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CROP PRODUCTION

High-density pecan trees subjected to hedge and central pruning and thinning in southern Brazil

Cristiano Geremias Hellwig[1*], Antonio Davi Vaz Lima[1], Roseli de Mello Farias[2], Carlos Roberto Martins[3] and Marcelo Barbosa Malgarim[1]

[1]Departamento de Fitotecnia, Programa de Pós-Graduação em Agronomia, Universidade Federal de Pelotas, Av. Eliseu Maciel, s/n, Cx. Postal 354, 96160-000, Capão do Leão, Rio Grande do Sul, Brazil. [2]Universidade Estadual do Rio Grande do Sul, São Borja, Rio Grande do Sul, Brazil. [3]Empresa Brasileira de Pesquisa Agropecuária, Embrapa Clima Temperado, Pelotas, Rio Grande do Sul, Brazil. *Author for correspondence. E-mail: cristiano.hellwig@gmail.com

ABSTRACT. Several high-density pecan orchards have exhibited unsatisfactory growth and production due to excessive shading. This study aimed to investigate hedge and central pruning and tree thinning as alternative solutions to increase the vegetative growth and production of pecan trees in high-density orchards. The experiment was conducted in Santa Rosa, Rio Grande do Sul State, Brazil, using a randomized block design with three replicates, each consisting of five trees. Treatments included: i) control (no treatment), ii) hedge pruning, iii) central pruning, and iv) tree thinning (tree removal). We evaluated vegetative growth, the number of dry branches, and aspects related to production and production efficiency. Tree thinning resulted in increased transverse width, canopy volume, and the number of basal branches, along with a decrease in dry branches per tree. Production was higher in trees subjected to thinning (42.89%), followed by central pruning (39.80%) and hedge pruning (37.03%), compared to the control. The average yield was higher than the control after both pruning methods; hedge and central pruning increased yield by 37.20 and 39.85%, respectively. However, tree thinning decreased yield by 10.80%. Trees subjected to hedge pruning achieved higher production efficiency relative to canopy volume than the control, while, concerning trunk cross-sectional area, tree thinning was more efficient than the control. Tree thinning increases vegetative growth, production, and production efficiency, while hedge pruning and central pruning lead to higher yields.

Keywords: *Carya illinoinensis*; spacing; yield; nuts.

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Introduction

Solar radiation is a key determinant of the productivity of photosynthetic organisms (Durand et al., 2021). The capacity to intercept incident radiation, plant architecture, and the conversion of captured energy into biomass also influence yield (Singh et al., 2020). However, insufficient spacing can increase shading within and among rows when plant height is not regulated (Anthony et al., 2020).

Planting density is a frequently debated topic in pecan cultivation. According to Wells (2017), it varies with region, cultivar, soil characteristics, and farmer preferences. There has been a global trend toward using high planting densities in fruit orchards to maximize production and achieve higher and more precocious profitability per area (Mayer et al., 2016; Azevedo et al., 2015; Souza et al., 2019; Manganaris et al., 2022; Mahmud et al., 2023). Success, however, depends on management techniques to control tree size, such as dwarfing rootstocks (Reig et al., 2020; Li et al., 2023), regular pruning (Zhang et al., 2015), and growth-regulating compounds (Carra et al., 2016).

For pecan trees, the lack of dwarfing rootstocks or cultivars makes size control challenging in high-density orchards (Zhu & Stafne, 2019). Pecan trees can grow up to 40 meters in height and have a spread of 20 meters (Fronza et al., 2018). Many Brazilian farmers have established high-density orchards with more than 100 trees per hectare to achieve high income as soon as the trees start bearing fruit. However, after 10 years, branch overlapping causes shading, which decreases production (Fronza et al., 2018; Fernández-Chávez et al., 2021). Shading reduces bud growth and negatively impacts pecan production and quality due to decreased sugar accumulation (Fernández-Chávez et al., 2021). Additionally, branches may die and cease to be productive in dense orchards with low sunlight penetration, small canopy volume, and fruit developing only in the upper canopy (Worley et al., 1996; Núñez et al., 2001; Lombardini, 2006). Therefore, pruning or thinning is essential to mitigate shading in lower branches (Wood, 2009).

Pruning is crucial for increasing tree production, especially in high-density orchards (Fernández-Chávez et al., 2021). In mature orchards with shading issues, two pruning methods have been tested to open up canopy cover and enhance production: hedge and central pruning. Hedge pruning is mechanized and involves pruning one or both sides of trees laterally to create a wall-like structure. This method, established in the western US, prevents branch overlapping and allows light and air to penetrate canopies, encouraging the growth of new branches (Lombardini, 2006; Wood, 2009; Wells, 2018; Toledo et al., 2024). Central pruning, or selective pruning, involves removing entire branches to allow more sunlight and air to reach the canopy (Worley et al., 1996; Lombardini, 2006).

Thinning or removing adult trees is a difficult decision for farmers due to the significant investment in resources over the years (Lombardini, 2006). While thinning is a common practice for light management in orchards, it temporarily decreases fruit yield per area (Worley et al., 1996; Gong et al., 2020). Tree removal can be done either through suppression with a chainsaw or tree transplanting.

Given the limited studies on this topic under southern Brazilian conditions, this study aimed to evaluate the influence of two pruning methods, tree thinning, and a control (no treatment) on the vegetative growth and production of pecan trees in a high-density orchard.

Material and methods

The experiment was conducted in a commercial pecan orchard in Santa Rosa, Rio Grande do Sul (RS) State, Brazil (27°55'15" S; 54°32'37" W). Five production cycles were evaluated from August 2018 to June 2023. According to the Köppen-Geiger classification, the climate in the area is Cfa (Alvares et al., 2013). The soil is typic dystroferric Red Latosol, and the altitude is 330 meters above sea level (Santos et al., 2018). The orchard was intercropped with sheep farming. Monthly rainfall and maximum and minimum temperatures were monitored throughout the five cycles using data from the Santa Rosa meteorological station - TRMM.291/Agritempo (Figure 1).

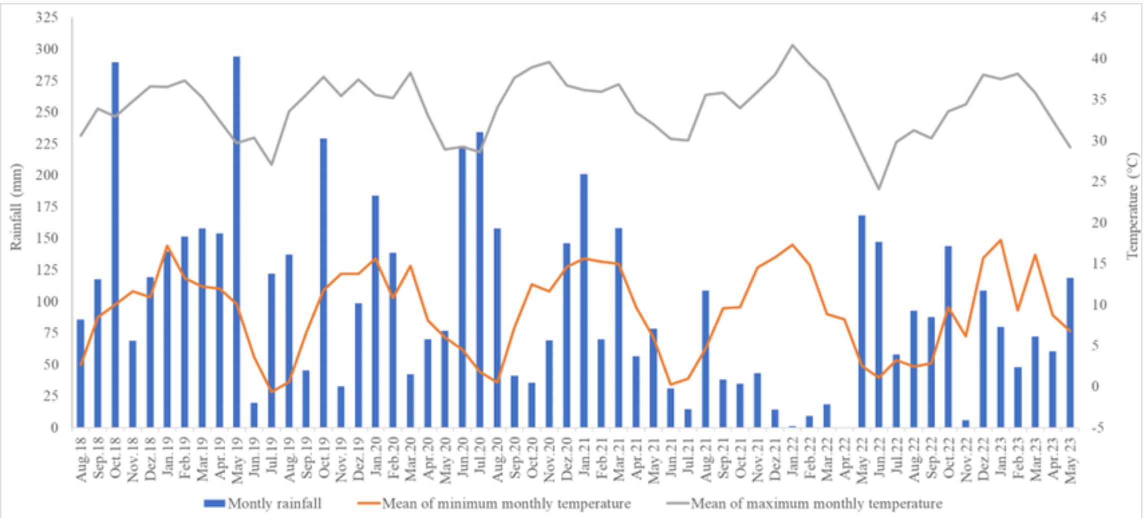

Figure 1. Average monthly minimum and maximum temperatures and rainfall in Santa Rosa, Rio Grande do Sul State, Brazil, during the 2018/2019, 2019/2020, 2020/2021, 2021/2022, and 2022/2023 growing cycles. Source: AGRITEMPO – Brazilian Agrometeorological Monitoring System.

The number of chilling hours was determined by summing the hours ⩽ 7.2°C from May to August from 2018 to 2022, based on data from the Santa Rosa meteorological station A810 (Figure 2).

Established in 2008, the orchard had a spacing of 7 x 7 m and a density of 204 trees per hectare. It lacked an irrigation system and had not undergone annual pruning before the experiment. The trees were 'Pitol 1' grafted, a Brazilian registered cultivar known for its vigorous growth and compact foliage. Also known as 'Melhorada', 'Pitol 1' is one of the most common cultivars in Brazil, comprising 19% of the country's orchards (Crosa et al., 2020). Other cultivars in the orchard included 'Barton', 'Success', and 'Shawnee'.

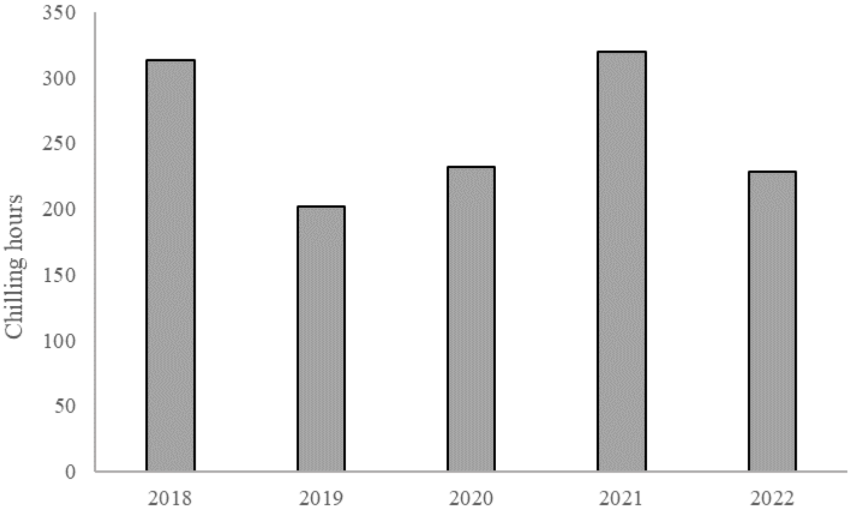

Figure 2. Number of chilling hours (≤ 7.2°C) between May and August from 2018 to 2022; data provided by the Santa Rosa meteorological station A810.

We used a randomized block design with three blocks of five replicates, totaling 15 trees per treatment. Treatments included: i) control; ii) hedge pruning; iii) central pruning; and iv) tree thinning.

Hedge pruning was conducted in two steps between rows (east to west). One side was pruned in August 2018, and the other side in August 2019. The side pruned in 2018 was pruned again in August 2021. Hedge pruning involved cutting lateral branches 2.5 meters from the trunk using a motor pole chainsaw, while a scissor pneumatic lift was used for small-diameter branches. A tractor and a wood trailer were used to reach the highest branches. The total average mass removed by hedge pruning on both sides in 2018 and 2019 was 7.6 kg.

Central pruning was performed only in August 2018. Central pruning involved removing one to three secondary branches from the center of the canopies with a motor pole chainsaw. Plastic paint was applied to large cuts to prevent pathogen activity. The average mass removed by central pruning was 18.6 kg per tree.

Thinning was performed once, in August 2018, by alternately removing trees, changing the original square design to a triangular one, and reducing the density from 204 to 102 trees per hectare. Thinning was carried out using a chainsaw. All treatments were conducted during the dormancy period.

Tree height, lateral width, and transverse width were measured using a measuring tape attached to a bamboo pole to reach the treetops. Canopy volume (CV) was calculated using the cone equation, while trunk cross-sectional area (TCSA) was derived from trunk diameter measurements taken 0.40 meters from the ground. Variables were evaluated in January 2019 and May 2023. Both CV and TCSA were calculated by the following equations:

$$\mathrm{CV} = \frac{1}{3} \cdot \pi \cdot \mathrm{r}^2 \cdot \mathrm{h}$$

where: CV = canopy volume, π = 3.1416, r = canopy radius, and h = tree height.

$$\mathrm{TCSA} = \pi . \mathrm{r}^2$$

where: TCSA = trunk cross-sectional area, π = 3.1416, and r = trunk radius.

Growth metrics for height, lateral width, transverse width, canopy volume, and TCSA were calculated based on data from the 2019 and 2023 evaluations. The number of basal branches, assessed in May 2023, was determined by counting secondary branches attached up to 3 meters high. The number of dry branches was evaluated annually during the vegetative period (January) from 2019 to 2023, including branches with no leaves or with dry leaves located in the canopy center and base.

Pecans were harvested from May 26th to 29th, 2019, from June 2nd to 4th, 2020, from June 15th to 18th, 2021, from May 20th to 25th, 2022, and from May 23rd to 26th, 2023. Harvesting was done using a tractor-mounted shaker, and pecans were collected manually. Production per tree was measured using a digital scale. Average production per tree for each cycle and overall, for the five cycles (2019-2023) was calculated. The number of fruits with closed epicarp (FCE) was also recorded during harvest.

Yield, production efficiency in relation to the canopy volume (PECV), and production efficiency in relation to the TCSA (PETCSA) were calculated for the cycles from 2018/2019 to 2022/2023. To reach the average among cycles, the average of sampling units was calculated. Afterward, followed by the general average of treatments was found using the following equations: yield (kg ha^{-1}) based on tree production and density; PECV = production/canopy volume (kg m^{-3}); and PETCSA = production/TCSA (kg cm^{-2}).

After verifying assumptions, results were subjected to analysis of variance, and averages were compared using Tukey's test at a 5% error probability with the SISVAR program, version 5.6 (Ferreira, 2014).

Results and discussion

Vegetative growth was significantly influenced by tree thinning (Table 1). Tree removal resulted in greater canopy transverse growth compared to hedge pruning, central pruning, and control. The canopy volume was also higher when compared to the control. However, there were no significant differences in height, lateral width of the canopy, and TCSA among the treatments.

Table 1. Average growth of plant height (GPH), the transverse width of the canopy (GTWC), the lateral width of the canopy (GLWC), canopy volume (GCV), and trunk cross-sectional area (GTCSA) of pecan trees subject to hedge and central pruning, tree thinning and the control from 2019 to 2023. Santa Rosa, Rio Grande do Sul State, Brazil.

Treatments	GPH (m)		GTWC (m)		GLWC(m)		GCV (m^3)		GTCSA (cm^2)	
	(2019 - 2023)									
Control	2.11 ± 1.07	ns	0.22 ± 1.13	b	0.85 ± 1.49	ns	52.36 ± 57.87	b	131.02 ± 108.80	ns
Hedge pruning	2.06 ± 1.04		0.22 ± 1.09	b	1.68 ± 1.49		66.52 ± 42.16	ab	163.76 ± 149.72	
Central pruning	2.15 ± 0.99		0.07 ± 1.99	b	0.84 ± 1.04		59.26 ± 71.44	ab	113.57 ± 135.70	
Tree thinning	1.34 ± 1.21		1.97 ± 1.19	a	1.51 ± 0.98		115.16 ± 53.23	a	164.07 ± 70.54	
P value	0.1242		0.0014		0.1757		0.0213		0.4440	

Averages followed by different letters within columns differ from each other by Tukey's test at 5% probability. ns = non-significant.

The results indicate that thinning leads to greater canopy growth. Thinning allows branches to grow horizontally due to increased space, higher sunlight incidence, and reduced competition for nutrients. In the other treatments, higher density resulted in taller trees with more vertical branches as they competed for sunlight. Sunlight is crucial for photosynthesis, where trees convert light energy into chemical energy, leading to the accumulation of photoassimilates (Taiz et al., 2017). Excessive shading reduces the photosynthetic activity of branches, causing trees to grow vertically in search of light. Pruning and tree thinning enhance the ability of branches to intercept sunlight, promoting homogeneous growth and resulting in more fruit-bearing branches. In orchards with ideal sunlight incidence, branches with more horizontal insertion angles, typically the basal ones, are the most productive (Hellwig et al., 2022).

The number of basal branches, those up to 3 meters high, was significantly higher after thinning compared to hedge pruning, central pruning, and control (Figure 3). After thinning, nearly 7 basal branches were counted per tree, whereas hedge pruning, central pruning, and the control each had an average of about 4 basal branches.

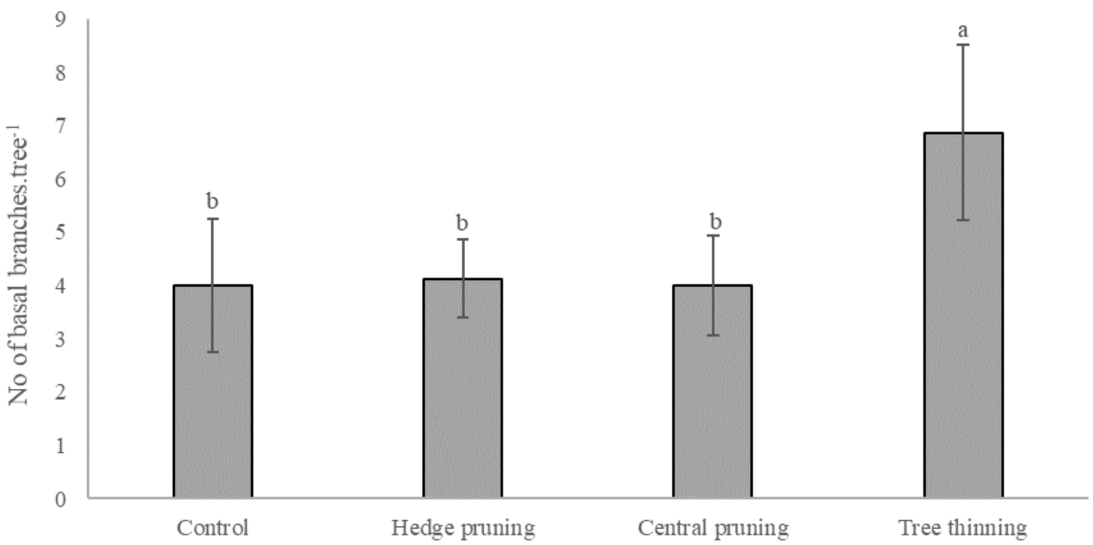

Figure 3. Number of basal branches (up to 3 meters high) on pecan trees subjected to four treatments: hedge pruning, central pruning, tree thinning, and a control group five years after the beginning of the experiment. Santa Rosa, Rio Grande do Sul State, Brazil.

Basal branches are located in the most productive stratum of trees. Thus, the more basal branches a tree has, the higher its production potential. When branches dry, they eventually break and fall, reducing the total number of branches.

In the 2018/2019 cycle, the number of dry branches per tree was smaller after central pruning compared to the other treatments (Figure 4). In the 2019/2020 cycle, the number of dry branches was smaller after central pruning and thinning than after hedge pruning and the control. In the 2020/2021 cycle, the number of dry branches was larger after hedge pruning than after the other treatments, while the control and central pruning resulted in more dry branches than thinning. In the 2021/2022 cycle, the control exhibited the highest number of dry branches, followed by hedge and central pruning, whereas thinning led to the fewest dry branches compared to the other treatments. In the 2022/2023 cycle, tree thinning also resulted in fewer dry branches compared to pruned and unpruned trees, with central pruning leading to fewer dry branches than hedge pruning.

Regarding the average across the five cycles, thinning resulted in the fewest dry branches, followed by central pruning and hedge pruning. There were no significant differences compared to the control.

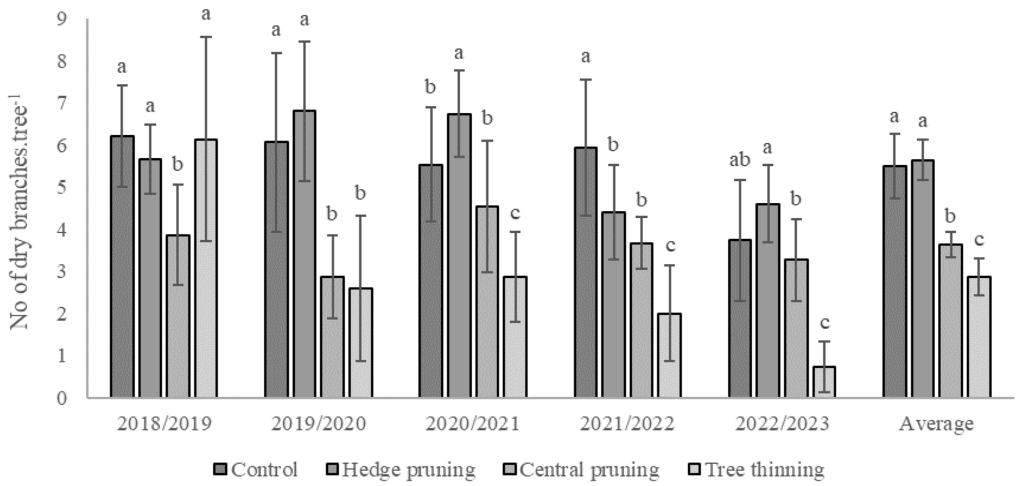

Figure 4. Number of dry branches per tree between the 2018/2019 and 2022/2023 growing cycles and their 2019-2023 average on pecan trees subjected to four treatments: hedge pruning, central pruning, tree thinning, and a control group. Santa Rosa, Rio Grande do Sul State, Brazil.

Results show that thinning, followed by central pruning, led to fewer dry branches on trees. Generally, hedge pruning did not decrease the number of dry branches; in some years, it resulted in more dry branches than the control. This can be attributed to the fact that hedge pruning led to dry branches not only from natural dryness caused by shading but also from pruned branches that failed to sprout and eventually dried. Since this did not occur after central pruning, this technique ranked second in reducing the number of dry branches, following thinning. In the last cycle under evaluation, trees subjected to thinning had very few dry branches (average was 0.73).

Dry branches, especially those in the basal part of trees, negatively impact production as it is primarily concentrated in the first stratum. These results align with Núñez et al. (2001), who reported that branches could dry and stop being productive in orchards where management practices reduce light intensity within the canopy. Additionally, dry branches that fall to the ground hinder management practices such as mowing, phytosanitary control, and pecan harvest. Therefore, thinning or using low-density planting can mitigate this issue.

Production per tree, evaluated over five cycles, exhibited alternate bearing regardless of the treatment (Figure 5). The 2018/2019, 2020/2021, and 2022/2023 cycles were characterized by high production-referred to as "on" years-while the 2019/2020 and 2021/2022 cycles showed low production, referred to as "off" years. Alternate bearing, observed in the cycles under study, is a common phenomenon in fruit trees. For pecan trees, it involves years of excessive load and low fruit quality followed by low production the next year. Factors such as late maturation close to leaf drop, high lipid concentration in pecans, and high production in some years contribute to low production in the subsequent year (Khalil et al., 2016; Noperi-Mosqueda et al., 2020).

Another phenomenon observed throughout the evaluation was La Niña, which mainly affected production in the 2021/2022 growing cycle. In the 2018/2019 cycle, thinning led to higher production compared to hedge pruning and control. Central pruning did not result in lower production than thinning but was not higher than hedge pruning and control.

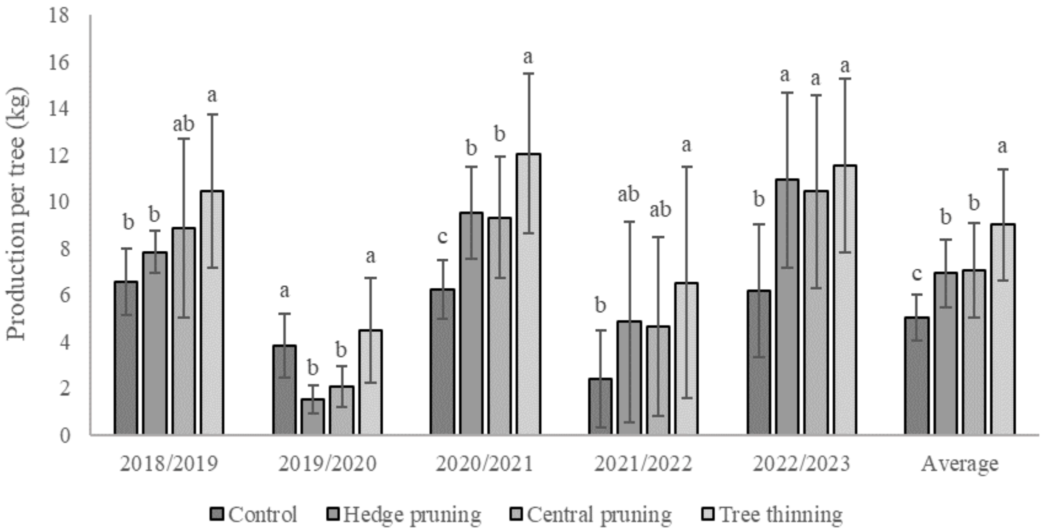

Figure 5. Fruit production per tree in the 2018/2019, 2019/2020, 2020/2021, 2021/2022, and 2022/2023 growing cycles and their 2019-2023 average on pecan trees subjected to four treatments: hedge pruning, central pruning, tree thinning, and a control group. Santa Rosa, Rio Grande do Sul State, Brazil.

In the atypical 2019/2020 cycle, the highest average production was 4.47 kg. In this cycle, both thinning and the control resulted in higher production than the pruning treatments. Monthly average rainfall values (Figure 3) show that October 2019 was very rainy, which may have affected tree pollination since pollen is distributed by wind (anemophily). In the 2020/2021 cycle, production after thinning was higher than the other treatments, followed by hedge and central pruning, which both led to higher production than the control. In the 2021/2022 cycle, thinning resulted in higher production than the control, while production after pruning did not differ significantly from thinning and control. In the 2022/2023 cycle, thinning and both pruning methods led to higher production than the control.

The average of all five cycles shows that thinning enabled higher production than the other treatments, followed by hedge and central pruning, which both resulted in higher production than the control. Compared to the control, thinning, central pruning, and hedge pruning increased production by 43.89, 39.80, and 37.03%, respectively. Accumulated production was 25.23 kg per tree for the control, 34.61 kg per tree for hedge pruning, 35.29 kg per tree for central pruning, and 45.00 kg per tree for thinning.

Pruning and thinning improved production per tree, especially in trees subjected to thinning, where accumulated production was double that of pruning. Fernández-Chávez et al. (2021) also found low production per tree in dense orchards due to low photosynthetic efficiency caused by leaf shading, which affected yield, fruit set, and floral bud formation. Hedge and central pruning, as well as thinning, allowed more sunlight to reach leaves compared to the control. According to Lombardini (2006), light interception in dense and unpruned orchards can be up to 95%. Basal branches are most affected by shading, causing them to stop producing and eventually dry out, as previously mentioned.

Fruit yield, which considers the number of trees per hectare, differed from production per tree results (Figure 6). In the 2018/2019 cycle, central pruning led to higher yield than thinning and control. Hedge pruning enabled higher yield than thinning but did not differ significantly from the control and central pruning. In the 2019/2020 cycle, the control had a higher yield than the other treatments. In the 2020/2021 and 2022/2023 cycles and the 2019-2023 average, hedge and central pruning led to higher yield than the control and thinning. In the 2021/2022 cycle, there were no significant differences among treatments. Therefore, hedge and central pruning exhibited more satisfactory results in yield compared to the control and thinning. Yield ranged from 310.35 to 2,227.00 kg ha^{-1}, depending on the year. The control had a higher yield than thinning only in the 2019/2020 cycle and did not show significant differences in the other cycles. The average yield of all cycles for the control, hedge pruning, central pruning, and thinning were 1,029.15, 1,412.06, 1,439.63, and 917.95 kg ha^{-1}, respectively. The five-cycle evaluation showed a 37.50% increase in yield after hedge pruning and a 39.88% increase after central pruning, but a 10.80% decrease after thinning compared to the control.

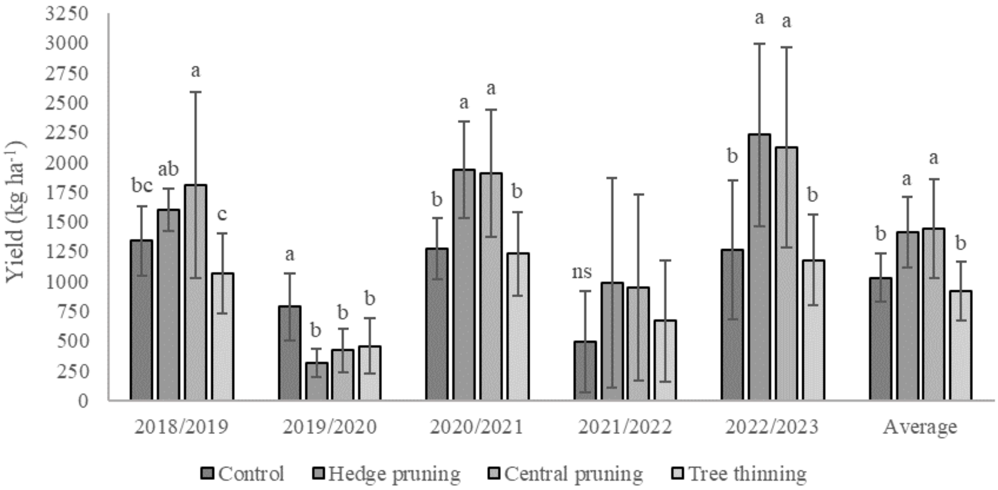

Figure 6. Fruit yield in the 2018/2019, 2019/2020, 2020/2021, 2021/2022, and 2022/2023 growing cycles and their 2019-2023 average on pecan trees subjected to four treatments: hedge pruning, central pruning, tree thinning, and a control group. Santa Rosa, Rio Grande do Sul State, Brazil.

The second cycle was the only one in which both pruning methods resulted in lower yield compared to the control. Factors such as the removal of branches with production potential by pruning and higher alternate bearing of trees that produced more in the previous cycle likely contributed to this outcome. For thinning, the key consideration is that this treatment removed 50% of the trees, meaning the remaining trees needed to double their production compared to the other treatments to achieve the same yield. Fernández-Chávez et al. (2021) evaluated yields in orchards with 100 and 204 trees per hectare and found higher yields at high density between the 7th and 11th years. It is important to note that in this study, trees were evaluated between the 11th and 15th years, i.e., in later years. Thinning led to better production than the control as years progressed, indicating its potential to eventually surpass the control in yield. Considering yield alone, pruning in dense orchards is beneficial, but the investment in labor and equipment for pruning must be considered.

The highest average yields (2019-2023) were achieved by both pruning treatments, which are in the range of the Brazilian average of 1,433 kg ha^{-1} (Fronza et al., 2018). Both the control and thinning exhibited lower yields; the former due to competition for sunlight and the latter due to fewer trees in the area. It is important to note that the orchard is rainfed, and that yield was affected by drought, particularly in the last two cycles. During the five critical months when the crop requires water (December to April), rainfall in the 2021/2022 and 2022/2023 cycles was only 42.8 and 368.4 mm, respectively. Fruit development occurs between December and April, initially growing and then entering the kernel-filling period. Marco et al. (2021) observed that water deficit periods primarily affect the dimensions and filling of pecans. Conversely, excessive rainfall in October 2019, when pecan pollination occurs, explains the low yield in that cycle. Some researchers did not find favorable yield results with hedge pruning (Wood, 2009; Wells, 2018). Lombardini (2006) evaluated the hedge and selective pruning of three cultivars over three cycles and found an increase in yield for one of them ('Desirable'), indicating that responses may vary among cultivars. The cultivar 'Pitol 1', evaluated in this study, responded well to both pruning methods, especially in high-production years. Its characteristics-compact foliage and vigorous growth-enhanced yield in high-density orchards, and pruning increased branch exposure to sunlight, thereby boosting photosynthetic processes and production.

Another factor that may be associated with varying production levels across different cycles is the number of chilling hours ($\leqslant$ 7.2°C), which ranged between 202 and 320 in the area. However, no direct connection was found between the number of chilling hours and the orchard's yield in the corresponding production cycle. For instance, the 2018/2019 and 2021/2022 cycles, which followed years with high accumulation of chilling hours, exhibited high and low production, respectively.

Production efficiency was evaluated in terms of CV and TCSA over five cycles and the average of these cycles (Table 2). Production efficiency related to CV (PECV) showed differences among treatments in the 2019/2020, 2020/2021, and 2022/2023 cycles, as well as in the average for 2019-2023. In the 2019/2020 cycle, the control and thinning treatments had higher PECV averages than hedge and central pruning. In the 2020/2021 cycle, hedge pruning and thinning achieved higher PECV averages than the control, while central pruning did not significantly differ from the other treatments. In the 2022/2023 cycle, hedge pruning had the highest PECV average, followed by central pruning, thinning, and control. The five-cycle average showed that hedge pruning led to higher production efficiency than the control, while central pruning and thinning did not significantly differ from the control or hedge pruning in terms of production efficiency.

Production efficiency related to TCSA (PETCSA) also exhibited differences in the 2019/2020 and 2022/2023 cycles, as well as in the 2019-2023 average (Table 2). In the 2019/2020 cycle, the control and thinning treatments led to higher PETCSA averages than hedge and central pruning. In the 2022/2023 cycle, hedge pruning, central pruning, and thinning resulted in higher PETCSA averages than the control. The average of all cycles indicated that thinning enabled higher production efficiency than the other treatments.

Hedge pruning, due to its impact on production and decrease in CV, emerged as the most efficient treatment in terms of yield relative to the canopy. Hedge pruning aims to shorten lateral branches and produce pecans closer to the central axis of the tree. Despite variations among cycles, thinning excelled in terms of PETCSA; trees with similar trunk dimensions were more productive when subjected to thinning. Therefore, production efficiency results indicate that hedge pruning was more efficient in the relationship between production and canopy while thinning was more efficient concerning trunk dimensions.

Table 2. Production efficiency of pecan trees subjected to hedge and central pruning, tree thinning, and the control in terms of canopy volume (PECV) and trunk cross-sectional area (PETCSA), and number of fruit with closed epicarp (FCE) between the 2018/2019 and 2022/2023 growing cycles and their 2019-2023 averages. Santa Rosa, Rio Grande do Sul State, Brazil.

Treatment	PECV (kg m^{-3})		PETCSA (kg cm^{-2})		FCE	
	2018/2019					
Control	0.056 ± 0.023	ns	0.027 ± 0.009	ns	33.07 ± 12.59	a
Hedge pruning	0.067 ± 0.014		0.025 ± 0.007		6.40 ± 2.99	c
Central pruning	0.053 ± 0.020		0.026 ± 0.008		6.27 ± 3.06	c
Tree thinning	0.060 ± 0.018		0.032 ± 0.007		19.13 ± 8.67	b
P value	0.1999		0.1949		<0.0001	
	2019/2020					
Control	0.032 ± 0.012	a	0.016 ± 0.008	a	22.60 ± 11.15	b
Hedge pruning	0.013 ± 0.006	b	0.005 ± 0.002	b	5.67 ± 4.65	c
Central pruning	0.013 ± 0.007	b	0.007 ± 0.004	b	4.67 ± 2.87	c
Tree thinning	0.025 ± 0.012	a	0.013 ± 0.006	a	34.00 ± 16.04	a
P value	<0.0001		<0.0001		<0.0001	
	2020/2021					
Control	0.048 ± 0.016	b	0.020 ± 0.007	ns	20.73 ± 10.53	b
Hedge pruning	0.069 ± 0.017	a	0.021 ± 0.005		18.33 ± 9.30	b
Central pruning	0.056 ± 0.016	ab	0.023 ± 0.005		19.87 ± 6.24	b
Tree thinning	0.066 ± 0.017	a	0.027 ± 0.008		49.13 ± 18.44	a
P value	0.0033		0.0611		<0.0001	
	2021/2022					
Control	0.017 ± 0.013	ns	0.007 ± 0.006	ns	7.80 ± 8.87	ns
Hedge pruning	0.035 ± 0.033		0.010 ± 0.009		18.67± 12.27	
Central pruning	0.032 ± 0.029		0.012 ± 0.011		8.40 ± 7.07	
Tree thinning	0.036 ± 0.027		0.014 ± 0.011		20.00 ± 20.30	
P value	0.1406		0.1586		0.0646	
	2022/2023					
Control	0.033 ± 0.012	c	0.015 ± 0.005	b	26.07 ± 12.36	b
Hedge pruning	0.057 ± 0.015	a	0.022 ± 0.005	a	39.40 ± 10.89	ab
Central pruning	0.047 ± 0.016	ab	0.023 ± 0.006	a	38.60 ± 21.01	ab
Tree thinning	0.039 ± 0.012	bc	0.023 ± 0.007	a	44.33 ± 16.99	a
P value	0.0001		0.0007		0.0195	
	Average (2019-2023)					
Control	0.037 ± 0.007	b	0.017 ± 0.003	b	22.05 ± 3.30	b
Hedge pruning	0.049 ± 0.008	a	0.017 ± 0.003	b	17.69 ± 4.90	b
Central pruning	0.040 ± 0.012	ab	0.018 ± 0.004	b	15.56 ± 5.20	b
Tree thinning	0.045 ± 0.008	ab	0.022 ± 0.004	a	33.32 ± 9.82	a
P value	0.0047		0.0016		<0.0001	

Averages followed by different letters within columns differ from each other by Tukey’s test at 5% probability. ns = non-significant.

The number of fruit with closed epicarp (FCE) was higher in the control compared to thinning in three out of five cycles under evaluation (2019/2020, 2020/2021, and 2022/2023) and in the average across all five cycles (Table 2). In the 2018/2019 cycle, the control led to the highest number of FCE, while in the 2021/2022 cycle, there were no significant differences among treatments.

Regarding losses, data on the average from 2019 to 2023 and calculations of mass using average fruit mass for each treatment (data not shown) indicate that thinning resulted in an estimated production loss of 293.88 g, while the control, hedge pruning, and central pruning led to losses of 164.93, 144.52, and 129.46 g, respectively. In terms of tree production expressed as a percentage, thinning and the control both resulted in a 3.13% loss, whereas hedge pruning and central pruning led to losses of 2.05 and 1.80%, respectively. Thus, pruning slightly decreased the percentage of FCE losses.

FCE are considered harvest losses because they cannot be marketed. The percentages resulting from the treatments are low compared to total production. Factors that can prevent pecans from opening, observed throughout this study, include pollination deficit, high temperatures, and water deficit in the pre-harvest period.

Conclusion

Both hedge pruning and central pruning increase pecan yield per hectare. Thinning leads to the highest growth in canopy volume, transverse width, and number of basal branches, while also increasing pecan production per tree and its production efficiency as well. Dry branches, a common issue in high-density orchards, can be mitigated primarily through thinning and also by central pruning.

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