eISSN 1981-1829

Ciência e Agrotecnologia
Science and Agrotechnology

Central and hedge pruning lead to improvement in pecan production and quality in high-density orchards

Podas central e hedge promovem melhoria na produção e qualidade de noz-pecã em pomares adensados

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

ABSTRACT

Shading limits pecan development, production, and quality in high-density orchards. In this study, we evaluated responses to hedge and central pruning given by 'Pitol 1' pecan trees implanted in high-density orchards regarding dry branches, production, and quality of fruit. The experiment was conducted in five cycles and had a randomized block design that included the following treatments: 1) no pruning, 2) hedge pruning, and 3) central pruning. The number of dry branches, production and yield, production efficiency, and variables of fruit quality were evaluated. Central pruning led to a 33.7% decrease in the number of dry branches. Hedge and central pruning enabled 37.2% and 39.9% increase in the mean production of trees, respectively. Hedge and central pruning decreased the number of fruits per kg and resulted in higher percentages of fruits in classes of larger sizes. Central pruning decreased the number of dry branches, whereas both hedge and central pruning increased fruit production and quality. Central and hedge pruning improved pecan production and quality in high-density orchards.

Indexation terms: *Carya illinoinensis*; canopy management; sunlight; shading; dry branches.

RESUMO

O sombreamento é um fator limitante no desenvolvimento, produção e qualidade de frutos em pomares adensados de nogueira-pecã. Objetivou-se com este estudo avaliar a resposta das podas hedge e central com a presença de ramos secos, na produção e na qualidade dos frutos de nogueira-pecã implantados em alta densidade. O experimento foi conduzido durante cinco safras em um delineamento de blocos casualizados, constituído dos tratamentos 1) sem poda; 2) poda hedge e 3) poda central. Foram avaliados: número de ramos secos, produção e produtividade, eficiência produtiva, além das variáveis de qualidade de frutos. A poda central promove a redução de 33,7% do número de ramos secos. A poda promoveu o aumento de 37,2% e 39,9% da produção média das árvores com as podas hedge e central respectivamente. As podas hedge e central reduziram a quantidade de frutos por quilo, assim como resultaram em maior porcentagem de frutos de classes de tamanhos maiores. Somente a poda central reduz o número de ramos secos nas árvores, porém ambas as podas de abertura aumentam a produção e o calibre dos frutos. A poda central é mais indicada pois, além de promover o aumento da produção e parâmetros de qualidade da noz-pecã, reduz o número de ramos secos nas árvores.

Termos de indexação: *Carya illinoinensis*; manejo de copa; radiação solar; sombreamento; ramos secos.

Agricultural Sciences

Ciênc. Agrotec., 49:e020224, 2025
http://dx.doi.org/10.1590/1413-7054202549020224

Editor: Renato Paiva

[1]Universidade Federal de Pelotas/UFPel, Departamento de Fitotecnia, Capão do Leão, RS, Brasil
[2]Embrapa Clima Temperado, Estação Experimental Cascata, Pelotas, RS, Brasil
[3]Universidade Estadual do Rio Grande do Sul/UERGS, São Borja, RS, Brasil

Corresponding author: cristiano.hellwig@gmail.com

Received in September 25, 2024 and approved in November 29, 2024

Introduction

Pecan requires a high initial investment but has a long-term return, considering that full production starts only 12–15 years after planting (Wells, 2017; Fronza et al., 2018). To start production earlier and obtain higher yields per area, about 39% of Brazilian orchards were implanted with more than 100 trees per hectare (Martins et al., 2023). Maintaining high-density orchards is a common practice in the case of some fruit trees, and it might be a future trend in the management of more species. Apple, peach, and olive are produced in denser orchards not only to increase production and annual turnover but also to ease management (Rallo et al., 2013; Mayer et al., 2016; Reig et al., 2020). One factor needed to produce fruits at high densities is the control of plant vigor, which, in the case of apple trees, is achieved using dwarf rootstocks (Reig et al., 2020; Li et al., 2023). However, pecan trees become very tall, and in their production system, unlike that of apple trees, there are neither dwarf cultivars nor dwarf rootstocks; this hinders the use of high-density orchards (Zhu & Stafne, 2019).

Many farmers who own high-density orchards must deal with excess shading caused by branch overlap, which may happen even before 10 years of implantation, depending on its density, particularly in dense cultivations (Zivdar et al., 2016; Souri, 2016; Fronza et al., 2018). Sunlight is essential for production, plant development, and fruit quality (Arreola Ávila et al., 2010). Shading decreases the production potential of trees because of the shortage of sunlight that is needed for photosynthetic processes and also causes the drying of basal branches, which are the ones that bear more fruit when sunlight conditions are ideal (Hellwig et al., 2022). Wood (2009) reported that pruning and tree thinning are alternative management practices to rehabilitate orchards by mitigating shading in low branches. Pruning is commonly practiced in high-density orchards to improve penetration and use of light so that flowering, fructification, and, consequently, production may increase (Lombardini, Restrepo-Diaz, & Volder, 2009; Fernández-Chavez et al., 2021).

Hedge pruning and central pruning, also known as selective pruning, increase the availability of sunlight inside the canopy. Mechanical hedge pruning, which involves hedging one or two sides of trees, has been traditionally conducted in the western part of the United States of America (USA) (Gong et al., 2020). Central pruning is a selective method in which whole secondary branches are removed to enable a higher incidence of sunlight within canopies (Lombardini, 2006). Researchers have highlighted that responses to pruning depend on edaphoclimatic conditions and cultivars under evaluation (Worley, Mullinix, & Daniel, 1996; Lombardini, 2006; Wood, 2009; Wells, 2018).

Therefore, in this study, we evaluated responses to hedge and central pruning by 'Pitol 1' pecan trees implanted in high-density orchards by recording dry branches, production, and quality of fruit in southern Brazil.

Material and Methods

The experiment was conducted in a commercial pecan orchard in Santa Rosa, Rio Grande do Sul (RS), Brazil (27° 55'15" S; 54° 32'37" W). The orchard was planted in 2008 with 204 trees per hectare; the spacing between plants was 7 m x 7 m. The area had no irrigation system, and the cultivars were Pitol 1 (Melhorada), Barton, Success, and Shawnee. In the study area, there were only 'Pitol 1' and 'Barton' pecan trees in alternate rows, but only the former were investigated in this study, while the latter consisted of the border. No pruning was conducted after the fifth year of grafted seedling implantation in the orchard.

This study was conducted from August 2018 to 2023, and five production cycles were evaluated. The soil in the orchard may be classified as typic dystropherric red latosol (Santos et al., 2018), and the climate in the area is Cfa. Mean temperature of the coldest month is below 18 °C while that of the warmest months is above 22 °C, in the Köppen-Geiger classification (Alvares et al., 2013). Data on monthly rainfall and maximum and minimum temperatures throughout the experiment were provided by the Santa Rosa Meteorological Station - TRMM.291/Agritempo (Figure 1).

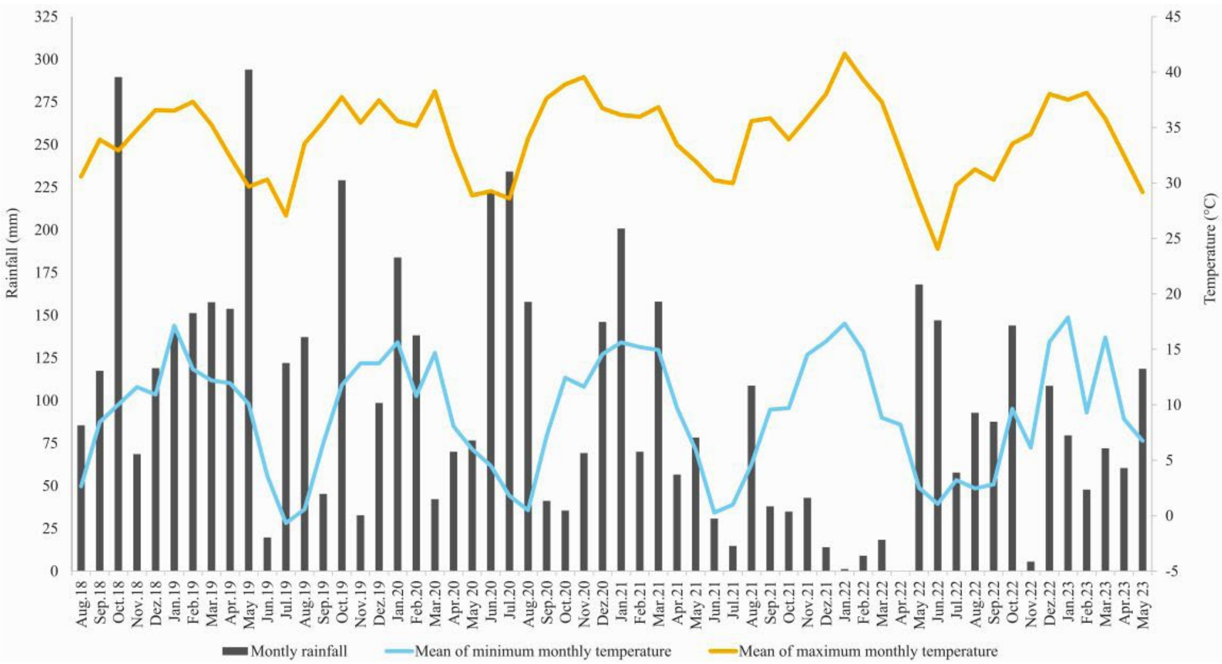

Figure 1: Rainfall and minimum and maximum monthly temperatures in Santa Rosa, RS, from August 2018 to May 2023. Source: the Agritempo-Agrometeorological Monitoring System.

The experiment was conducted in three randomized blocks. All blocks comprised three treatments and five replicates; thus, a total of 45 trees were evaluated. The trees selected were of similar sizes and development stages; all were subject to equal spacing conditions. Besides, experimental trees were surrounded by other trees. Blocks were based on the location of trees in the orchard. Block 1 was located in the east, while block 3 was located in the west. 'Pitol 1' was selected for administering treatments because this cultivar has vigorous trees with compact leaves, its branches break easily in strong winds, and its fruits are large, i.e., about 107.05 fruits weigh 1 kg (Bilharva et al., 2018; Hellwig et al., 2022; Hamann et al., 2024). The experiment consisted of the following treatments: 1) no pruning (Figure 2a), 2) hedge pruning (Figure 2b), and 3) central pruning (Figure 2c). Pruning was conducted throughout the vegetative rest period of trees, i.e., at the beginning of August. Hedge pruning consisted of cutting back branches that grew farther than 2.5 m from the trunk of the tree. It was conducted on one side of the trees (from east to west) in August 2018 and on the opposite side in August 2019. Semi-mechanical pruning was conducted using a motor pruner again on the first side in August 2021 and on the opposite side in August 2022. The sum of mean masses removed after hedge pruning on both sides in 2018 and 2019 was 7.6 kg per tree.

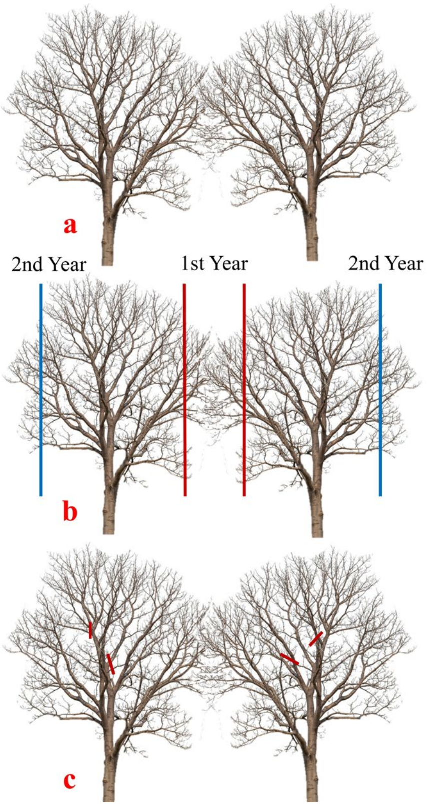

Figure 2: Schematic representation of pecan trees and pruning methods that they were subject to: no pruning (a), hedge pruning (b), and central pruning (c).

Central pruning was also conducted using a motor pruner in August 2018. It is a better method for selecting branches to be removed than hedge pruning. Around one to three secondary branches were removed from the trees. This methodology was used because branches had different sizes and were overlapping. It also allowed sunlight to penetrate the canopy. The mean mass removed by central pruning was 18.6 kg per plant. Mass removed by hedge pruning, expressed as a percentage, on both sides of trees, was 3.5% of the total weight of the aerial part, while central pruning removed about 8.5% of the total weight (Hellwig et al., 2022).

The number of dry branches in trees was evaluated in vegetative periods of all five cycles. The visual evaluation method included counting branches with no leaves and with dry leaves on basal parts and within canopies. In the five cycles under evaluation, harvest took place from May to the beginning of June. Farmers determined when the harvest should start, i.e., when most epicarps were open. Production per plant was evaluated immediately after harvest using a portable digital hanging scale. Mean production and accumulated production were also calculated in all five cycles. The mean yield resulted from the mean production per plant in the cycles divided by the number of trees per hectare. To calculate the canopy volume, some variables, such as plant height and canopy radius, were recorded by a measuring tape and a bamboo that reached the treetops. Canopy volume was used to calculate the production efficiency of trees. The canopy volume, cone volume, and production efficiency were calculated using the following Equations 1 and 2:

$$CV = \frac{1}{3} \cdot \pi \cdot r^2 \cdot h \quad (1)$$

CV = canopy volume; π = 3.1416; r = canopy radius; h = plant height

$$PECV(kgm^3) = \frac{\text{Production per plant}}{CV} \quad (2)$$

PECV = production efficiency in relation to the canopy volume.

While evaluating harvest, tree samples that weighed about 1.4 kg were dried in a forced air oven up to approximately 4% humidity. After drying, the number of fruits per kg was determined. To evaluate kernel yield (KY) (%) and the percentage of commercial kernels, 25 fruits per sample were evaluated individually. KY was determined by weighing each whole fruit and kernel after shelling using the following Equation 3:

$$KY(\%) = \frac{\text{kernel mass}}{\text{fruit mass}} * 100 \quad (3)$$

The percentage of commercial kernels consisted of sorting kernels with defects (shriveled, oxidized, stained by diseases, or attacked by insects); only those kernels that had no defects were selected for the calculation. Fruit classification was performed following the official Mexican guidelines, with some modifications (NMX-FF-084-SCFI, 2009). It considers the number of fruits per kg. However, to classify the fruits of the samples under evaluation, fruit mass was used to distribute and calculate the percentages of every category. This evaluation used masses of all fruits evaluated in all five cycles. The fruits were classified into the following categories: small (< 4.76 g), medium (4.76 to 5.84 g), large (5.85 to 7.14 g), extra-large (7.15 to 8.13 g), and oversize (> 8.13 g).

After analyzing the assumptions, the data were evaluated by the analysis of variance, and the mean values were compared by Tukey's test at 5% error probability using the Sisvar program, version 5.6 (Ferreira, 2014).

Results and Discussion

The central pruning technique most effectively decreased the number of dry branches in pecan trees; this was found in three out of five cycles and in the mean of cycles (Table 1). Although it could not eliminate the problem, central pruning decreased dry branches by 33.70% and 35.46% compared to unpruned trees and trees subject to hedge pruning, respectively. When there is a decrease in branch drying, trees keep more structures that have production potential, which leads to higher production (Hellwig et al., 2022).

Hedge pruning did not show the same benefits, which occurred probably because this method allows an increase in the incidence of sunlight among trees, rather than within canopies (Malstrom, Riley, & Jones, 1982). Hedge pruning and central pruning increased fruit production, mainly in those years in which production was high (Table 1).

In the 2018/2019, 2020/2021, and 2022/2023 cycles, differences in production increased between pruned and unpruned trees. Hedge pruning showed differences of 19.51%, 52.57%, and 76.70%, whereas central pruning showed differences of 34.91%, 49.83%, and 68.60%, respectively. These results indicated the limitation in the production of trees affected by shading and showed that pruning improved responses with time.

In the 2019/2020 and 2021/2022 cycles, production was low after administering all treatments. Additionally, pruned trees did not exhibit higher production than unpruned trees. The mean production of cycles was also higher when both pruning methods were used. Pruning facilitated an increase in sunlight incidence; thus, photosynthetic processes and productive branches improved over the years, leading to higher production.

This study showed alternate bearing among cycles, i.e., years with high production were followed by years with low production. Noperi-Mosqueda et al. (2020) reported that this phenomenon is common in pecan crops and is associated not only with carbohydrate shortage resulting from late fruit ripening, which limits carbohydrate storage for the next cycle but also with the high content of lipids found in the fruit. However, some factors, such as excess fruit load, pests, diseases, mineral deficiencies (Souri & Hatanian, 2019), and lack of an irrigation system, also contribute to alternate bearing. In the 2019/2020 cycle, rain at the beginning of flowering harmed pollination (Figure 1). This happened because pecan pollination is mainly wind-mediated, and pollen transportation occurs when relative air humidity is below 85% (Wells, 2017; De Marco et al., 2021). The low production of trees pruned in 2019/2020 may be explained by the high exposure of male and female flowers to rain, while, in unpruned trees, branch overlapping probably protected their flowers, thus resulting in effective fructification and fruit production. In the 2021/2022 cycle, the drought caused by La Niña affected the production potential of trees.

Production efficiency in relation to the canopy volume increased after hedge pruning (Table 1). This can be partly explained by the fact that lateral pruning led to a decrease in canopy volume and, along with high production, resulted in a high ratio of kg/m³. High-density systems aim to achieve shorter and more compact trees of several fruit crops, as they facilitate easy harvest and high production per unit area (Majid, Khalil, & Nazir, 2018). On the other hand, as shown by the number of dry branches, this pruning method did not mitigate all problems caused by shading in high-density orchards. In central pruning, since branches are removed inside the canopy, the methodology used for evaluation did not help subtract part of the canopy area; thus, the results of central pruning did not differ from those of unpruned trees. However, pruning masses removed by every treatment showed that central pruning removed larger volumes (8.5%) than hedge pruning (3.5%).

Regarding other aspects related to production, hedge pruning, and central pruning led to an increase of 9.38 kg and 10.06 kg in accumulated production in all five cycles, respectively, compared to unpruned trees (Figure 3). The mean yield for the treatment with no pruning was 37.21% and 39.88% higher relative to hedge pruning and central pruning treatments, respectively. Pruning enabled sunlight penetration in the canopy and increased photosynthesis, carbohydrate accumulation, and production. Additionally, pruning favored the emission of production branches (shorter branches) inside canopies in the case of central pruning and increased the number of sprouted lateral branches in the case of hedge pruning, a fact that explains the increase in production. However, Wood (2009) stated that hedge pruning did not increase the number of production branches in canopies; this result is associated with the shortage of sunlight in canopies. Regarding yield, previous studies showed neither an increase after hedge pruning was conducted (Wood, 2009; Wells, 2018) nor differences in responses of pruned cultivars (Lombardini, 2006). Shading performed in an advanced stage of the experiment probably led to more promising results.

Table 1: Dry branches, production per tree, production efficiency (PECV), fruit per kg, kernel yield, and commercial kernels in a high-density orchard with pecan trees that underwent hedge pruning, central pruning, and no pruning in five cycles.

Treatment	Dry branches tree^{-1}	Production per tree (kg)	PECV (kg m³)	Fruit kg^{-1}	Kernel yield (%)	Commercial kernels (%)
			2018/2019			
No pruning	6.20a	6.56b	0.056ns	113.55ns	53.68ns	89.44ns
Hedge pruning	5.67a	7.84ab	0.067	118.44	53.69	91.11
Central pruning	3.87b	8.85a	0.053	114.00	53.05	91.11
p-value	<0.0001	0.0511	0.1043	0.2505	0.4993	0.8422
			2019/2020			
No pruning	6.07a	3.84a	0.032a	119.90b	55.02ns	92.00ns
Hedge pruning	6.80a	1.52b	0.013b	125.90ab	55.92	91.55
Central pruning	2.87b	2.05b	0.013b	128.90a	55.34	94.22
p-value	<0.0001	<0.0001	<0.0001	0.0078	0.3215	0.4117
			2020/2021			
No pruning	5.53b	6.22b	0.048b	117.01a	53.97a	88.00ns
Hedge pruning	6.73a	9.49a	0.069a	112.66ab	52.28b	88.44
Central pruning	4.53c	9.32a	0.056ab	107.82b	52.21b	89.33
p-value	<0.0001	0.0001	0.0025	<0.0030	0.0145	0.9205
			2021/2022			
No pruning	5.93a	2.42ns	0.017b	191.51a	54.65ns	97.33ns
Hedge pruning	4.40b	4.84	0.035a	142.58b	54.78	96.44
Central pruning	3.67b	4.65	0.032ab	145.56b	54.77	96.89
p-value	<0.0001	0.0519	0.0299	<0.0001	0.9377	0.866
			2022/2023			
No pruning	3.73ab	6.18b	0.033b	160.83a	58.21ns	93.78b
Hedge pruning	4.60a	10.92a	0.057a	136.46b	57.48	99.11a
Central pruning	3.27b	10.42a	0.047a	133.41b	57.13	98.22a
p-value	0.0063	0.0014	0.0002	<0.0001	0.2591	0.0109
			Mean (2019-2023)			
No pruning	5.49a	5.05b	0.037b	140.91a	55.10ns	92.11ns
Hedge pruning	5.64a	6.92a	0.049a	126.85b	54.83	93.33
Central pruning	3.64b	7.06a	0.040b	125.78b	54.50	93.95
p-value	<0.0001	0.0008	0.0023	<0.0001	0.0895	0.3462

Means followed by different letters on a column differ from each other by Tukey's test at 5% probability; ns = non-significant.

Trees that underwent hedge and central pruning bore fewer fruits per kg (Table 1) and exhibited an increase in fruit size. The difference increased every year. In the first two cycles, pruning did not decrease the number of fruits per kg. From the 2020/2021 cycle, central pruning showed the best results. In the other cycles, both pruning methods yielded better results than unpruned trees and confirmed their benefits. The mean of cycles showed that the control needed 14–15 more fruits to bring up the mass to 1 kg, compared to pruning treatments. The results also indicated that, due to the drought (in the 2021/2022 cycle, the area received only 42.80 mm of rainfall from December to April), the control required up to 191 fruits per kg; a fact that also interfered with production, as mentioned earlier.

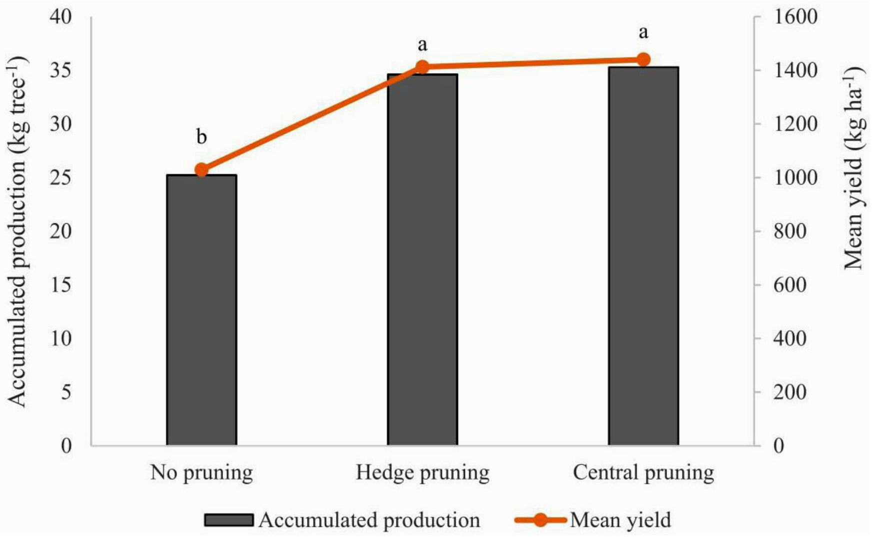

Figure 3: Accumulated production and mean yield from the 2018/2019 to 2022/2023 cycles of pecan trees grown in a high-density orchard with no pruning, hedge pruning, and central pruning. Different letters above the bars and points in the line indicate significant differences, as determined by Tukey's test at a 5% error probability.

In the classification of fruit size, hedge and central pruning also led to higher percentages of fruit in the highest size categories (Figure 4). In the treatment with no pruning, the sum of fruits classified into the extra-large and oversize categories represented 54.63% of the total, while, after hedge and central pruning, they accounted for 73.81 and 77.09% of the total, respectively. On the other hand, the lowest categories, i.e., small and medium, represented 23.91% of fruits borne by unpruned trees and 4.83% and 4.72% of fruits recorded after hedge and central pruning, respectively. The pecan classification confirmed that quality increased after both pruning methods were implemented. Wells (2018) also stated that hedge pruning may favor fruit size and quality. In the export market, pecan size is an important parameter and represents an increase in production and revenue.

Kernel yield did not increase after pruning (Table 1). Overall, no significant differences were found among treatments in the cycles under evaluation, but in the 2020/2021 cycle, unpruned trees exhibited a higher percentage than trees that underwent pruning. 'Pitol 1' showed interesting results, since its mean KY was about 52% in all cycles and treatments. Bilharva et al. (2018) reported that this cultivar reached a mean yield of 55.24%. The percentage of commercial kernels was not significantly different among most cycles and their mean, except for those in the 2022/2023 cycle, in which both pruning methods resulted in a higher percentage of kernels with no defects relative to that recorded in the control. Hedge pruning and central pruning were conducted individually throughout all five cycles, but, considering their positive results in the experiment, they may reach even better results not only due to sunlight incidence within canopies and among trees but also because of air circulation, which is important for pollination.

Wells and Sawyer (2023) stated that hedge pruning in high-density orchards, such as the one described in this study (7m x 7m), should be conducted from the seventh year on. The authors complemented lateral pruning with topping to decrease tree height. Topping is conducted to prevent trees from growing taller than the spacing used in the orchard. Had we performed topping, tree height would have been decreased to 7 m. Limiting tree height avoids self-shading, favors the application of phytosanitary products, and decreases the severity of diseases of susceptible cultivars (Bock et al., 2017). However, some studies that investigated the application of hedge pruning (lateral) and topping did not find short-term benefits in production (Wood, 2009; Wells, 2018). Their results differed from the findings of this study, where we showed that accumulated production increased significantly after five cycles. Hedge pruning was conducted from east to west in this experiment since rows, where management practices were applied, followed this direction. According to Wood and Stahmann (2004) and Wells and Sawyer (2023), north-south pruning can increase production more efficiently. This study could have achieved more positive results if this direction had been considered. Thus, further field studies should take this fact into account. Considering that production increased after both pruning techniques were used simultaneously, further studies should evaluate them in association with the increase in sunlight within canopies and among trees.

This study showed that pruning is an alternative strategy to maintain the viability of high-density pecan orchards. In the absence of pruning, problems related to production, branch drying, and fruit quality occur commonly.

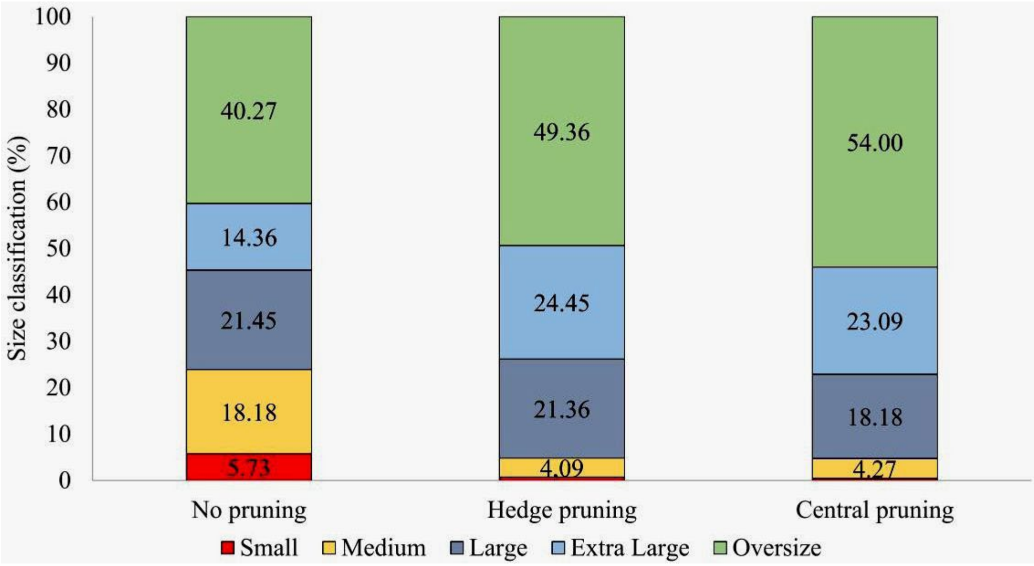

Figure 4: Classification of fruits borne by pecan trees into different size groups – small, medium, large, extra-large, and oversize – in high-density orchards subject to no pruning, hedge pruning, and central pruning.

Conclusions

Central pruning decreases dry branches in pecan trees grown in high-density orchards. In high-density orchards where annual pruning is not performed in the first 10 years, hedge and central pruning can increase pecan production. Hedge and central pruning decrease the number of fruits per kg and increase the percentage of fruits in high size categories.

Authors Contributions

Conceptual idea: Martins, C.R.; Malgarim, M.B.; Methodology design: Hellwig, C.G.; Martins, C.R.; Malgarim, M.B.; Data collection: Hellwig, C.G.; Lima, A.D.V.; Data analysis and interpretation: Hellwig, C.G.; Writing and editing: Hellwig, C.G.; Farias, R. de M.; Martins, C.R.; Malgarim, M.B.

Acknowledgments

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the scholarship and research funds, the Fazenda Müller for enabling the experiment to be conducted, the Embrapa Clima Temperado for its structure and the Universidade Federal de Pelotas and the Post-graduate Program in Agronomy for the support given to the experiment.

References

Alvares, C. A. et al. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*(6):711-728.

Arreola Ávila, J. G. et al. (2010). Disponibilidad de luz y producción de nuez después del aclareo de árboles de nogal pecanero (Carya *illinoinensis*). *Revista Chapingo. Serie Ciencias Forestales Y Del Ambiente*, *16*(2):147-154.

Bilharva, M. G. et al. (2018). Pecan: From research to the Brazilian reality. *Journal of Experimental Agriculture International*, *23*(6):1-16.

Bock, C. H. et al. (2017). Severity of scab and its effects on fruit weight in mechanically hedge-pruned and topped pecan trees. *Plant Disease*, *101*(5):785-793.

De Marco, R. et al. (2021). Ciclo de desenvolvimento da nogueira-pecã – Escala fenológica. *Revista de Ciências Agroveterinárias*, *20*(4):260-270.

Fernández-Chávez, M. et al. (2021). Análisis de diversos aspectos económicos de la producción en huertas de nogales de alta y baja densidad. Estudio de caso. *Cultivos Tropicales*, *42*(2):e01.

Ferreira, D. F. (2014). Sisvar: A guide for its bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia*, *38*(2):109-112.

Fronza, D. et al. (2018). Pecan cultivation: general aspects. *Ciência Rural*, *48*(2):e20170179.

Gong, Y. et al. (2020). Pecan kernel phenolics content and antioxidant capacity are enhanced by mechanical pruning and higher fruit position in the tree canopy. *Journal of the American Society for Horticultural Science*, *145*(3):193-202.

Hamann, J. J. et al. (2024). Cultivares. In C. R. Martins., M. Lazarotto., & M. B. Malgarim. *Nogueira-pecã: Cultivo, benefícios e perspectivas*. Brasília-DF, Brasil: Embrapa, v.1, (pp.133-168).

Hellwig, C. G. et al. (2022). Hedge and central pruning in a high-density pecan orchard in southern Brazil. *Comunicata Scientiae*, *13*:e3842.

Li, Q. et al. (2023). Transcriptome analysis of the effects of grafting interstocks on apple rootstocks and scions. *International Journal of Molecular Sciences*, *24*(1):807.

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.

Lombardini, L., Restrepo-Diaz, H., & Volder, A. (2009). Photosynthetic light response and epidermal characteristics of sun and shade pecan leaves. *Journal of the American Society for Horticultural Science*, *134*(3):372-378.

Majid, I., Khalil, A., & Nazir, N. (2018). Economic analysis of high-density orchards. *International Journal of Advance Research in Science & Engineering*, *7*(4):821-829.

Malstrom, H. L., Riley, T. D., & Jones, J. R. (1982). Continuous hedge pruning affects light penetration and nut production of 'Western' pecan trees. *Pecan Quarterly*, *16*(3):193-202.

Martins, C. R. et al. (2023). *Panorama da produção, processamento e comercialização de noz-pecã no Sul do Brasil.* Pelotas: Embrapa Clima Temperado, 36p. (Embrapa Clima Temperado. Documentos, 535).

Mayer, N. A. et al. (2016). Adensamento de plantio em pessegueiros "Chimarrita". *Revista de Ciências Agroveterinárias*, *15*(1):50-59.

Noperi-Mosqueda, L. C. et al. (2020). Yield, quality, alternate bearing and long-term yield index in pecan, as a response to mineral and organic nutrition. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *48*(1):342-353.

Norma Oficial Mexicana - NMX-FF-084-SCFI-2009. (2009). *Productos alimenticios no industrializados para consumo humano - Fruto fresco - Nuez pecanera Carya illinoensis (Wangenh) K. Koch - Especificaciones y métodos de prueba.* Available in: <http://www.comenuez.com/assets/nmx-ff-084-scfi-2009.pdf>.

Rallo, L. et al. (2013). High-density olive plantations. *Horticultural Reviews*, *41*:303-384.

Reig, G. et al. (2020). Long-term performance of "Delicious" apple trees grafted on geneva® rootstocks and trained to four high-density systems under New York State climatic conditions. *HortScience*, *55*(10):1538-1550.

Santos, H. G. et al. (2018). *Sistema brasileiro de classificação de solos.* 5ed. Brasília, DF, Brasil: Embrapa. 356p.

Souri, M. K. (2016). Plants adaptation to control nitrification process in tropical region: Case study with *Acrocomia totai* and *Brachiaria humidicola* plants. *Open Agriculture*, *1*(1):144-150.

Souri, M. K., & Hatamian, M. (2019). Aminochelates in plant nutrition: A review. *Journal of Plant Nutrition*, *42*(1):67-78.

Wells, L. (2017). *Southeastern pecan grower's handbook*. 1ed. Athens, University of Georgia, USA. 236p.

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.

Wells, L., & Sawyer, A. (2023). *Hedge pruning pecan trees in the southeastern U.S.* Georgia: University of Georgia, 6p. (UGA Cooperative Extension Bulletin, 1557).

Wood, B. W. (2009). Mechanical hedge pruning of pecan in a relatively low-light environment. *HortScience*, *44*(1):68-72.

Wood, B. W., & Stahmann, D. (2004). Hedge pruning pecan. *HortTechnology*, *14*(1):63-72.

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*:79-85.

Zhu, H., & Stafne, E. T. (2019). Influence of paclobutrazol on shoot growth and flowering in a high-density pecan orchard. *HortTechnology*, *29*(2):210-212.

Zivdar, S. et al. (2016). Physiological and biochemical response of olive (*Olea europaea* L.) cultivars to foliar potassium application. *Journal of Agriculture, Science and Technology*, *18*:1897-1908.