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Effect of a Reduced Irrigation Rate on Hedge- and Nonhedge-pruned Pecan Trees in the Southeastern United States

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Abstract. **The United States is the leading producer of pecans worldwide, and Georgia, USA, often leads production within the nation. Since 2010, pecan (*Carya illinoinensis*) trees in Georgia have been planted at a higher density, which enhances the need for better water use efficiency. We investigate the effect of reduced irrigation and hedge pruning on pecan yield, nut quality, and water efficiency in Georgia's pecan orchards. Although irrigation practices are essential for maintaining pecan yield and quality, improper scheduling can lead to inefficient water use. Our 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 nonhedged) 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, and 3) nonirrigated control using individual trees. Hedged blocks were replicated four times; the nonhedged blocks were replicated three times. Hedge pruning did not affect water stress significantly in our study, with the exception of year 2 (2022), which was a result of the successive removal of fruiting wood during the first 2 years. However, by the third year, yield differences between hedged and nonhedged trees were nonsignificant. In addition, 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 affect yield or nut quality negatively for hedged or nonhedged trees, suggesting that irrigation rates could be reduced safely by 34% from April to 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 United States.**

Georgia, USA, accounts for nearly one third of US pecan production, leading the nation with 59,084 ha in 2022, producing 59,420 mt of pecans (US Department of Agriculture 2024). The pecan crop in Georgia was valued at $211 million in 2022, making it a vital horticultural crop for Georgia's agricultural economy (US Department of Agriculture 2024). Georgia's pecan acreage endured a significant period of growth from 2010 to 2018 as a result of 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 produce the crop and reduce stress on the trees consistently (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 United States has hot summers and an annual average rainfall of 127 cm or more (Worley 1982). Although Georgia, USA, 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). Irrigation management strategies such as regulated deficit irrigation may be used to conserve water during periods of low water demand (Costa et al. 2007). The pecan's physiological development along with climatological factors affect the trees' water demand. Before canopy development and nut set in late spring, there is less demand for water compared with the nut development and kernel filling period from mid-June through September in the southeastern United States (Sammis et al. 2013; Zhang et al. 2025). In response, irrigation scheduling techniques for pecans in the southeastern United States 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, 2016).

Mature pecan orchards intercept between 65% and 70% of sunlight, affecting photosynthetic rates (Wood 1996). Tree overcrowding results in competition for nutrients and lower yields if not managed properly (Andales et al. 2006; Wood and Stahmann 2004). Hedge pruning is a practice that has been rapidly adopted to help combat excessive shading while maintaining yields (Wood and Stahmann 2004). 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 12 m. 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 as a result of a smaller canopy size, while maintaining quality and yield in the southeastern United States (Wells 2018). The pruning of crops in general, not specific to pecans, can be beneficial for water availability and efficiency. In a study (Jackson et al. 2000) conducted in an agroforestry system in Kenya that analyzed *Grevillea robusta*, southern silky oak tree, and maize (*Zea mays*), water balance was improved significantly by pruning, resulting in a decreased water demand. This suggests 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 our study were to determine the effect of a reduced irrigation rate on pecan yield, nut size, nut quality, and pecan leaf area in hedge-pruned and nonhedge-pruned trees.

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

	Irrigation water application rate (L/tree/week)	
Month	Full schedule	Reduced schedule
April	726	477
May	1090	715
June	1453	954
July	1817	1193
August	5087	5087
September	5087	5087

Materials and Methods

Studies were conducted in 2022, 2023, and 2024 at the University of Georgia Ponder Research Orchard near Tifton, GA, USA. 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 12.2 × 12.2 m 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 3.7 m 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. Single-tree experimental units were used. Hedging treatments (hedged or nonhedged) 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, and 3) nonirrigated control using individual trees. Hedged blocks were replicated four times; the nonhedged blocks were replicated three times.

Hedge-pruned trees had all growth beyond 2.4m from the trunk on the east side of the tree pruned in Jan 2022, and on the west side of the tree in Jan 2023, using a mechanical hedge pruner (Tol Inc., Tulare, CA, USA). Trees were topped on each side in their respective years at an angle with a peak at 12.2 m. Trees were not pruned in 2024.

The orchard is irrigated with microsprinkler irrigation using one microsprinkler per tree positioned on the north 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 to July, and daily in August and September, for varying durations each month as the season progressed (Table 1). Irrigation was stopped for 3 d after a rainfall event of 2.5 cm or more from April to July. The full irrigation rate was based on the University of Georgia's recommended irrigation schedule for pecans (Wells 2016). Irrigation rates were controlled by varying the size of microsprinkler emitters (full = 60.56 $L \cdot h^{-1}$, reduced = 39.7 $L \cdot h^{-1}$, control = 0 $L \cdot h^{-1}$) from April to 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.

Midday stem osmotic potential (ψ) was determined using a pump-up pressure chamber (PMS Instruments, Albany, OR, USA) by measuring the ψ of leaves located near the trunk or a main scaffold branch that had been enclosed in a foil-covered bag for 20 min (Begg and Turner 1970; Wells 2015). Measurements were made weekly between 1300 and 1500 HR once per week for 16 weeks from June through September. One leaf per tree was measured on each sampling date to keep measurements within close temporal proximity. Soil moisture was measured at the same time as stem ψ with a Field Scout TDR 300 (Spectrum Technologies, Aurora, IL, USA) at a 20-cm depth within the wetted zone of microsprinklers ~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, USA). Leaf area samples included three leaflets per tree collected from the mid to low canopy level.

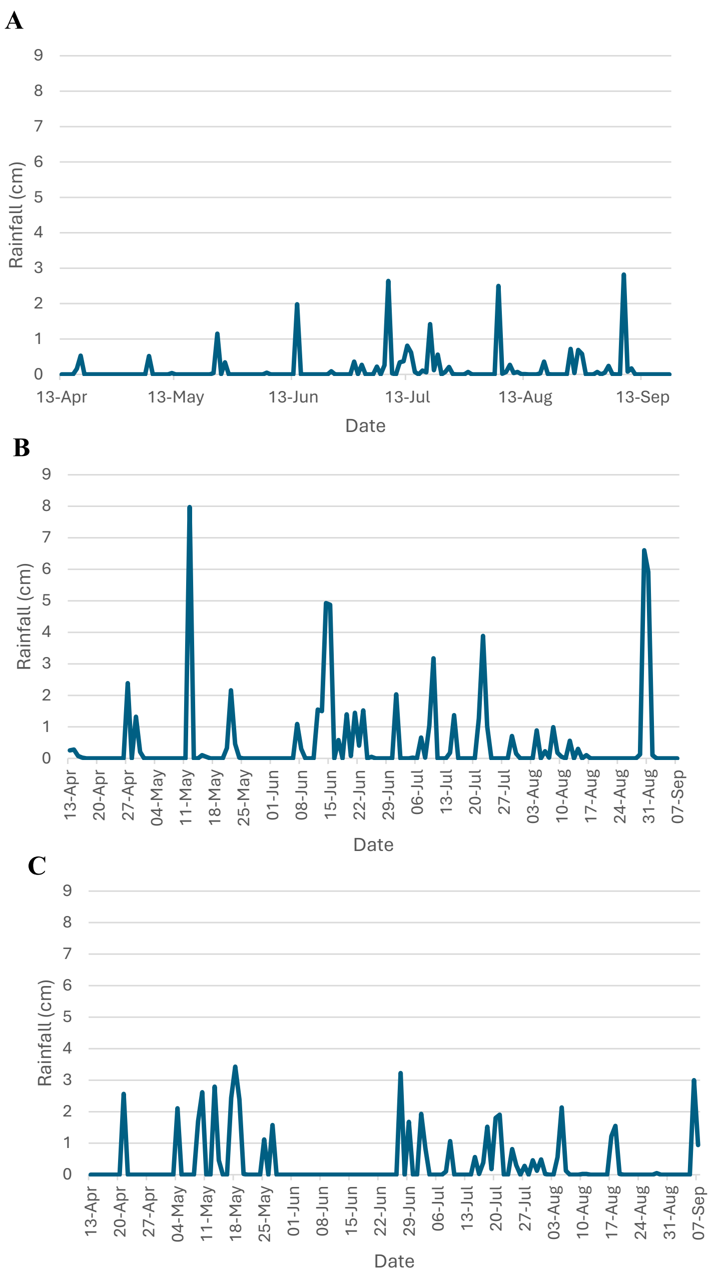

Fig. 1. Daily rainfall distribution from April to September during 2022 (**A**), 2023 (**B**), and 2024 (**C**) at the University of Georgia Ponder Research Farm, Tifton, GA, USA.

Fig. 2. Mean stem water potential of pecan trees in full irrigation, reduced irrigation, and nonirrigated treatments during 2022 (**A**), 2023 (**B**), and 2024 (**C**).

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 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 14 (Systat Software Inc, San Jose, CA, USA).

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 to 2024 was excessive, given the mean annual rainfall of 60 cm for this same period from 1981 to 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 Jun 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 affect stem ψ significantly (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 nonhedged trees for 2022, 2023, and 2024, respectively. A previous study by Wells (2018) demonstrated enhancement of stem ψ with hedge pruning. Although there was a slight trend for improved stem ψ with hedging in our study, the high degree of tree-to-tree variation coupled with rainfall during the study period resulted in a lack of statistical significance. From 2022 to 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 or in 2024 (Table 2). The average yield for hedge-pruned trees was 41.3, 15.4, and 44.9 kg/tree in 2022, 2023, and 2024, respectively; and 51.2, 58.9, and 34.9 kg/tree for nonhedged trees in 2022, 2023, and 2024 (Fig. 3). The yield reduction by hedge pruning in 2023 was likely the result of two repeated years of hedge pruning. Trees beyond ∼12 years of age generally lose a larger amount of fruiting wood in the initial stages of a hedge-pruning program because 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 4-year cycle rather than a 3-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 greater ($P \leq 0.05$) in the reduced-rate irrigation treatment than in the other treatments (Table 2). Yields were 50.3, 46.7, and 41.3 kg/tree for the full, reduced, and control treatments, respectively, in 2022; 35.3, 43.1, and 33.1 kg/tree for the full, reduced, and control treatments in 2023; and 46.7, 37.2, and 36.3 kg/tree for the full, reduced, and control treatments in 2024. Rainfall was significant in each year of the study; therefore, irrigation treatment effects

Table 2. Mean stem water potential, pecan tree yield, nut weight, percent kernel, and leaf area of pecan trees for hedged and nonhedged pecan trees under full irrigation, reduced irrigation, and nonirrigated control treatments from 2022 to 2024.

Year, treatment, *P* value	Stem water potential (MPa)	Yield (kg/tree)	Nut weight (g)	Percent kernel	Leaf area (mm)
2022 Hedged					
Full schedule	–0.53	34.2	9.7	54.7	—
Reduced schedule	–0.58	41.7	10.1	55.6	—
Nonirrigated	–0.64	48.2	9.3	56.2	—
2022 Nonhedged					
Full schedule	–0.57	67.2	10.2	54.2	—
Reduced schedule	–0.61	40.8	10.2	55.4	—
Nonirrigated	–0.71	45.4	9.7	54.9	—
P value					
Hedging	0.12	0.16	0.29	0.17	—
Irrigation	0.006*	0.52	0.24	0.13	—
Hedging × irrigation	0.83	0.08	0.83	0.61	—
2023 Hedged					
Full schedule	–0.58	13.8	9.6	54.3	34.4
Reduced schedule	–0.63	17.7	9.5	53.8	27.3
Nonirrigated	–0.67	14.4	9.1	52.5	31.4
2023 Nonhedged					
Full schedule	–0.58	56.7	10.1	49.7	27.2
Reduced schedule	–0.59	68.4	9.1	51.7	30.5
Nonirrigated	–0.77	51.4	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
Hedging × irrigation	0.26	0.27	0.38	0.03*	0.21
2024 Hedged					
Full schedule	–0.67	45.9	9.0	53.2	27.8
Reduced schedule	–0.72	47.6	9.2	53.0	29.7
Nonirrigated	–0.79	41.5	8.2	54.0	31.0
2024 Nonhedged					
Full schedule	–0.75	47.4	10.4	51.6	27.2
Reduced schedule	–0.69	26.9	10.1	52.1	30.5
Nonirrigated	–0.88	30.6	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
Hedging × irrigation	0.22	0.60	0.49	0.76	0.80

*Significant at $P < 0.05$ for main (hedging) and split-plot (irrigation) effects, and interactions for 2022, 2023, and 2024.

were minimal. There were no hedging × irrigation treatment interactions with regard to yield.

Nut weight was affected by hedging treatment only in 2024, when nut weight was heavier in nonhedged than in hedged trees (Table 2). Previous studies have demonstrated an increase in nut weight with hedge pruning (Wells 2018, 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 2 to 3 years (Wells 2018, 2024). The greater nut weight we observed for nonhedged trees in 2024 could have been related to fewer nuts per tree on nonhedged trees, as reflected in the lower yield per tree for nonhedged trees in that year, as well as suitable rainfall in addition to irrigation to aid in nut sizing.

Percent kernel was significantly greater ($P < 0.05$) 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, 2024). Irrigation treatment did not affect percent kernel during any year of our study; however, there was a significant hedging × irrigation interaction in 2023, in which hedge-pruned trees had a greater percent kernel than nonhedged trees under the full irrigation treatment (Table 2). Yield for hedged trees was also significantly less than nonhedged trees in 2023, which often leads to greater percent kernel.

Pecan leaf area was significantly ($P < 0.001$) larger in hedge-pruned than nonhedge-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 because that was scheduled as the off year for pruning. Leaf area was unaffected by irrigation treatment throughout the study.

Conclusion

Our study demonstrates benefits of hedge pruning for pecan production in the southeastern United States. Among these was an increase in percent kernel for hedged vs. nonhedged trees and increased leaf area for hedged trees in the year of hedging. This is similar to the findings of previous studies (Wells 2018, 2024). In the second year of the

Table 3. Average stem water potential among irrigation treatments in full, reduced, and nonirrigated control treatments during 2022, 2023, and 2024 at Ponder Research Farm, Tifton, GA, USA.

Year and treatment	Stem water potential (MPa)
2022	
Full schedule	–0.55 b[i]
Reduced schedule	–0.60 b
Nonirrigated	–0.67 a
2023	
Full schedule	–0.58 b
Reduced schedule	–0.61 b
Nonirrigated	–0.72 a
2024	
Full schedule	–0.71 b
Reduced schedule	–0.70 b
Nonirrigated	–0.84 a

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

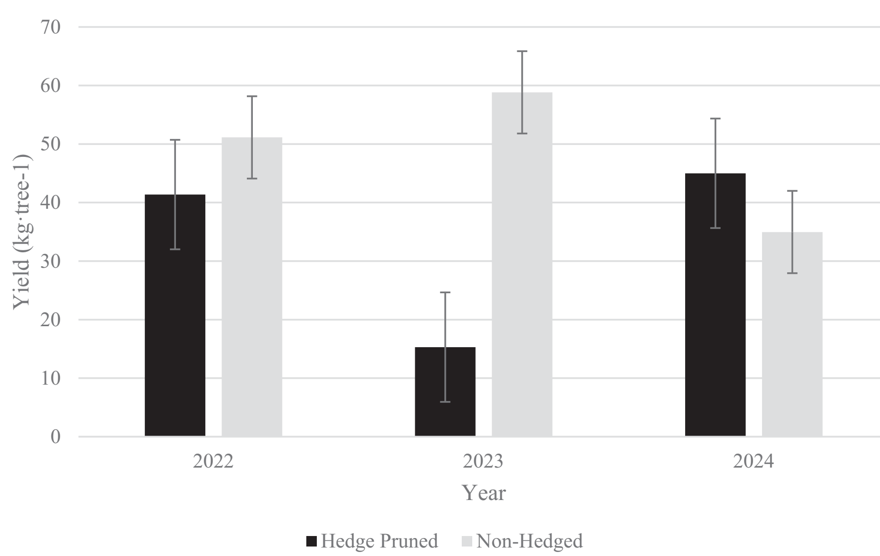

Fig. 3. Pecan yield of hedged and nonhedged pecan trees in 2022, 2023, and 2024 at Ponder Research Farm, Tifton, GA, USA. Values represent means ± standard error.

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 our study because 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 nonhedged trees. This suggests that the currently recommended irrigation schedule for Georgia, USA, pecan production (Wells 2015) could be further reduced from April to July with no impact on pecan production for both hedged and nonhedged trees under the environmental conditions found in our study, which are indicative of conditions found in the humid, southeastern United States. This represents a potential 34% reduction in irrigation water application for the April to 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.

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