Asterisks indicate significant difference from control at 5% level of significance.

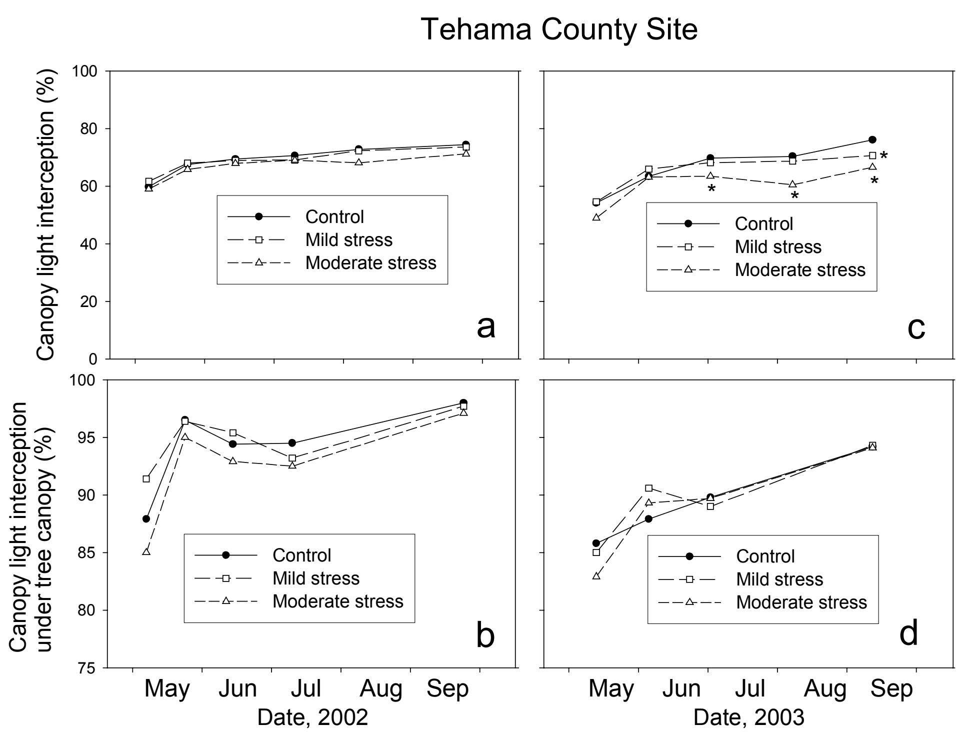


Figure 9. 2003 cumulative shoot growth by treatment for 'Chandler' walnuts on Paradox rootstock for San Joaquin County site.

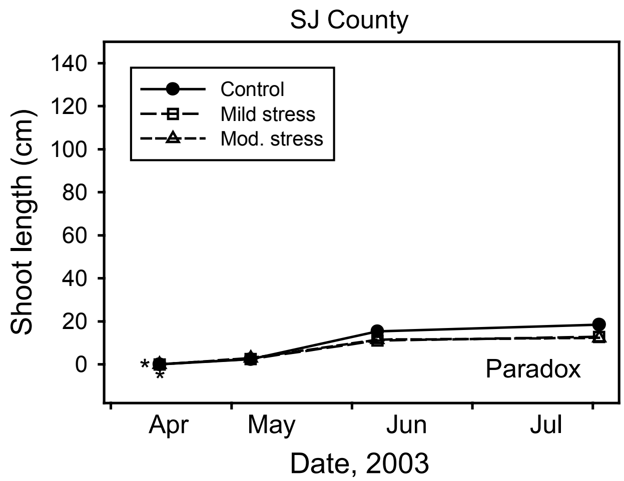


Figure 10. 2003 cumulative shoot growth for 'Chandler' walnuts on Northern California Black and Paradox rootstock for Tehama County site. Asterisks indicate significant difference from control at 5% level of significance.

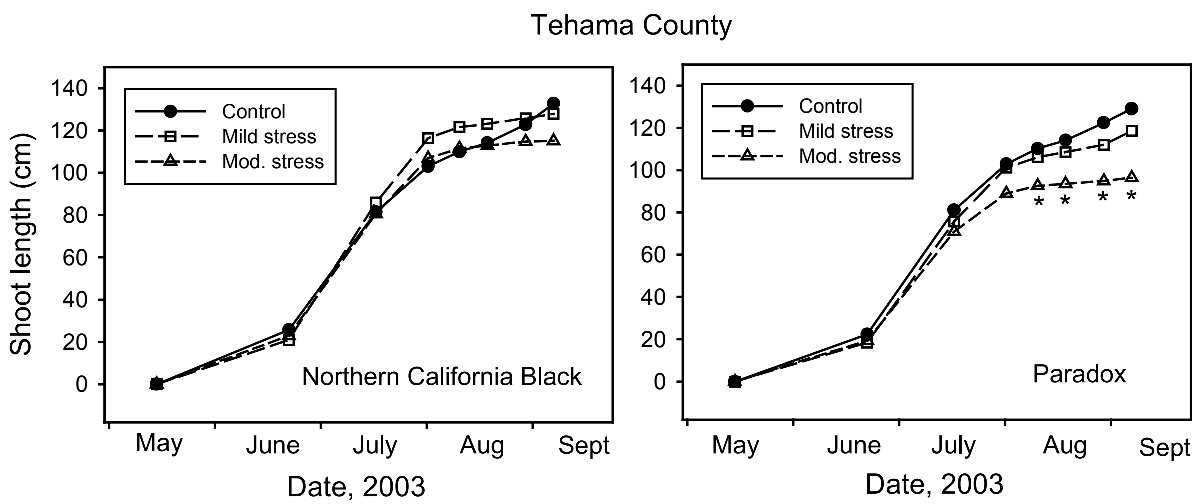


Figure 11. Cumulative growth of 'Chandler' walnuts at the San Joaquin County site for the 2002 season. Asterisks indicate significant different from control at 5% level.

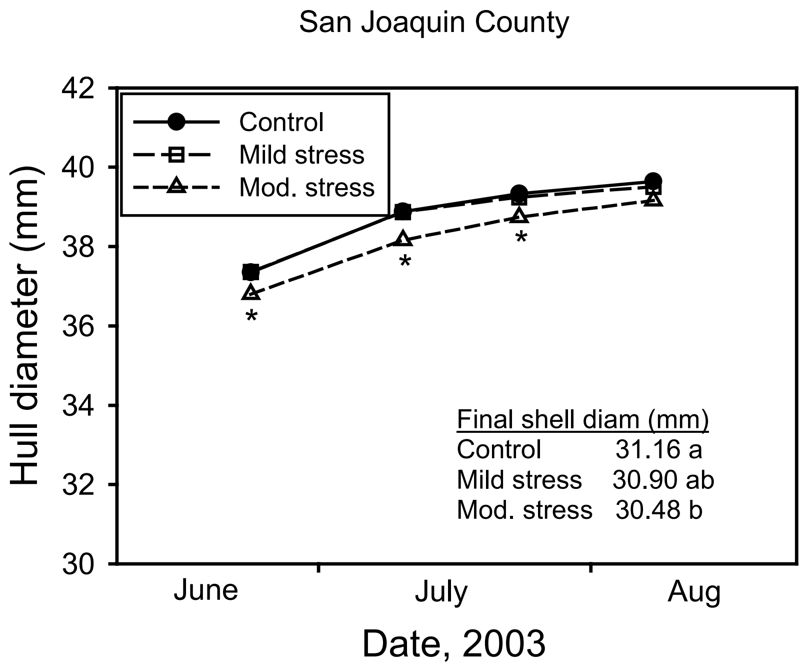


Figure 12. Cumulative growth of 'Chandler' walnuts at the Tehama County site for the 2002 season on a) Northern California Black and b) Paradox rootstocks.

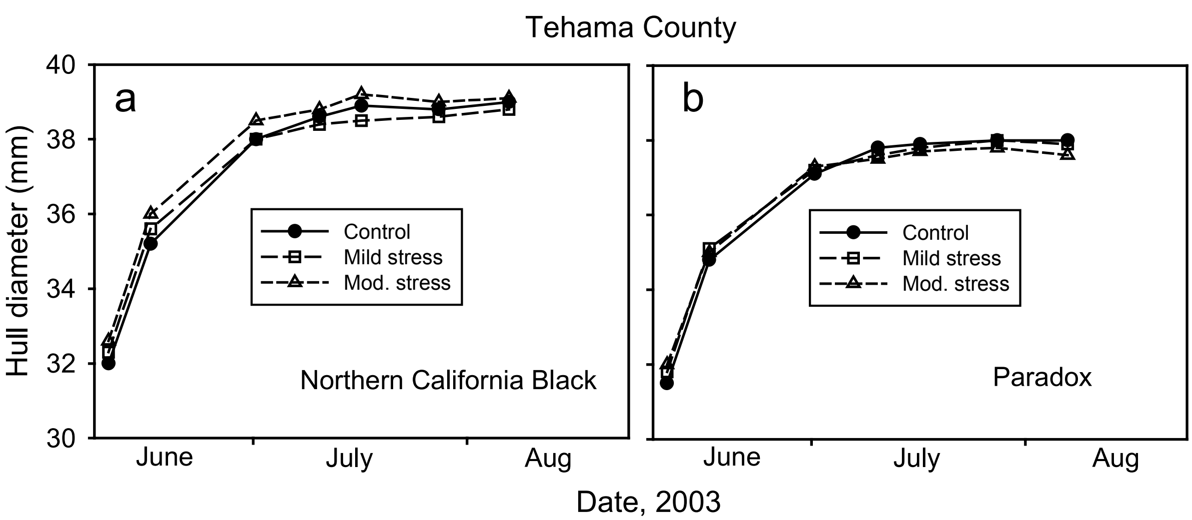


Figure 13. Total black nuts (adhering hulls) that fell in early September at the Tehama site.

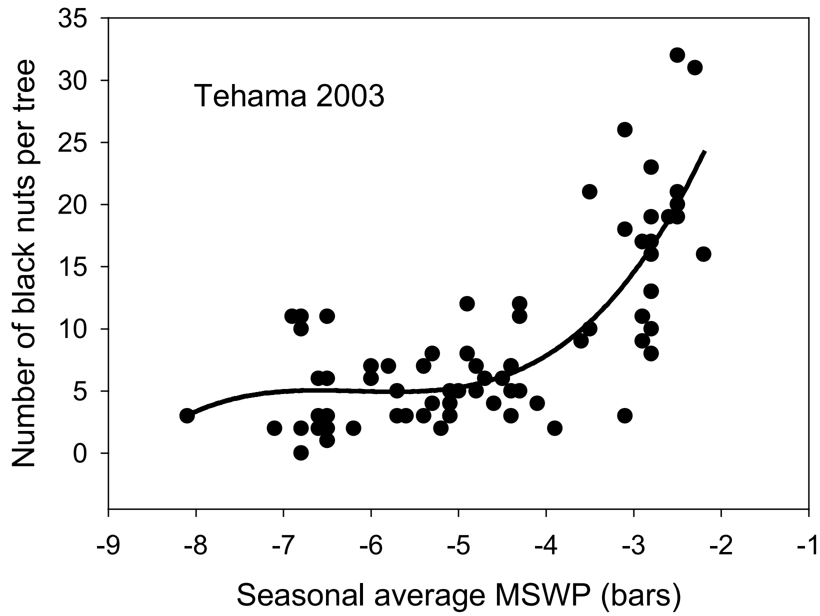
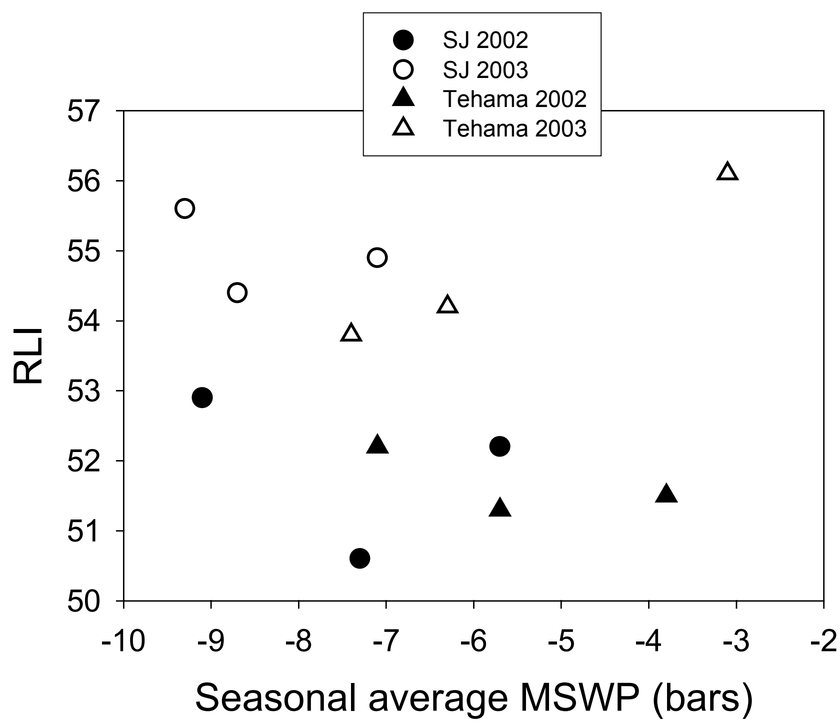


Figure 14. Treatment average RLI versus seasonal average midday stem water potential. A higher RLI means a lighter kernel color.



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