ENHANCING THE SUSTAINABILITY OF PECAN PRODUCTION THROUGH HEDGE-PRUNING IN THE SOUTHEASTERN UNITED STATES

by

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(Under the Direction of Lenny Wells)

ABSTRACT

The United States is the leading producer of pecans worldwide, and Georgia is the leading production state within the United States. Over the years, pecan (*Carya illinoinensis*) trees have experienced higher density plantings which enhances the need for better water use efficiency to increase the sustainability of the orchard. As tree nut crops, such as pecans, face challenges related to water use efficiency and environmental sustainability, it is essential to develop practices that optimize resource use while maintaining high-quality yields. Hedge pruning, a technique that reduces tree canopy size, is increasingly adopted in pecan orchards to improve water efficiency, enhance light penetration, and manage tree growth. Additionally, hedge pruning enables more efficient water use in the humid climate of the southeastern United States. The objectives of this study were to determine if irrigation rates can be reduced on hedge-pruned pecan trees with no loss in pecan yield or nut quality. The study is a split-plot design with pruning serving as the main plot effect and irrigation serving as the split plot effect. On hedge-pruned trees, all growth beyond 8’ from the trunk on the east side of the tree was pruned in year 1 and on the west side of the tree in year 2. Trees were topped on each side in their respective years at an angle with a peak at 40’. No pruning was done in year 3. Hedging treatments are arranged in three tree blocks with each irrigation treatment occurring once per block as follows: 1) Full irrigation; 2) Reduced irrigation; 3) Non-irrigated control. Hedged blocks were replicated four times, and the non-hedged blocks were replicated three times. Hedge pruning did not significantly affect water stress in the current study, although it did reduce yield in the initial years due to the removal of fruiting wood. However, by the third year, yield differences between hedged and non-hedged trees were minimal. Additionally, hedge pruning increased percent kernel and leaf area in pruned trees, highlighting its potential for improving nut quality. Furthermore, the reduced irrigation rate did not negatively affect yield or nut quality on hedged nor on non-hedged trees, suggesting that irrigation rates could be safely reduced by 34% from April-July, offering a sustainable approach to water conservation without compromising production. These findings underscore the potential for hedge pruning and irrigation adjustments to enhance pecan orchard management and sustainability in the southeastern U.S.

INDEX WORDS: *Carya illinoinensis, hedging*, irrigation, stem water potential

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B.S., University of Georgia, 2023

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTERS OF SCIENCE

ATHENS, GEORGIA

2025

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May 2025

ACKNOWLEDGEMENTS

I would first like to express my appreciation and gratitude to my advisor, Dr. Wells for giving me the opportunity to pursue my master's degree at The University of Georgia. My research project would not have been possible without his guidance and support over the last two years. I will be forever indebted to you because of the career opportunities, advice, patience, and knowledge that you have kindly shared with me.

Secondly, I would like to also express my appreciation to Dr. Patrick Conner, Dr. Luan Oliveira, and Dr. Wesley Porter for serving on my graduate committee. I am fortunate to have been surrounded by a committee that serves the pecan and agriculture industry so well in the state of Georgia. I appreciate the knowledge, guidance, and advice that you all have provided.

I would like to thank Chad Walker, Mike Crumley, and our team of student workers. My research projects would not have been possible without your work in the orchard and maintenance throughout the year.

I would also like to thank the American Pecan Council and American Pecan Promotion Board for the support during my studies, and the opportunity to work hard for the American Pecan industry.

Additionally, I would also like to extend deepest thanks to my family who has extended patience, guidance, and love throughout my graduate school journey. I am thankful for the sacrifices you have made to support my education.

Lastly, I would like to extend sincere thanks and gratitude to the Georgia Pecan Commission and USDA NIFA for their contributions to make this research project possible.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Sustainable agriculture is defined by United States Department of Agriculture (USDA) as an "integrated system of plant and animal production practices having a site specific application that will, over the long term: (a) satisfy human food and fiber needs; (b) enhance environmental quality; (c) make efficient use of non-renewable resources and on-farm resources and integrate appropriate natural biological cycles and controls; (d) sustain the economic viability of farm operations; and (e) enhance the quality of life for farmers and society as a whole." To meet demands from consumers and continue improving production agriculture methods for the present and future, sustainability must be improved. Hedge pruning of pecan orchards has the potential to improve water use efficiency and orchard management techniques.

The United States (U.S.) is the second largest producer of tree nuts worldwide. Commercial production of almonds, walnuts, pistachios, pecans, macadamias, and hazelnuts occurs primarily in the western United States (Asci, 2021). Tree nuts produced in the U.S. are typically exported to foreign countries, but there is a growing demand for trees nuts from domestic consumers. However, the expansion of U.S. tree nut production sustainability is challenged by environmental and water shortages issues (Asci, 2021).

Pecan trees (*Carya illinoinensis*) are native to North America with a natural range from as far north as Clinton, Iowa, southward along the Mississippi River and southwest to Oaxaca, Mexico (Wells, 2017). In 2023 the U.S. pecan crop was valued at 500 million dollars (USDA, 2024). Regarding world production, the United States and Mexico are the largest pecan producers, responsible for supplying nearly 300 million pounds each. The pecan industry began in the early 1900s with low land values in the southeastern states and inflated reports of pecan production compared to cotton which led to investments in pecan orchards. Currently, the U.S. has 409,000 bearing pecan acres producing 278 million pounds of pecans (NASS, 2022).

Trade disruptions between the United States, China, and pecan importation from Mexico have led to significant pecan market fluctuation in recent years (Silva et al., 2024). Exports and imports are important for U.S. pecan producers due to the historical stagnation of domestic use and demand (Capps et al., 2019). Since 1980, there has been increased demands to numerous countries with the greatest increase occurring in Asia from 2009-2018 (Wells, 2014 and USDA ERS, 2024). The export market to China, Vietnam, and Hong Kong from 1980's to mid-2000's was consistently minimal, but in 2009 there was a steep increase in export which continued to grow until 2018 when Chinese tariffs were increased causing a sudden reduction in exports from 76.8 million pounds to 16 million pounds within 1 year (Capps and Williams, 2019). Hong Kong has been the largest export market due to shipment of pecans going to China and Vietnam (Capps and Williams, 2019). The price of nuts (in-shell) rose from 98.5 cents per pound in the 1990's to average of 206 cents per pound between 2009-2018 in the U.S. (Capps and Williams, 2019). These trade issues led to an increase in pecan planting after 2010. In 2014, there was double the amount planted compared to 2010 which allowed Georgia's pecan acreage to continue to grow until 2018 (Wells, 2014; Fronza et al., 2018; Slade and Wells, 2022). The cost of pecan production rose to $1,400 per acre in 2022 from $850 per acre in 2002, but grower prices for pecans rose less than 30 cents per pound during the same period, with the exception of 2009-2018 (Fonsah et al., 2023). This led to more densely populated pecan orchards in Georgia (Wells 2014), as growers attempted to maximize production per acre.

The state of Georgia accounts for nearly 1/3 of United States production (NASS, 2022). Georgia is the leading state in pecan production with 147,000 bearing acres in 2022 producing 88-92 million pounds of pecans (USDA, 2024). The pecan crop in Georgia was valued at 212.6 million dollars in 2022, making it a vital horticultural crop to Georgia's agricultural economy (USDA, 2024). Georgia's pecan acreage continued to grow due to elevated prices in comparison to timber until 2018 (Wells and Sawyer, 2022).

The southeastern and southwestern portions of the United States have different climates which impact pecan production in a variety of ways. The climate in the southeastern U.S. is characterized by high humidity, high average rainfall, and warmer temperatures. The climatic factors of southern Georgia where pecan production is prevalent impact cultural management practices and overall pecan production (Thompson and Conner, 2011). This region consists of hot summers and an annual rainfall average of 127 cm or more (Sammis et al., 2004). Pecan scab, a disease caused by *Venturia effusua*, is the most detrimental disease of pecan production in the southeastern U.S. due to the humid, warm climatic conditions in summer (Bock et al., 2016). Pecan scab is prevalent in the southeastern U.S. due to susceptible varieties grown in orchards along with an increase in fungicide resistance, which makes management more difficult (Slade and Wells, 2022). Scab not only reduces yields, but the stress on the tree can induce alternate bearing cycles which affect production (Bock et al., 2016). Pecan scab can be a major limiting factor to production because of the deterioration of the quality of the crop if proper management techniques of the orchard are not implemented to reduce prevalence of the disease.

Although Georgia receives high annual rainfall, the consistency and timing of rainfall does not align with the growing season of pecans to be a solely sufficient water source. Despite the high humidity and rainfall, the warmer temperatures benefit pecan production. An average of

555 hours of temperatures above 65 degrees Fahrenheit are required for pecan production (Wells, 2015). The growing season requires warm temperatures while the process of budbreak requires between 300-1000 chilling hours, depending on pecan variety (Wells, 2015). Overall, the climate is ideal for pecan production if proper cultural management strategies are implemented to allow growers to minimize inputs while maintaining high yields.

The agriculture sector is a major consumer of ground and surface water to support crop production. Tree nut crops like almonds, walnuts, pistachios, and pecans are classified as fruiting deciduous trees, and their morphological anatomy requires certain amounts of water for adequate growth and production (Ibraimo, 2018). Although tree nuts are a healthy source of food, tree nuts have a high-water requirement, which leads to concerns over water sustainability and the implementation of new production methods (Vanham et al., 2020). Pecan trees may require greater water use than many agronomic row crops, so a thorough understanding of water use in a given growing environment is crucial (Andales et al., 2006). Irrigation is one of the crucial factors in pecan production because it directly affects yield, nut size, and nut quality, but a common issue among the industry is improper management of irrigation frequencies and scheduling (Stein et al., 1989). Rainfall is variable in the southeastern U.S. and the region frequently suffers dry periods in spring, summer, and fall, therefore evaporation can exceed rainfall received during those months which are crucial periods for nut set, nut growth, and nut development (Worley, 1982). Because pecans are prone to alternate bearing like many other fruit trees, adequate amounts of water are needed to produce the crop and reduce stress on the trees (Conner and Worley, 2000). In addition to water being essential for pecan crop production, the importance of irrigation methods and scheduling are crucial for growers to reduce inputs, conserve limited water resources, and maintain consistent production (Garrot et al., 1993).

Irrigation practices and the appropriate timing of water availability determine pecan yield and quality (Stein et al., 1989). Water stress can be detrimental to a pecan crop's yield and quality, but pecan's physiological development throughout a growing season impacts the trees' water demand. The early portion of the season in late spring and early summer creates less demand for water than that for nut development and kernel filling from mid-June through September in the southeastern United States (Sammis et al., 2013). If there is inadequate water during the nut sizing and kernel filling stages, the nuts will not develop in size and kernels will not develop properly (Wells, 2015). Shuck splitting can also be delayed and an increase in embryo rot and vivipary can occur due to lack of water after kernel filling or if weather conditions turn dry prior to shuck split with a heavy crop load on the trees (Stein et al., 1989; Wells, 2023). In response, irrigation techniques for pecans have evolved to meet demands while becoming more efficient. Irrigation requirements vary by growing region due to climate and soil texture differences that affect the soil's water holding capacity and need for water throughout the growing season (Carroll & Smith, 2017). A common method of irrigation in arid regions of the U.S. is basin flood irrigation which rapidly provides fields and orchards with water. Although flood irrigation enhances soil moisture quickly, it also creates runoff, leaches nutrients from the soil, and leads to increased evapotranspiration, but the advancements of laser leveling in arid orchard systems has enhanced the efficiency of flood irrigation (Miyamoto et al., 1995).

Irrigation is required to produce crops in arid regions of the western United States. However, in the southeastern United States rainfall can account for a significant portion of the crop's water requirement and irrigation is therefore designed to be supplemental to rainfall (USDA, 2024). The overall concept of agricultural water use is a controversial issue throughout the U.S., including southern Georgia where pecan production is predominant. The need for better agricultural water application is vital to ensure there is enough water to support the needs of population, industry, and production agriculture. The amount of water needed varies depending on the crop and geographic location of production.

Although Georgia has an estimated 127 cm of rainfall each year, pecan trees may undergo water stress during intermittent droughts typically in August and September (Wells, 2015). Climatic changes have a significant impact on the growth and productivity of trees, and weather events such as heavy precipitation, summer droughts, and heat waves continue to increase tree stress (Sangines de Carcer et al., 2017). The vapor pressure deficit (VPD) is a measure of the difference between the amount of moisture the air can hold when fully saturated and the amount of moisture present in the air at a given time. The sensitivity of stomatal conductance in relation to vapor pressure deficit leads to diverse responses in growth, and numerous studies have been conducted describing how stomata react to VPD (Sangines de Carcer et al., 2017).

Previous studies have indicated that stomatal closure occurs when there is a high VPD and stomatal opening occurs when there is a low VPD, and environmental factors such as temperature, water, and moisture availability impact VPD (Brodribb & McAdam, 2011; Mott & Peak, 2013; Sellin, 2001; McAdam & Brodribb, 2015). When VPD is elevated, the tree will experience more water stress than when VPD is low. The correlation of VPD to water stress allows VPD to act as an indicator of tree stress, and growers can mitigate with irrigation regimes to reduce stress when needed throughout the growing season. The comparably low vapor pressure deficit (VPD) in the southeastern U.S. is a result of its high humidity, which can further enhance water use efficiency (McCutchan and Shackel, 1992).

Drip irrigation and micro sprinkler irrigation are the primary irrigation methods used for pecan in the southeastern U.S. Both methods have higher water use efficiency than flood and solid-set sprinkler irrigation. Worley (1982) found the response to drip irrigation is favorable to increased yields and quality of nuts compared to no irrigation. The annual rainfall in Georgia is favorable for pecan production, but irrigation is essential to consistent yield, nut size, and quality (Wells, 2015). In addition to drip and micro sprinkler irrigation minimizing evaporation losses, fertilizing through irrigation systems increased fertilizer efficiencies and effectiveness (Li, 2018).

The primary source of irrigation water in southern Georgia is the underground aquifer system, which is composed of confined and semi-confined layers of saturated limestone. The region is underlain by multiple aquifer systems. Some of these aquifers are recharged annually via precipitation. The most common aquifer used in South Georgia for agriculture is derived from the Floridan aquifer (Hawkins, 2021). However, the impact of climate change and unsustainable water withdrawals threaten to reduce the amount of available ground water in Georgia (Sutton et al., 2021).

The amount of water removal by Alabama, Georgia, and Florida from the Apalachicola-Chattahoochee- Flint River basin has drastically increased due to population increase and agricultural intensity in the region. Much of the pecan growing region of Georgia relies heavily on the Flint River basin as a water source (Wells, 2017). Agriculture water withdrawals from the Flint River basin are more than that for the public water supply. The three states supplied by this basin have a recent history of conflict regarding water use (Lawerence, 2016). Thus, improved sustainability and water efficiency of pecan production through more precise irrigation practices in the southeastern United States may enhance tree nut production and the future availability of water resources.

Irrigation scheduling is a vital component to improving water use efficiency (Ganjegunte et al. 2012). Peak water demand for pecans occurs in August and September during the kernel filling stage (Wells, 2010). Implementation of methods to calculate and maintain soil moisture levels within the orchard are helpful for irrigation schedules. Application of irrigation at peak times and reduction in water use during less demanding periods, with the help of modern technology, can improve orchard sustainability (Nikolaou et al., 2020).

In response to an increasing lack of water resources, deficit irrigation is a technique that can be implemented to improve water use efficiencies while maintaining optimal water levels for crop production (Fereres & Soriano, 2007). The concept of deficit irrigation is to reduce the amount of irrigation by exposing the crop to a certain level of water stress at certain times during the season, but the lack of water does not significantly impact the yield and quality of the crop (Kirda, 2002). The common deficit irrigation technique is regulated deficit irrigation which supplies irrigation below full evapotranspiration throughout the growing season to improve water use efficiency, and horticultural crops such as fruit trees have greater potential of improving water use efficiency using deficit irrigation techniques (Costa et al., 2007). Previous studies have been conducted on deciduous fruit trees in high density orchards such as apples and pears, and the main goal is aimed at reducing vegetative growth while maintaining fruit yields and reducing need for significant pruning (Costa et al., 2007). Tree nuts have high water requirements compared to other crops, and almonds specifically have higher demands for water than most crops rendering the need for management techniques to reduce water use. In a study conducted on an almond orchard in California under deficit irrigation, the crop saved around 5.3 inches of water annually over a 5-year period while also increasing yields over that period (Stewart et al., 2011). This study supports the benefits of deficit irrigation to improve water use efficiency while maintaining minimal crop stress and producing optimal yields. Although there have been minimal studies conducted on pecan trees specifically in the southeast, there was a study conducted in New Mexico on deficit irrigation in pecans and the results supported improved water use efficiency and sustainable crop yields (Pierce, 2021).

In addition to proper irrigation scheduling, cultural management of pecan tree canopies also enhances orchard success. A concern associated with dense tree planting is the potential for excess shading and the rate at which it occurs (Lombardini, 2006). Tree overcrowding results in competition for nutrients and lower yields if not managed properly (Anadales et al., 2006; Wood and Stahmann, 2004). Hedge pruning is a practice that has been rapidly adopted to help combat excessive shading while maintaining higher yields and a healthy orchard. Hedge pruning involves limb removal at a certain distance from the trunk combined with a reduction in tree height by topping the tree at a height no greater than 40 feet. This creates a smaller, more compact tree. Mature non-hedged pecan orchards intercept between 65% to 70% of sunlight, affecting photosynthetic rates (Wood, 1996). Thus, hedge pruning allows growers to manage the size and shape of the trees to prevent canopy overlap, manage crop load, enhance quality, maintain better spray coverage, reduce storm damage, and enhance water efficiency (Wells, 2018).

A concern with pecan tree canopy encroachment is the profitability of the orchard declining due to the increase in alternate bearing intensity, especially in low light environments (Wood, 1996). The southeastern United States has low light intensity compared to more arid regions as a result of increased cloud cover, so the need for a solution to enhance light penetration in canopies is crucial for pecan production. Reducing the overcrowding of orchards and increasing sunlight exposure may be done more effectively with hedge pruning than with tree removal from orchards (Worley et al., 1996). Wood and Stahmann, (2004) found that pecan orchards can maintain high productivity while reducing alternate bearing with hedged-row type pruning, at a north to south orientation. A study was conducted on hedge- pruning that exhibited the same results of improved alternate bearing intensity and improved quality, but there was a reduction in yield. However, if the canopies were not reduced it is expected that there would eventually be a decline in crop production due to canopy encroachment and competition (Wood, 2009). In an additional study investigating the effect of a one-time hedging application, the results indicated a difference in light penetration compared to non-hedged and nut quality was maintained (Lombardini, 2006). This suggests potential for growers in the southeast to prune according to alternate bearing to improve yield fluctuations and price through hedging. Wells (2015) determined that midday stem potential (ψ) was higher in hedged trees compared to non-hedged trees, which indicates less water stress on hedge-pruned trees. Nut weight was also found to be higher in hedged trees which is related to better water use efficiency as the nut sizes during the growing season (Wells, 2018). The difference in water stress is likely due to the size and height of the canopy in a non-hedged tree compared to a hedged tree because water must reach further distances in non-hedged trees (Deb et al. 2012). This would indicate that hedged pecan trees may exhibit lower water use and improved water efficiency due to smaller canopy size while maintaining quality and yield.

Wells (2018) found that hedge pruning in the southeast can be beneficial for water status, nut quality, wind resistance, and nut weight. This supports an increase in pecan quality with hedge pruning, although there may be an initial yield reduction when hedging regimes begin. In the western portion of the U.S., hedging of pecans has increased due to increased density of pecan orchards and light penetration becoming an issue just as it is in the southeast. There have been studies conducted in the west on hedge pruning pecan trees and results indicate improved alternate bearing habits and no reduction in quality, but there is still a slight reduction in yield early on (Heerema et al., 2012). The older pecan trees are when the hedging program begins, the greater the reduction in fruiting wood, and thus the greater reduction in yield. This suggests that the timing of the initiation of hedge pruning is important.

The benefits of hedge pruning include potential effects on plant pathogens and pests in orchards. A study that analyzed pest pressure in hedged canopies found that hedging increased *Phylloxera* infestations, but it did not affect other pests such as mites (Toledo et al., 2024). A reduced canopy size also allows for better spray coverage with fungicide, which is critical in the southeastern U.S. to prevent and manage scab pressure (Bock et al., 2017). Additionally, previous studies conducted on hedge pruning indicate that hedging pecan trees promotes vegetative growth of the trees and has no negative effects on the fruit (Hellwig et al., 2022).

The pruning of crops in general, not specific to pecans, can be beneficial for water availability and efficiency. In a study conducted in an agroforestry system in Kenya which analyzed *Grevillea robusta*, southern silky oak tree, and maize, indicated that the water balance was significantly improved by pruning, resulting in a decreased water demand (Jackson et al., 1999). In another study investigating crop water use with a pruning treatment, winter wheat that was root pruned indicated better water use efficiency and less water uptake compared to un-pruned while also showing no significant difference between the yields (Shou et al., 2008). These results from crop water use studies with pruning and hedging treatments indicate improved use of water resources while maintaining yields which is vital to increasing the sustainability of crop production.

Overall, hedge pruning of pecan orchards and irrigation regimes can improve water efficiency and economic viability of pecan operations, increasing the sustainability of pecan production. Hedge pruning is recognized for the role it plays in enhancing light penetration, tree health, and air circulation which leads to better yields and quality of pecan crops. Tree nut producers must implement the most efficient irrigation systems and cultural management techniques to minimize water waste while producing high quality tree nuts and maintaining sustainable profits. In response to concerns of limited water resources and agricultural water use quantity, it is crucial to understand the interactions between water use, irrigation practices, and cultural management techniques to improve efficiencies while maintaining crop yields to enhance the sustainability of pecan production.

As pecan tree plantings have become more densely populated and more constraints on water sources arise, the process of hedge pruning serves to mitigate canopy encroachment while also improving the water use efficiency of orchard. This research aims to investigate the effects of hedge pruning on pecan trees under varying irrigation regimes, with a focus on optimizing water use efficiency without compromising tree productivity. The study has three main objectives:

1. Determine if irrigation rates can be reduced on hedged-pruned pecan trees with no loss in pecan tree yield or nut quality, addressing the need for enhanced sustainable water management in pecan production.

2. Determine if hedge pruning affects leaf area under varying irrigation regimes, which may indicate interactions between pruning and water availability that influence tree canopy development.

3. Determine if hedge pruning affects the rate of nut growth and development.

References

Andales, A., Wang, J., Sammis, T. W., Mexal, J. G., Simmons, L. J., Miller, D. R., & Gutschick, V. P. (2006). A model of pecan tree growth for the management of pruning and irrigation. *Agricultural Water Management*, *84*(1-2), 77–88. https://doi.org/10.1016/j.agwat.2006.02.012

Asci, S., & Devadoss, S. (2021). *Trends and Issues Relevant for the US Tree Nut Sector*. Agricultural and Applied Economics Association. https://www.jstor.org/stable/27098588

Bock, C. H., Grauke, L. J., Conner, P., Burrell, S. L., Hotchkiss, M. W., Boykin, D., & Wood, B. W. (2016). Scab susceptibility of a provenance collection of pecan in three different seasons in the Southeastern United States. *Plant Disease*, *100*(9), 1937–1945. https://doi.org/10.1094/PDIS-12-15-1398-RE

Bock, C. H., Hotchkiss, M. W., Brenneman, T. B., Stevenson, K. L., Goff, W. D., Smith, M. W., Wells, L., & Wood, B. W. (2017). Severity of scab and its effects on fruit weight in mechanically hedge-pruned and topped pecan trees. *Plant Disease*, *101*(5), 785–793. https://doi.org/10.1094/PDIS-10-16-1473-RE

Brodribb, T., & McAdam, S. (2011). Passive Origins of Stomatal Control in Vascular Plants. *Science*, *331*(6017), 578–582. https://doi.org/10.1126/science.1197175

Capps, O., & Williams, G. (2019). *ECONOMIC BENCHMARK MODEL AND ANALYSIS OF THE EFFECTS OF THE CHINESE TARIFF ON THE U.S. PECAN INDUSTRY*.

Carroll, B., & Smith, M. (2017). *Establishing a Pecan Orchard*. http://osufacts.okstate.edu

Conner, P. J., & Worley, R. E. (2000). Alternate Bearing Intensity of Pecan Cultivars. *HortScience*, *35*(6), 1067–1069. https://doi.org/10.21273/hortsci.35.6.1067 Costa, J. M., Ortuño, M. F., & Chaves, M. M. (2007). Deficit irrigation as a strategy to save water:

Physiology and potential application to horticulture. In *Journal of Integrative Plant Biology* (Vol. 49, Issue 10, pp. 1421–1434). https://doi.org/10.1111/j.1672-9072.2007.00556.x

Deb, S. K., Shukla, M. K., & Mexal, J. G. (2012, July 1). *Estimating midday leaf and stem water potentials of mature pecan trees from soil water content and climatic parameters*. hortsci. https://journals.ashs.org/hortsci/view/journals/hortsci/47/7/article-p907.xml

Fereres, E., & Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany*, *58*(2), 147–159. https://doi.org/10.1093/jxb/erl165

Fonsah, G., & Hancock, G. (2024). *Georgia Pecan Production Budget*. Budgets - Extension | Agricultural & Applied Economics. https://agecon.uga.edu/extension/budgets.html

Fronza, D., Hamann, J. J., Both, V., Anese, R. D. O., & Meyer, E. A. (2018). Pecanicultura: Aspectos gerais da cultura. *Ciencia Rural*, *48*(2). https://doi.org/10.1590/0103-8478cr20170179

Ganjegunte, G. K., Sheng, Z., & Clark, J. A. (2012, February 21). *Evaluating the accuracy of soil water sensors for irrigation scheduling to conserve freshwater - applied water science*. SpringerLink. https://link.springer.com/article/10.1007/s13201-012-0032-7

Garrot, D. J., Kilby, M. W., Fangmeier, D. D., Husman, S. H., & Ralowicz, A. E. (1993). Production, Growth, and Nut Quality in Pecans under Water Stress Based on the Crop Water Stress Index. *Journal of the American Society for Horticultural Science*, *118*(6), 694–698. https://doi.org/10.21273/JASHS.118.6.694

Hawkins, G. (2021). *Groundwater usage in Georgia*. Water at UGA. https://site.extension.uga.edu/water/2021/03/groundwater-usage-in-georgia/

Hellwig, C. G., Martins, C. R., Lima, A. D. V., Barreto, C. F., Medeiros, J. C. F., & Malgarim, M. B. (2022, November 17). *Hedge and central pruning in a high-density pecan orchard in southern Brazil.* Alice. https://www.alice.cnptia.embrapa.br/alice/handle/doc/1148402

Heerema, R., Lewis, B., & Fontes, B. (2012). Impact of Hedge Pruning (New Mexico). https://pecans.nmsu.edu/documents/wpga-2012-proceedings-new.pdf

Ibraimo, N. A. (2018). *Water Use of Deciduous and Evergreen Tree Nut Crops: A Case Study Using Pecans and Macadamias* (Order No. 30710582). Available from ProQuest Dissertations & Theses A&I; ProQuest Dissertations & Theses Global. (2901493722). https://www.proquest.com/dissertations-theses/water-use-deciduous-evergreen-tree-nut-crops-case/docview/2901493722/se-2

Jackson , N. A., Wallace, J. S., & Ong, C. K. (1999, December 27). *Tree pruning as a means of controlling water use in an agroforestry system in Kenya*. Forest Ecology and Management.https://www.sciencedirect.com/science/article/pii/S0378112799000961?casa_token=MNUQRlvh4qYAAAAA%3ATWCm3aIIJkdkQ0M9l3KyvPar8nR-sOFxGRI85Vuf82SntVP5sDNNmL47DsmKODp4g7zpDe4hyw

Kirda, C. (2002). *Deficit irrigation scheduling based on plant growth stages showing water stress tolerance*. Deficit irrigation practices. https://www.fao.org/4/y3655e/y3655e03.htm

Lawrence, S. J. (2016, February 25). *Water use in the Apalachicola-Chattahoochee-Flint River Basin, Alabama, Florida, and Georgia, 2010, and water-use trends, 1985-2010*. Scientific Investigations Report. https://pubs.usgs.gov/publication/sir20165007

Li, J. (2018). Increasing Crop Productivity in an Eco-Friendly Manner by Improving Sprinkler and Micro-Irrigation Design and Management: A Review of 20 Years' Research at the IWHR, China. *Irrigation and Drainage*, *67*(1), 97–112. https://doi.org/10.1002/ird.2139

Lombardini, L. (2006). One-time pruning of pecan trees induced limited and short-term benefits in canopy light penetration, yield, and nut quality. *HortScience*, *41*(6), 1469–1473. https://doi.org/10.21273/hortsci.41.6.1469

Ma, S. C., Li, F. M., Xu, B. C., & Huang, Z. bin. (2009). Effects of root pruning on the growth and water use efficiency of winter wheat. *Plant Growth Regulation*, *57*(3), 233–241. https://doi.org/10.1007/s10725-008-9340-1

McAdam, S. A. M., & Brodribb, T. J. (2015). The evolution of mechanisms driving the stomatal response to vapor pressure deficit. *Plant Physiology*, *167*(3), 833–843. https://doi.org/10.1104/pp.114.252940

McCutchan, H., & Shackel, K. A. (1992). *Stem-water potential as a sensitive indicator of water stress in prune trees (Prunus domestica L. cv. French)*. Cabi Digital Library. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20173332765

Miyamoto, S., Henggeler, J., & Storey, J. B. (1995). Water Management in Irrigated Pecan Orchards in the Southwestern United States. *HortTechnology*, *5*(3), 214–218. https://doi.org/10.21273/horttech.5.3.214

Mott, K. A., & Peak, D. (2013). Testing a vapour-phase model of stomatal responses to humidity. *Plant, Cell and Environment*, *36*(5), 936–944. https://doi.org/10.1111/pce.12026

Nikolaou, G., Neocleous, D., Christou, A., Kitta, E., & Katsoulas, N. (2020). Implementing sustainable irrigation in water-scarce regions under the impact of climate change. In *Agronomy* (Vol. 10, Issue 8). MDPI AG. https://doi.org/10.3390/agronomy10081120

Painter, J. A. (2019). *ofr20191095.pdf - Estimated Use of Water in Georgia for 2015 and Water-Use Trends, 1985–2015*.

Pierce, C. (2021). *Deficit Irrigation and Partial Root-Zone Drying in Field-Grown Pecan: Leaf Gas Exchange, Tree Water Status And Nut Production Factors*. https://www.proquest.com/dissertations-theses/deficit-irrigation-partial-root-zone-drying-field/docview/2622966362/se-2

Sammis, T., Gutschick, V., Wang, J., & Miller, D. R. (2013). Model of water and nitrogen management in pecan trees under normal and resource-limited conditions. *Agricultural Water Management*, *124*, 28–36. https://doi.org/10.1016/j.agwat.2013.03.012

Sanginés de Cárcer, P., Vitasse, Y., Peñuelas, J., Jassey, V. E. J., Buttler, A., & Signarbieux, C. (2018). Vapor–pressure deficit and extreme climatic variables limit tree growth. *Global Change Biology*, *24*(3), 1108–1122. https://doi.org/10.1111/gcb.13973

Silva, A., Barrera, A., Ribera, L., & del Valle, M. (2024). Food sovereignty, food security, and international trade: evidence from Chile. Frontiers in Sustainable Food Systems, 8. https://doi.org/10.3389/fsufs.2024.1388498

Slade, H., & Wells, L. (2022). Soil Quality Enhancement with Orchard Age in Pecan Orchards of the Southeastern U.S. Coastal Plain. *HortScience*, *57*(9), 1099-1105. https://doi.org/10.21273/HORTSCI16685-22

Stewart, Wi., Fulton, A., & Krueger, W. (2011). *Regulated deficit irrigation reduces water use of almonds without affecting yield*. https://escholarship.org/uc/item/1zs9g8mk

Sparks, D. (1986). *CRC Handbook of Fruit Set and Development- Pecan*.

Stein, L. A., McEachern, G. R., & Storey, J. B. (1989). Summer and Fall Moisture Stress and Irrigation Scheduling Influence Pecan Growth and Production. *HortScience*, *24*(4), 607–611. https://doi.org/10.21273/HORTSCI.24.4.607

Sutton, C., Kumar, S., Lee, M. K., & Davis, E. (2021). Human imprint of water withdrawals in the wet environment: A case study of declining groundwater in Georgia, USA. *Journal of Hydrology: Regional Studies*, *35*. https://doi.org/10.1016/j.ejrh.2021.100813

Thompson, T.E., Conner, P.J. (2012). Pecan. In: Badenes, M., Byrne, D. (eds) Fruit Breeding. Handbook of Plant Breeding, vol 8. Springer, Boston, MA. https://doi.org/10.1007/978-1-4419-0763-9_20

Toledo, P. F. S., Phillips, K., Schmidt, J. M., Bock, C. H., Wong, C., Hudson, W. G., Shapiro-Ilan, D. I., Wells, L., & Acebes-Doria, A. L. (2024). Canopy hedge pruning in pecan production differentially affects groups of arthropod pests and associated natural enemies. *Crop Protection*, *176*. https://doi.org/10.1016/j.cropro.2023.106521

USDA. (2022). *New Mexico: 2020 – 2022 Pecan Bearing Acreage*. https://www.nass.usda.gov/Statistics_by_State/New_Mexico/Publications/Special_Interest_Reports/NM-Pecan-County-Estimates-05122023.pdf

USDA ERS. (2024). *Data by Commodity - Imports and Exports*. USDA ERS - Data Products. https://data.ers.usda.gov/reports.aspx?programArea=fruit&top=5&HardCopy=True&RowsPerPage=25&groupName=Tree+nuts&commodityName=Pecans&ID=17851#Pc9ff0bfa5ea149d6866663efe4ce1660_3_1273

USDA. (2024). *USDA*. USDA Regional News Release. https://www.nass.usda.gov/Statistics_by_State/New_Mexico/Publications/News_Releases/2023/NM-Crop-Production-12082023.pdf

Vanham, D., Mekonnen, M., & Hoekstra, A. (2020, February 13). *Treenuts and groundnuts in the eat-lancet reference diet: Concerns regarding sustainable water use*. Global Food Security. https://www.sciencedirect.com/science/article/pii/S2211912420300109

Walworth, J., Lewis, B., Fontes, B., & Heerema, R. (2012). *Impact of Hedge Pruning (New Mexico)*. https://pecans.nmsu.edu/documents/wpga-2012-proceedings-new.pdf#page=16

Wells, M. L., & Harrison, K. A. (2010). Cultural management of commercial pecan orchards.

Wells, L. (2014). Pecan Planting Trends in Georgia. *HortTechnology*, *24*(4), 475–479. https://doi.org/10.21273/horttech.24.4.475

Wells, L. (2015a). Irrigation Water Management for Pecans in Humid Climates. *HortScience*, *50*(7), 1070–1074. https://doi.org/10.21273/hortsci.50.7.1070

Wells, L. (2015b, February 23). *Pecans and Chilling | UGA Pecan Extension*. Site.extension.uga.edu. https://site.extension.uga.edu/pecan/2015/02/pecans-and-chilling/

Wells, L. (2015c, June 18). *Irrigation Schedule for Pecan Production | UGA Pecan Extension*. Site.extension.uga.edu. https://site.extension.uga.edu/pecan/2015/06/irrigation-schedule-for-pecan-production/

Wells, L. (2017a). *Pecan: America's native nut tree*. The University Of Alabama Press.

Wells, L. (2017b). Response of Young Pecan Trees to Irrigation in a Humid Climate. *HortScience*, *52*(3), 457–462. https://doi.org/10.21273/hortsci11664-16

Wells, L. (2018). Mechanical Hedge Pruning Affects Nut Size, Nut Quality, Wind Damage, and Stem Water Potential of Pecan in Humid Conditions. *HortScience*, *53*(8), 1203–1207. https://doi.org/10.21273/hortsci13217-18

Wells, L., & Sawyer, A. (2022). Planting Site Effects on Early Growth of Pecan Tree Transplants. *HortScience*, *57*(7), 806–810. https://doi.org/10.21273/hortsci16627-22

Wells, L. (2023). *Nutritional, Environmental, and Cultural Disorders of Pecan*.

Wood, B. W. (1996). Establishing Pecan Transplants. *HortTechnology*, *6*(3), 276–279. https://doi.org/10.21273/horttech.6.3.276

Wood, B. W., & Stahmann, D. (2004). *Hedge pruning pecan.* Cabi Digital Library. https://www.cabidigitallibrary.org/doi/abs/10.5555/20203451423

Wood, B. W. (2009). *Mechanical Hedge Pruning of Pecan in a Relatively Low-light Environment.* HortScience horts, 44(1), 68-72. https://doi.org/10.21273/HORTSCI.44.1.68

Worley, R. E. (1982). Tree Yield and Nut Characteristics of Pecan with Drip Irrigation under Humid Conditions1. *Journal of the American Society for Horticultural Science*, *107*(1), 30–34. https://doi.org/10.21273/JASHS.107.1.30

Worley, R. E., Mullinix, B. G., & Daniel, J. W. (1996). Selective limb pruning, tree removal, and paclobutrazol growth retardant for crowding pecan trees. *Scientia horticulturae*, *67*(1-2), 79-85.

CHAPTER 2

EFFECT OF A REDUCED IRRIGATION RATE ON HEDGED AND NON-HEDGE PRUNED PECAN TREES IN THE SOUTHEASTERN UNITED STATES[1]

[1] Rayfield, B.A. and Wells, M.L. To be submitted to a peer-reviewed journal Hort Science.

Abstract

The United States is the leading producer of pecans worldwide, and Georgia often leads production within the nation. Since 2010, pecan (*Carya illinoinensis*) trees in Georgia have experienced higher density plantings which enhances the need for better water use efficiency. This study investigates the impact of reduced irrigation and hedge pruning on pecan yield, nut quality, and water efficiency in Georgia's pecan orchards. While irrigation practices is essential for maintaining pecan yield and quality, improper scheduling can lead to inefficient water use. This research focuses on two primary variables: irrigation rate and hedge pruning, a technique that modifies tree structure to manage canopy size and improve water use efficiency. The study was arranged as a split-plot design with pruning serving as the main plot effect and irrigation serving as the split plot effect. Hedging treatments (Hedged or Non-Hedged) were arranged in blocks of three trees each with each irrigation treatment occurring once per block as follows: 1) full rate irrigation; 2) reduced rate irrigation; 3) non-irrigated control using individual trees. Hedged blocks were replicated four times, and the non-hedged blocks were replicated three times. Hedge pruning did not significantly affect water stress in the current study, although it did reduce yield in the initial years due to the removal of fruiting wood. However, by the third year, yield differences between hedged and non-hedged trees were minimal. Additionally, hedge pruning increased percent kernel and leaf area in pruned trees, highlighting its potential for improving nut quality. Furthermore, the reduced irrigation rate did not negatively affect yield or nut quality on hedged nor on non-hedged trees, suggesting that irrigation rates could be safely reduced by 34% from April-July, offering a sustainable approach to water conservation without compromising production. These findings underscore the potential for hedge pruning and irrigation adjustments to enhance pecan orchard management and sustainability in the southeastern U.S.

INDEX WORDS: *Carya illinoinensis,* hedging, sustainability, water use efficiency

Introduction

The state of Georgia accounts for nearly 1/3 of United States pecan production (NASS, 2022), leading the nation with 147,000 bearing acres in 2022, producing 131 million pounds of pecans (USDA, 2024). The pecan crop in Georgia was valued at 212.6 million dollars in 2022, making it a vital horticultural crop for Georgia's agricultural economy (USDA, 2024). Georgia's pecan acreage endured a significant period of growth from 2010-2018, due to elevated pecan prices resulting from the burgeoning Chinese market (Wells, 2018).

Tree nuts have a high-water requirement, which leads to concerns about water sustainability (Vanham et al., 2020). Pecan trees may require greater water use than many agronomic row crops, so a thorough understanding of water use in a given growing environment is crucial (Andales et al., 2006). Irrigation is valuable for pecan production because it directly affects yield, nut size, and nut quality, but a common issue among the industry is improper management of irrigation frequency and scheduling (Stein et al., 1989).

Rainfall is variable in the southeastern United States and the region frequently suffers dry periods in spring, summer, and fall, therefore evaporation can exceed rainfall received at crucial periods for nut set, nut growth, and nut development (Worley, 1982). Because pecans are prone to alternate bearing like many other fruit trees, adequate amounts of water are needed to consistently produce the crop and reduce stress on the trees (Conner and Worley, 2000). In addition to its value for pecan crop production, responsible irrigation offers a means for growers to reduce inputs, conserve limited water resources, and maintain consistent production (Garrot et al., 1993).

The Southeastern U.S. consists of hot summers with an annual rainfall average of 127 cm or more (Sammis et al., 2004). Although Georgia has significant rainfall each year, pecan trees may undergo water stress during intermittent droughts typically in August and September (Wells, 2015). Irrigation practices and the appropriate timing of water availability determine pecan yield and quality (Stein et al. 1989). The pecan's physiological development along with climatological factors impact the trees' water demand. Prior to canopy development and nut set in late spring there is less demand for water compared to the nut development and kernel filling period from mid-June through September in the southeastern United States (Sammis et al., 2013). In response, irrigation scheduling techniques for pecans in the region have evolved to meet this demand during critical times, while taking advantage of periods of less water demand, to reduce irrigation water application (Wells, 2015).

Mature pecan orchards intercept between 65% to 70% of sunlight, affecting photosynthetic rates (Wood, 1996). Tree overcrowding results in competition for nutrients and lower yields if not managed properly (Anadales et al., 2006; Wood and Stahmann, 2004). Hedge pruning is a practice that has been rapidly adopted to help combat excessive shading while maintaining higher yields. Hedge pruning involves limb removal at a certain distance from the trunk combined with a reduction in tree height by topping the tree at a height no greater than forty feet. This creates a smaller, more compact tree. Thus, hedge pruning allows growers to manage the size and shape of the trees to prevent canopy overlap, manage crop load, enhance quality, maintain better spray coverage, and reduce storm damage (Wells, 2018).

There is also evidence to suggest that hedge-pruned pecan trees may exhibit lower water use and improved water efficiency due to smaller canopy size while maintaining quality and yield in the southeastern U.S. (Wells, 2018). The pruning of crops in general, not specific to pecans, can be beneficial for water availability and efficiency. In a study conducted in an agroforestry system in Kenya which analyzed *Grevillea robusta*, southern silky oak tree, and maize, indicated that the water balance was significantly improved by pruning, resulting in a decreased water demand (Jackson et al., 1999). In another study investigating crop water use with a pruning treatment, winter wheat that was root pruned indicated better water use efficiency and less water uptake compared to un-pruned while also showing no significant difference between the yields (Shou et al., 2008). These studies suggest the potential for hedge pruning as a tool to minimize use of water resources while maintaining yield which is vital to increasing the sustainability of crop production.

The objectives of this study were to determine the effect of a reduced irrigation rate on pecan yield, nut size, and nut quality in hedge pruned and non-hedge pruned trees. Additionally, this study attempted to determine if hedge pruning affects leaf area and the rate of nut development under varying irrigation rates.

Materials and Methods

Studies were conducted in 2022, 2023 and 2024 at the University of Georgia Ponder Research Orchard near Tifton, GA. The orchard was located at lat. 31°51′N and long. 83°64′W. Orchard soils consisted of Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). 'Cape Fear' pecan trees were planted in 2008 and are spaced at 40 × 40 ft throughout the orchard. The orchard was managed under commercial conditions in accordance with the University of Georgia Cooperative Extension recommendations (Wells, 2017). Vegetation-free strips 12 ft wide were maintained along each tree row using the herbicides glyphosate and indaziflam. Row middles consisted of Bermudagrass (*Cynodon dactylon*) sod.

The study was arranged as a split-plot design with pruning serving as the main plot effect and irrigation serving as the split plot effect. Hedging treatments (Hedged or Non-Hedged) were arranged in blocks of three trees each with each irrigation treatment occurring once per block as follows: 1) full rate irrigation; 2) reduced rate irrigation; 3) non-irrigated control using individual trees. Hedged blocks were replicated four times, and the non-hedged blocks were replicated three times.

Hedge-pruned trees had all growth beyond 8' from the trunk on the East side of the tree pruned in January 2022 and on the West side of the tree in January 2023 using a mechanical hedge-pruner (Tol Incorporated, Tulare, Ca). Trees were topped on each side in their respective years at an angle with a peak at 40'. Trees were not pruned in 2024.

The orchard is irrigated with micro sprinkler irrigation using one micro sprinkler per tree positioned on the N side of the tree within the vegetation free strip ≈1.2 m from the base of the tree. Irrigation was set on a timer with irrigation occurring every other day from April-July and daily in August and September for varying duration times each month as the season progressed

(Table 1). Irrigation was stopped for 3 days following a rainfall event of 1" or more from April to July. The full irrigation rate was based on the UGA recommended irrigation schedule for pecans (Wells, 2015). Irrigation rates were controlled by varying the size of micro sprinkler emitters (full = 60.56 l/h, reduced = 39.7 l/h, control= 0 l/h) from April-July. In August and September both irrigated treatments received the 100% daily irrigation rate to ensure kernel filling was not inhibited during peak water demand.

Mid-day stem water potential (ψ) was measured using a pump pressure chamber (PMS Instruments, Albany, OR) to assess water stress on a weekly basis for 16 weeks from June through September. Soil moisture was measured at the same time as stem ψ with a Field Scout TDR 300 (Spectrum Technologies, Aurora, IL) at 20 cm depth within the wetted zone of micro sprinklers ≈1.2 m from the base of the tree.

Leaf area was measured once during the growing season in 2023 and 2024 between September and October using a LI-COR LI-3000C portable area meter (LI-COR Technologies, Lincoln, NE). Leaf area samples included three leaflets per tree collected from mid to low canopy level.

At harvest, nuts were shaken from the trees onto tarps under each tree and all nuts were hand harvested and weighed. A 50-nut sample was collected from each tree to assess individual nut weight and pecan kernel quality (nut size and percent kernel). Two-way analysis of variance (ANOVA) was used to determine significant differences in yield, nut growth, and nut quality among and between treatments. Means were separated using Tukey's honestly significant difference test ($P \leq 0.05$). Statistical analysis was conducted using SigmaPlot statistical software.

Results and Discussion

A weather station at the study site recorded 61.0, 74.4, and 74.1 cm of rainfall from April through September for 2022, 2023, and 2024, respectively. The rainfall total for the study period from 2022-2024 was excessive, given the mean annual rainfall of 60 cm for this same period from 1981-2010. Suggested seasonal total water requirements of pecan range from 127 to 147 cm (Madden, 1969; Sammis et al., 2004). Precipitation was not evenly distributed throughout the growing season, suggesting a need for irrigation (Fig. 1).

Stem ψ was variable over the course of each growing season (Fig. 2). Dry conditions throughout June of 2022 led to reduced stem ψ during that period but trees recovered quickly. In 2023 and 2024, the greatest reduction in stem ψ occurred in August (Fig. 2). Pecan trees grown in humid climates may undergo water stress at ≈−0.78 MPa (Wells, 2015). Hedge-pruning, alone, did not significantly impact stem ψ (Table 2). Season long stem ψ averaged -0.58, -0.62, and -0.73 MPa for hedged trees and -0.63, -0.65, and -0.77 MPa for non-hedged trees for 2022, 2023, and 2024, respectively. A previous study by Wells (2018) demonstrated enhancement of stem water potential with hedge-pruning. Although there was a slight trend for improved stem ψ with hedging in the current study, the high degree of tree-to-tree variation within single tree replications coupled with rainfall during the study period likely resulted in the lack of statistical significance. From 2022-2024, stem ψ was lower in the control treatment than the two irrigation treatments, indicating greater water stress for the control treatment (Table 3). Average stem ψ was -0.55, -0.58, and -0.71 MPa for full irrigation, -0.60, -0.61, and -0.70 MPa for reduced irrigation and -0.67, -0.72, and -0.84 MPa for the control in 2022, 2023, and 2024, respectively.

Hedge pruning led to a significant ($P \leq 0.05$) reduction in pecan yield per tree in 2023, but not in 2022, nor in 2024 (Table 2). Average yield for hedge-pruned trees was 91, 34, and 99 lbs. per tree in 2022, 2023, and 2024, respectively and 113, 130, and 77 lbs. per tree for non-hedged trees in 2022, 2023, and 2024. The yield reduction by hedge pruning in 2023 was likely the result of two repeated years of hedge pruning. Trees beyond about 12 years of age generally lose a larger amount of fruiting wood in the initial stages of a hedge-pruning program as a significant amount of fruiting wood is removed. This loss of fruiting wood can lead to a temporary reduction in fruit production, but over time, with proper management, the new growth of fruiting wood may enhance overall yield and fruit quality (Lombardini, 2006). Thereafter, yield tends to be less affected by pruning because smaller cuts are made to the tree, and less fruiting wood is removed when trees are hedged. Pruning any given face of the tree on a four-year cycle rather than a three-year cycle may likely reduce yield loss as well, because additional time is provided between pruning cuts, potentially maintaining more fruiting wood and enhancing yield.

In 2023, yield was significantly ($P \leq 0.05$) higher in the reduced rate irrigation treatment than in the other treatments (Table 2). Yields were 111, 103, and 91 lbs. per acre for the full, reduced, and control treatments, respectively, in 2022; 78, 95, and 73 lbs. per acre for the full, reduced, and control treatments in 2023; and 103, 82, and 80 lbs. per acre for the full, reduced, and control treatments in 2024. Rainfall was significant in each year of the study; therefore, irrigation treatment effects were minimal. There were no hedging X irrigation treatment interactions with regard to yield.

Nut weight was affected by hedging treatment only in 2024, when nut weight was heavier in non-hedged than in hedged trees (Table 2). Previous studies have demonstrated an increase in nut weight with hedge pruning (Wells, 2018; Wells, 2024). The fact that we saw no difference in nut weight in 2022 and 2023 is consistent with the onset of previous hedging studies, which have shown similar results in initial study years, followed by an increase in nut weight of hedged trees after two to three years (Wells, 2018; Wells, 2024). The larger nut weight we observed for non-hedged trees in 2024 could have been related to fewer nuts per tree on on-hedged trees as reflected in the lower yield per tree for non-hedged trees in that year, as well as suitable rainfall in addition to irrigation to aid in nut sizing.

Percent kernel was significantly($P<0.05$) higher from hedged trees in 2023 and 2024 (Table 2). This is consistent with results from previous studies demonstrating that hedge pruning enhances percent kernel (Lombardini, 2006; Wells, 2018; Wells, 2024). Irrigation treatment did not affect percent kernel during any year of the current study; however, there was a significant hedging X irrigation interaction in 2023, in which hedge-pruned trees had a higher percent kernel than non-hedged trees under the full irrigation treatment (Table 2). Yield for hedged trees was also significantly lower than non-hedged trees in 2023, which often leads to higher percent kernel.

Pecan leaf area was significantly ($p<0.001$) larger in hedge pruned than non-hedge pruned trees in 2023 but not in 2024 (Table 2). This likely results from the fact that trees in the hedging treatment were hedge-pruned in 2023, but no trees were pruned in 2024 since that was scheduled as the off year for pruning. Leaf area was not affected by irrigation treatment throughout the study.

Conclusion

The current study demonstrated benefits of hedge pruning for pecan production in the southeastern United States. Among these was an increase in percent kernel for hedged vs. non-hedged trees and increased leaf area for hedged trees in the year of hedging. This is similar to the findings of previous studies (Wells, 2018; Wells, 2024). In the second year of the study (2023), pecan yield was reduced by hedge pruning, but this is not uncommon when the hedge pruning system is initially implemented on trees outside the optimal age window for initiation of hedge pruning. In such situations, this reduction is only temporary and appears to result from the removal of excess fruiting wood when large hedging cuts are made. This appeared to be the case for the current study as there was no significant difference in pecan yield between hedging treatments in years 1 (2022) and 3 (2024) of the study. Extending the period between hedge pruning cuts would also be likely to minimize or eliminate yield reduction with hedging.

These results demonstrate that the reduced rate irrigation schedule did not result in any negative impact on pecan yield, nut weight, or percent kernel (Table 2) for both hedged and non-hedged trees. This suggests that the currently recommended irrigation schedule for Georgia pecan production (Wells, 2015), could be further reduced from April-July with no impact on pecan production for both hedged and non-hedged trees under the environmental conditions found in this study, which are indicative of conditions found in the southeastern United States. This represents a potential 34% reduction in irrigation water application for the April-July period of the growing season. Further work should focus on an examination of this irrigation regime under drought conditions and in deep sand soils to determine its application potential under such conditions.

References

Andales, A., Wang, J., Sammis, T. W., Mexal, J. G., Simmons, L. J., Miller, D. R., & Gutschick, V. P. (2006). A model of pecan tree growth for the management of pruning and irrigation. *Agricultural Water Management*, *84*(1-2), 77–88. https://doi.org/10.1016/j.agwat.2006.02.012

Conner, P. J., & Worley, R. E. (2000). Alternate Bearing Intensity of Pecan Cultivars. *HortScience*, *35*(6), 1067–1069. https://doi.org/10.21273/hortsci.35.6.1067 Costa, J. M., Ortuño, M. F., & Chaves, M. M. (2007). Deficit irrigation as a strategy to save water: Physiology and potential application to horticulture. In *Journal of Integrative Plant Biology* (Vol. 49, Issue 10, pp. 1421–1434). https://doi.org/10.1111/j.1672-9072.2007.00556.x

Garrot, D. J., Kilby, M. W., Fangmeier, D. D., Husman, S. H., & Ralowicz, A. E. (1993). Production, Growth, and Nut Quality in Pecans under Water Stress Based on the Crop Water Stress Index. *Journal of the American Society for Horticultural Science*, *118*(6), 694–698. https://doi.org/10.21273/JASHS.118.6.694

Jackson, N. A., Wallace, J. S., & Ong, C. K. (1999). *Tree pruning as a means of controlling water use in an agroforestry system in Kenya*.

Lombardini, L. (2006). One-time pruning of pecan trees induced limited and short-term benefits in canopy light penetration, yield, and nut quality. *HortScience*, *41*(6), 1469–1473. https://doi.org/10.21273/hortsci.41.6.1469

Madden, G.D. 1969 Effects of supplemental irrigation of pecans *Proc. Texas Pecan Growers Assn. 48* 54 56

Ma, S. C., Li, F. M., Xu, B. C., & Huang, Z. bin. (2009). Effects of root pruning on the growth and water use efficiency of winter wheat. *Plant Growth Regulation*, *57*(3), 233–241. https://doi.org/10.1007/s10725-008-9340-1

Sammis, T. W., Mexal, J. G., & Miller, D. (2004, August 17). *Evapotranspiration of flood-irrigated pecans*. Agricultural Water Management. https://www.sciencedirect.com/science/article/pii/S0378377404001490

Sammis, T., Gutschick, V., Wang, J., & Miller, D. R. (2013). Model of water and nitrogen management in pecan trees under normal and resource-limited conditions. *Agricultural Water Management*, *124*, 28–36. https://doi.org/10.1016/j.agwat.2013.03.012

Stein, L. A., McEachern, G. R., & Storey, J. B. (1989). Summer and Fall Moisture Stress and Irrigation Scheduling Influence Pecan Growth and Production. *HortScience*, *24*(4), 607–611. https://doi.org/10.21273/HORTSCI.24.4.607

USDA. (2022). *New Mexico: 2020 – 2022 Pecan Bearing Acreage*. https://www.nass.usda.gov/Statistics_by_State/New_Mexico/Publications/Special_Interest_Reports/NM-Pecan-County-Estimates-05122023.pdf

USDA ERS. (2024). *Data by Commodity - Imports and Exports*. USDA ERS - Data Products. https://data.ers.usda.gov/reports.aspx?programArea=fruit&top=5&HardCopy=True&RowsPerPage=25&groupName=Tree+nuts&commodityName=Pecans&ID=17851#Pc9ff0bfa5ea149d6866663efe4ce1660_3_1273

USDA. (2024). *USDA*. USDA Regional News Release. https://www.nass.usda.gov/Statistics_by_State/New_Mexico/Publications/News_Releases/2023/NM-Crop-Production-12082023.pdf

Vanham, D., Mekonnen, M., & Hoekstra, A. (2020, February 13). *Treenuts and groundnuts in the eat-lancet reference diet: Concerns regarding sustainable water use*. Global Food Security. https://www.sciencedirect.com/science/article/pii/S2211912420300109

Wells, L. (2015a). Irrigation Water Management for Pecans in Humid Climates. *HortScience*, *50*(7), 1070–1074. https://doi.org/10.21273/hortsci.50.7.1070

Wells, L. (2015c, June 18). *Irrigation Schedule for Pecan Production | UGA Pecan Extension*. Site.extension.uga.edu. https://site.extension.uga.edu/pecan/2015/06/irrigation-schedule-for-pecan-production/

Wells, L. (2017a). *Pecan: America's native nut tree*. The University Of Alabama Press.

Wells, L. (2017b). Response of Young Pecan Trees to Irrigation in a Humid Climate. *HortScience*, *52*(3), 457–462. https://doi.org/10.21273/hortsci11664-16

Wells, L. (2018). Mechanical Hedge Pruning Affects Nut Size, Nut Quality, Wind Damage, and Stem Water Potential of Pecan in Humid Conditions. *HortScience*, *53*(8), 1203–1207. https://doi.org/10.21273/hortsci13217-18

Wells, L. (2024). Summer Hedge Pruning of Pecan in the Southeastern United States. *HortScience*, *59*(6), 756-758. https://doi.org/10.21273/HORTSCI17775-24

Wells, L., & Sawyer, A. (2022). Planting Site Effects on Early Growth of Pecan Tree Transplants. *HortScience*, *57*(7), 806–810. https://doi.org/10.21273/hortsci16627-22

Wood, B. W., & Stahmann, D. (2004). *Hedge pruning pecan.* Cabi Digital Library. https://www.cabidigitallibrary.org/doi/abs/10.5555/20203451423

Worley, R. E. (1982). Tree Yield and Nut Characteristics of Pecan with Drip Irrigation under Humid Conditions1. *Journal of the American Society for Horticultural Science*, *107*(1), 30–34. https://doi.org/10.21273/JASHS.107.1.30

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

Month	Irrigation Water Application Rate	
	Full Schedule (liters per tree per week)	Reduced Schedule (liters per tree per week)
April	726	477
May	1090	715
June	1453	954
July	1817	1193
August	5087	5087
September	5087	5087

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

Year Treatment		Stem ψ (MPa)	Yield (lb./tree)	Nut Weight (g)	Percent Kernel	Leaf Area (mm)
2022						
Hedged						
Full Schedule		-0.53	75.5	9.7	54.7	---
Reduced Schedule		-0.58	91.9	10.1	55.6	---
Non-Irrigated		-0.64	106.2	9.3	56.2	---
Non-Hedged						
Full Schedule		-0.57	148.1	10.2	54.2	---
Reduced Schedule		-0.61	89.9	10.2	55.4	---
Non-Irrigated		-0.71	100.1	9.7	54.9	---
P value	Hedging	0.12	0.16	0.29	0.17	---
	Irrigation	0.006	0.52	0.24	0.13	---
	HedgingXIrrig.	0.83	0.08	0.83	0.61	---

2023						
Hedged						
Full Schedule		-0.58	30.4	9.6	54.3	34.4
Reduced Schedule		-0.63	39.1	9.5	53.8	27.3
Non-Irrigated		-0.67	31.7	9.1	52.5	31.4
Non-Hedged						
Full Schedule		-0.58	124.9	10.1	49.7	27.2
Reduced Schedule		-0.59	150.8	9.1	51.7	30.5
Non-Irrigated		-0.77	113.4	9.4	52.3	29.0
P value	Hedging	0.45	<0.001	0.47	0.002	<0.001
	Irrigation	0.003	0.05	0.14	0.61	0.38
	HedgingXIrrig.	0.26	0.27	0.38	0.03	0.21
2024						
Hedged						
Full Schedule		-0.67	101.3	9.0	53.2	27.8
Reduced Schedule		-0.72	104.9	9.2	53.0	29.7
Non-Irrigated		-0.79	91.4	8.2	54.0	31.0
Non-Hedged						
Full Schedule		-0.75	104.5	10.4	51.6	27.2
Reduced Schedule		-0.69	59.4	10.1	52.1	30.5

Non-Irrigated		-0.88	67.6	10.1	52.4	29.0
P value	Hedging	0.16	0.26	<0.001	0.02	0.72
	Irrigation	<0.001	0.58	0.36	0.36	0.44
	HedgingXIrrig.	0.22	0.60	0.49	0.76	0.80

Table 3. Average stem water potential (ψ) among irrigation treatments in full, reduced, and non-irrigated control treatments during 2022, 2023, 2024.

Year Treatment	Stem ψ (MPa)
2022	
Full Schedule	-0.55b
Reduced Schedule	-0.60b
Non-Irrigated	-0.67a
2023	
Full Schedule	-0.58b
Reduced Schedule	-0.61b
Non-Irrigated	-0.72a
2024	
Full Schedule	-0.71b
Reduced Schedule	-0.70b
Non-Irrigated	-0.84a

Figure 1**A**. Daily rainfall distribution from April to September during (**A**) 2022 at the University of Georgia Ponder Research Farm.

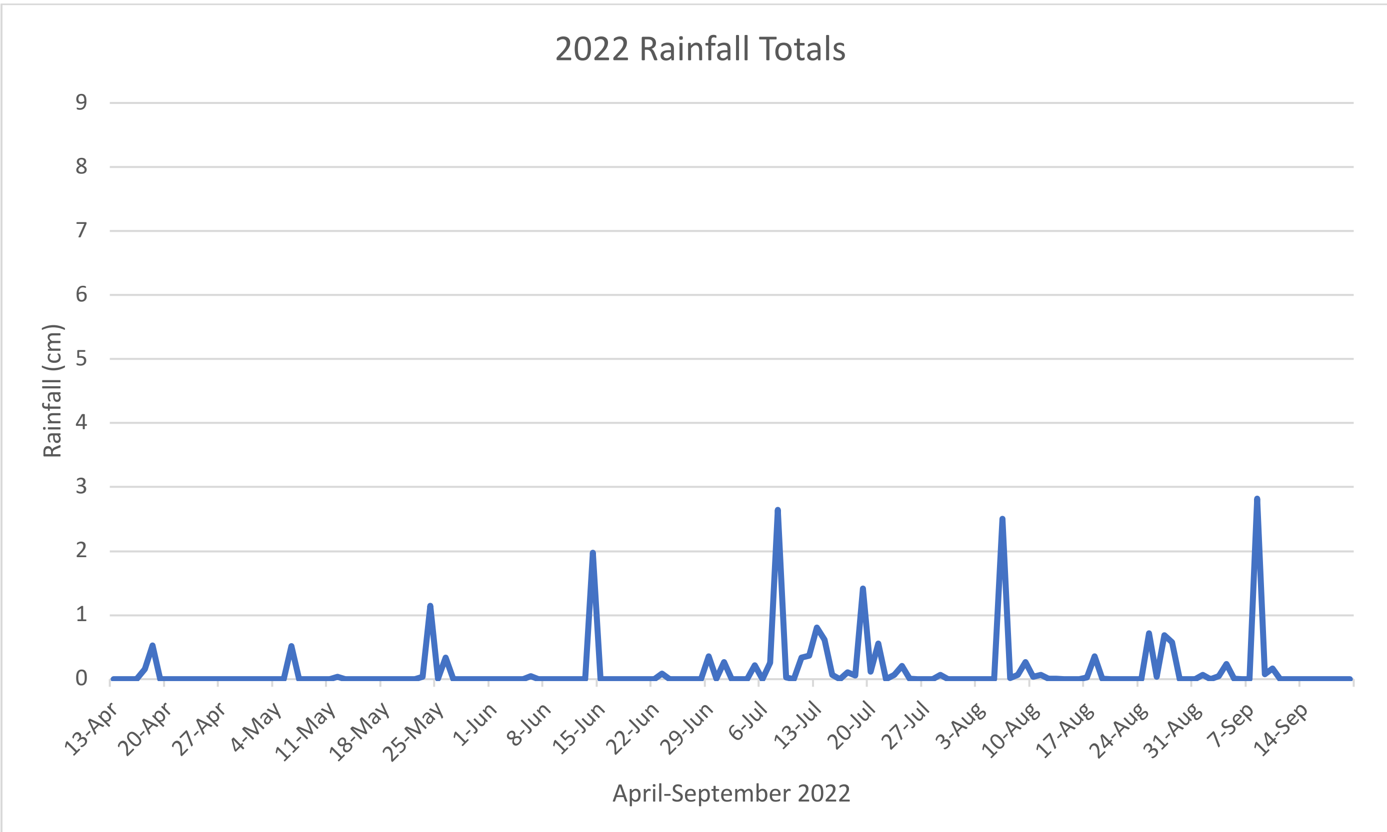

Figure 1**B**. Daily rainfall distribution from April to September during (**B**) 2023 at the University of Georgia Ponder Research Farm.

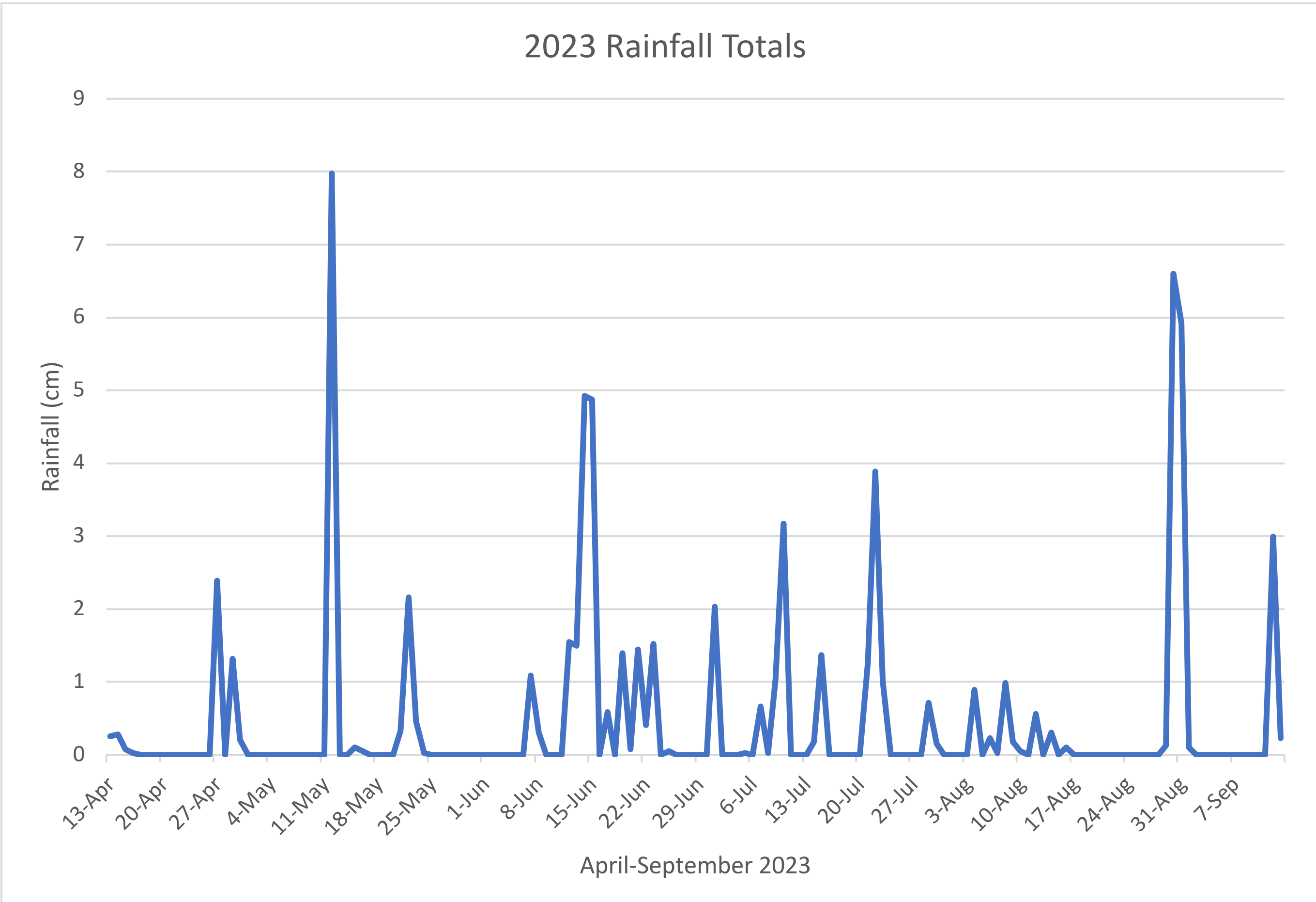

Figure 1**C**. Daily rainfall distribution from April to September during (**C**) 2024 at the University of Georgia Ponder Research Farm.

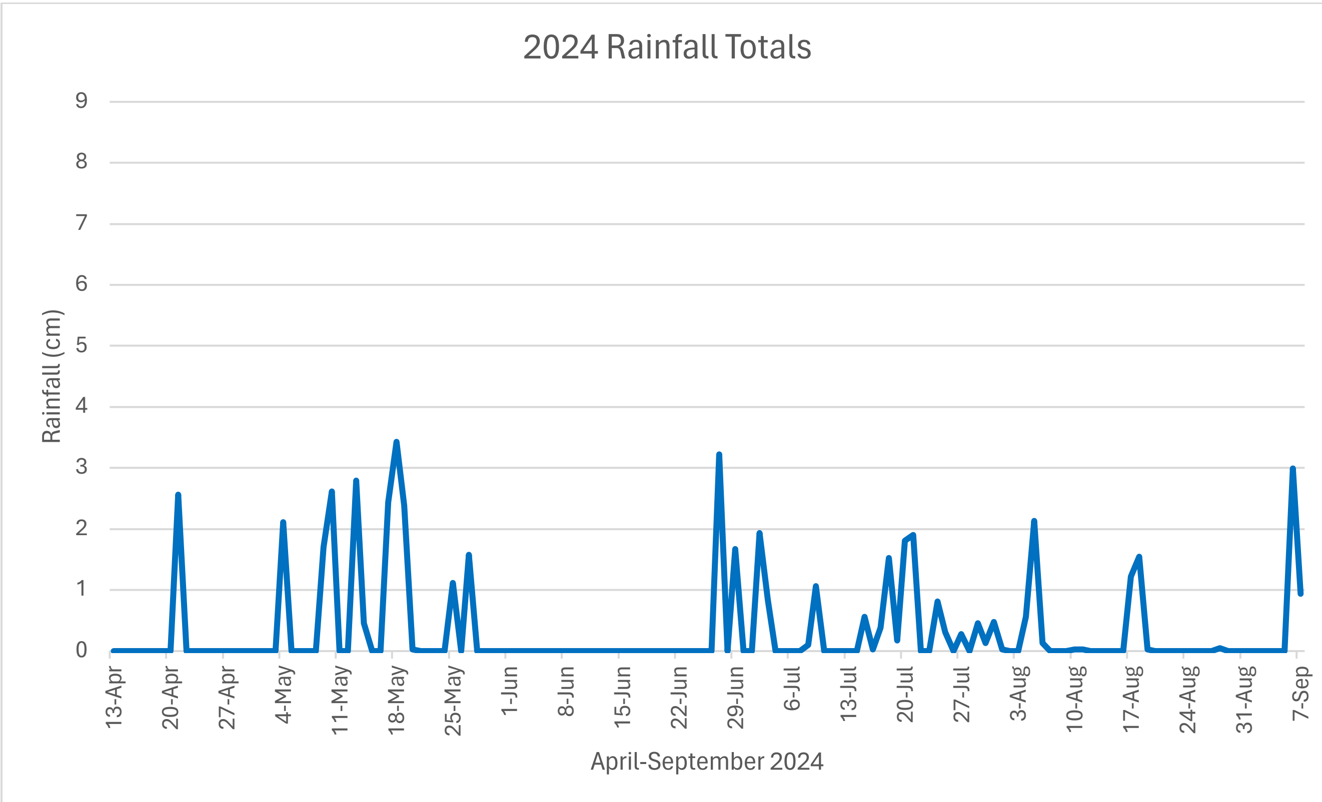

Figure 2**A**. Mean stem water potential (ψ) of pecan trees in full irrigation, reduced irrigation, and non-irrigated treatments (**A**) 2022.

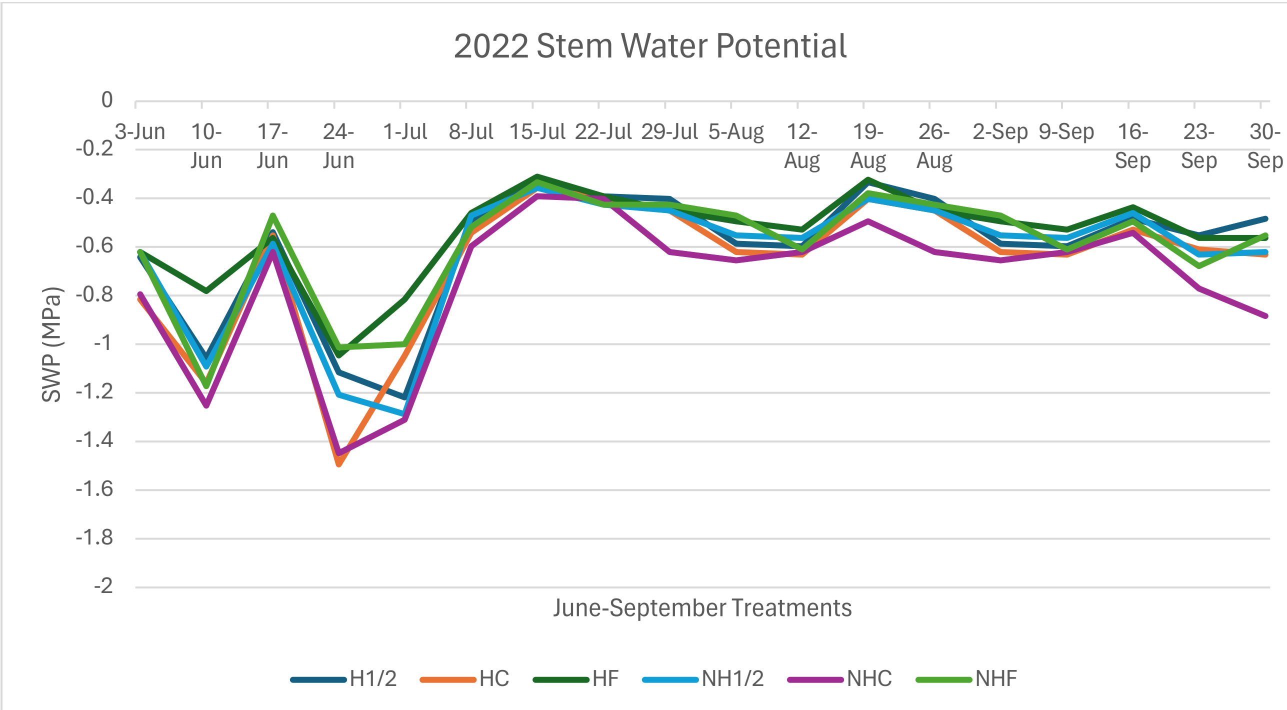

Figure 2**B**. Mean stem water potential (ψ) of pecan trees in full irrigation, reduced irrigation, and non-irrigated treatments (**B**) 2023.

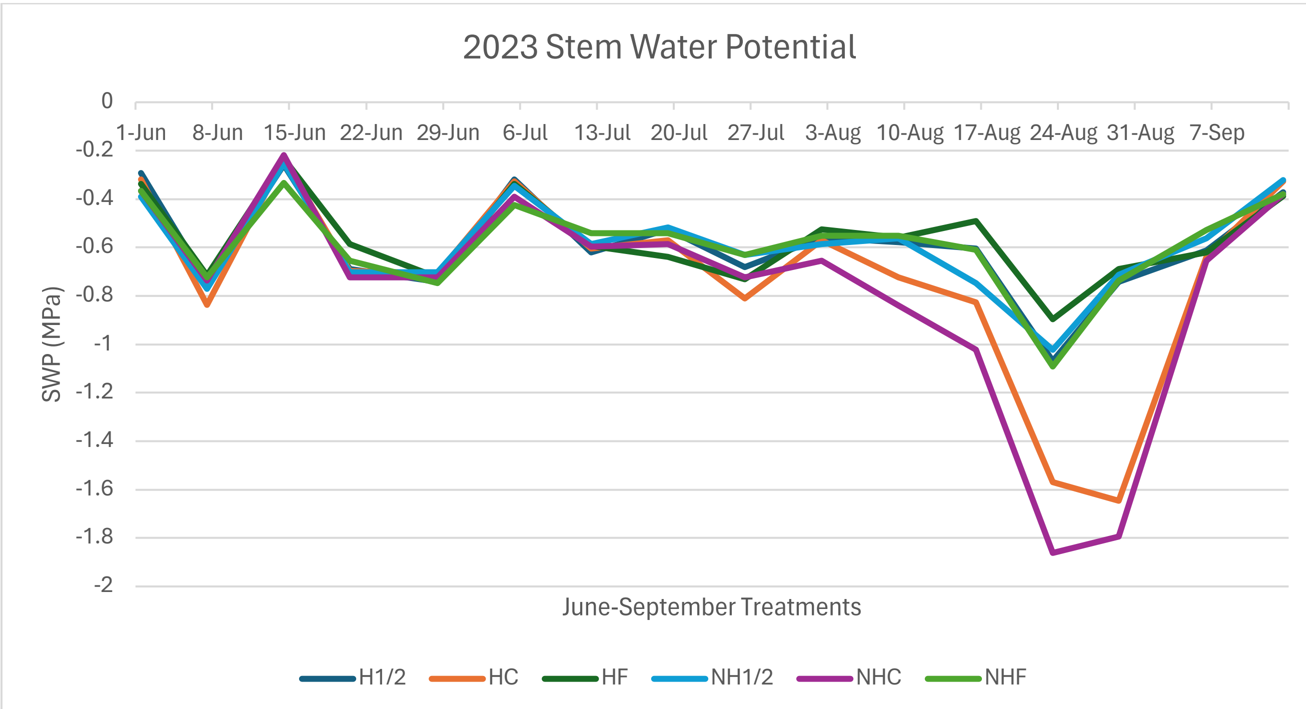

Figure 2**C**. Mean stem water potential (ψ) of pecan trees in full irrigation, reduced irrigation, and non-irrigated treatments (**C**) 2024.