RELATIONSHIPS BETWEEN MIDDAY STEM WATER POTENTIAL, SOIL MOISTURE MEASUREMENT, AND WALNUT SHOOT GROWTH

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ABSTRACT

Measuring midday stem water potential (SWP) with a pressure chamber is an emerging technology for guiding irrigation management in walnut. This study looks at relationships between SWP, soil moisture measurement, and walnut shoot growth in one walnut orchard in Tehama County. The goal was to evaluate the merits for adopting this technology at the farm level. SWP did not correlate well to soil water content measurement without converting the soil water content to soil water depletion. SWP and soil water depletion correlated reasonably well in this study indicating SWP measurement is a valid indicator of orchard water status. Both SWP and soil water depletion correlated equally with average monthly shoot growth. While adaptability of SWP for on-farm use has been questioned for pragmatic reasons such as limiting measurement to mid afternoon hours and in the heat of the day, it may be more precise and practical than measurement of soil water depletion because it is a direct measurement of orchard water status and is not contingent upon the validity of assumptions made to estimate soil water depletion.

INTRODUCTION

Midday stem water potential (SWP) measurement with a pressure chamber is a relatively new plant-based tool available to assist walnut growers with making irrigation management decisions. In general, growers are more accustom to adopting water budget methods where climate based estimates of crop evapotranspiration (ETc) are used or methods of soil moisture monitoring to guide their irrigation decisions.

Since SWP is relatively new in terms of on-farm adoption, questions remain about its practical application, and validity and interpretation of information. Questions include: 1) how well does SWP relate to soil water content and levels of soil water depletion in the root zone? 2) how well does SWP relate to walnut tree growth and other crop responses? and 3) what advantage does SWP measurement offer over soil moisture monitoring to merit learning the technique and concepts to properly apply this new on-farm irrigation management tool?

OBJECTIVES

- To understand correlations between SWP and levels of soil water content and soil water depletion in irrigated walnuts
- To evaluate the relationship between SWP and shoot growth in walnut
- To evaluate two different methods of analyzing SWP data and their effects on interpretation
- Identify potential advantages that SWP measurement may have over soil moisture monitoring

METHODS

Two on-farm experiments were conducted in 2002 in Tehama County. One study was performed in 8th leaf Chandler walnut southwest of Corning, California. Details of the experimental setting for this first 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 second study was conducted in 4th leaf Howard walnut east of Cottonwood California. Data analysis has not yet been completed and reported for the second 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 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. The surrounding orchard (outside of experiment) was irrigated at the same irrigation frequency as the low stress experimental treatment, however, the hourly water application rate was 0.052 inches per hour or 5 percent less. 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 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 was taken to provide an accurate record of applied water.

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). 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.

Neutron probe soil moisture measurements were taken adjacent to one tree (Paradox rootstock) in each replication of all treatments to a minimum depth of five feet. Neutron probe measurements were read every 3 or 4 days beginning in mid May through mid September on the same days that midday stem water potential measurements were taken.

Shoot growth was measured on approximately 2 un-pruned and 2 pruned shoots on each of the same 24 trees from mid May through mid August.

Regression analysis was used to evaluate correlations between SWP, soil water content, soil water depletion, and shoot growth. Monthly cumulative shoot growth was correlated against monthly average SWP, monthly average soil water content, and monthly average soil-water depletion. Also, the correlation between monthly average SWP expressed as bars below baseline was regressed against soil water depletion and shoot growth to assess whether this method of standardizing SWP field data improved the correlations.

RESULTS AND DISCUSSION

Figures 1 and 2 show illustrations of the relationship between SWP and soil water content. Figure 1 exhibits little correlation between SWP and soil water content in the five-foot root zone of this orchard. Soil water content levels did not correspond to SWP measurements taken in September. Figure 2 shows the regression trend line for SWP regressed against soil water content in the five-foot root zone. As expected, the general trend was for SWP to decline as soil-water content decreased but the correlation was not strong, the regression coefficient (R^2) equal 32.2 percent, even after excluding the September data from the analysis since those points were clearly outliers. Had the September data been included, the correlation would have been even less.

Figures 3 and 4 show illustrations of the relationship between SWP and depletion of the available soil water in the five-foot root zone. Converting soil water content measurements to levels of soil water depletion is usually necessary to account for effects of soil texture and structure on soil water holding capacity and to accurately understand the soil water status. The conversion is not simple, to the extent that anyone can convert the data, and the conversion is subjective and may require iterations. To express the soil water content in the five-foot root zone in terms of percent depletion requires defining an upper level of soil water content that represents soil water conditions at field capacity, a condition where the root zone has been fully wetted but given sufficient time to drain excess water. Also, a lower level of soil water content must be defined to represent the soil water content where irrecoverable plant wilting will be experienced. The difference in soil water content at field capacity and soil water content at wilting point is defined as the total plant available water. The field measurement of soil water content typically falls between these two extremes. The difference between the field capacity soil water content and the field measurement for a specific day represents the soil water deficit for a given day. Dividing the soil water deficit on a specific day by the total plant available water and multiplying by 100 expresses the soil water status in terms of percent soil water depletion.

Figure 3 shows the general trend when average monthly SWP was plotted against average monthly soil water depletion. Similarly to Figure 1, the levels of soil water depletion measured in September did not correspond to SWP and appeared as outliers in the data. The relationship between average monthly SWP and average monthly soil water depletion appeared linear for the months of May, June, July, and August. Figure 4 shows a linear relationship where SWP declined as soil water depletion declined. The regression coefficient (R^2) increased from 32.2 percent to 61.0 percent when SWP was regressed against soil water depletion rather than soil water content, excluding measurements for September. SWP levels of –3.2, -5.2, and –7.0 bars tension corresponded approximately to 10, 30, and 50 percent depletion of the plant available soil water under these orchard conditions.

Explanations for the poor correlation between SWP and both soil water content and soil water depletion in the month of September is not fully understood but may be related to some physiological response in the walnut trees, possibly declining day length and declining carbohydrate sink are factors since the crop is mature. The fact that SWP appeared to recover when the soil water content remained relative low, or in other words, soil water depletion was relatively high is significant to note even though it is not well understood. This finding gives merit to further investigation and may lend rational for some modest level of deficit irrigation in walnut in the late summer and fall.

Standardization of SWP field measurements for variable weather conditions each time determinations are made in an orchard have been proposed. The purpose of standardizing SWP is to distinguish temporarily high or low field SWP measurements due to temporary changes in weather from real changes in orchard water status. One proposed method for standardization is to predict a "baseline" SWP for walnut based upon vapor pressure deficit (air temperature and relative humidity) at the time of field measurement of SWP. The baseline SWP is a prediction of SWP expected for a fully irrigated walnut tree under a specific combination of air temperature and relative humidity. Refer to the report titled FIELD EXPERIENCES WITH INTERPRETING MIDDAY STEM WATER POTENTIAL LEVELS FOR WALNUT in 2001 walnut research reports for further discussion. The proposed method of standardization calculates a term referred to as "bars tension below baseline" and is computed by subtracting the predicted baseline value from the field-measured value of SWP.

Figure 5 shows the relationship and correlation between SWP expressed in bars tension below baseline and soil water depletion. A linear trend is apparent with the bars below baseline declining as soil water depletion increases. The regression coefficient (R^2) of 54.4 percent suggests a reasonable correlation but there is no apparent advantage in standardizing the SWP measurements to bars below baseline, since the regression coefficient (R^2) was 61.0 percent when non-standardized SWP field measurements were regressed with soil water depletion. This is a noteworthy finding because assisting new users with the pressure chamber and SWP measurements with understanding the purpose and method for determining the baseline SWP is a challenge and added constraint to gaining adoption of this irrigation management tool. A second notable finding in Figure 5 is that while a soil water deficit was measured for all points on the graph, 14 of the plotted points correspond to positive standardized SWP values, meaning the field measured SWP was higher than the predicted baseline SWP for fully irrigated trees by as much as -2.2 bars tension. This suggests that the baseline prediction of SWP for fully irrigated trees may be underestimated using the present model of prediction.

Figures 6, 7, and 8 illustrate the relationship and correlation between average monthly shoot growth and SWP (bars tension), standardized SWP (bars tension below baseline), and soil water depletion, respectively. Measurements shown in these figures are for pruned shoots of Chandler walnut on Paradox rootstock only. Figure 6 shows an exponential relationship between SWP and average monthly shoot growth. Shoot growth declines as SWP declines. The correlation is modest with a regression coefficient (R^2) of 42.0 percent. Shoot growth is highest, ranging from 15 to 45 centimeters cumulative growth per month when SWP are sustained between –3.5 and –5 bars tension. Cumulative monthly shoot growth ranges from 5 to 15 centimeters when SWP range from –5 to –7 bars tension and shoot growth ceases when SWP is less than –7 bars tension.

Figure 7 shows the relationship between standardized SWP (bars tension below baseline) and monthly average shoot growth. Like SWP (non-standardized), the relationship between the standardized SWP and cumulative shoot growth is exponential with shoot growth declining as the bars below baseline declines. Cumulative shoot growth ranged from 1 to 45 centimeters per month when SWP ranged from 1.0 to –1.0 bars below baseline. Cumulative shoot growth ranged from 0 to 25 centimeters when SWP ranged from –1.0 to –3.0 bars below baseline. The regression coefficient (R^2) of 30.8 percent also suggests that there is no advantage in taking the extra step to standardize SWP measurements with the baseline SWP. Figure 8 shows the relationship and correlation between average monthly shoot growth and soil water depletion. Again, the trend line was exponential with monthly average shoot growth declining as soil water depletion increased. The correlation is modest, R^2 of 49.7 percent, although slightly better than for SWP and substantially higher than the standardized SWP. Monthly shoot growth averaged 30 to 40 centimeters growth when soil water depletion was between 5 and 20 percent depletion. Monthly shoot growth averaged 10 to 30 centimeters when soil water depletion was between 20 and 40 percent and shoot growth was below 10 centimeters per month when soil water depletion exceeded 40 percent.

CONCLUSIONS

The use of the pressure chamber and midday SWP is a new and emerging tool to assist walnut growers manage irrigation. As with adopting any new technology, there is the need to learn new principles and techniques to correctly use the technology. This raises the question whether there are sufficient advantages in this plant-based irrigation scheduling technique to merit time spent in adopting it as an irrigation management tool. Findings from this study show that SWP is more accurate in measuring crop water status than measuring soil water content without converting measurements to percent soil water depletion. If soil water content measurements are correctly converted to soil water depletion, then SWP and soil water depletion appear to have equal utility and value. Converting soil water content measurements to soil water depletion requires specific skills, knowledge of soils and their water holding capacity, and iterations to validate the assumptions. In particular, knowledge of the soil water content corresponding to when the crop will experience wilting to unrecoverable levels is needed. In most cases, this is estimated because such extremely dry soil water levels are avoided to prevent crop injury. A major advantage of the pressure chamber and SWP is that orchard water status is measured directly and eliminates the need for estimations.

Other notable findings from this study include: 1) SWP measurements did not correlate well with soil water depletion in September. The reasons are unclear but may be related to physiological tree responses to reduced carbohydrate sink since the crop is nearing maturity and shortened day length. Tree water status recovered despite significant soil water depletion being sustained. This may lend merit to potential for deficit irrigation in the late summer and fall season; 2) including the extra step of standardizing SWP measurement by using a predicted baseline SWP for fully irrigated walnut trees did not seem to improve the relationships between SWP and soil water depletion nor the relationship between SWP and shoot growth. 3) the predicted baseline SWP may be an underestimation using the current predictive model; 4) average monthly shoot growth was highest (30 to 45 cm) when SWP ranged between –3.5 and –5 bars; and 5) average monthly shoot growth was highest, ranging from 30 to 40 cm per month, when soil water depletion was between 5 and 20 percent.

Figure 1. Relationship between volumetric soil-water content and midday stem water potential.

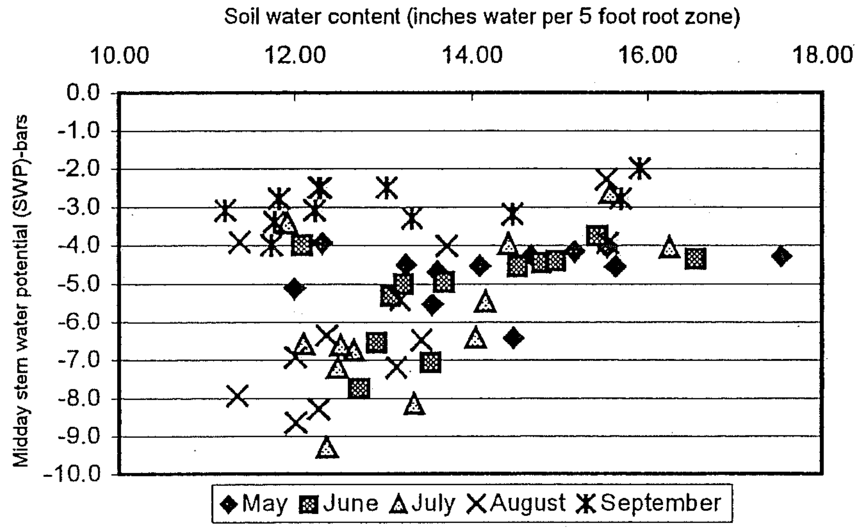


Figure 2. Correlation between volumetric soil-water content and midday stem water potential.

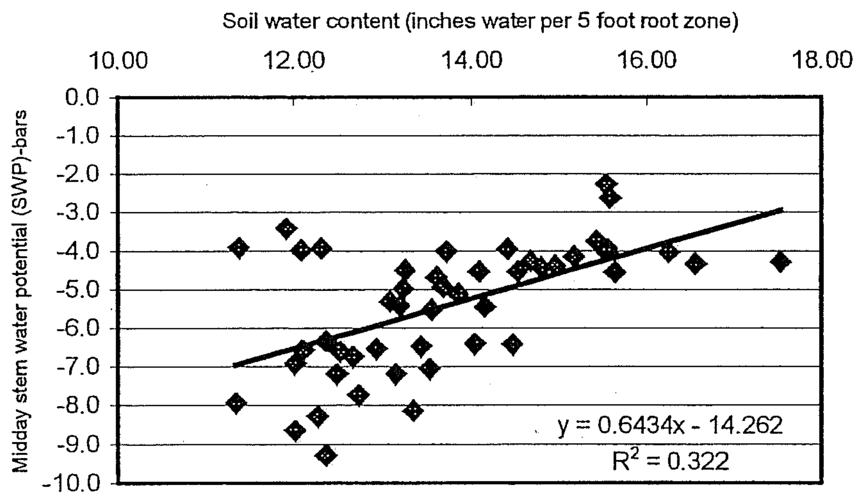


Figure 3. Relationship between percent depletion of available soil water and midday stem water potential.

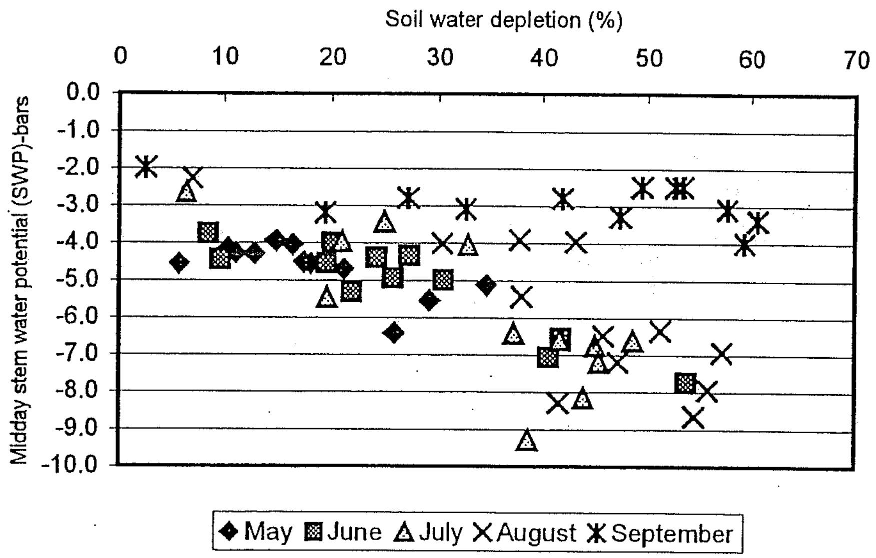
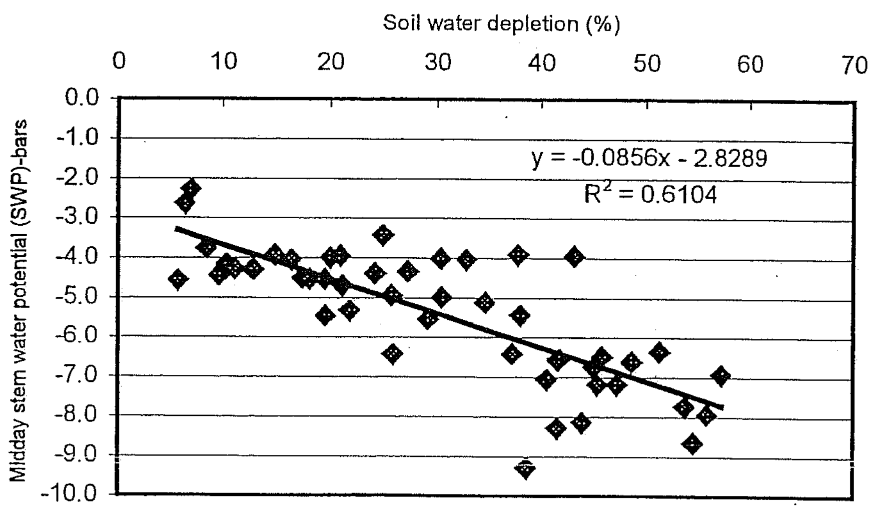


Figure 4. Correlation between soil water depletion and midday stem water potential.



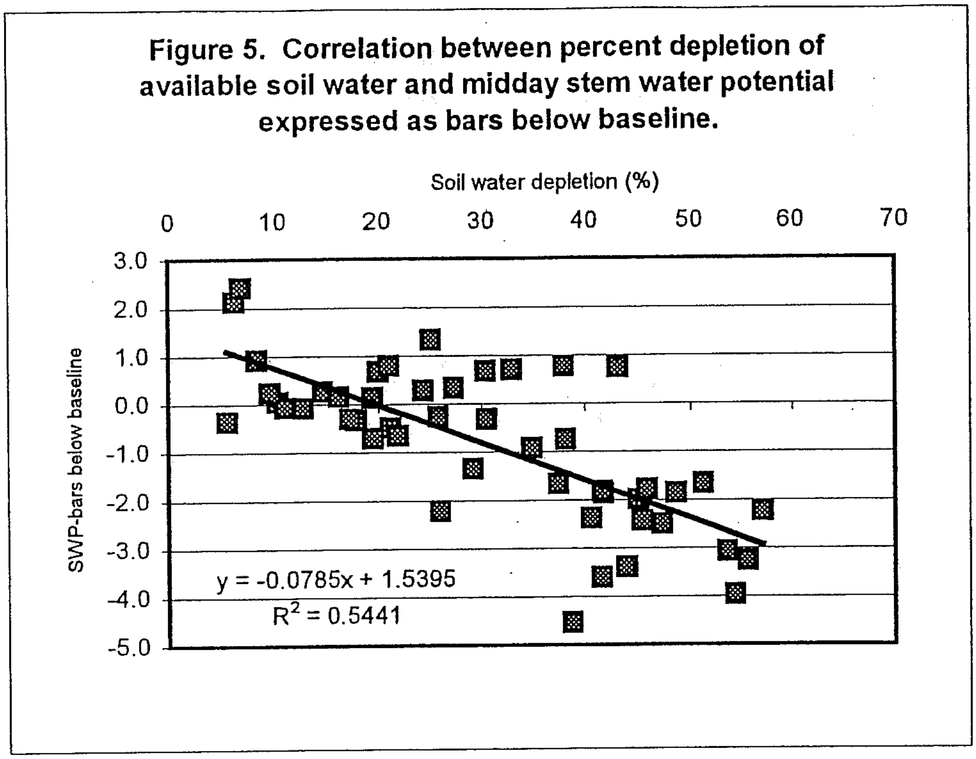


Figure 5. Correlation between percent depletion of available soil water and midday stem water potential expressed as bars below baseline.
Soil water depletion (%)
0
10
20
30
40
50
60
70
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
SWP-bars below baseline
y = -0.0785x + 1.5395
R2 = 0.5441

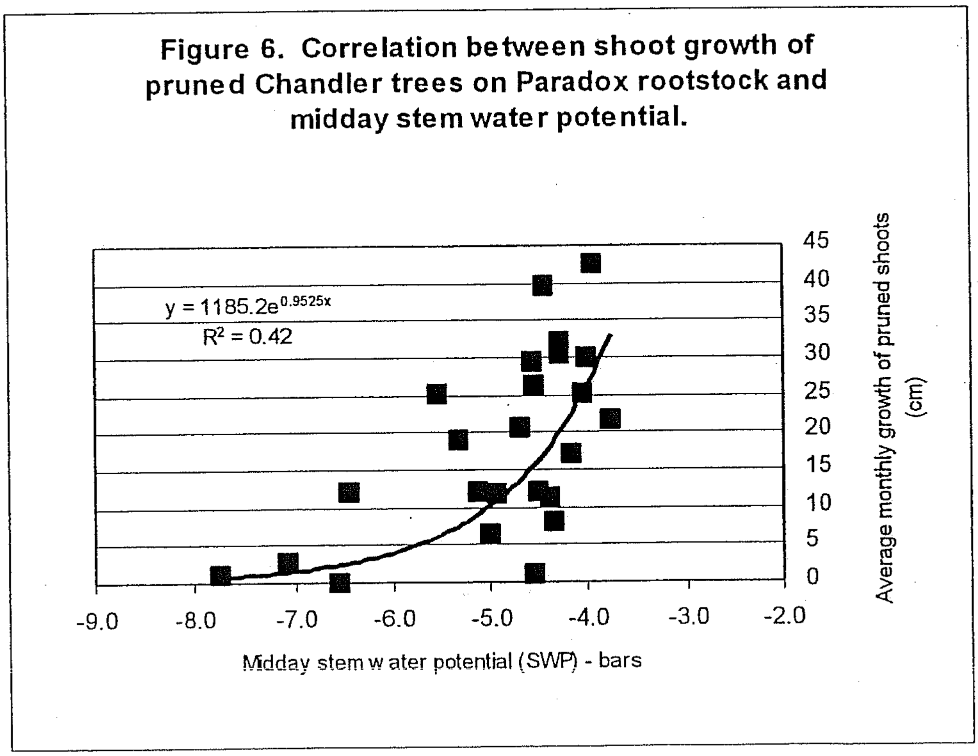


Figure 6. Correlation between shoot growth of pruned Chandler trees on Paradox rootstock and midday stem water potential.
y = 1185.2e0.9525x
R2 = 0.42
45
40
35
30
25
20
15
10
5
0
Average monthly growth of pruned shoots (cm)
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
Midday stem water potential (SWP) - bars

Figure 7. Correlation between shoot growth of pruned Chandler trees on Paradox rootstock and midday stem water potential.

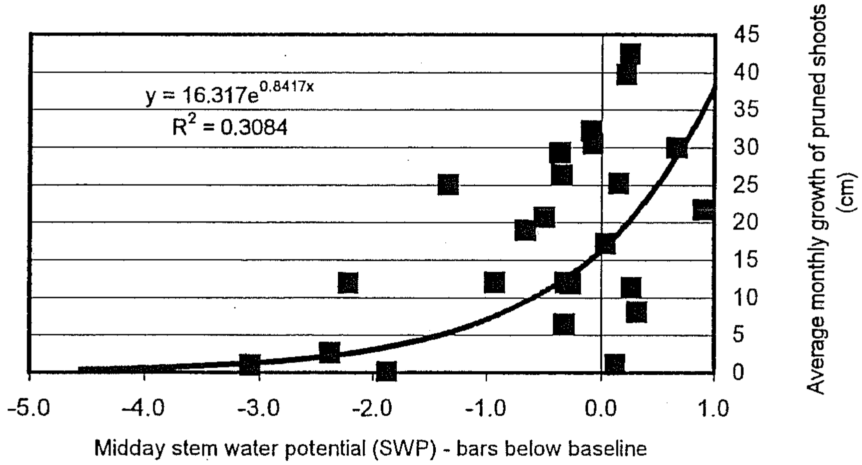


Figure 8. Correlation between shoot growth of pruned Chandler trees on Paradox rootstock and soil water depletion.