

EVALUATION OF TRUNK OR SCAFFOLD SHRINKAGE IN WALNUT AS AN INDICATOR OF ORCHARD WATER STATUS

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ABSTRACT

After about a decade invested in development of plant-based techniques to diagnose tree water status in orchards, midday Stem Water Potential (SWP) is being adopted at the farm level as a irrigation management tool in orchard crops such as walnut and almond. An alternative technique referred to as midday, shaded Leaf Water Potential (LWP) has also been developed for use at the farm level. Effective use of a plant-based indicator of orchard water status such as SWP has been shown to result in a variety of benefits such as improved growth in developing orchards, reduced risk of root diseases associated with over-irrigation or under-irrigation and longer tree life, more consistent nut yield and quality, and water savings. However, farm level adoption of SWP has been constrained because it is considered labor intensive and monitoring must be completed during a 2 to 4 hour period occurring after 12:00 noon to attain reliable information and this limits the acreage that can be monitored with a costly pressure chamber. In response to these constraints with midday SWP and shaded LWP, researchers have been working to develop alternative plant-based methods to guide orchard water management decisions. Findings from this preliminary experiment indicate that electronic sensors referred to as LVDT sensors can be used to continuously measure trunk or scaffold diameter in walnut and provide a plant-based technique that can accurately diagnose orchard water status. Furthermore it appears that it can be automated rendering it far less labor intensive and more flexible to on-farm use than either midday SWP or midday, shaded LWP. This technology warrants further research and development in walnut.

INTRODUCTION

Midday stem water potential (SWP) measurement with a pressure chamber is a plant-based procedure that has recently gained acceptance among some walnut growers to assist them with making irrigation management decisions. It is a relatively simple procedure that measures the plant-water tension of a covered, non-transpiring terminal walnut leaf that has been given adequate time to equilibrate with the entire tree canopy.

For over a decade, many scientists have recognized that direct measurement of tree water status offers advantages over measurement of soil moisture status or climate-based estimates of crop evapotranspiration (ET_c) in determining orchard water management needs. The primary advantage of midday SWP is that it integrates numerous factors that can influence the need for irrigation such as weather conditions, root volume and health, soil-water holding capacity, and opportunity to use controlled levels of crop water stress beneficially. Effective use of a plant-based indicator of orchard water status such as midday SWP has been shown to

result in a variety of benefits such as improved growth in young, developing orchards, reduced risk of root diseases associated with extreme over-irrigation or under-irrigation and longer tree life, more desirable shoot growth, more consistent nut yield and quality, and water savings largely due to more effective use of stored soil-water and appropriate response to short-term weather conditions.

While midday SWP has gained some degree of on-farm adoption due to its merits, this plant-based method of irrigation management is often considered infeasible for on-farm adoption. Re-occurring criticisms are the labor intensiveness of midday SWP and that SWP measurements are somewhat inflexible because they must be acquired during a 2 to 4 hour period occurring after 12:00 noon to attain reliable information and this limits the acreage that can be monitored with a pressure chamber. Researchers have worked to simplify the procedure to the extent possible and refine it into a grower friendly procedure. Fulton et.al. demonstrated a minimum time of 10 minutes opposed to 2 hours was adequate to assure a covered (with a foil bag) walnut leaf has equilibrated with the tree canopy and will give a reliable measure of tree water status. This finding eliminated two separate trips to the orchard to collect the field data. Furthermore, to no avail, they evaluated whether mid-morning measurements could be adjusted for the effects of time of day and be used as an alternative to mid afternoon measurements, thus expanding the period and flexibility that midday SWP measurement could be acquired for orchard water management. Goldhamer et.al. developed shaded Leaf Water Potential (LWP) as a simpler alternative to SWP for on-farm use. In essence, they showed that a leaf wrapped in moist cheesecloth or a damp rag for less than a minute equilibrates rapidly and relatively well with the tree canopy. Again, the time required to wait in the field while the sample leaf equilibrates with the tree canopy so that the SWP measurement can be completed was minimized. Another less common but re-occurring criticism of midday SWP and shaded LWP is the importance of the same person operating the pressure chamber throughout the irrigation season because determining the “end point”, where the sap exudes from the cut surface of the sample leaf petiole is somewhat subjective for each measurement.

In response to these concerns about midday SWP and shaded LWP, researchers have been working to develop alternative plant-based methods to guide orchard water management decisions. The application of Linear Variable Differential Transformers (LVDT electronic sensors) to measure trunk or scaffold diameter has been under investigation during the past decade primarily in almond, citrus, and peach (Feres and Goldhamer, 2003 and Goldhamer and Salinas, 2000). This technique is automated and utilizes a datalogger to store growth data and minimizes labor needs. Trunk or scaffold diameter is also an objective measure of tree growth that can be clearly measured with continuous, automated monitoring. The working hypothesis for LVDT sensors and trunk or scaffold diameter measurements is that more trunk or scaffold shrinkage will occur when a tree is under increasing levels of water deprivation. During the course of a 24-hour day a tree trunk or scaffold of a tree deprived for water will shrink more in the midday and correspondingly expand more during the late night and early morning hours of recovery. Therefore, maximum daily shrinkage (MDS) has been proposed as the key signal to indicate tree water status when using LVDT sensors to measure trunk or scaffold diameter. The high frequency LVDT measurements detect the maximum and

minimum trunk or scaffold diameter that occurs each day and the difference is calculated as the MDS.

Very little experience has been obtained with LVDT sensors in walnut and none of the experiences have been published widely. Walnut poses some unique challenges because it is among the largest trees in commercial orchard production. The large trunk diameters present a relatively large cross-section or proportion of woody tissue relative to the outer cambium where the xylem tissue is located for conducting water, thus, trunk shrinkage is more difficult to detect. Furthermore, it is difficult to install the LVDT sensors on larger tree trunks and keep them stable and in place to give a reliable measure of trunk diameter and shrinkage.

OBJECTIVES

A preliminary evaluation using LVDT sensors and trunk shrinkage in walnut as a potential irrigation management tool was conducted in Tehama County in 2003. This was a supplemental study conducted at the same location where irrigation research is underway to further develop midday SWP as an irrigation management tool in walnut (Refer to Lampinen et.al. 2003). The experimentation with midday SWP is funded by the Walnut Marketing Board but the preliminary investigations with LVDT sensors and trunk or scaffold shrinkage was supported independently through collaboration with Dr. David Goldhamer, UC Irrigation Extension Specialist, UCD.

Objectives included:

- ❑ To understand the relationship between shaded LWP and Maximum Daily Shrinkage (MDS) measured with automated LVDT electronic sensing devices;
- ❑ To understand the relationship between midday SWP and Maximum Daily Shrinkage (MDS) measured with automated LVDT electronic sensing devices;
- ❑ To observe the relationship between shaded LWP and midday SWP in walnut; and
- ❑ To determine whether MDS in walnut measured with LVDT sensors is a reliable indicator of tree water status and warrants further consideration for development in walnut.

METHODS

The study was performed in 9th leaf Chandler walnut southwest of Corning, California. Three irrigation regimes: low, mild, and moderate stress regimes were imposed. Details of the experimental setting for this study are described in the report titled IRRIGATION MANAGEMENT IN WALNUT USING EVAPOTRANSPIRATION, SOIL AND PLANT BASED DATA also published in this annual report.

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 to 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. Water applications in the mild and moderate stress treatments represent a 16 and 30 percent reduction in the hourly water application rate, respectively. Typically, during the summer, the low stress irrigation treatment was irrigated every third day for 24 hours. Automated shutoff valves were placed on each irrigation line to allow turning the water on and off to individual plots as needed to achieve irrigation treatment affects. Flow meters were installed in-line for each row of trees where crop response data was taken and weekly measurement were recorded to provide an accurate record of applied water.

One plot from each of the three irrigation regimes was used in this experiment. Each plot consisted of 3 rows per plot with 12 or 13 trees per row as well as guard rows between plots. The middle row of trees in each plot was used for data collection. An LVDT electronic sensor was installed to monitor trunk diameter on four trees located in the center (data) row of each plot. In total, scaffold shrinkage was monitored on 12 trees. Ten trees were Chandler scion on Paradox rootstock and two trees were Chandler scion on California Black Walnut rootstock. Based upon prior experience the LVDT sensors were placed on a primary scaffold approximately 6 feet above ground level rather than locating the sensors on the tree trunk. The scaffolds on each tree were approximately 6 to 8 inches (150 to 200 mm) in diameter. Each LVDT sensor was hard-wired to a battery-powered datalogger. A measurement of trunk diameter was logged every 20 seconds for each tree throughout the season creating a large database that was managed and analyzed using an Excel spreadsheet. Maximum Daily Shrinkage (MDS) was designated as the key signal to indicate tree water status when using LVDT sensors to measure trunk or scaffold diameter and calculated within the database.

Due to the high frequency and low volume irrigation, midday SWP and shaded LWP was measured approximately every 3-4 days on each of the four trees where the LVDT sensors were installed. Two different pressure chambers were used to measure midday SWP and shaded LWP each operated by a different person. Midday SWP and shaded LWP were measured from June 30 through September 10, 2003 for purposes of this experiment. In total, midday SWP and shaded LWP were measured on 15 different days of which midday SWP and shaded LWP were measured on the same day 10 times. Midday SWP and shaded LWP were measured just prior to irrigation to the extent possible.

Neutron probe soil moisture measurements were taken adjacent to one tree (Paradox rootstock) in each plot to a minimum depth of five feet. Neutron probe measurements were read weekly beginning in early May and continued through mid October.

Regression analysis was used to evaluate correlations between midday SWP and scaffold shrinkage, between shaded LWP and scaffold shrinkage, and between midday SWP and shaded LWP.

RESULTS AND DISCUSSION

Table 1 describes the three irrigation regimes imposed in the experiment for evaluation of the LVDT sensors and measurement of scaffold diameter and shrinkage. The plot designated as “low stress” received 45.99 inches of applied water and utilized only 0.24 inches of stored soil-water. The “mild stress” plot received 28.19 inches of applied water and used 3.02 inches of stored soil water. The “moderate stress” plot received 24.45 inches of applied water and also consumed 3.02 inches of stored soil water. The reduction in stored soil-water use in the low stress treatment reflects more intensive irrigation that exceeded real-time estimates of crop ET. The combination of applied water and stored soil-water exceeded real-time estimates of crop ET by 23 percent in the “low stress” plot, whereas, crop ET exceeded the combination of applied water and consumption of stored soil-water by 17 and 27 percent in the mild and moderate stress irrigation plots, respectively. These three irrigation regimes appeared sufficiently different to effectively test the usefulness of midday SWP, shaded LWP, and Maximum Daily Shrinkage (MDS) as useful indicators of tree water status.

Figure 1 presents the available soil-water profiles for the three irrigation regimes measured with a neutron probe. A clear delineation was observed between the low stress and mild and moderate irrigation regimes. Depletion of the available soil-water was maintained between 0 and 30 percent in the low stress irrigation regime. The delineation between the mild and moderate stress regimes was not as clear as was expected based upon the irrigation records summarized in Table 1. Depletion levels ranged from 0 to about 50 percent in the mild stress irrigation regime with depletion levels stabilizing at about 40 to 50 percent from mid July until the end of the season. Levels of soil-water depletion were slightly higher in the moderate stress irrigation regime ranging from 40 to 60 percent and stabilizing at about 50 to 60 percent depletion from mid July until the end of the season. Since the three irrigation regimes could be distinguished with soil moisture monitoring when the measurements were expressed as percent depletion of the available soil-water, it verified that the three regimes should be detectable using midday SWP, shaded LWP, and MDS if they were effective indicators of tree water status.

Figure 2 displays the average midday SWP levels for the three irrigation regimes. Midday SWP levels ranged from -0.2 to -0.4 MPa (-2.0 to -4.0 bars) throughout the season in the low stress irrigation regime. Midday SWP levels ranged from about -0.45 to -1.10 MPa (-4.5 to -11.0 bars) in the mild stress irrigation regime and from about -0.6 to -1.23 MPa (-6.0 to -12.3 bars) in the moderate stressed irrigation regime. These results showed that midday SWP effectively detected these three irrigation regimes from each other and with more resolution than the soil moisture determinations.

Figure 3 shows the average midday, shaded LWP for the three irrigation regimes. The trends were similar for both midday SWP and midday, shaded LWP. Both techniques effectively distinguished the three irrigation regimes, however, the absolute values were different. Midday SWP measurements were higher (less negative) than midday, shaded LWP measurements. Midday, shaded LWP measurements ranged from -0.40 to -0.60 MPa (-4.0 to -6.0 bars) in the low stress treatment. Shaded LWP measurements ranged from -0.59 to -

1.22 MPa (-5.9 to -12.2 bars) in the mild stressed treatment and ranged from -1.0 to -1.42 MPa (-10.0 to -14.2 bars) in the moderate stressed treatment. There was one notable exception in the trends occurring around July 23 to July 25. During this period, midday SWP measurements detected distinctly different tree water status in the three irrigation regimes, whereas, midday shaded LWP indicated similar tree water status in the three regimes. This break in common trends is not attributable to an error with either the SWP or shaded LWP, rather it simply illustrates that the measurements were not taken on the exact same day relative to the irrigation cycle. The shaded LWP measurements were taken very soon after irrigation whereas the midday SWP measurements were taken just prior to irrigation.

Figure 4 charts the Maximum Daily Shrinkage (MDS) determined with LVDT sensors for the three irrigation regimes. The three irrigation regimes were clearly detected and delineated based upon scaffold diameter measurements. MDS predominantly ranged from: about 0.1 to 0.2 mm per day in the low stress irrigation regime; 0.2 to 0.5 mm per day in the mild stress irrigation regime; and 0.25 to 0.7 mm in the moderate stress irrigation regime. As hypothesized, increased water deprivation appeared to increase the maximum daily trunk shrinkage that was detected with the LVDT sensors.

Figures 5 and 6 illustrate the linear relationship between midday SWP and MDS and between midday shaded LWP and MDS, respectively. A significant linear relationship was evident between SWP and MDS and between LWP and MDS. As either SWP or LWP decreased (became more negative) MDS increased. Interestingly, the relationship between shaded LWP and MDS was more highly correlated than the relationship between midday SWP and MDS ($R^2=0.53$ for SWP versus $R^2=0.72$ for shaded LWP). This difference was largely related to two outlying data points out of a total of 30 data points that cannot be clearly explained but may be related to the fact that two different people measured LWP and SWP with two different pressure chambers. More importantly, though, MDS measurements determined with LVDT sensors appear to correlate significantly with shaded LWP and midday SWP. These findings suggest that measurement of scaffold diameter and use of a key signal such as MDS may be a viable plant-based alternative worthy of further development in walnut to quantify tree water stress. It appears more feasible to automate, less labor intensive, and to be a less subjective measurement. Further research is needed to define critical levels to guide management decisions, to field test advances in electronic sensors and dataloggers, and to develop database management software that could eventually result in a plant-based water management tool that is more useable at the farm level.

As an aside, Figure 7 illustrates the relationship between midday SWP and midday, shaded LWP when measured on the same days in walnut. A significant linear relationship existed ($R^2=0.68$) even when two different people completed the measurements with two different pressure chambers at slightly different times in the afternoon. Granted, they were not as highly correlated as has been reported in other publications when both measurements are taken by one person operating the same pressure chamber within moments of each other. This experience points out that either technique midday SWP or midday shaded LWP is a valid means of monitoring tree water status. More importantly, though, this correlation shows that it is not a 1:1 relationship between measurements obtained with the two different

techniques. This will have important implications as research continues to develop critical levels and management guidelines. Either SWP or shaded, LWP should be consistently used to assure that critical levels and interpretive guidelines are valid.

CONCLUSIONS

Significant correlations between midday SWP measurements and MDS measurements using LVDT sensors existed as well as between midday, shaded LWP measurements and MDS measurements in walnut. These findings suggest that measurement of scaffold diameter and use of a key signal such as MDS may be a viable plant-based alternative worthy of further development in walnut to quantify tree water stress. It appears more feasible to automate, less labor intensive, and to be a less subjective measurement. Further research is needed to define critical levels to guide management decisions, to field test advances in electronic sensors and dataloggers, and to develop database management software that could eventually result in a plant-based water management tool that is more useable at the farm level.

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Table 1. Summary of Applied Water, Stored Soil Water Contribution, and ETc for Walnut Irrigation Trial. Tehama County, 2003.

Treatment	Irrigation Water	Soil Storage	ETc	% ETc
	(inches)			
Low Stress	45.99	0.24	37.47	123
Mild Stress	28.19	3.02	37.47	83
Mod Stress	24.45	3.02	37.47	73

Figure 1. Soil Water Depletion in Five-foot root zone of Chandler Walnut in Low, Mild, and Moderate Stress Plots, Tehama 2003.

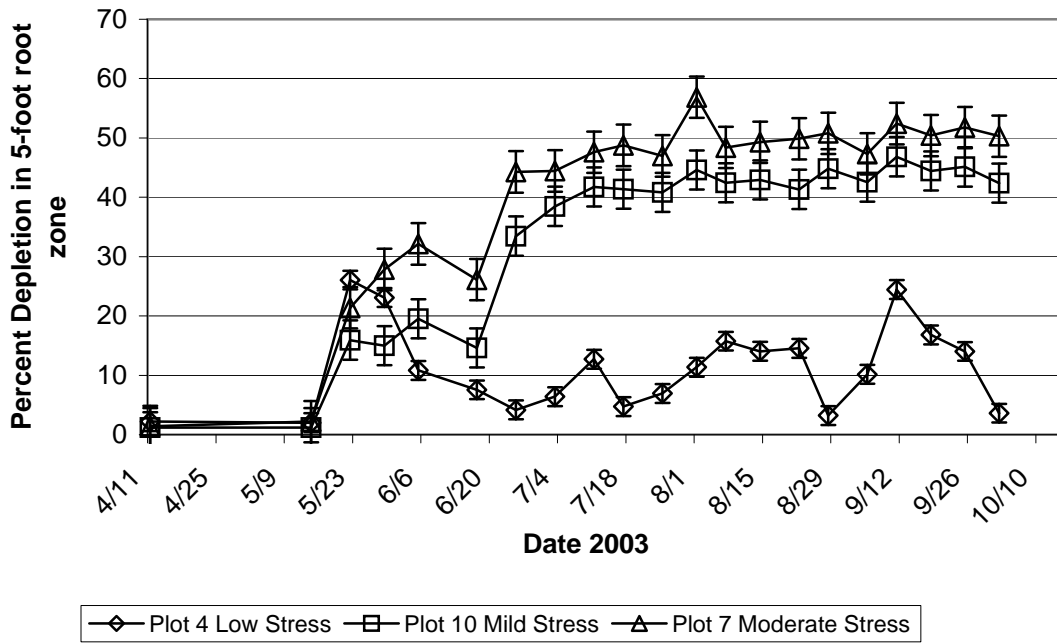


Figure 2. Midday Stem Water Potential Levels in Low, Mild, and Moderate Stress Irrigation Treatments

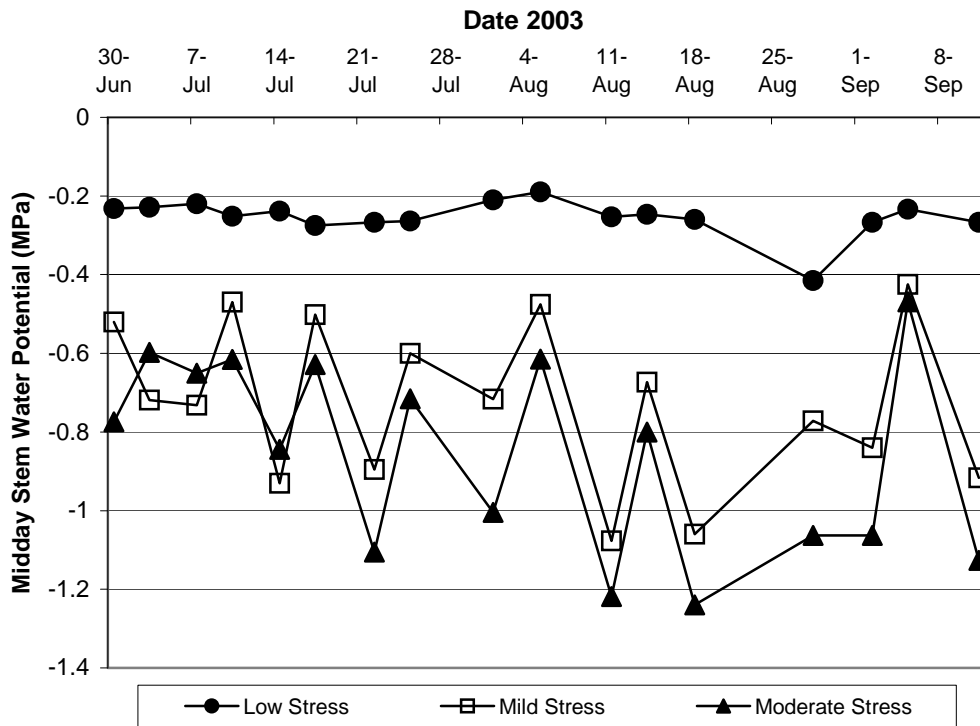


Figure 3. Midday, Shaded Leaf Water Potential in Low, Mild, and Moderate Stress Irrigation Treatments.

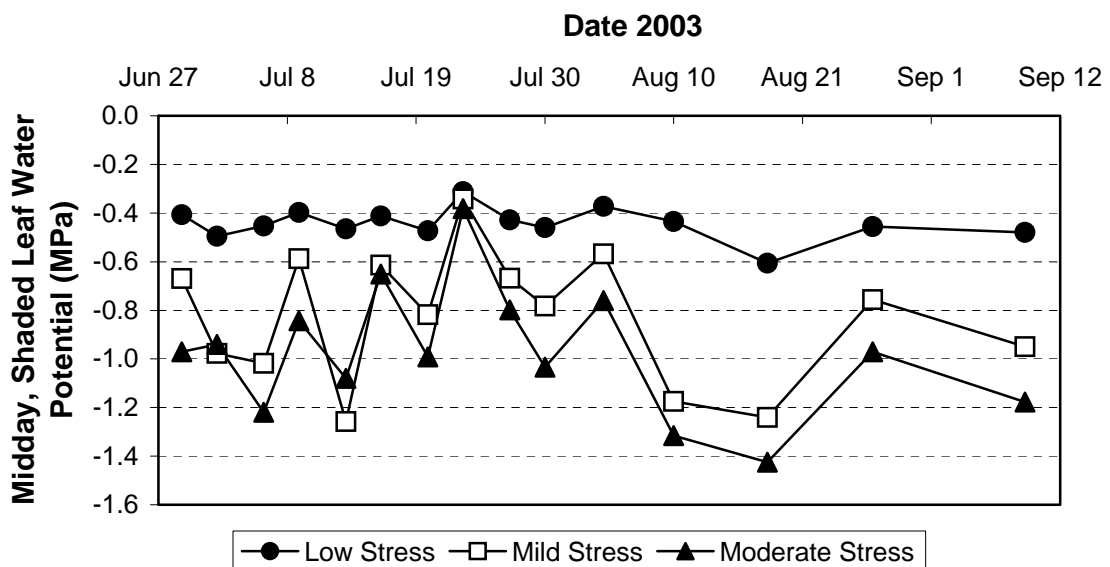


Figure 4. Maximum Daily Shrinkage in Low, Mild, and Moderate Stress Irrigation Treatments Determined with LVDT sensors.

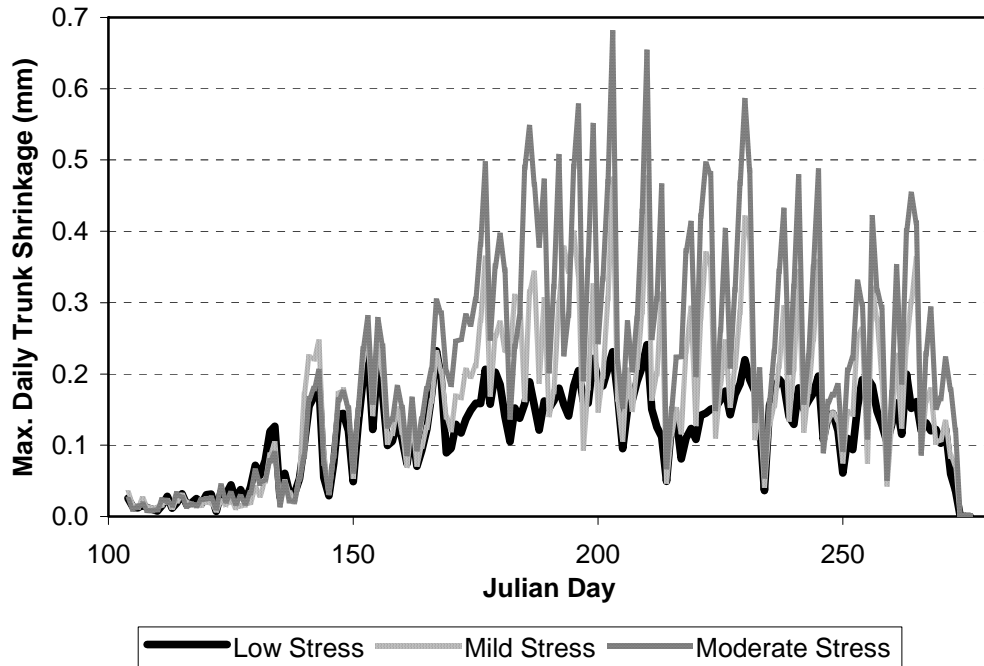


Figure 5. Relationship Between Midday Stem Water Potential (SWP) and Maximum Daily Shrinkage (MDS) Measured with LVDT Sensors.

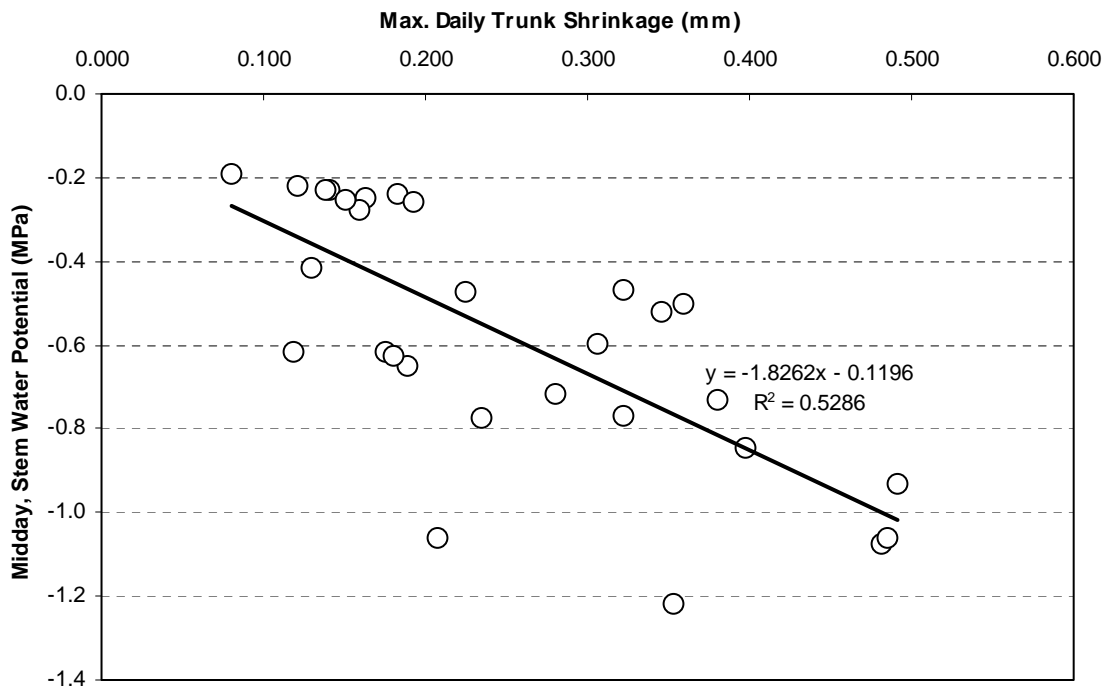


Figure 6. Relationship Between Maximum Daily Shrinkage (MDS) and Midday, Shaded Leaf Water Potential (LWP).

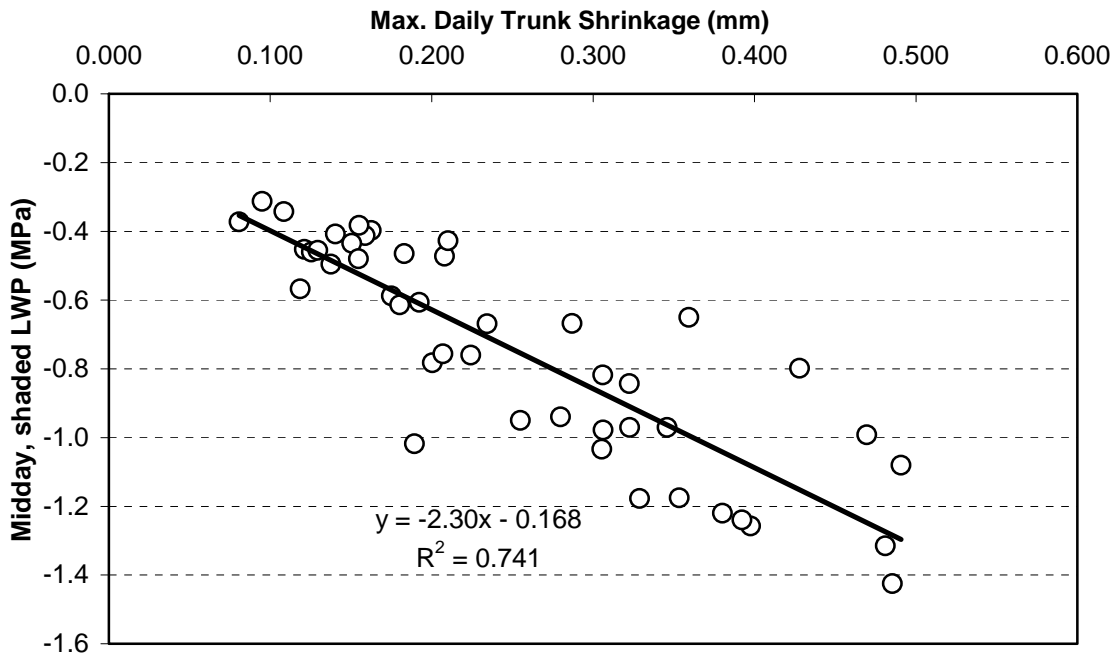


Figure 7. Relationship between Midday Stem Water Potential (SWP) and Midday, Shaded Leaf Water Potential (LWP) in Walnut.

