EVALUATION OF PACLOBUTRAZOL IN PECAN NUT TREES: FINAL REPORT ON GROWTH, YIELD AND RESIDUE MEASUREMENTS

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INTRODUCTION

Paclobutrazol, a registered plant growth regulator, is commonly used on pecan nut trees in South Africa. This triazole-based compound also serves as a fungicide at different dosages. While the growth-retarding effects of paclobutrazol are well-documented on pecan nuts (Wood 1988; Andersen 1988; Worley et al., 1996), its impact on pecan yield and other parameters such as shoot growth and nut quality remains unclear (Zhu & Stafne 2019).

Some studies reported a decline in yield following single paclobutrazol applications (Andersen 1988; Worley et al., 1996). Work was conducted to better understand the long-term effects of a single or repeated application of paclobutrazol on pecan nuts in South Africa.

Paclobutrazol is commercially available for use on pecan nuts as ‘Cultar’ (Act 36 of 1947 registration no. L3693) and ‘Avocet’ (Act 36 of 1947 registration no. L7368). In this research report, the 250 g/L formulation of paclobutrazol in 'Cultar' was applied at three dosages on younger and more mature pecan trees to assess the effects of these applications on shoot growth, stem radius, stem circumference, yield, sticktights, quality, and residues. The effects after repeated (year-on-year) applications were also investigated.

METHODS

Treatments were applied as a drench around the tree stems in October 2022, with the desired concentration diluted in 5L water per tree, repeated on ten data trees per treatment, tree age and farm. Organic material was removed from the application area prior to drenching. The effects of single applications were evaluated on three farms on the cultivar ‘Wichita’ while the effects of multiple (year-on-year) applications were evaluated on ‘Western Schley’ and ‘Wichita’ from one farm in the Hartswater pecan nut production region, Northern Cape, South Africa.

Single applications

Single applications were done in October 2020 according to registration label recommendations on young trees (8-10 years old) and mature trees (15+ years). The dosages evaluated on young trees were: 0, 5, and 10 ml/tree while the dosages evaluated on mature trees were 0, 20 and 40 ml/tree.

Repeated applications

The effects of multiple applications repeated most seasons from 2015 up to 2022 were evaluated on ‘Western Schley’ and ‘Wichita’. The repeated applications were 8-10 ml/tree. Applications were not done in the 2018-2019 season on ‘Western Schley’ and not done on any of the two evaluated cultivars during the 2019-2020 season.

Measurements

During February of 2021, 3 months after the application, shoot lengths were measured from 5 replicated branches per data tree. Reproductive and vegetative shoot lengths were measured separately during February 2022, 2023, and 2024 from four replicated wind directions (North, East, South, and West) per data tree from the top and bottom of each data tree for more uniform measures. Stem diameters and circumferences were also measured at this time. Yields were measured during July 2021, 2022, 2023 and 2024. The weight of dropped nuts per tree, and weight and number (count) of sticktights per tree were determined per data tree. Yield quality parameters were evaluated at a processor from three grouped samples per treatment, age group and farm. Kernel quality parameters evaluated against paclobutrazol treatment outcomes included sound edible nuts and nut sizes: OS1, OS2, J, XL, L, M, and S. Paclobutrazol residue analysis included 54 replicated pecan nut samples and 6 replicated soil samples (two samples from the 40 ml/tree treatments per farm) during the 2021 harvesting season and 42 pecan nut samples and 10 soil samples in July 2022.

Statistical analysis

Data were analysed in RStudio: R Core Team (2015), v 4.2.3. Before statistical tests were performed, outliers were excluded from the datasets per treatment using the Interquartile Range (IQR) method. The IQR represents the central 50% of the dataset, between the 25^{th} and 75^{th} percentile of the data distribution. Outliers are identified as points 1.5 times smaller or larger than the IQR.

The main effect of each treatment (i.e. dosage) was analysed per age group as described in Patil (2021). Shapiro-Wilk tests of normality of model residuals and Levene's Test for Homogeneity of Variance were used prior to statistical analysis with the R packages 'ggisgnif' (Ahlmann-Eltze, 2021) and 'ggstatsplot' (Patil, 2021). Results were plotted using the R package 'ggplot' (Wickham, 2016) after obtaining basic statistical summaries with the R package 'Rmisc' (Hope, 2022) to visualize statistical significance as determined with appropriate post-hoc tests on an alpha level of 0.05 (95% confidence limit). Mean and std. error (se) plots were provided using the package: ggpubr (Kassambara 2020). Statistical results of each effect were summarized in a table format using the package: Rmisc (Hope 2022) giving the sample size (N), average (mean), standard deviation (sd), standard error (se) and 95% confidence intervals (ci).

RESULTS

Reproductive shoot lengths from young and mature trees were statistically significantly influenced by the single application of paclobutrazol during October 2020 (Table 1, Figure 1). Measurements of February 2022 showed that the reproductive shoots were significantly shorter after the 10 ml/tree dosage on young trees and the 20 and 40 ml/tree dosage on mature trees (Table 1). Measurements of February 2023 showed that the reproductive shoots were significantly shorter after all the treatments on young and mature trees compared to the untreated control (Table 1). Measurements of February 2024 showed that only the reproductive shoots from the 40 ml/tree dosage on mature trees were significantly shorter than the untreated control, while the reproductive shoots were significantly longer after 5 and 10 ml/tree treatments on young trees (Table 1).

Vegetative shoot lengths from young and mature trees were significantly influenced by the single application of paclobutrazol during October 2020 (Table 2, Figure 2). By contrast to the reproductive shoots, the vegetative shoot measurement results from February 2022 showed significantly longer shoot lengths after 5 and 10 ml/tree treatments compared to the untreated control (Table 2). Mature tree results showed significantly shorter vegetative shoots on the treatments, with the 20 ml/tree treatment resulting in the shortest vegetative shoots measured during February 2022 (Table 2). Young and mature trees showed significantly shorter vegetative shoot lengths during February 2023 compared to the untreated control groups, followed by no significant difference in vegetative shoot lengths on young trees during February 2024 (Table 1). Mature tree results showed significantly shorter vegetative shoots on the 40 ml/tree treatment measurements during February 2024 compared to the control (Tabel 2).

Repeated applications on Western-Schley showed no significant reproductive or vegetative shoot length differences during February 2024 (Table 3), while repeated applications on Wichita showed significantly longer vegetative shoots where treatments (8-10 ml/tree) were applied year-on-year (Table 3).

Table 1. Reproductive shoot length (mean ± se in cm) after a single paclobutrazol application in October 2020. Different letters indicate significance groupings per tree age group and season, and sample sizes are given in brackets after outliers were removed.

Treatment	February 2022	February 2023	February 2024
Young trees			
0 ml/tree	11.29 ± 0.39^a (152)	16.26 ± 0.44^a (367)	10.38 ± 0.13^a (1134)
5 ml/tree	12.97 ± 0.51^a (219)	12.86 ± 0.37^b (340)	11.70 ± 0.22^b (570)
10 ml/tree	18.49 ± 0.60^b (322)	13.18 ± 0.58^b (169)	12.32 ± 0.23^b (586)
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}(2) = 66.70, p < 0.001$	$\chi^2_{Kruskal\text{-}Wallis}(2) = 36.53, p < 0.001$	$\chi^2_{Kruskal\text{-}Wallis}(2) = 53.76, p < 0.001$
Mature trees			
0 ml/tree	11.15 ± 0.30^a (233)	12.32 ± 0.28^a (383)	9.22 ± 0.12^a (1218)
20 ml/tree	7.10 ± 0.11^b (417)	6.82 ± 0.14^b (167)	9.08 ± 0.12^a (1224)
40 ml/tree	6.89 ± 0.13^b (200)	7.46 ± 0.14^b (373)	8.00 ± 0.10^b (1181)
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}(2) = 170.64, p < 0.001$	$\chi^2_{Kruskal\text{-}Wallis}(2) = 252.00, p < 0.001$	$\chi^2_{Kruskal\text{-}Wallis}(2) = 49.92, p < 0.001$

Table 2. Vegetative shoot length (mean ± se in cm) after a single paclobutrazol application in October 2020. Different letters indicate significance groupings per tree age group and season, and sample sizes are given in brackets after outliers were removed.

Treatment	February 2022	February 2023	February 2024
Young trees			
0 ml/tree	4.89 ± 0.16^a (106)	10.40 ± 0.39^a (315)	7.47 ± 0.13^a (1134)
5 ml/tree	7.29 ± 0.28^b (229)	8.19 ± 0.24^b (298)	7.55 ± 0.20^a (570)
10 ml/tree	9.23 ± 0.25^c (334)	7.12 ± 0.26^b (132)	7.76 ± 0.18^a (586)
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}(2) = 94.28, p < 0.001$	$\chi^2_{Kruskal\text{-}Wallis}(2) = 15.92, p < 0.001$	$\chi^2_{Kruskal\text{-}Wallis}(2) = 4.33, p = 0.11$
Mature trees			
0 ml/tree	7.01 ± 0.21^a (224)	6.40 ± 0.16^a (347)	7.76 ± 0.15^a (568)
20 ml/tree	4.10 ± 0.08^b (384)	4.10 ± 0.12^b (162)	7.65 ± 0.14^a (590)
40 ml/tree	4.83 ± 0.12^c (298)	3.68 ± 0.08^b (216)	7.03 ± 0.13^b (593)
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}(2) = 155.03, p < 0.001$	$\chi^2_{Kruskal\text{-}Wallis}(2) = 187.74, p < 0.001$	$\chi^2_{Kruskal\text{-}Wallis}(2) = 11.22, p < 0.01$

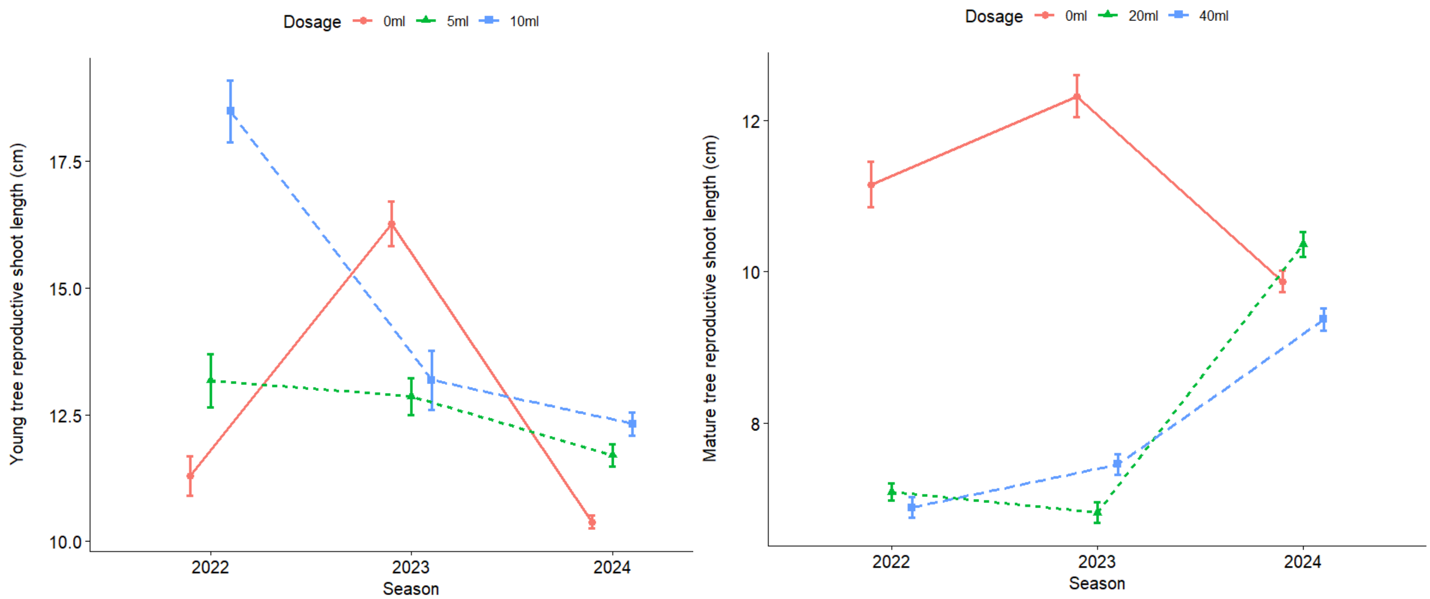

Figure 1. Reproductive shoot length (mean ± std error) measured during February of consecutive seasons following a single paclobutrazol application in October 2020 (2020-2021 season) on young (left) and mature (right) pecan nut trees.

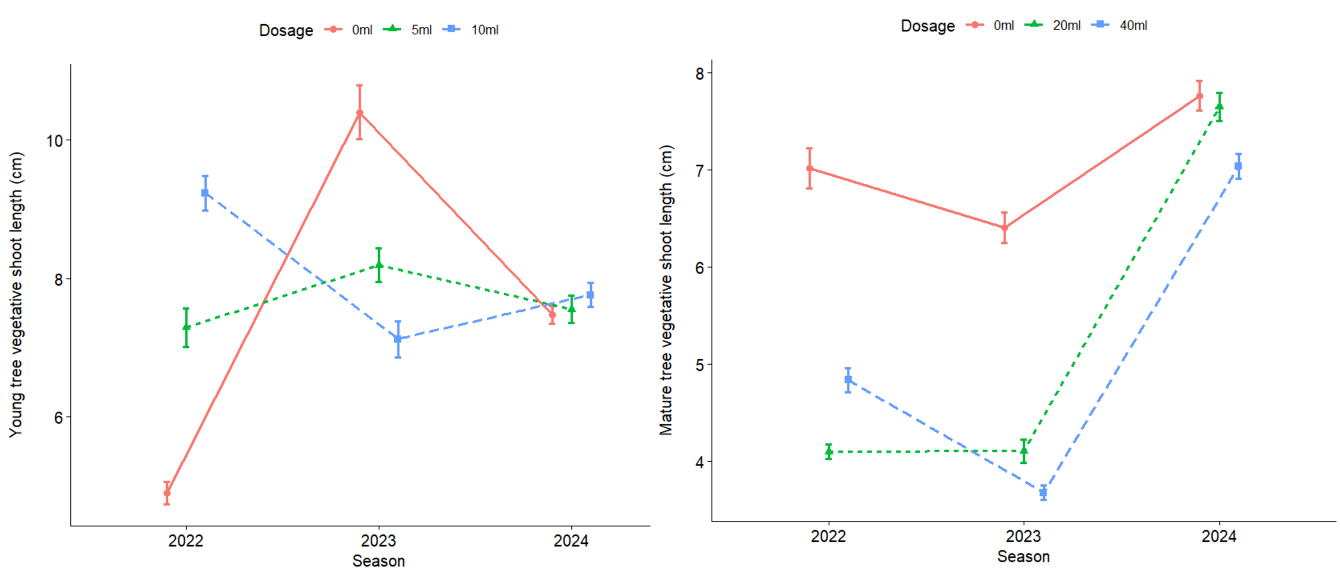

Figure 2. Vegetative shoot lengths (means ± std error) measured in February of consecutive seasons following a single paclobutrazol application in October 2020 (2020-2021 season) on young (left) and mature (right) pecan nut trees.

Table 3. Lengths of reproductive and vegetative shoots (mean ± se in cm) during February 2024 after repeated paclobutrazol applications since 2015. Different letters indicate significance groupings per cultivar and shoot type, and sample sizes are given in brackets after outliers were removed.

Treatment	Reproductive shoots	Vegetative shoots
Western-Schley		
0 ml/tree	9.32 ± 0.20^{a} (311)	7.29 ± 0.23^{a} (275)
8-10 ml/tree	8.81 ± 0.20^{a} (304)	7.41 ± 0.19^{a} (299)
T-test results:	$W_{Mann\text{-}Whitney} = 51048.50$, p = 0.09	$W_{Mann\text{-}Whitney} = 39041.00$, p = 0.30
Wichita		
0 ml/tree	8.39 ± 0.17^{a} (302)	6.82 ± 0.23^{a} (263)
8-10 ml/tree	8.64 ± 0.16^{a} (307)	7.62 ± 0.23^{b} (297)
T-test results:	$W_{Mann\text{-}Whitney} = 43994.00$, p = 0.28	$W_{Mann\text{-}Whitney} = 34353.50$, p = 0.01

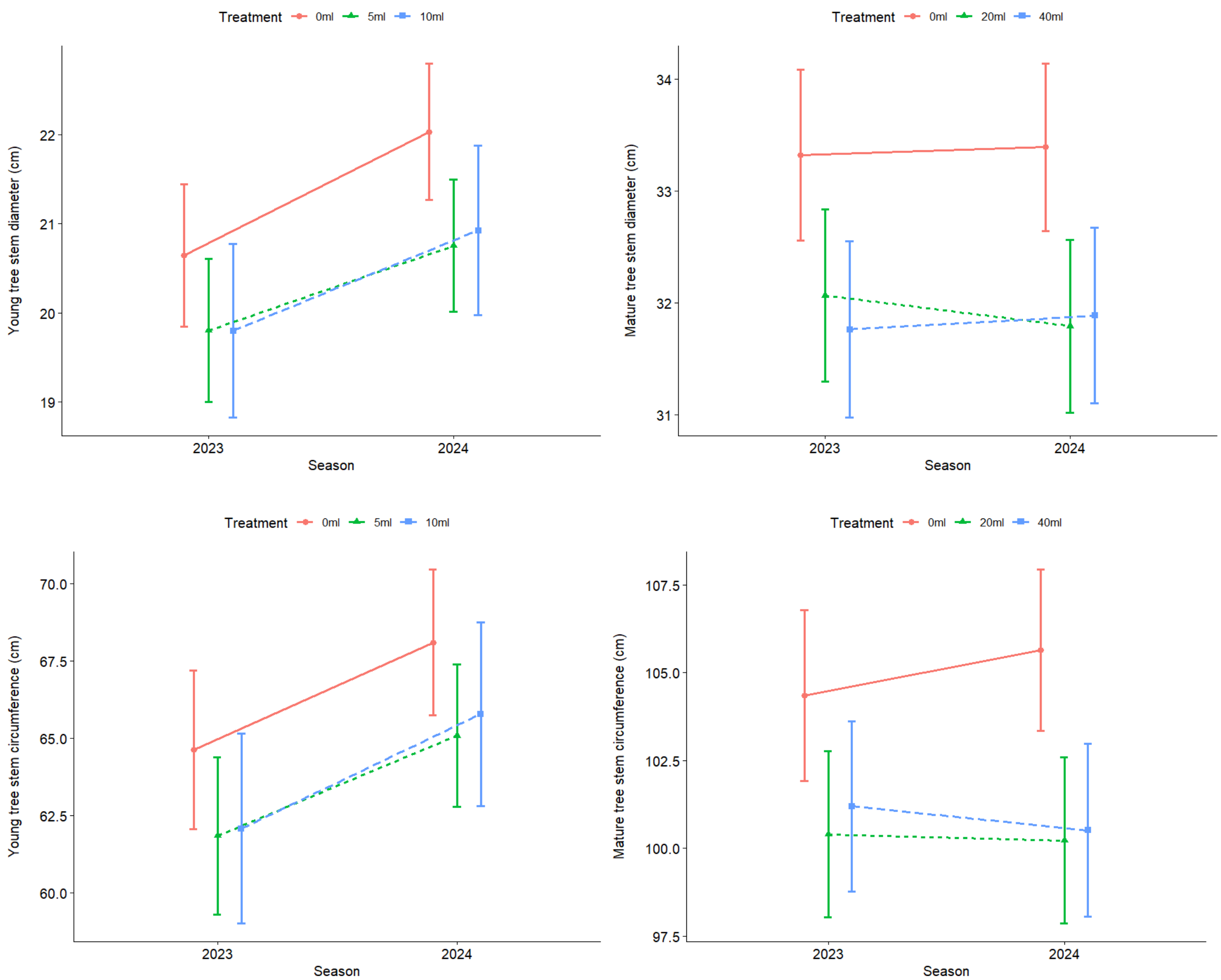

Figure 3. Stem diameter and circumference results across two consecutive seasons after different application dosages of paclobutrazol in October 2020.

Table 4. Stem circumference and diameter measurement (mean ± se cm) results after a single application in October 2020. Different letters annotate significant treatment differences and sample sizes are given in brackets.

	Stem circumference			Stem diameter	
Treatment	**February 2022**	**February 2023**	**February 2024**	**February 2023**	**February 2024**
Young trees					
0 ml/tree	66.10 ± 2.67[a] (30)	64.62 ± 2.56[a] (367)	68.10 ± 2.35[a] (20)	20.65 ± 0.80[a] (20)	22.03 ± 0.76[a] (20)
5 ml/tree	65.13 ± 2.91[a] (30)	61.85 ± 2.54[a] (340)	65.08 ± 2.30[a] (20)	19.81 ± 0.80[a] (20)	20.76 ± 0.74[a] (20)
10 ml/tree	65.37 ± 5.82[a] (30)	62.09 ± 3.07[a] (169)	65.78 ± 2.97[a] (20)	19.80 ± 0.98[a] (20)	20.93 ± 0.95[a] (20)
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 0.29, p = 0.87	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 1.91, p = 0.38	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 2.22, p = 0.33	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 2.25, p = 0.33	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 2.85, p = 0.24
Mature trees					
0 ml/tree	98.05 ± 2.33[a] (30)	104.35 ± 2.42[a] (20)	105.64 ± 2.30[a] (20)	33.32 ± 0.76[a] (20)	33.39 ± 0.75[a] (20)
20 ml/tree	95.25 ± 2.21[a] (30)	100.40 ± 2.36[a] (20)	100.23 ± 2.37[a] (20)	32.07 ± 0.77[a] (20)	31.79 ± 0.77[a] (20)
40 ml/tree	96.17 ± 2.47[a] (30)	101.20 ± 2.42[a] (20)	100.52 ± 2.45[a] (20)	31.76 ± 0.79[a] (20)	31.89 ± 0.79[a] (20)
ANOVA results:	F_{fisher} (2, 87) = 0.37, p = 0.69	F_{Fisher} (2, 57) = 0.75, p = 0.47	F_{Fisher} (2, 57) = 1.64, p = 0.20	F_{Fisher} (2, 57) = 1.14, p = 0.33	F_{Fisher} (2, 57) = 1.37, p = 0.26

Table 5. Stem measurement (mean ± se cm) results during February 2024 after repeated applications from October 2015 on young trees of different cultivars. Different letters annotate significant treatment differences and sample sizes are given in brackets.

Treatment	**Stem circumference**	**Stem diameter**
Western-Schley		
0 ml/tree	87.55 ± 2.61[a] (10)	25.08 ± 2.57[a] (10)
8-10 ml/tree	96.64 ± 2.01[b] (8)	30.65 ± 0.54[b] (8)
T-test results:	$t_{Student}$ (16) = -2.64, p = 0.02	$W_{Mann\text{-}Whitney}$ = 12.00, p = 0.01
Wichita		
0 ml/tree	94.65 ± 2.91[a] (10)	29.95 ± 0.92[a] (10)
8-10 ml/tree	90.15 ± 3.79[a] (10)	28.29 ± 1.14[b] (10)
T-test results:	$t_{Student}$ (18) = 0.94, p = 0.36	$t_{Student}$ (18) = 1.13, p = 0.27

Stem circumference and diameter measurement results showed no significant treatment effect on young or mature trees during any season after a single application in October 2020 (Figure 3, Table 4). Repeated applications significantly increase the stem circumference and diameter of Western-Shley (Table 5), while the stem diameters were significantly smaller after repeated treatments on Wichita (Table 5).

Yield results showed that the weights of the nuts that dropped naturally did not differ significantly across treatments on young and mature trees (Table 6, Figure 4). However, the cumulative weights over the season were significantly influenced after once-off application on young trees (Table 6). The weights of sticktights were not significantly differences across treatments on young and mature trees, except for the July 2022 and July 2024 measurements on young trees that showed significantly lower sticktight weights after 5 and 10 ml/tree treatments compared to the untreated control (Table 7, Figure 5). The sums of the nuts that dropped naturally and the sticktights (total yield) were not significantly different across treatments and tree ages (Table 8), except for mature tree treatments 20 and 40 ml/tree results measured during July 2021 (Table 8). Edible nut analysis results showed no significant differences between treatments from young and mature trees (Table 9).

Repeated applications resulted in significant lower natural nut drop (yield) on Western-Schley in 2023 and Wichita in 2024 (Table 10). The sticktight measurement results in 2024 showed significantly lower weights where repeated applications on Wichita (Table 10). The combined yield was significantly lower after repeated applications in Wichita (Table 10). Edible nut analysis results showed no significant differences between treatments after repeated applications (Table 10).

Kernel size results analysis showed very few significant differences between the treatments. The exceptions are summarized as 1) more size J kernel obtained in July 2022 on young trees (Figure 6, 11.02 and 10.41 % from 5 and 10 ml/tree respectively, compared to 3.40 % in the untreated control); 2) significantly more size OS 1 kernel from the 20 ml/tree treated mature trees during July 2023 (Figure 6, 3.50 % compared to 0.63 % in the untreated control); and 3) significantly more size OS 1 kernel from the 5 ml/tree treated young trees during July 2023 (Figure 6, 7.67 % compared to 0.63 % in the untreated control and 1.93% after 10 ml/tree treatment).

No paclobutrazol residues were detected in pecan nuts across all replicated treatment samples from all farms during the first- and second harvest following the highest single application treatments on young and mature trees. During the second harvesting season (2022), 42 residue samples were analyzed and again no residues were detected above the limit of quantification.

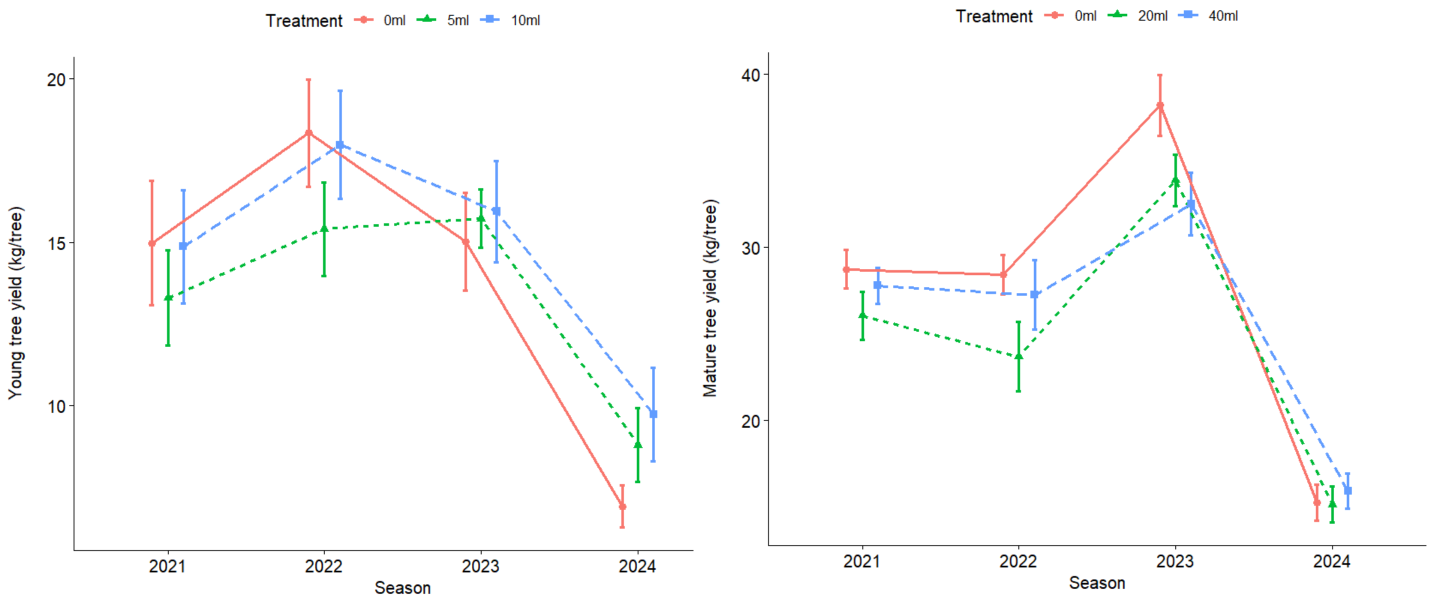

Figure 4. Yield results (means ± std error) measured in July for consecutive seasons following a single paclobutrazol application in October 2020 from young (left) and mature (right) pecan nut trees.

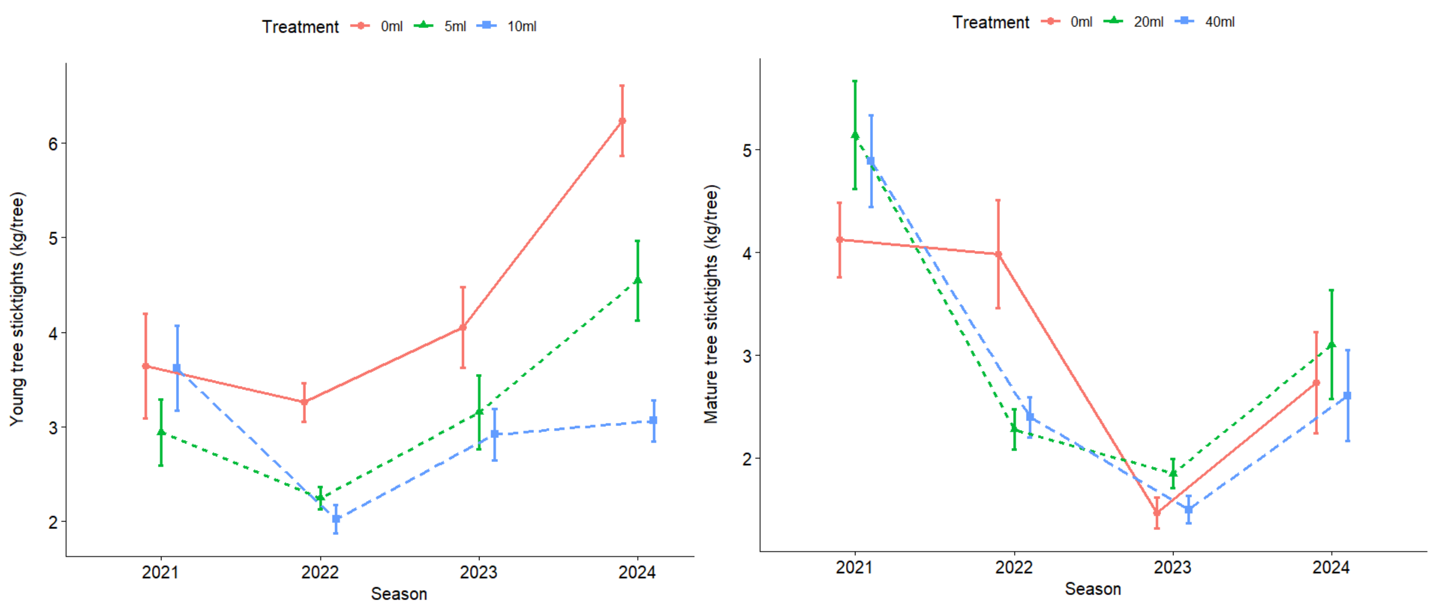

Figure 5. Sticktight results (means ± std error) measured in July for consecutive seasons following a single paclobutrazol application in October 2020 from young (left) and mature (right) pecan nut trees.

Table 6. Yield (mean ± se) measured as the kg nuts that naturally dropped from the tree after a single application in October 2020. Different letters indicate significant differences, and sample sizes are given in brackets.

Treatment	July 2021	July 2022	July 2023	July 2024	Cumulative
Young trees					
0 ml/tree	14.97 ± 1.91[a] (30)	18.35 ± 1.64[a] (30)	15.03 ± 1.50[a] (20)	6.89 ± 0.65[a] (17)	239.7 ± 8.11[a]
5 ml/tree	13.29 ± 1.46[a] (30)	15.40 ± 1.44[a] (30)	15.72 ± 0.89[a] (18)	8.78 ± 1.14[a] (20)	132.3 ± 2.35[b]
10 ml/tree	14.86 ± 1.74[a] (30)	17.99 ± 1.66[a] (30)	15.94 ± 1.55[a] (20)	9.72 ± 1.44[a] (20)	149.84 ± 5.94[c]
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 0.17, p = 0.92	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 1.98, p = 0.37	F_{Welch} (2, 35) = 0.10, p = 0.90	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 0.96, p = 0.62	F_{Welch} (2, 14) = 78.37, p < 0.001
Mature trees					
0 ml/tree	28.74 ± 1.10[a] (30)	28.45 ± 1.15[a] (28)	38.22 ± 0.89[a] (20)	15.29 ± 1.05[a] (8)	262.51 ± 11.56[a]
20 ml/tree	26.06 ± 1.39[a] (30)	23.69 ± 2.01[a] (30)	33.89 ± 1.08[a] (20)	15.17 ± 1.06[a] (10)	232.21 ± 9.59[a]
40 ml/tree	27.80 ± 1.05[a] (29)	27.26 ± 2.00[a] (30)	32.52 ± 1.01[a] (20)	15.92 ± 1.02[a] (10)	244.24 ± 6.38[a]
ANOVA results:	F_{Fisher} (2, 86) = 1.31, p = 0.27	F_{Welch} (2, 53.14) = 2.09, p = 0.13	F_{Fisher} (2, 57) = 3.12, p = 0.05	F_{Fisher} (2, 27) = 0.15, p = 0.86	F_{Fisher} (2, 27) = 2.62, p = 0.09

Table 7. Sticktights (mean ± se kg) per tree results after a single application in October 2020. Different letters indicate significant differences, and sample sizes are given in brackets.

Treatment	July 2021	July 2022	July 2023	July 2024
Young trees				
0 ml/tree	3.64 ± 0.55[a] (30)	3.26 ± 0.20[a] (29)	4.05 ± 0.43[a] (30)	6.24 ± 0.37[a] (18)
5 ml/tree	2.94 ± 0.35[a] (30)	2.25 ± 0.12[b] (30)	3.15 ± 0.39[a] (20)	4.54 ± 0.42[b] (18)
10 ml/tree	3.62 ± 0.45[a] (30)	2.02 ± 0.15[b] (29)	2.92 ± 0.27[a] (20)	3.06 ± 0.22[c] (19)
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 0.74, p = 0.69	F_{Welch} (2, 54) = 12.82, p < 0.001	F_{Fisher} (2, 57) = 2.63, p = 0.08	F_{Fisher} (2, 52) = 21.49, p < 0.001
Mature trees				
0 ml/tree	4.12 ± 0.36[a] (79)	3.99 ± 0.52[a] (29)	1.47 ± 0.15[a] (20)	2.74 ± 0.49[a] (10)
20 ml/tree	5.14 ± 0.53[a] (30)	2.28 ± 0.20[a] (30)	1.85 ± 0.14[a] (20)	3.11 ± 0.53[a] (10)
40 ml/tree	4.89 ± 0.44[a] (30)	2.40 ± 0.19[a] (30)	1.50 ± 0.13[a] (19)	2.61 ± 0.44[a] (10)
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 1.76, p = 0.41	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 6.15, p = 0.05	F_{Fisher} (2, 56) = 2.22, p = 0.12	F_{Fisher} (2, 27) = 0.28, p = 0.76

Table 8. Total yield (mean ± se) calculated as naturally dropped nuts plus sticktights per tree after a single application in October 2020. Different letters indicate significant differences, and sample sizes are given in brackets.

Treatment	July 2021	July 2022	July 2023	July 2024
Young trees				
0 ml/tree	18.61 ± 2.29[a] (30)	21.73 ± 1.60[a] (30)	19.87 ± 1.32[a] (19)	14.83 ± 1.23[a] (19)
5 ml/tree	16.23 ± 1.71[a] (30)	17.64 ± 1.47[a] (30)	19.14 ± 0.87[a] (18)	13.89 ± 1.36[a] (20)
10 ml/tree	18.47 ± 1.98[a] (30)	20.14 ± 1.77[a] (30)	18.86 ± 1.54[a] (20)	12.95 ± 1.41[a] (20)
ANOVA results:	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 0.49, p = 0.78	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 3.47, p = 0.18	F_{Welch} (2, 34) = 0.15, p = 0.86	F_{Fisher} (2, 56) = 0.49, p = 0.62
Mature trees				
0 ml/tree	31.76 ± 0.90[a] (28)	32.42 ± 1.23[a] (28)	39.68 ± 1.80[a] (20)	9.01 ± 2.16[a] (20)
20 ml/tree	31.20 ± 1.48[b] (30)	25.97 ± 1.91[a] (30)	35.74 ± 1.49[a] (20)	9.14 ± 2.16[a] (20)
40 ml/tree	34.40 ± 1.85[b] (19)	29.66 ± 1.94[a] (30)	34.11 ± 1.78[a] (20)	9.26 ± 2.18[a] (20)
ANOVA results:	F_{Welch} (2, 40) = 1.00, p = 0.38	F_{Welch} (2, 54) = 4.06, p = 0.02	F_{Fisher} (2, 57) = 2.85, p = 0.07	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 0.05, p = 0.98

Table 9. Edible nuts (mean ± se %) per sample after a single application in October 2020. Different letters indicate significant differences, and sample sizes are given in brackets.

Treatment	July 2021	July 2022	July 2023	July 2024
Young trees				
0 ml/tree	55.99 ± 1.24[a] (9)	58.78 ± 0.46[a] (6)	58.40 ± 0.72[a] (6)	57.76 ± 0.40[a] (5)
5 ml/tree	55.02 ± 1.42[a] (9)	59.60 ± 0.24[a] (5)	57.07 ± 1.69[a] (6)	58.87 ± 0.60[a] (6)
10 ml/tree	57.84 ± 0.77[a] (9)	57.57 ± 0.85[a] (6)	57.57 ± 1.39[a] (6)	59.33 ± 0.42[a] (6)
ANOVA results:	F_{Fisher} (2, 24) = 1.48, p = 0.25	F_{Welch} (2, 8) = 3.18, p = 0.09	F_{Fisher} (2, 15) = 0.26, p = 0.78	F_{Fisher} (2, 14) = 2.55, p = 0.11
Mature trees				
0 ml/tree	55.91 ± 1.14[a] (9)	59.47 ± 0.37[a] (6)	59.23 ± 0.39[a] (6)	57.73 ± 0.78[a] (6)
20 ml/tree	54.98 ± 1.26[a] (9)	58.83 ± 0.83[a] (6)	58.84 ± 0.64[a] (5)	59.6 ± 0.51[a] (5)
40 ml/tree	56.40 ± 0.61[a] (9)	58.33 ± 0.76[a] (6)	58.95 ± 0.95[a] (6)	57.13 ± 1.22[a] (6)
ANOVA results:	F_{Fisher} (2, 24) = 0.48, p = 0.62	F_{Fisher} (2, 15) = 0.69, p = 0.52	$\chi^2_{Kruskal\text{-}Wallis}$ (2) = 0.84, p = 0.66	F_{Fisher} (2, 14) = 1.82, p = 0.20

Table 10. Yield and quality (mean ± se cm) results measured during July of 2023 and 2024 after repeated applications on different cultivars. Different letters annotate significant treatment differences and sample sizes are given in brackets.

Treatment	Yield (kg/tree)	Sticktights (kg/tree)	Total yield (kg/tree)	Edible kernel (%)
2023				
Western-Schley				
0 ml/tree	15.02 ± 1.46[a] (10)	1.22 ± 0.21[a] (10)	16.24 ± 1.47[a] (10)	57.60 ± 0.40 (2)
8-10 ml/tree	10.59 ± 1.32[b] (9)	1.20 ± 0.20[a] (10)	13.20 ± 1.98[a] (10)	57.00 ± 0.00 (1)
T-test results:	$t_{Student}$ (17) = 2.23, p = 0.04	$t_{Student}$ (18) = 0.09, p = 0.93	$t_{Student}$ (18) = 1.24, p = 0.23	*Too few replicates*
Wichita				
0 ml/tree	17.65 ± 1.10[a] (9)	6.03 ± 0.59[a] (10)	23.76 ± 0.89[a] (9)	56.00 ± 2.50[a] (2)
8-10 ml/tree	19.40 ± 1.25[a] (10)	6.81 ± 0.59[a] (10)	26.21 ± 1.61[a] (10)	58.40 ± 1.60[a] (2)
T-test results:	$t_{Student}$ (17) = -1.04, p = 0.31	$t_{Student}$ (18) = -1.29, p = 0.21	$t_{Student}$ (17) = 0.94, p = 0.36	t_{Welch} (1.7) = -0.81, p = 0.52
2024				
Western-Schley				
0 ml/tree	33.53 ± 0.79[a] (8)	0.66 ± 0.06[a] (10)	33.51 ± 0.92[a] (9)	57.60 ± 0.61[a] (3)
8-10 ml/tree	34.52 ± 1.28[a] (9)	0.56 ± 0.08[a] (8)	35.18 ± 1.26[a] (9)	57.27 ± 1.43[a] (3)
T-test results:	$t_{Student}$ (15) = -0.64, p = 0.53	$t_{Student}$ (16) = 0.99, p = 0.34	$t_{Student}$ (16) = -1.07, p = 0.30	$t_{Student}$ (4) = 0.21, p = 0.84
Wichita				
0 ml/tree	28.44 ± 1.64[a] (10)	3.39 ± 0.30[a] (9)	32.35 ± 1.95[a] (10)	59.00 ± 0.58[a] (3)
8-10 ml/tree	21.72 ± 1.74[b] (10)	1.99 ± 0.20[b] (10)	23.71 ± 1.85[b] (10)	59.67 ± 0.33[a] (3)
T-test results:	$t_{Student}$ (18) = 2.81, p = 0.01	$t_{Student}$ (17) = 3.97, p < 0.01	$t_{Student}$ (18) = 3.21, p < 0.01	t_{Welch} (3.2) = -1.00, p = 0.39

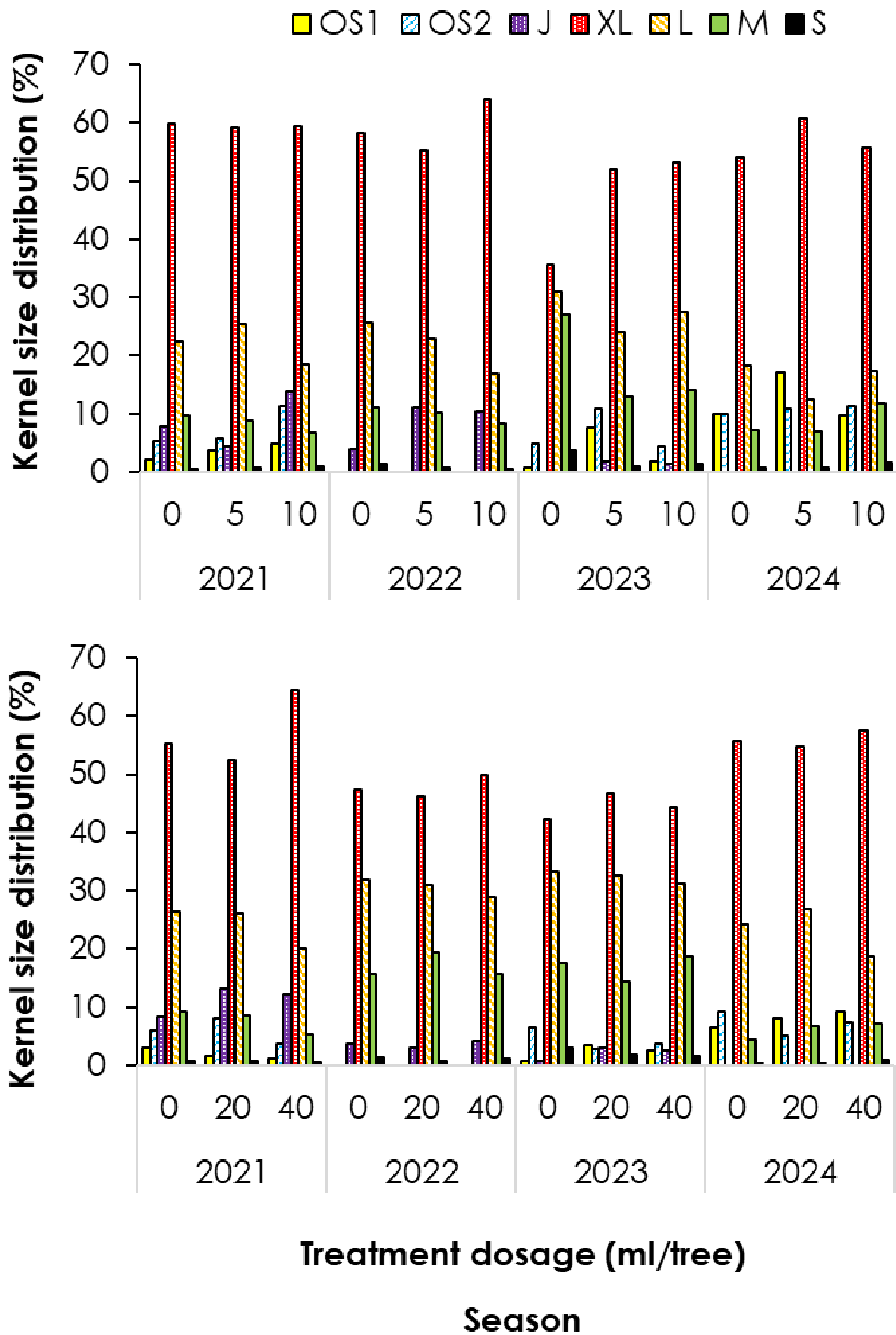

Figure 6. Kernel size distribution (%) observed over the trial period after a single application of paclobutrazol in October 2020.

CONCLUSIONS

Growth measurements after a single paclobutrazol application confirmed the growth inhibiting effect of paclobutrazol in young and mature trees. Reproductive shoots were generally shorter after applications of paclobutrazol, and this effect lasted for 3 seasons after the applications were done on young trees, and 4 seasons on the highest dosage applied on mature trees. Vegetative shoots were also generally shorted after the application, however there were some initial observation exceptions on mature trees. Repeated applications of paclobutrazol on Western-Schley did not show significant shoot length differences during February 2024 while vegetative shoots were longer on Wichita. Stem circumferences and diameters were not influenced by the single applications, while the repeated applications significantly increased the stem circumference and diameter of Western-Shley while the stem diameters were significantly smaller after repeated treatments on Wichita. There were no significant yield effects on young or mature trees following a single application, however the total yield (dropped plus stick tights) was higher during July 2021 on mature trees treated with 40 ml/tree paclobutrazol in October 2020. This effect was however not observed in consecutive seasons. Repeated applications had a negative total yield outcomes on Wichita. Nut quality analysis results did not show significant differences between treatments that were noteworthy.

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REFERENCES

Ahlmann-Eltze, C. & Patil, I. (2021). ggsignif: R Package for Displaying Significance Brackets for 'ggplot2'. PsyArxiv. doi:10.31234/osf.io/7awm6.

Andersen, P.C. (1988), Vegetative and reproductive effects of Cultar applied to ‘Cape Fear’ and ‘Desirable’ pecan trees. Proc. Flo. State. Hort. Soc. 101: 254-256.

Hope, R.M. (2022). _Rmisc: Ryan Miscellaneous_. R package version 1.5.1, <https://CRAN.R-project.org/package=Rmisc>.

Kassambara, A. (2020). _ggpubr: 'ggplot2' Based Publication Ready Plots_. R package version 0.4.0, <https://CRAN.R-project.org/package=ggpubr>.

Kassambara, A. (2021). _rstatix: Pipe-Friendly Framework for Basic Statistical Tests_. R package version 0.7.0, <https://CRAN.R-project.org/package=rstatix>.

Patil, I. (2021). Visualizations with statistical details: The 'ggstatsplot' approach. Journal of Open-Source Software, 6(61), 3167, doi:10.21105/joss.03167.

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Wood, B.W. (1988). Paclobutrazol suppresses vegetative growth of large pecan trees. HortScience 23: 341-343.

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