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Does the application of growth bioregulators improve the foliar concentration of nutrients, non-structural carbohydrates and yield in pecan?

A aplicação de bioreguladores de crescimento melhora a concentração foliar de nutrientes, carboidratos não estruturais e rendimento em pecan?

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ABSTRACT

Carya illinoinensis (Wangenh.) K. Koch. is a deciduous fruit species with high economic impact and nutritional value that exhibits alternate bearing behavior. In this study, the concentration of foliar nutrients, non-structural carbohydrates and yield were evaluated in cultivar Western Schley pecan in response to the foliar application of gibberellic acid (50 mg L^{-1} GA_3), prohexadione calcium (500 mg L^{-1} PCa) and thidiazuron (10 mg L^{-1} TDZ).The statistical analysis reveals that between agricultural cycles, the treatments showed no variation in the foliar concentration of nitrogen total (N-total), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn) and non-structural carbohydrates (fructose, glucose, sucrose and starch). However, the application of PCa showed no significant effect on the concentration of phosphorus (P) (1.5 and 1.9 g kg^{-1}). On the other hand, the concentration of zinc (Zn) (27.0-60.1 mg kg^{-1}) showed a significant difference between years, with no effect due to the application of growth bioregulators. The trees treated with GA_3 minimized alternate bearing by presenting similar values (12.4 and 15.3 kg $tree^{-1}$) of yield. Likewise, the applied treatments did not affect the nut weight per kilogram (kg) (5.5-6.8 g) and kernel percentage (56.5-60.8). These data provide a new perspective on the complex nature of alternate bearing production in cultivar Western Schley pecan and are interpreted to indicate that alternate production could be regulated by carbohydrate reserve, nutrient concentration, and gibberellins.

Index terms: *Carya illinoinensis*; alternate bearing; gibberellic acid; prohexadione calcium; thidiazuron.

RESUMO

Carya illinoinensis (Wangenh.) K. Koch. é uma espécie frutífera decídua com alto impacto econômico e valor nutricional que apresenta comportamento alternativo de produção. Neste estudo, a concentração de nutrientes foliares, carboidratos não estruturais e produtividade foram avaliados na cultivar Western Schley pecan em resposta à aplicação foliar de ácido giberélico (50 mg L^{-1} GA_3), prohexadiona cálcio (500 mg L^{-1} PCa) e thidiazuron (10 mg L^{1} TDZ). A análise estatística revela que entre os ciclos agrícolas, os tratamentos não apresentaram variação na concentração foliar de nitrogênio total (N-total), potássio (K), cálcio (Ca), magnésio (Mg), ferro (Fe), cobre (Cu), manganês (Mn) e carboidratos não estruturais (frutose, glicose, sacarose e amido). Porém, a aplicação do PCa não apresentou efeito significativo sobre a concentração de fósforo (P) (1,5 e 1,9 g kg^{-1}). Por outro lado, a concentração de zinco (Zn) (27,0 60,1 mg kg^{-1}) apresentou diferença significativa entre os anos, sem efeito devido à aplicação de biorreguladores de crescimento. As árvores tratadas com GA_3 minimizaram a produção alternada por apresentar valores semelhantes (12,4 e 15,3 kg $árvore^{-1}$) de produtividade. Da mesma forma, os tratamentos aplicados não afetaram o peso da castanha por quilograma (kg) (5,5-6,8 g) e a porcentagem de grãos (56,5-60,8). Esses dados fornecem uma nova perspectiva sobre a natureza complexa da produção alternada na cultivar Western Schley pecan e são interpretados para indicar que a produção alternativa pode ser regulada pela reserva de carboidratos, concentração de nutrientes e giberelinas.

Termos para indexação: *Carya illinoinensis;* produção alternada; ácido giberélico; prohexadiona cálcio; thidiazuron.

INTRODUCTION

Pecan [*Carya illinoinensis* (Wangenh.) K. Koch.] is a deciduous crop of high profitability and nutritional value (Wood, 2011). Among the cultivars with the largest planted area are Pawnee, Western Schley, Wichita and Stuart (Ojeda-Barrios et al., 2009; Wells, 2014). Similar to some other nut trees, pecans have alternate bearing which affects the yield and quality of the harvested nut (Smith; Rohla; Goof, 2012). In addition, that can considerably reduce producers income and its market power (Castillo-Gonzalez et al., 2019). However, alternate bearing is a natural physiological survival process that trees present to regulate their reserves and maintain fruit production (Wood, 2014; Zivdar et al., 2016).

The optimal supply of nutrients affects the synthesis and accumulation of carbohydrates, that can improve the yield and quality of nut (Balandrán-Valladares et al., 2021; Souri; Hatamian, 2019). The fertilisation programs in pecan usually consider nitrogen (N) and zinc (Zn) as the two most important nutrients in the commercial production of this fruit (Castillo-González et al., 2019). In particular, N is directly associated with the conformation of the tree canopy (Smith; Rohla; Goof, 2012) and plant enrichment with sugars, amino acids and proteins that are very important in constant bearing and productivity of crops (Hatamian et al., 2018; Aghaye-Noroozlo; Souri; Delshad, 2019). On the other hand, Zn is involved in the elongation of shoots, chlorophyll synthesis and plays an outstanding role in pecan metabolism, because it is part of the oxidoreductase, lyase, isomerase, transferase, hydrolases, and ligases enzymes (Castillo-González et al., 2018; Ojeda- Barrios et al., 2009; Smith; Cheary, 2013).

Alternate bearing is a multifactorial process associated with carbohydrate reserve and flowering, which in turn is regulated by physiological, biochemical, environmental, and genetic factors (Sharma et al., 2019). The reserve carbohydrates in the tree are important in flower induction and is the first requirement to consider in agronomic management to minimize alternate bearing (Wood, 2014; Zivdar et al., 2016). These macromolecules are classified as structural (lignin and cellulose) and non-structural (glucose, fructose, sucrose and starch), which make up tissues, provide chemical energy for metabolic reactions, and as long-term reserves (Pérez-Barraza et al., 2017). Starch accumulates in the roots during the dormancy period to be a source of energy during vegetative growth, budding and flowering (Valenzuela-Núñez et al., 2019).

Among the agronomic management strategies for avocado (*Persea americana* L.), citrus (*Citrus volkameriana* L.), cherry (*Prunus cerasus* L.), mango (*Mangifera indica* L.), apple (*Malus domestica* Borkh), gibberellic acid is used (GA_3), prohexadione calcium (PCa) and thidiazuron (TDZ) were used to minimize the negative effect of alternate bearing (Pérez-Barraza et al., 2017; Wood, 2011). The exogenous application of growth bioregulators in low concentrations promote, inhibit, or modify the morphological and physiological behaviour of plants (Tejacal et al., 2020; Souri; Bakhtiarizade, 2019; Aslani; Souri, 2018). These compounds are classified according to the response of the plant when applied (Martinez-Damián et al., 2019).

GA_3 application has been shown to promote shoot growth and influence flower induction (Wood, 2011). In addition, it increases the fruit set (Pérez-Barraza et al., 2017). PCa (3-oxide-4-propionyl-5-oxo-3-cyclohexene-carboxylate) is a chemical product that when foliarly applied to mango (*Mangifera indica* L.), apple (*Malus domestica* Borkh) and pear (*Pyrus communis* L.), inhibits the synthesis of gibberellins in the apices, thus reducing their growth (Rehman; Singh; Khurshid, 2018). TDZ [1-phenyl-3- (1, 2, 3 thidiazol-5-yl) urea] is classified within the group of cytokinins and its application is associated with cell division (Pasa et al., 2017). This bioregulator plays an important role in flower induction and additionally increases the size and number of fruits (Pérez-Barraza et al., 2017). There is little information associated with the agronomic management of the alternate bearing in pecan through the application of chemical products that have been found to be beneficial in other fruit trees. The objective of this work was to evaluate the concentration of foliar nutrients, non-structural carbohydrates and yield in cultivar Western Schley pecan as a response to the foliar application of growth bioregulators.

MATERIAL AND METHODS

Experimental location and management of the orchard

The research was carried out for two consecutive years (2017-2018) in an orchard located in Mexico (28°57’1.44”N, 106°14’2.73”W), an altitude of 1440 meters above sea level, precipitation and average annual temperature of 366.5 mm and 17.8 °C, respectively. The soil was characterized by presenting a crumb-sandy texture with 0.95% organic matter, pH (7.6), 10.69% carbonate and electrical conductivity of 2.5 dS m^{-1}. The chemical analysis provided indicates a composition (mg kg^{-1}): 18 N-total, 8 P, 275 K, 5.4 Ca, 320 Mg, 139 Fe, 180 Mn, 13 Zn and 4 Cu. Pecan cultivar Western Schley plants were used at native rootstocks with 9 years of age and planted at 6 x 12 m (139 trees ha^{-1}).

In the first week of March of each evaluation year, fertilization was carried out using the general formula (per ha) of 150-100-100 N, P and K in the form of ammonium sulphate [$(NH_4)_2SO_4$] (20.5% N and 24% sulfur), phosphoric acid [H_3PO_4] (49% P_2O_5) and potassium sulfate [K_2SO_4] (50% K_2O). Likewise, when the trees showed 80% sprouting, six applications of zinc nitrate (17% $ZnNO_3$) were made with GoZinc 17® (Gowan, Mexico). Irrigation was applied by micro-sprinkling with a total sheet of approximately 16,800 m^3 ha^{-1} per vegetative cycle. The damage caused by screwworm (*Acrobasis nuxvorella* Neunzig) was controlled chemically with the application of 0.5 L ha^{-1} of Intrepid™ (Dow AgroSciences®, USA). Weed control was carried out manually.

Experimental design

A completely randomized design with five replicates was used, where the experimental unit consisted of a tree with an average height and trunk perimeter of 8 ± 1 m and 63 ± 2 cm, respectively. The treatments were T1: 50 mg L^{-1} GA_3 (ProGibb®, Bayer Crop Science, USA), T2: 500 mg L^{-1} PCa (Apogee®, BASF, USA) T3: 10 mg L^{-1} TDZ (Revent® 500 SC, Bayer Crop Science, USA); T4: Control (water). 1 ml L^{-1} of surfactant (INEX-A™, Cosmocel, Mexico) and 1% foliar urea were applied as penetrant. The pH was adjusted to 5.8 with phosphoric acid (Sigma-Aldrich®, USA). The treatments were applied at 0, 56,70 and 84 days after flowering for two years (2017-2018).

Leaf mineral nutrients

In the middle part from canopy of tree (four cardinal points) 40 pairs of leaflets were selected without mechanical damage, pests and diseases. The leaflets were washed with a 0.1% phosphate-free detergent solution, rinsed with deionized water and dried at 80 °C for 72 hours in a Heratherm™ VCA 230 oven (Thermo Scientific™, USA). The samples were homogenized in a mill (Wiley®, USA) with a 1 mm mesh (Balandran-Valladares et al., 2021). The concentration of N-total was determined by the Kjeldhal method (Novatech®, USA and Micro Kjeldahl Labconco®, USA), (Lanza; Churión; Gómez, 2016). The determination of the P concentration was by the ammonium metavanadate method (NH_4VO_3) and by spectrophotometry (Thermo Scientific™, USA). 1 g of the dry sample was taken, and the concentration of K, Ca, Mn, Mg, Fe, Cu and Zn was determined by triacid digestion (HNO_3, $HClO_4$ and H_2SO_4) (25 mL of the mixture in a 10:10:25 ratio). Analyte quantifications were performed using an Analyst 100® atomic absorption spectrophotometer (PerkinElmer®, USA). The results were expressed g kg^{-1} and mg kg^{-1} for macro and micronutrients, respectively (Fernández-Valencio; Sánchez-Chávez, 2017).

Quantification of non-structural carbohydrates

The determination of glucose, fructose, sucrose, and starch in leaflets (non-structural carbohydrates) was carried out according to the method described by Sánchez et al. (2005). 20 leaflets were collected in which the cardinal points were considered. A sample of 0.5 g of fresh tissue was taken and homogenized twice, the first with 5 mL of 95% ethanol (v:v) and the second with 70% ethanol (v:v). The mixture was centrifuged at 5500 g for 10 min at 4 °C. 0.1 mL of the supernatant was taken and 3 mL of anthrone solution (100 mg of anthrone dissolved in 100 mL of 70% H_2SO_4) were added. The mixture was placed in a water bath for 10 min and after the time necessary to cool down, the absorbance value was taken at 650 nm with a UV-vis Evolution 201 spectrophotometer (Thermo Scientific™, USA). For the determination of starch, the dry residue of the extraction was taken and incubated in acetate buffer (4.5 M), 0.5% α-glucoamylase (w:v) and water at 37 °C for 48 h. The results were expressed in mg g^{-1} fresh weight (fw).

Yield and nut quality

The harvest for each evaluation year (2017 and 2018) was carried out in the third week of November, where each experimental unit was mechanically vibrated, the nuts were collected and weighed with a Combo-Rhino-122 scale (Rhino®, México) with a sensitivity of 0.1 g, this to obtain the yield in kg $tree^{-1}$. The nut weight per kilogram and kernel percentage were determined according to what is indicated by the Mexican Standard NMX-FF-084-SCFI-2009. The average nut weight per kilogram was obtained, for which one kg was taken to count the number of nuts. To obtain the kernel percentage, 300 g of nuts were selected per experimental unit, the shell of the kernel (edible part) was separated and the weight was obtained with a portable electronic scale Scout Pro SP202 (Ohaus®, USA) with a sensitivity of 0.01 g. The calculation of the kernel percentage was obtained as the quotient between the weight and the initial value of the sample (300 g) multiplied by 100.

Statistical analysis

Previously statistical analysis, the data were subjected to the Shapiro-Wilk test ($P \leq 0.05$) to verify their normal distribution. Statistical analysis was performed using a GLM with the effects of year and treatment. A multiple comparison of means was performed on the data obtained from the evaluate parameters using the Tukey test ($P \leq 0.05$). In all cases, the statistical analysis software (SAS/STAT) version 9.3 was used.

RESULTS AND DISCUSSION

Leaf mineral nutrients

The pecan tree fertilization programs consider total N and Zn as the most important nutrients for the commercial production of this deciduous fruit tree (Balandrán-Valladares et al., 2021). The foliar application of growth bioregulators showed significant interaction ($P \leq 0.05$) between years and treatments on leaf mineral nutrients (Table 1 and 2, Figure 1 and 2). The trees treated with GA_3, PCa and TDZ kept the foliar concentration of N-total, K, Ca, Mg, Fe, Cu and Mn stable, in addition, the PCa affected to P. The foliar concentration of N-total, P, K, Mg, Fe, Cu and Mn are in normal ranges (Pond et al., 2006; Smith; Rhola; Goof, 2012), with the exception of Ca (26.9-34.1 g kg^{-1}), which can be considered high according to Pond et al. (2006). These results could be linked to the calcareous soil where the orchard is planted.

On the other hand, among the peculiarities of the pecan tree is its high requirement of Zn during the shoot growth stage (Hounnou et al., 2019). The application of bioregulators did not show a stable behaviour with respect to the concentration of Zn whose values fluctuated between 27.0 and 60.0 mg kg^{-1} between the evaluation years. However, these values are in the range of sufficiency according to Castillo-González et al. (2019). In other species such as peach (*Prunus persica* L.) cultivar Peento. Al-Rawi, Al.Aadethi and Abdul-Kareem (2016) report an increase in the foliar concentration of N-total and P, however, they did not observe significant changes for Zn when evaluating the application of 100 mg L^{-1} GA_3 for two years. A similar behaviour is reported in olive (*Olea europaea* L.) cultivar Ashrasi with GA_3 applications (100 and 200 mg L^{-1}) (Soliemanzadeh; Mozafari, 2014). On the other hand, previous studies carried out on lemon (*Citrus volkameriana* L.) cultivar Volkamer (Tsagkarakis; Rogers; Spann, 2012) and tomato (*Solanum lycopersicum* L.) cultivar Raptor-F1 (Ramírez et al., 2018) indicate that there was no effect on the concentration of N-total, P, Zn6 with the application of 0.7 g L^{-1} and 50 mg L^{-1} PCa, respectively.

Non-structural carbohydrates in leaflets

Carbohydrates play an important role in the development and growth of plants because they are part of their morphological structure and are the main source of metabolic energy (Valenzuela-Núñez et al., 2019). In this study, the application of GA_3, PCa and TDZ kept the concentration of non-structural carbohydrates between the evaluation years (Table 3). In contrast, Wood (2014) when evaluating xylem exudates in years of high and low yield in cultivar Cheyenne pecan, reports a variation in the concentration of sucrose between years with values of 8.7 and 0.4 mM respectively, which is attributed to alternate bearing. For their part, Al-Rawi, Al.Aadethi and Abdul-Kareem (2016) when evaluating the application of GA_3 at 50 and 100 mg L^{-1} in peach trees (*Prunus persica* L.) cultivar Peento reported an increase in the concentration of carbohydrates in leaves. While between the treatments, no effect on the concentration of parameters could be detected (Figure 3). The variation between the results can be associated with the analytical method used, sample size and organ evaluated (Wood, 2014).

Table 1: Concentration of macronutrients in Western Schley pecan leaflets with application of growth bioregulators.

T	Macronutrients (g kg^{-1})									
	N-total		P		K		Ca		Mg	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
GA_3	19.9±0.9a	18.2±2.8a	1.2±0.4a	1.8±0.1b	10.9±0.5a	10.5±0.2a	34.1±1.4a	31.9±2.0a	3.3±0.4a	3.5±0.3a
PCa	23.9±1.2a	24.7±0.6a	1.5±0.5a	1.9±0.2a	11.3±0.7a	10.2±0.9a	31.7±a1.0	31.8±1.9a	3.1±0.3a	3.2±0.1a
TDZ	26.2±1.7a	24.1±1.8a	1.7±0.3a	2.6±0.2b	11.4±0.5a	11.9±0.8a	31.2±1.0a	32.4±1.5a	3.2±0.4a	3.1±0.3a
Control	19.1±1.4a	14.2±0.7b	1.7±0.2a	1.7±0.3a	9.0±0.3a	8.8±0.8a	26.9±2.7a	26.9±2.1a	2.9±0.2a	3.1±0.2a
CV	14.5	23.5	24.3	18.4	11.0	12.9	9.9	9.1	9.3	8.2

T - treatments, GA_3 - gibberellic acid (50 mg L^{-1}), PCa - prohexadione calcium (100 mg L^{-1}) and TDZ – thidiazuron (500 mg L^{-1}), CV - coefficient of variation (%). Values with the different letters between rows represent significant differences according to Tukey's test (P ≤ 0.05).

Table 2: Concentration of micronutrients in Western Schley pecan leaflets with application of growth bioregulators.

T	Micronutrients (mg kg^{-1})							
	Fe		Cu		Mn		Zn	
	2017	2018	2017	2018	2017	2018	2017	2018
GA_3	134.7±8.4a	135.0±5.0a	5.9±0.3a	6.4±0.2a	229.7±4.5a	232.0±10.6a	58.6±5.0a	35.7±3.2b
PCa	138.0±6.1a	141.7±3.2a	6.0±0.2a	6.2±0.3a	236.3±9.6a	234.3±8.6a	38.3±4.1a	27.0±1.8b
TDZ	151.7±3.5a	147.3±10.8a	6.8±0.2a	6.2±0.3a	244.7±9.5a	234.3±5.5a	60.0±2.2a	29.3±6.2b
Control	120.5±21.2a	107.7±2.4a	5.7±0.4a	5.3±0.3a	217.0±2.6a	205.7±6.7a	36.8±0.8a	29.0±1.5b
CV	11.3	12.6	8.6	8.3	5.3	6.4	24.2	15.3

T - treatments, GA_3 - gibberellic acid (50 mg L^{-1}), PCa - prohexadione calcium (100 mg L^{-1}) and TDZ – thidiazuron (500 mg L^{-1}), CV - coefficient of variation (%). Values with the different letters between rows represent significant differences according to Tukey's test ($P \leq 0.05$).

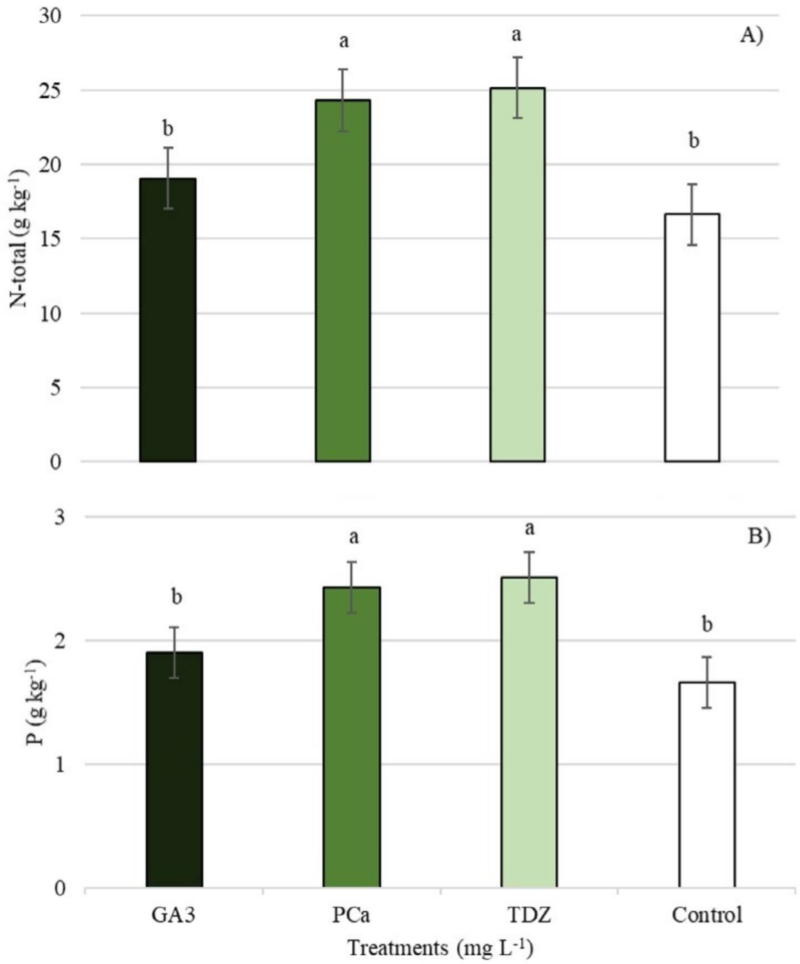

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Figure 1: Concentration of N-total (A), P (B), K(C), Ca (D) and Mg (E) in Western Schley pecan trees with the application of foliar treatments of growth bioregulators. The data correspond to the mean obtained by treatment (2017 and 2018). GA_3 - gibberellic acid (50 mg L^{-1}), PCa - prohexadione calcium (500 mg L^{-1}), TDZ - thidiazuron (10 mg L^{-1}) and control. Bars with the same letter are equal according to Tukey's test ($P \leq 0.05$). Error bars represent standard deviations (n = 5).

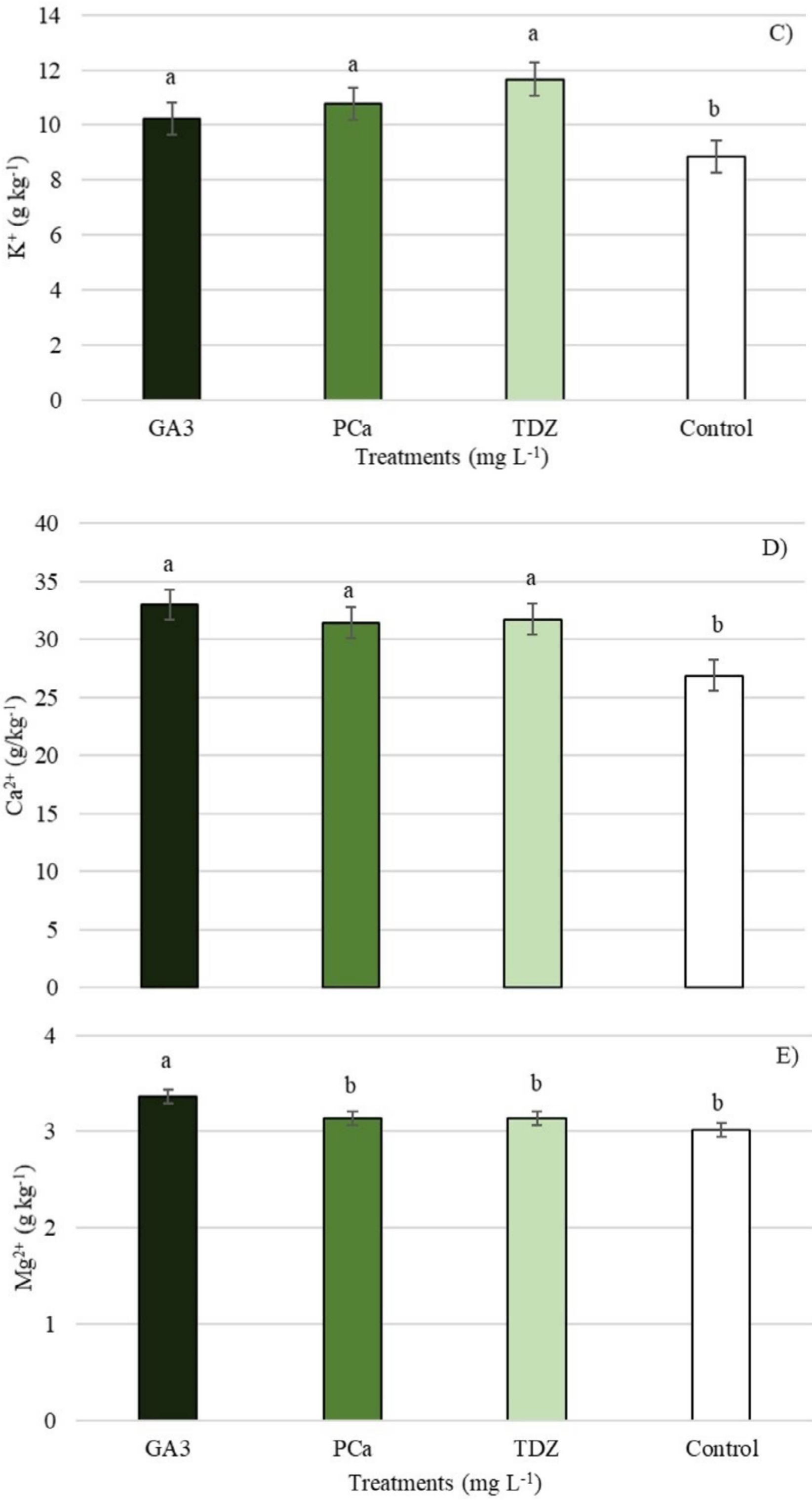


Figure 1: Continuation...

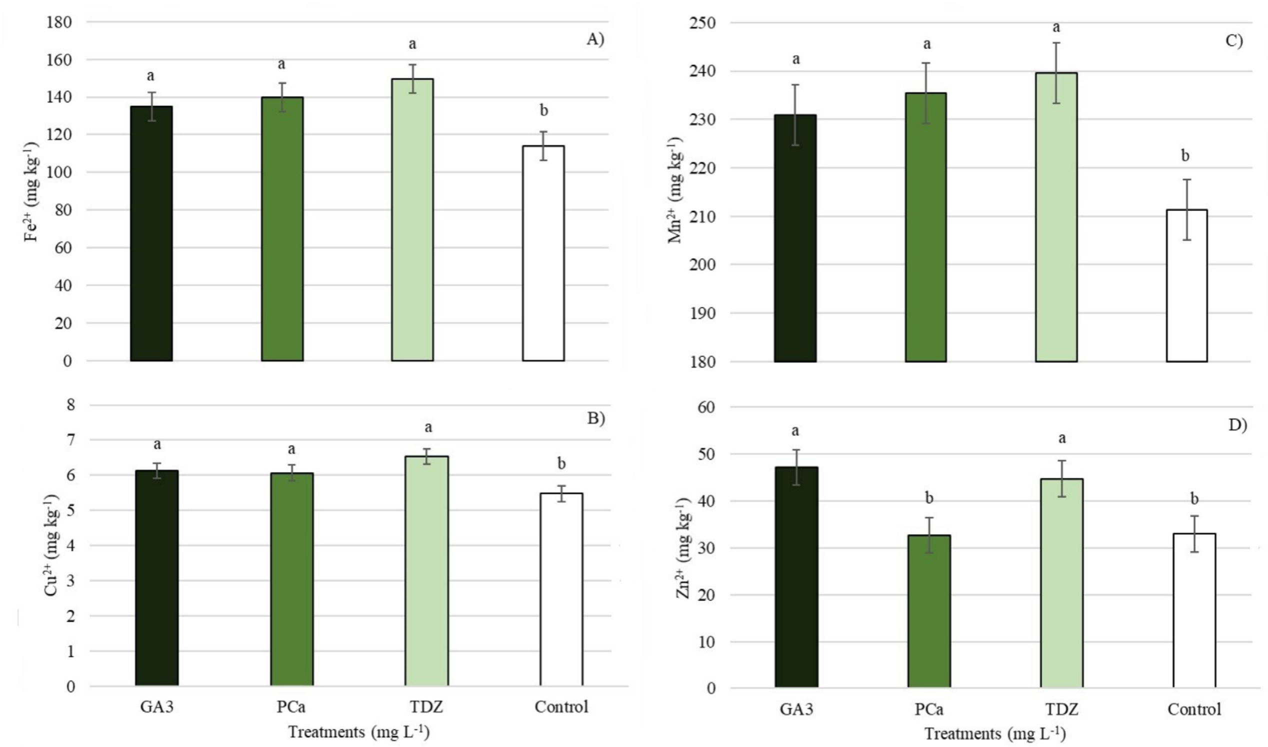


Figure 2: Concentration of Fe (A), Cu (B), Mn (C) and Zn (D) in Western Schley pecan trees with the application of foliar treatments of growth bioregulators. The data correspond to the mean obtained by treatment (2017 and 2018). GA_3 - gibberellic acid (50 mg L^{-1}), PCa - prohexadione calcium (500 mg L^{-1}), TDZ - thidiazuron (10 mg L^{-1}) and control. Bars with the same letter are equal according to Tukey's test ($P \leq 0.05$). Error bars represent standard deviations (n = 5).

Table 3: Concentration of non-structural carbohydrates in Western Schley pecan leaflets treated with growth bioregulators.

T	Non-structural carbohydrates (mg g^{-1} fw)							
	Fructose		Glucose		Sucrose		Starch	
	2017	2018	2017	2018	2017	2018	2017	2018
GA_3	36.1±3.0a	41.8±2.3a	40.0±3.3a	46.2±2.6a	39.9±1.8a	45.9±1.6a	38.4±2.8a	39.9±2.4a
PCa	37.7±2.8a	38.6±6.7a	41.6±3.1a	42.6±7.4a	34.8±8.2a	42.2±6.3a	31.8±7.5a	40.3±3.7a
TDZ	42.4±3.2a	38.0±1.4a	46.9±3.5a	42.0±1.6a	37.7±2.2a	40.8±3.7a	34.3±2.2a	40.9±3.6a
Control	40.9±1.6a	29.5±4.5b	45.2±1.8a	32.6±5.0b	33.5±5.4a	43.5±1.3b	30.6±4.9a	41.3±3.8b
CV	8.9	16.2	8.9	16.2	13.9	8.8	15.3	7.3

T - treatments, GA_3 - gibberellic acid (50 mg L^{-1}), PCa - prohexadione calcium (100 mg L^{-1}) and TDZ – thidiazuron (500 mg L^{-1}), CV - coefficient of variation (%). Values with the different letters between rows represent significant differences according to Tukey's test ($P \leq 0.05$).

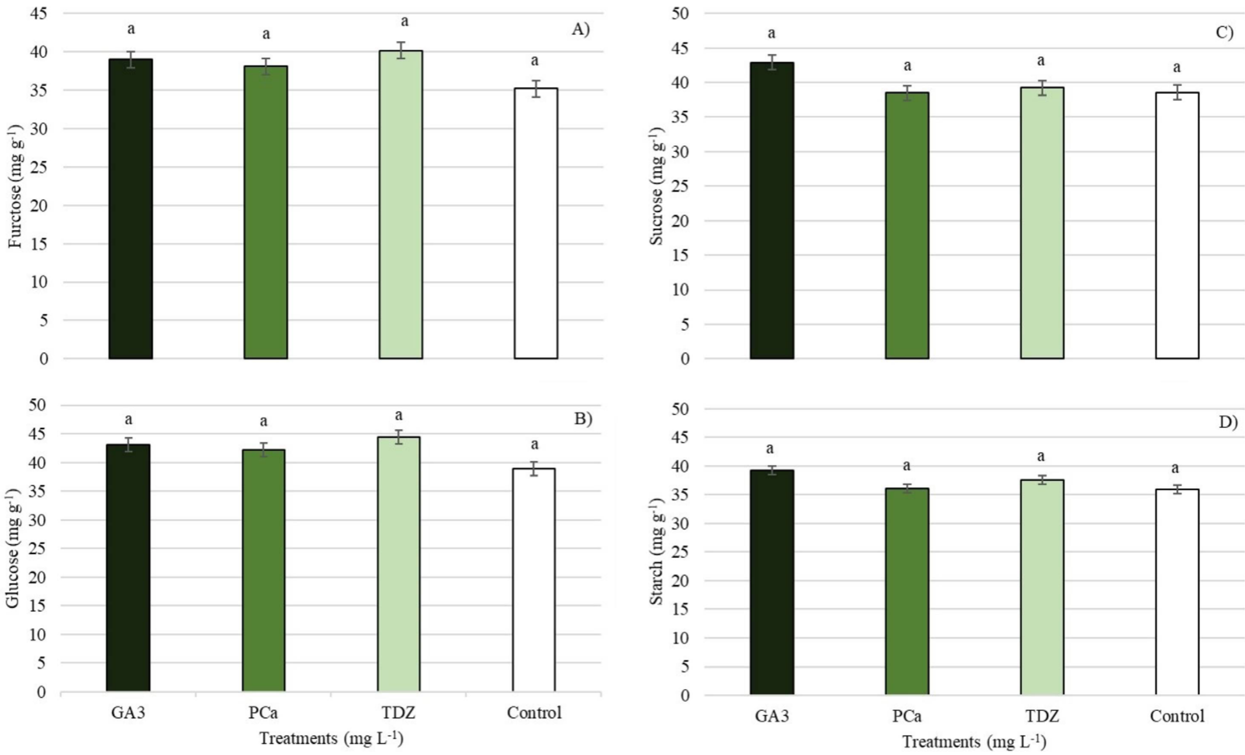


Figure 3: Concentration of fructose (A), glucose (B), sucrose (C) and starch (D) in Western Schley pecan trees with the application of foliar treatments of growth bioregulators. The data correspond to the mean obtained by treatment (2017 and 2018). GA_3 - gibberellic acid (50 mg L^{-1}), PCa - prohexadione calcium (500 mg L^{-1}), TDZ - thidiazuron (10 mg L^{-1}) and control. Bars with the same letter are equal according to Tukey's test (*P* ≤ 0.05). Error bars represent standard deviations (n = 5).

Yield and nut quality

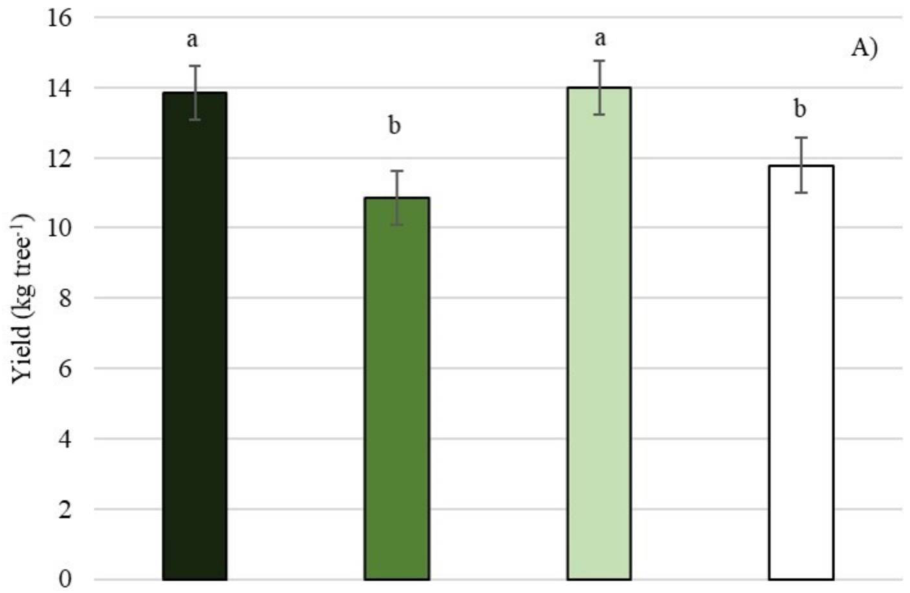
The high economic value and commercial demand of nut have favoured an increase in the planted area; however, pecan trees show alternate bearing and affect the yield and quality of the harvested product (Wells, 2014). In this study, the yield values were found in a range between 7.1 and 17.0 kg $tree^{-1}$, where the treatment with GA_3 (12.4 and 15.3 kg $tree^{-1}$) showed the least fluctuation between years (Table 4). This behaviour helps to understand the physiological importance of maintaining the foliar concentration of nutrients and non-structural carbohydrates with the application of GA_3 in pecan. This result coincides with Wood (2011) who reports that the use of GA_3 can be effective to minimize alternate bearing. The analysis between treatments indicated that the trees treated with GA_3 and TDZ showed the highest average yield with values of 13.9 and 14.0 kg $tree^{-1}$, respectively (Figure 4A). Previous studies indicate that the application of TDZ and PCa in pear (*Pyrus communis* L.) cultivar Le Conte (Carra et al., 2016) and avocado (*Persea americana* L.) cultivar Hass (Brogio et al., 2018) increase the yield, however, its effect can be modified by agronomic management. If the yield data are compared with those obtained by Wood (2014) (5.5-71.5 kg $tree^{-1}$), a significant variation is observed, however, this can be linked to the alternate bearing, age of the tree, agronomic management, and density plantation (Castillo-González et al., 2019).

The nut weight showed significant inter-annual variation, however, there was no difference between treatments. Likewise, between the years of evaluation and applied treatments, no effect was found in the kernel percentage of the harvested nuts (Table 4 and Figure 4B and 4C). In this sense, the accumulation of reserves has a direct effect at the quality of the nut, which in turn is associated with genetic, edaphoclimatic and agronomic factors (Sharma et al., 2019; Smith; Rhola; Goof, 2012). Our data indicate that nut quality is a parameter that cannot be easily modified by applying bioregulators. In contrast, when spraying GA_3, PCa and TDZ at avocado (*Persea americana* L.) cultivar Hass (Garner et al., 2011) and pear (*Pyrus communis* L.) cultivar Blanquilla and cultivar Hosui (Lordan et al., 2019; Pasa et al., 2017) report an increase in firmness, size, and concentration of total soluble solids in harvested fruits. On the other hand, the quality of nut obtained in this work is suitable for export (quality I) according to the Mexican Standard (NMX-FF-084 SCFI, 2009).

Table 4: Application of growth bioregulators in Western Schley pecan and their inter-annual effect on yield and nut quality.

T	Yield (kg tree^{-1})		Nut quality			
			Nut weight per kg (g)		(%) Kernel	
	2017	2018	2017	2018	2017	2018
GA3	12.4±0.8a	15.3±3.2a	5.6±0.6a	6.4±0.5b	60.4±2.5a	58.5±1.8a
PCa	14.6±2.0a	7.1±2.3b	5.5±0.5a	6.5±0.4b	58.5±1.4a	56.5±2.3a
TDZ	11.0±1.0a	17.0±1.1b	5.7±0.2a	6.8±0.3b	60.3±1.6a	59.6±2.1a
Control	14.7±0.6a	8.9±1.0b	5.7±0.2a	6.3±0.3a	59.6±2.0a	60.0±2.6a
CV	14.6	29.1	6.2	5.8	3.0	4.0

T - treatments, GA_3 - gibberellic acid (50 mg L^{-1}), PCa - prohexadione calcium (100 mg L^{-1}) and TDZ – thidiazuron (500 mg L^{-1}), CV - coefficient of variation (%). Values with the different letters between rows represent significant differences according to Tukey's test ($P \leq 0.05$).



Continue...

Figure 4: Yield (A), nut weight (B) and kernel percentage (C) in Western Schley pecan trees with the application of foliar treatments of growth bioregulators. The data correspond to the mean obtained by treatment (2017 and 2018). GA_3 - gibberellic acid (50 mg L^{-1}), PCa - prohexadione calcium (500 mg L^{-1}), TDZ - thidiazuron (10 mg L^{-1}) and control. Bars with the same letter are equal according to Tukey's test ($P \leq 0.05$). Error bars represent standard deviations (n = 5).

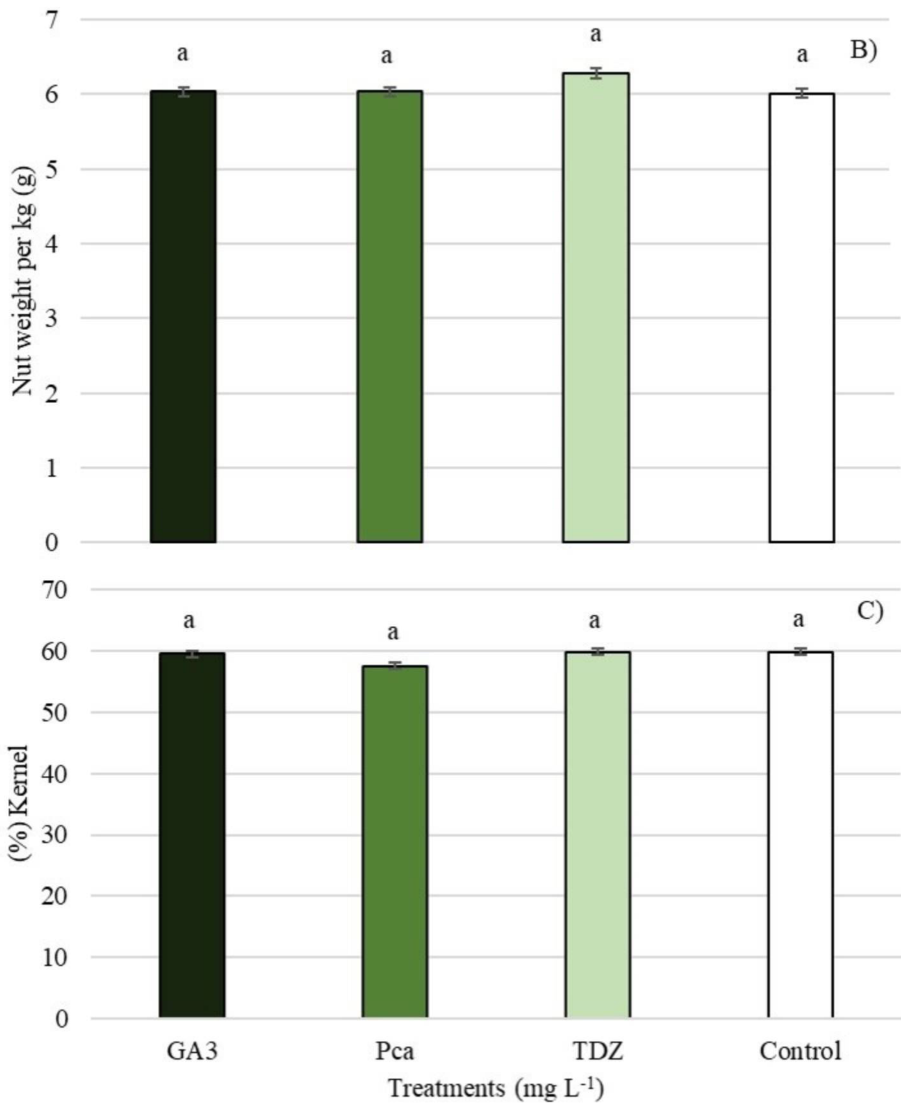


Figure 4: Continuation...

CONCLUSIONS

The application of GA_3 maintained the yield values (12.4 and 15.3 kg tree^{-1}), minimizing the alternate bearing, where the PCa showed the greatest fluctuation in pecan yield. However, the nut weight per kilogram and kernel percentage were not affected by the applied treatments. On the other hand, the application of GA_3, PCa and TDZ showed a similar effect on the leaf concentration of sucrose, starch and N-total, however, P only showed a positive effect (1.5 and 1.9 g kg^{-1}) under application of PCa. The application of bioregulators did not show a stable behaviour with respect to the concentration of Zn whose values fluctuated between 27.0 and 60.0 mg kg^{-1} between the evaluation years. According to our results, the application of GA_3 could be considered as part of the agronomic management to minimize alternate bearing in Western Schley pecan tree.

REFERENCES

AGHAYE-NOROOZLO, Y.; SOURI, M. K.; DELSHAD, M. Effects of foliar application of glycine and glutamine amino acids on growth and quality of sweet basil. **Advances in Horticultural Science**, 33(4):495-501, 2019.

AL RAWI, W. A. A.; AL-AADETHI, M. E. A.; ABDUL-KAREEM, A. A. Effect of foliar application of gibberellic acid and seaweed extract spray on growth and leaf mineral content on peach trees. **Iraqi Journal of Agricultural Science**, 47(7):98-105, 2016.

ASLANI, M.; SOURI, M. K. Growth and quality of green bean (*Phaseolus vulgaris* L.) under foliar application of organic chelate fertilizers. **Open Agriculture**, 3:146-154, 2018.

BALANDRÁN-VALLADARES, M. I. et al. Changes in nutrient concentration and oxidative metabolism in pecan leaflets at different doses of zinc. **Plant, Soil and Environment**, 67(1):33-39, 2021.

BROGIO, B. D. A. et al. Influence of gibberellin inhibitors applied during flowering of non-irrigated 'Hass' avocado trees. **Pesquisa Agropecuária Brasileira**, 53(8):918-923, 2018.

CARRA, B. et al. Prohexadione calcium affects shoot growth, but not yield components, of 'Le Conte' pear in warm-winter climate conditions. **Scientia Horticulturae**, 209:241-248, 2016.

CASTILLO-GONZÁLEZ, J. et al. Zinc metalloenzymes in plants. **Interciencia**, 43(4):242-248, 2018.

CASTILLO-GONZÁLEZ, J. et al. Zinc nutritional status of pecan trees influences physiological and nutritional indicators, the metabolism of oxidative stress, and yield and fruit quality. **Notulae Botanicae Horti Agrobotanici Cluj-Napoca**, 47(2):531-537, 2019.

FERNÁNDEZ-VALENCIANO, A. F.; SÁNCHEZ-CHÁVEZ, E. Study of physicochemical properties and nutritional quality in different varieties of beans consumed in Mexico. **Nova Scientia**, 9(18):133-148, 2017.

GARNER, L. et al. Response of evergreen perennial tree crops to gibberellic acid is crop load-dependent: II. GA_3 increases yield and fruit size of 'Hass' avocado only in the on-crop year of an alternate bearing orchard. **Scientia Horticulturae**, 130(4):753-761, 2011.

HATAMIAN, M. et al. Interactions of lead and nitrate on growth characteristics of ornamental Judas Tree (*Cercis siliquastrum*). **Open Agriculture**, 3(1):386-392, 2018.

HOUNNOU, L. et al. Foliar applied zinc and the performance of pecan trees. **Journal of Plant Nutrition**, 42(5):512-516, 2019.

LANZA, J. G.; CHURIÓN, P. C.; GÓMEZ, N. Comparison between kjelfdahl traditional method and automated dumas (N Cube) method for determination of proteins in several kinds of food. **Saber**, 28(2):245-249, 2016.

LORDAN, J. et al. Post petal fall applications of gibberellins improve fruit set on pear. **Scientia Horticulturae**, 252:149-155, 2019.

MARTÍNEZ-DAMIÁN, M. T. et al. Effect of preharvest growth bioregulators on physicochemical quality of saladette tomato. **Revista Chapingo. Serie Horticultura**, 25(1):29-43, 2019.

NORMA OFICIAL MEXICANA - NMX-FF-084-SCFI-2009. **Productos alimenticios no industrializados para consumo humano - Fruto fresco - Nuez pecanera *Carya illinoensis* (Wangenh) K. Koch - Especificaciones y métodos de prueba.** 2009. Available in: <http://comenuez.com/>. Access in: January, 22, 2019.

OJEDA-BARRIOS, D. L. et al. Foliar application of zinc chelates on pecan. **Revista Chapingo Serie Horticultura**, 15(2):205-210, 2009.

PASA, M. S. et al. Thidiazuron (TDZ) increases fruit set and yield of 'Hosui' and 'Packham´s Triumph' pear trees. **Anais da Academia Brasileira de Ciências**, 89(4):3103-3110, 2017.

PÉREZ-BARRAZA, M. H. et al. Mango growth regulators: Their relationship with carbohydrates number and size of cells. **Revista Mexicana de Ciencias Agrícolas**, 8(19):3855-3868, 2017.

POND A. P. et al. Leaf nutrient levels for pecans. **HortScience**, 41:1339-1341, 2006.

RAMÍREZ, H. et al. P-Ca, AG4/7 and 6-BAP in the physiology and nutrition of tomato in the greenhouse. **Revista Mexicana de Ciencias Agrícolas**, 9(4):747-759, 2018.

REHMAN, M.; SINGH, Z.; KHURSHID, T. Pre-harvest spray application of prohexadione-calcium and paclobutrazol improves rind colour and regulates fruit quality in M7 Navel oranges. **Scientia Horticulturae**, 234:87-94, 2018.

SÁNCHEZ, E. et al. Biosynthesis of non-structural carbohydrates and their distribution in greenbean plants (*Phaseolus vulgaris* L. Cv. Strike): Deficiency vs toxicity of nitrogen. **Revista Fitotecnia Mexicana**, 28(1):55-61, 2005.

SHARMA, N. et al. Physiological and molecular basis of alternate bearing in perennial fruit crops. **Scientia Horticulturae**, 243:214-225, 2019.

SMITH, M. W.; CHEARY, B. S. Response of pecan to annual soil band applications of phosphorus and potassium. **HortScience**, 48(11):1411-1415, 2013.

SMITH, M. W.; ROHLA, C. T.; GOFF, W. D. Pecan leaf elemental sufficiency ranges and fertilizer recommendations. **HortTechnology**, 22(5):594-599, 2012.

SOLIEMANZADEH, A.; MOZAFARI, V. Response of pistachio trees to alternate bearing and foliar application of zinc and iron. **International Journal of Fruit Science**, 14(2):174-187, 2014.

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

SOURI, M. K.; BAKHTIARIZADE, M. Biostimulation effects of rosemary essential oil on growth and nutrient uptake of tomato seedlings. **Scientia Horticulturae**, 243:e472476, 2019.

TEJACAL, I. A. et al. Growth regulators on poinsettia (*Euphorbia pulcherrima* Willd. Ex Klotzsch) quality. **Acta Agrícola y Pecuaria**, 6(1):e0061010, 2020.

TSAGKARAKIS, A. E.; ROGERS, M. E.; SPANN, T. M. Applications of plant growth regulators to container-grown citrus trees affect the biology and behavior of the asian citrus psyllid. **Journal of the American Society for Horticultural Science**, 137(1):3-10, 2012.

VALENZUELA-NÚÑEZ, L. M. et al. Seasonal changes in soluble sugar concentration in pecan perennial organs (*Carya illinoiensis* [Wangenh.] Koch). **Acta Universitaria**, 29:e2423, 2019.

WELLS, L. Pecan planting trends in Georgia. **HortTechnology**, 24(4):475-479, 2014.

WOOD, B. W. Influence of plant bioregulators on pecan flowering and implications for regulation of pistillate flower initiation. **HortScience**, 46(6):870-877, 2011.

WOOD, B. W. Flow volume and carbohydrate composition of late winter xylem sap influences subsequent crop load in pecan. **HortScience**, 49(7):886-890, 2014.

ZIVDAR, S. et al. Physiological and biochemical response of olive (*Olea europaea* L.) cultivars to foliar potassium application. **JAST - Journal of Agricultural Science and Technology**, 18(17):1897-1908, 2016.