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Irrigation Water Management for Pecans in Humid Climates

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Abstract. **Pecan [*Carya illinoinensis* (Wangenh.) K. Koch] tree stem water potential (ψ), shoot length, nut yield, and nut quality for the following treatments were evaluated in a commercial pecan orchard in Berrien County, GA; 1) current recommended irrigation schedule, 2) a reduced early season irrigation schedule, and 3) non-irrigated control. Water Stress on pecan occurred at ≈ −0.78 MPa using the pressure chamber to measure stem water potential. Regression analysis suggests that irrigation scheduling for mature pecan trees may be needed when volumetric water content reaches 10% on Tifton loamy sand soil. Water stress in pecan is correlated with soil moisture from budbreak through the end of nut sizing. Pecan trees bearing a moderate to heavy crop load may undergo water stress during the kernel-filling stage regardless of soil moisture level. Therefore, it is suggested that water stress during the kernel-filling period is a function of nut development, crop load, or both in addition to soil moisture. The reduced early season irrigation schedule provided a 38% reduction in irrigation water use with no significant effect on pecan tree water stress, yield, or quality, suggesting that pecan trees can tolerate moderate early season water stress with no effect on pecan yield or quality under southeastern U.S. environmental conditions.**

Irrigation is one of the most important management tools used in pecan production and results in increased nut size, yield, nut quality, and precocity (Alben, 1957; Brison, 1974; Daniell, et al., 1979; Stein et al., 1989; Worley, 1982). Despite variations in available water resources among pecan producing regions, the question of irrigation frequency and the amount of water applied to pecan is a common concern. Much of the irrigation research regarding water use of pecan has occurred in arid and semiarid climates (Garrott et al., 1993; Miyamoto, 1983; Sammis et al., 2004; Wang et al., 2007). Georgia is the largest pecan producer in the United States with over 56,000 ha of mature commercial pecan orchards (USDA, 2012). This region of the humid southern United States receives an average of 127 cm or more rainfall annually; however, periods of moisture stress occur during the growing season, particularly during the months of August and September when pecans are in the kernel-filling stage and water demand is at its peak. Thus, irrigation has been proven to markedly enhance pecan production in the region (Worley, 1982). Yet, irrigation scheduling and management of pecans in humid climates is not well established. Daniell (1985) suggested an irrigation application rate of 22,440 $L \cdot ha^{-1} \cdot d^{-1}$ for mature pecans during the kernel-filling stage under drip irrigation based on 70% evaporation from a class A evaporation pan in Georgia. However, the study was conducted on a heavy clay soil and may underestimate the water requirements of pecan on the lighter textured soils in most of the southeastern U.S. pecan production region.

Current recommended irrigation schedules for pecan (Wells, 2007) in the region are based largely on a study by Daniell (1985) and data related to plant water stress, evapotranspiration, and soil water depletion generated in more arid climates. These schedules often fail to take into account that supplemental rainfall may reduce the need for irrigation water before the nut sizing period in humid climates. Trees within the pecan producing region of Georgia are commonly irrigated at rates and frequencies based mainly on grower experience and observation of crop growth and yield rather than on quantitative scientific information. With increasing agricultural water use, a growing population, and declining groundwater levels, irrigation efficiency in the region is necessary for sustainability.

A plant-based measurement, such as ψ, should be a straightforward indicator of plant water stress and, hence, of the need for irrigation (Peretz et al., 1984), because it measures the integrated effect of soil, plant, and atmospheric conditions on water availability within the plant itself. Midday stem ψ measurement can be used as a tool to indicate plant water stress and assist with irrigation management decisions. The relation of leaf ψ to leaf conductance in transpiring leaves may be obscured by the occurrence of a within-leaf ψ gradient, which is positively associated with the rate of leaf transpiration (Shackel and Brinckmann, 1985). Postexcision errors in leaf ψ (Turner and Long, 1980) have a similar obscuring effect on the relation between leaf ψ and leaf conductance, since excised leaves with a high conductance would desiccate and decline more rapidly in ψ than leaves with a low conductance. Excision artifacts and within-leaf ψ gradients can be eliminated by stopping leaf transpiration with a plastic or foil bag before leaf ψ is measured (Begg and Turner, 1970; Garnier and Berger, 1985; Meyer and Green, 1981), allowing leaf ψ to equilibrate with the ψ of the stem, and, therefore, would be a measure of stem ψ. Stem ψ is less influenced by short-term environmental variability than is transpiring leaf ψ (Meyer and Green, 1981) and, under some conditions, has been found to be more clearly related to soil-water conditions.

The purpose of this study was to compare a proposed reduced early season irrigation schedule for pecans in humid climates with the currently recommended schedule (Wells, 2007) using midday stem ψ as measured by the pressure chamber. Stem ψ was also correlated with volumetric soil moisture in the non-irrigated trees to establish a baseline relationship between the two on Tifton loamy sand, a common agricultural soil in the southeastern United States.

Materials and Methods

The study was conducted in a 30-year-old microsprinkler-irrigated commercial 'Stuart' pecan orchard on a 15.2 m × 15.2 m spacing growing on Tifton loamy sand (fine-loamy, siliceous, thermic Plinthic Paleudult) in Berrien County, GA in 2012. Neither saturated hydraulic conductivity, field capacity, nor permanent wilting point of soil at 0–20 cm depth was measured during the course of the study. However, published values for these soil properties are as follows: hydraulic conductivity, 6.1 $cm \cdot h^{-1}$; field capacity, 13% volumetric soil moisture; permanent wilting point, 5% volumetric soil moisture (Rawls et al., 1982).

Two microsprinklers were positioned per tree with one each on the N and S side of the tree within the vegetation free strip ≈1.2 m from the base of the tree. Each microsprinkler delivered 56.8 $L \cdot h^{-1}$ for a total of 113.6 $L \cdot h^{-1}$ per tree. The following treatments were evaluated: 1) full irrigation schedule (current recommended irrigation schedule for southeastern pecan production; Wells, 2007;

Table 1. Irrigation water application rate per tree for the full and reduced irrigation schedules.

	Irrigation water application rate	
	Full schedule	Reduced schedule
Mo.	(liters per tree per day)	(liters per tree per day)
April	852	227
May	965	352
June	1,079	454
July	1,249	549
August	1,363	1,363
September	1,363	1,363

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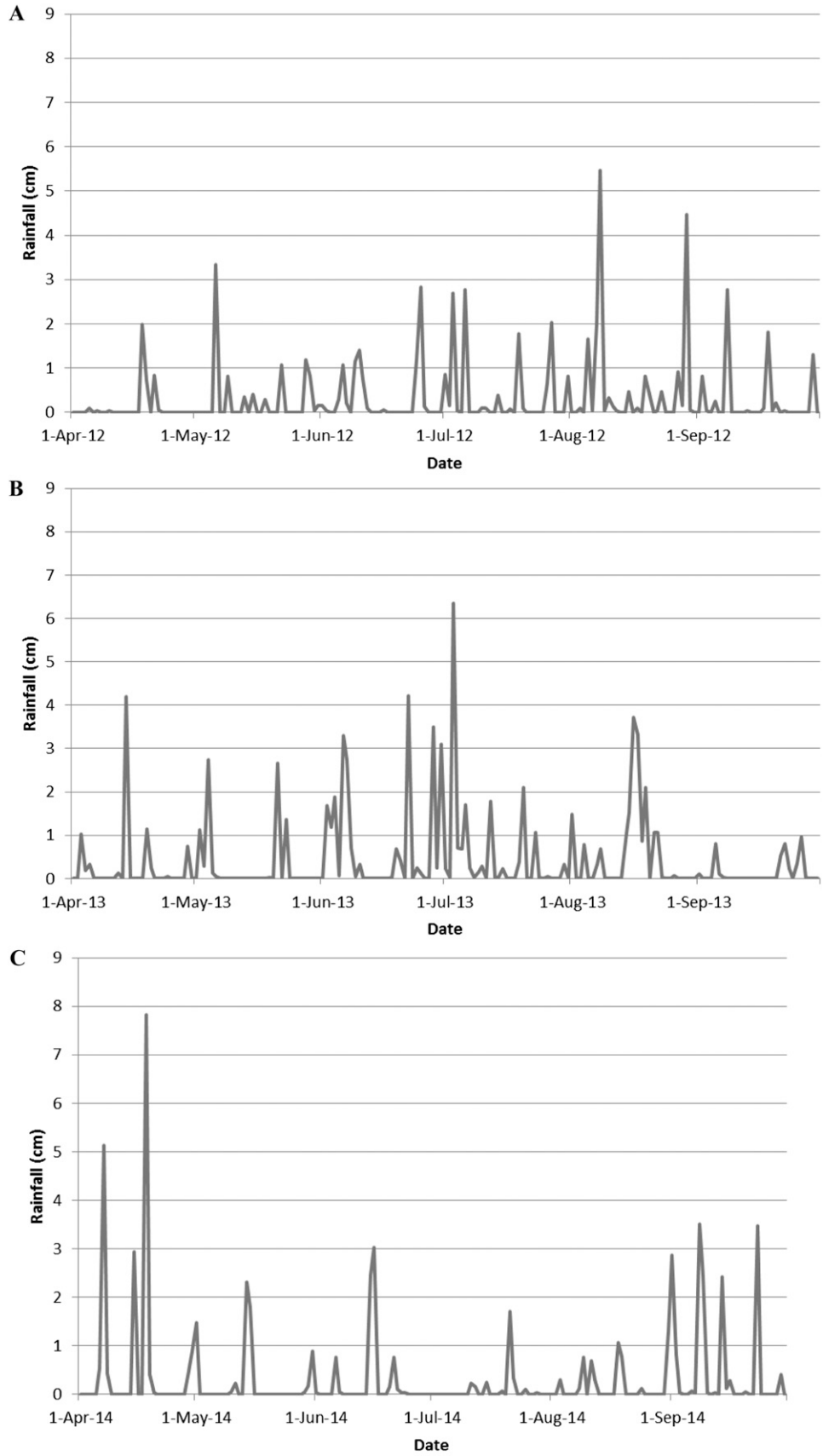

Fig. 1. Daily rainfall distribution from Apr. 1 to Sept. 30 during (**A**) 2012, (**B**) 2013, and (**C**) 2014 at the University of Georgia Alapaha Blueberry Farm located ≈11.2 km from the study site.

Table 1); 2) reduced early season irrigation schedule (Table 1); 3) non-irrigated control. Treatments were arranged in a randomized block design using five single-tree plots per treatment.

Irrigation occurred daily throughout the study in the full irrigation schedule. Irrigation occurred every other day from April through July and daily from August through September for the reduced early season irrigation schedule. Irrigation in both treatments was stopped for 3 d following a rainfall event of 2.5 cm or more from April to July.

Midday stem ψ was determined using a pump-up pressure chamber (PMS Instruments, Albany, OR) by measuring the ψ of leaves located near the trunk or a main scaffold branch, which had been enclosed in a foil-covered bag for 20 min (Begg and Turner, 1970). Measurements were made weekly between 1300 and 1500 HR from 26 Apr. to 20 Sept. 2012, 21 May to 19 Sept. 2013, and 19 June to 12 Sept. 2014. Measurements were delayed in 2013 and 2014 because of repairs to the irrigation system in both years and delayed budbreak because of cool spring temperatures. One leaf per tree was measured on each sampling date to keep measurements within close temporal proximity.

Soil moisture was measured with a Field Scout TDR 300 Soil moisture meter (Spectrum Technologies, Aurora, IL) at 20 cm depth within the wetted zone of microsprinklers ≈1.2 m from the base of the tree on each sampling date at the same time that stem ψ was measured for each tree.

At harvest, yield was estimated by shaking trees and measuring the weight of nuts in a wedge-shaped grid consisting of 1/100 of the area beneath the tree (Conner and Worley, 2000). Four subsample grids were used per tree, the weight summed, and multiplied by 25 to obtain the total tree yield. Only non-germinated, marketable nuts were used to measure yield. A 50-nut sample was collected from each tree for analysis of individual nut weight and percent kernel. Nuts were shelled and percentage of edible kernel was calculated by dividing the kernel weight for the 50-nut sample by total nut weight. Rainfall was recorded at a weather station located ≈11.2 km from the study site.

Repeated measures analysis of variance was used to measure treatment effects on stem ψ. Analysis of variance was used to measure treatment effects on pecan yield and nut quality parameters. Means were separated using Tukey's honestly significant difference test ($P < 0.05$). Linear regression was performed on data from non-irrigated trees to develop baseline data regarding the relationship between midday stem ψ and soil moisture.

Results and Discussion

A weather station ≈11.2 km from the study site recorded 58.9, 79.2, and 57.9 cm of rainfall from April through September for 2012, 2013, and 2014, respectively. The rainfall total for the study period for 2013

Table 2. Mean stem water potential (ψ), pecan tree yield, nut weight, percent kernel, and shoot length of pecan trees for full and reduced irrigation schedules and non-irrigated controls.

Yr/treatment	Stem ψ	Yield (kg/tree)	Nut wt (g)	Percent kernel	Shoot length (cm)
2012					
Full schedule	–0.67 a[z]	36 a	9.05 b	46.5 a	10.7 a
Reduced schedule	–0.67 a	28 a	9.53 a	46.5 a	8.9 b
Non-irrigated	–0.78 b	21 b	9.03 b	44.8 a	7.9 b
2013					
Full schedule	–0.59 a	39 a	10.2 a	47.7 a	13.3 a
Reduced schedule	–0.59 a	47 a	10.0 a	48.1 a	12.8 a
Non-irrigated	–0.62 a	43 a	10.0 a	46.2 a	10.6 a
2014					
Full schedule	–0.83 a	16 a	8.10 b	51.6 a	12.7 a
Reduced schedule	–0.81 a	12 a	9.16 a	49.0 a	12.7 a
Non-irrigated	–1.10 b	3 b	7.50 b	52.2 a	11.9 a

[z]Means followed by the same letter in each column are not different at $P < 0.05$ by Tukey's honestly significant difference test.

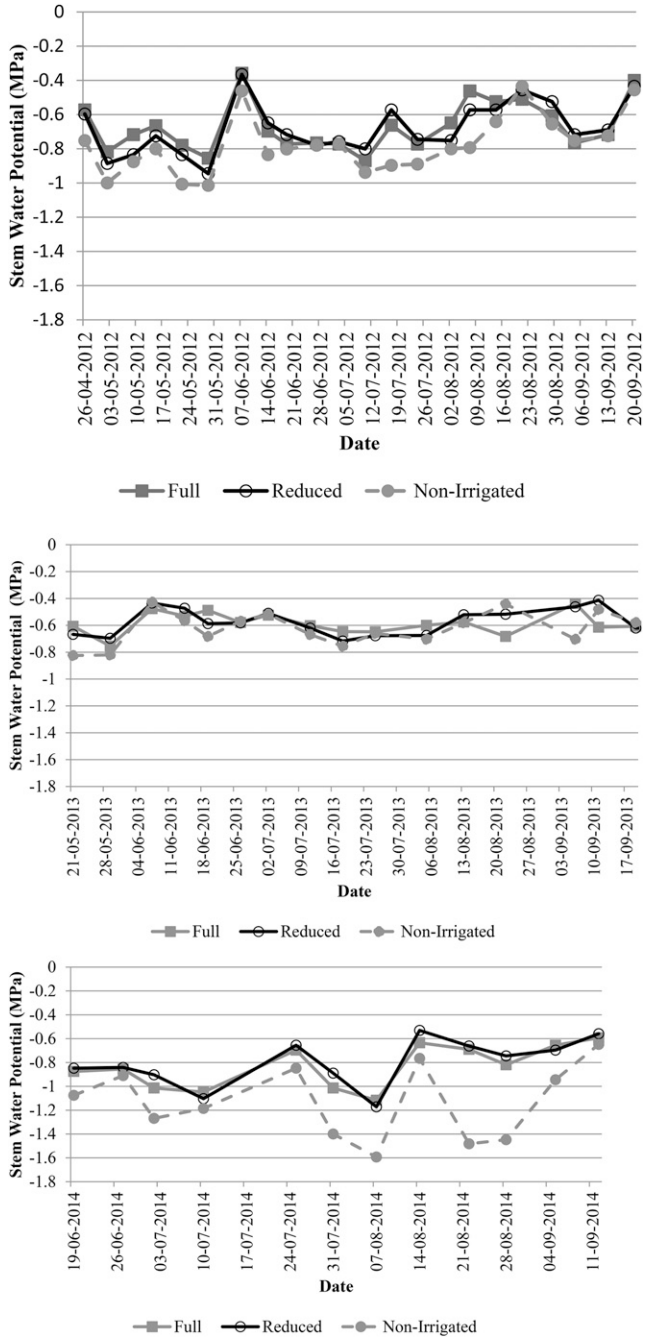

Fig. 2. Mean stem water potential (ψ) of pecan trees in full irrigation, reduced irrigation, and non-irrigated treatments during 2012, 2013, and 2014.

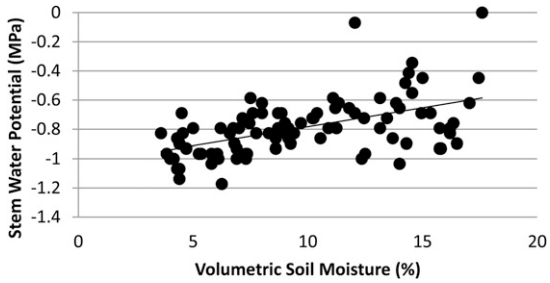

Fig. 3. Relationship between stem water potential (ψ) of non-irrigated pecan trees and volumetric soil moisture on Tifton loamy sand ($y = 0.0259x - 1.0421$, $R^2 = 0.28$).

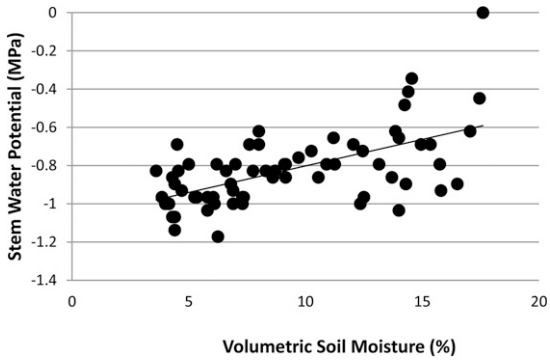

Fig. 4. Relationship between stem water potential (ψ) of non-irrigated pecan trees and volumetric soil moisture on Tifton loamy sand from Apr. to July 2012 ($y = 0.0277x - 1.079$, $R^2 = 0.35$).

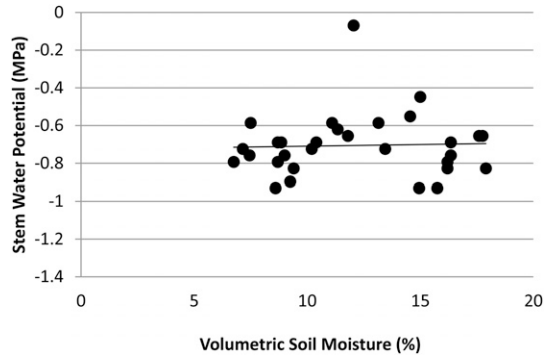

Fig. 5. Relationship between stem water potential (ψ) of non-irrigated pecan trees and volumetric soil moisture on Tifton loamy sand from Aug. to Sept. 2012 ($y = 0.0017x + 0.7263$, $R^2 = 0.0014$).

was excessive, totaling 21.3 cm more than the mean annual rainfall from 1971 to 2000 for this location. Suggested seasonal total water requirements of pecan range from 127 to 147 cm (Madden, 1969; Sammis et al., 2004). Precipitation totals were below the recommended range for pecan production and rainfall was not evenly distributed throughout the growing season, suggesting a need for irrigation. This is particularly evident for 2014 (Fig. 1).

Stem ψ was higher ($P < 0.05$) in the full irrigation schedule treatment and in the reduced early season irrigation schedule than in the non-irrigated control during 2 of the 3 years of study (Table 2). This indicates that tree water stress was reduced with irrigation; however, season-long water status was similar for both the current and reduced irrigation schedules. During 2012, stem ψ was somewhat lower (more stress) for the reduced schedule early in the growing season. As the nut sizing period began in early June, tree water status was enhanced as the irrigation amount increased and the reduced schedule tree water status became more similar to that for the fully irrigated trees (Fig. 2). This suggests that pecan trees can recover relatively quickly from early season water stress when they have access to sufficient soil moisture to meet the water demand as the nuts begin to size and irrigation amounts increase.

Pecan yield was higher ($P < 0.05$) for both irrigated treatments than for the non-irrigated control in 2012 and 2014 (Table 2). There were no differences in yield between the full and reduced irrigation schedules. Nut weight was greater for the reduced irrigation schedule trees than for the full schedule and non-irrigated trees in 2012 and 2014. Because of excessive rainfall, there were no treatment differences for yield or nut weight in 2013. Shoot length was enhanced by the full irrigation schedule in 2012, which applied more water during shoot elongation. However, early season rainfall in 2013 and 2014 likely improved shoot growth in all treatments during those seasons. These results suggest that the reduced irrigation schedule provides a 38% reduction in irrigation water application compared with the previously recommended irrigation schedule for pecans grown under southeastern U.S. conditions with no loss in yield or pecan quality.

Since 2012 was the only growing season in which measurements were taken from April to September (Fig. 2), stem ψ and soil moisture from 2012 were used to establish relationships between midday stem ψ and soil moisture. There was a positive linear relationship between stem ψ and volumetric soil moisture (Fig. 3). Based on mean stem ψ in the non-irrigated trees, it appears that pecan trees grown in humid climates such as southern Georgia may undergo water stress at ≈–0.78 MPa (Table 2). Deb et al. (2012) reported stem ψ values for pecan of up to –1.72 MPa under dry soil conditions on silty clay loam and –1.46 MPa on sandy loam in New Mexico. Pecan stem ψ following flood irrigation events in New Mexico ranged from –0.76 to –0.23 MPa on sandly loam. During the current study, mean stem ψ values for 2012 ranged from –0.36 to –1.01 under wet and dry soil conditions, respectively (Fig. 2); however, the maximum stem ψ value for non-irrigated pecan trees observed in the current study was –1.17 MPa in 2012 and –1.58 MPa in 2014 (Fig. 2). Mean stem ψ fell below –0.78 MPa on only two sampling dates in 2013.

The higher stem ψ (less water stress) observed in the humid conditions found in Georgia is not surprising. Vapor pressure deficit (VPD) is a function of air humidity and temperature and is linearly related with stem ψ (McCutchan and Shackel, 1992). Although VPD was not measured in the current study, the high temperatures and high relative humidity characteristic of southern Georgia would be expected to generate more favorable VPD and stem ψ values than those for the arid conditions of New Mexico. However, stem ψ values observed in Georgia reach the level of water stress for pecan at various times during crop development because of the variability in the distribution of rainfall during individual growing seasons and between years.

Regression analysis suggests that the point of water stress may be reached in pecan throughout most of the growing season at ≈10% volumetric soil moisture at 20 cm depth on the Tifton loamy sand soil on which the study occurred (Fig. 3). This value falls among published values for the permanent wilting point and field capacity of the soil (Rawls et al., 1982). While this relationship was significant, it was relatively weak because of the amount of variation in the season-long data. As a result, the point of water stress suggested above may be only

a general approximation and may shift with variations in soil type, temperature, crop load, crop maturity stage, etc. Regression analysis indicated a stronger linear relationship between stem water potential and volumetric soil moisture from April through July (Fig. 4), although it is only slightly more significant than that of the season-long data. While to a lesser degree than leaf ψ, stem ψ may still be influenced to some degree by environmental factors such as relative humidity, solar radiation, air temperature, and windspeed (Meyer and Green, 1981). McCutchan and Shackel (1992) found day-to-day fluctuations in midday stem ψ were associated with parallel variations in midday VPD. Although, these environmental parameters were not measured in the current study, they may have accounted for some of the variation in the data.

There was no relationship between stem ψ and volumetric soil moisture in August and September (Fig. 5), when the kernel-filling process was taking place. Since, this is the period of peak water demand for pecan (Stein et al., 1989), it would seem that trees bearing a moderate to heavy crop load may undergo water stress at this time. The orchard received significant rainfall in Aug. and Sept. 2012 (Fig. 1), leading to higher stem ψ for trees during this period than for April–July. While this indicates comparatively less stressed conditions during August and September, stem ψ was often ≤–0.78 MPa (Fig. 5), indicating water stress. The lack of a relationship between stem ψ and soil moisture during August and September suggests that soil moisture alone does not necessarily provide the best indicator of the tree's water status during peak water demand. It is possible that water stress during the kernel-filling period is influenced by growth stage/nut development and may be a function of crop load in addition to soil moisture.

Conclusions

The reduced early season irrigation schedule provided a 38% reduction in irrigation water use with no significant effect on pecan tree water stress, yield, or quality, suggesting that pecan trees can tolerate moderate early season water stress with no effect on pecan yield or quality under southeastern U.S. environmental conditions. Water Stress on pecan occurred at ≈–0.78 MPa using the pressure chamber to measure stem ψ. Regression analysis suggests that irrigation scheduling for mature pecan trees may be needed when volumetric water content reaches ≈10% on Tifton loamy sand soil. Water stress in pecan is correlated with soil moisture from budbreak through the end of nut sizing but not during kernel filling. Pecan trees bearing a moderate-to-heavy crop load may undergo water stress during the kernel-filling stage regardless of soil moisture level. Therefore, it is suggested that water stress in pecan is influenced by growth stage/nut development. During the kernel-filling period water stress may be a function of crop load in addition to soil moisture.

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