

Yield, quality, alternate bearing and long-term yield index in pecan, as a response to mineral and organic nutrition

Linda C. NOPERI-MOSQUEDA¹, Juan M. SOTO-PARRA^{1*},
Esteban SÁNCHEZ², Eloy NAVARRO-LEÓN³,
Ramona PÉREZ-LEAL¹, María A. FLORES-CÓRDOVA¹,
Nora A. SALAS-SALAZAR¹, Rosa M. YÁÑEZ-MUÑOZ¹

¹Universidad Autónoma de Chihuahua, Facultad de Ciencias Agrotecnológicas, Campus Universitario I, C.P. 31310, Chihuahua, México; lindanoperi@gmail.com; jmsotoparra@gmail.com (*corresponding author); perezleal@hotmail.com; mariflor_556@hotmail.com; nora.salas09@yahoo.com.mx; rosky1388@gmail.com

²Centro de Investigación en Alimentación y Desarrollo, Unidad Delicias, Chihuahua, México; esteban@ciad.mx

³Universidad de Granada, Facultad de Ciencias, Departamento de Fisiología Vegetal, Granada, Spain; enleon@ugr.es

Abstract

The pecan nut is produced in 57 countries in the world. Alternate bearing is one of the main biological problems that affect pecan cultivation. Mineral and organic fertilization is a good strategy to maintain and increase pecan nut production. In this study, several mineral and organic doses of fertilization were tested using a factorial arrangement 5⁶ bounded to 25 treatments was used in structure Taguchi L25: nitrogen (N) 0 - 240 kg ha⁻¹, phosphate (P₂O₅) 0 - 120 kg ha⁻¹, potassium (K₂O) 0 - 100 kg ha⁻¹, calcium (CaO) 0 - 400 kg ha⁻¹, liquid humus 0 - 3600 L ha⁻¹ and solid humus 0 - 8000 kg ha⁻¹. The study was carried out in Aldama city, Chihuahua (Mexico). An average yield of 2.4 t ha⁻¹ was obtained, 157 nuts per kilogram and 58.9% of edible nut. The average alternate bearing intensity was 31.58%, and the long-term yield index (IRLP) was 9.59%. It is concluded that the factors which had the greatest impact on the analyzed variables were N and P₂O₅. In addition, it was found that these mineral and organic fertilization systems help to reduce alternate bearing in pecan and simultaneously improve production and long-term productivity index. Optimal fertilization doses were defined: 181.4 kg ha⁻¹ of N, 93.5 kg ha⁻¹ of P₂O₅ and 3287.2 L ha⁻¹ of liquid humus. Finally, the mineral fertilization complemented with organic fertilization is considered a good fertilization strategy for pecan trees, to increase production and with lower environmental impact.

Keywords: alternate bearing intensity; *Carya illinoensis*; edible nut percentage; long-term yield index; nuts per kilogram

Introduction

Alternate bearing is a condition that affects some fruit trees which consists of the variation of yield presenting a high yield (year "ON") and the following year a low yield (year "OFF"). This pattern repeats year after year (Wood *et al.*, 2003). Alternate bearing occurs at different scales: ranging from a branch, a tree, an

orchard and to an entire region (Delgado *et al.*, 2000). This phenomenon was reported in fruit trees such as mango, pistachio, pecan nut, avocado, apple, olive, and citrus (Dahal *et al.*, 2019). The mechanisms that regulate alternate bearing are unknown and appear to be complex. The main reported factors are: the level of carbohydrate reserves within the tree; endogenous hormone growth regulators produced by fruits or leaves; a dual mechanism based on carbohydrate levels within the balance of trees and phytohormones (Wood, 1995).

Pecan nut is produced in 57 countries in the world and Mexico ranks 5th in pecan nut production worldwide (FAO, 2018; SAGARPA, 2018). Alternate bearing is considered as one of the main biological problems that affect pecan cultivation (Wood *et al.*, 2003). It was linked to three inherent pecan features: the fruit maturity time, the fruit growth type and the kernel chemical composition. Contrary to many fruit crops, pecan nut ripens at the end of the season close to the autumn. Because of this, leaves have a short time to store carbohydrates for the development of flowers and fruits in the next season. In addition, kernels contain more than 70% of lipids, which require considerable energy amounts to its synthesis. When these situations are combined, trees may present a shortage of carbohydrate reserves, especially in roots. This can lead to the establishment of deficient fruits in the next production cycle and the decrease in production (Conner and Worley, 2000).

Improved horticultural practices have reduced the gravity of alternate bearing in pecan culture (Conner and Worley, 2000). One of these practices is fertilization. Ojeda-Barrios *et al.* (2016) mentioned that fertilization in pecan trees has a direct impact on crop quality and yield. However, although mineral fertilization in the soil is the most used strategy to improve crop production and quality, it could not be the most effective technique to maintaining soil fertility and balance in the long-term (Cucci *et al.*, 2019). On the other hand, it was reported that organic fertilization application improves physical properties, biological activity, soil fertility and crop nutrition (Zaragoza-Lira *et al.*, 2011; Márquez-Quiroz *et al.*, 2014; Bastida *et al.*, 2017). This is why, currently, organic fertilization with a low chemical contribution is preferred (Cucci *et al.*, 2019).

Recent research in pecan reported that mineral and organic fertilization is a good strategy to maintain and increase production in this crop (Soto *et al.*, 2016; Flores *et al.*, 2018). However, these studies only show the impact of this fertilization system on pecan production and quality. Thus, there is not enough information about how this fertilization system impacts on the alternate bearing intensity and the long-term yield index (IRLP). Therefore, the objective of this work was to test different mineral and organic fertilization doses in pecan cultivation and its impact on production, quality, alternate bearing intensity, and IRLP.

Materials and Methods

Experimental area and treatments

The study was conducted during the production cycles of 2016, 2017, 2018 in the Aldama municipality, Chihuahua, Mexico in 34-year-old Western Schley pecan trees, 12 × 12 m planting distance (69 trees ha⁻¹). The region presents a dry climate. The maximum average temperature during the three years was 28.35 °C (83 °F) and the average minimum temperature was 11.9 °C (53.4 °F). Rainfall shows an annual average of 1.2 mm, being July, August, and September the highest rainfall time of the year (INIFAP, 2019). Due to the few rainfalls in the region, trees were watered for 24 hours, every 10 days. The predominant soil type is Xerosol and its physical-chemical properties were the following: pH 7.86, electrical conductivity (EC) 0.80 dS m⁻¹, 0.88 % organic matter (OM) content. The macronutrients values were: Nitrogen (N) 18.90 parts per million (ppm), Phosphate (P) 25.1 ppm, Potassium (K) 1075.0 ppm, Calcium (Ca) 3800 ppm, Magnesium (Mg) 300 ppm. The micronutrient values were: Iron (Fe) 1.88 ppm, Manganese (Mn) 6.92 ppm, Zinc (Zn) 142 ppm and Copper (Cu) 0.46 ppm.

A factorial arrangement 5^6 bounded to 25 treatments was used in structure Taguchi L25 (Table 1) using the statistical package Minitab version 16.1.0. The experiment consists of 25 treatments (Table 2) arranged in three repetitions. Each replicate consisted in one tree. In addition, Mg was incorporated as a dynamic factor the doses applied were 0 kg ha⁻¹ in repetition 1, 10 kg ha⁻¹ in repetition 2 and 20 kg ha⁻¹ in repetition 3.

Table 1. Factors and levels of Taguchi L25 application structure

Concentration	Factors / Levels					
	kg ha ⁻¹				L ha ⁻¹	kg ha ⁻¹
	N	P ₂ O ₅	K ₂ O	CaO	Liquid Humus	Solid Humus
0	0.0	0.0	0.0	0.0	0.0	0.0
1	12	6.0	5.0	20.0	180.0	400.0
5	60	30	25.0	100.0	900.0	2000.0
10	120	60	50.0	200.0	1800.0	4000.0
20	240	120	100.0	400.0	3600.0	8000.0
Simple average	120	60	50.0	200.0	1800.0	4000.0

Table 2. Treatments formed in Taguchi L25 structure

Treatments	N	P ₂ O ₅	K ₂ O	CaO	Liquid Humus	Solid Humus
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	6.0	5.0	20.0	180.0	400.0
3	0.0	30.0	25.0	100.0	900.0	2000.0
4	0.0	60.0	50.0	200.0	1800.0	4000.0
5	0.0	120.0	100.0	400.0	3600.0	8000.0
6	12.0	0.0	5.0	100.0	1800.0	8000.0
7	12.0	6.0	25.0	200.0	3600.0	0.0
8	12.0	30.0	50.0	400.0	0.0	400.0
9	12.0	60.0	100.0	0.0	180.0	2000.0
10	12.0	120.0	0.0	20.0	900.0	4000.0
11	60.0	0.0	25.0	400.0	180.0	4000.0
12	60.0	6.0	50.0	0.0	900.0	8000.0
13	60.0	30.0	100.0	20.0	1800.0	0.0
14	60.0	60.0	0.0	100.0	3600.0	400.0
15	60.0	120.0	5.0	200.0	0.0	2000.0
16	120.0	0.0	50.0	20.0	3600.0	2000.0
17	120.0	6.0	100.0	100.0	0.0	4000.0
18	120.0	30.0	0.0	200.0	180.0	8000.0
19	120.0	60.0	5.0	400.0	900.0	0.0
20	120.0	120.0	25.0	0.0	1800.0	400.0
21	240.0	0.0	100.0	200.0	900.0	400.0
22	240.0	6.0	0.0	400.0	1800.0	2000.0
23	240.0	30.0	5.0	0.0	3600.0	4000.0
24	240.0	60.0	25.0	20.0	0.0	8000.0
25	240.0	120.0	50.0	100.0	180.0	0.0

The fertilizer application consisted on: N (UAN 32, 33.67% N, D 1.32), P (phosphoric acid, 49.02% P₂O₅, D 1.61), K (potassium thiosulfate 12.63% K₂O, S 17.0%, D 1.46), Ca (calcium sulphate Solugyp^{MR}, 31.31% CaO, 17.0% S), liquid humus (8.20 pH, 10.18 ds m⁻¹ EC, Ratio C/N 3.13, composition in percentages:

0.11 OM, 0.06 C, 0.02 N, 0.13 P, 0.13 K, 0.01 Ca, 0.004 Mg, 0.02 Sodium (Na); in mg kg⁻¹: 3.70 Fe, 1.10 Mn, 0.11 Zn, 0.60 Cu, 7.33 Boron (B), solid humus, OptiHumus^{MR} (8.12 pH, 10.18 ds m⁻¹ EC, Ratio C/N 6.57, composition in percentages: 21.70 OM, 12.59 C, 1.91 N, P 0.96, 1.68 K, 3.52 Ca, 1.35 Mg, 0.27 Na; in mg kg⁻¹: 11850.29 Fe, 458.80 Mn, 173.65 Zn, 34.04 Cu, 164.74 B). The fertilizers were applied in a band at a depth of 10 cm, at a distance of 2 meters from the tree trunk. Fertilizers were applied twice during the production cycle, the first during the flowering season (early April) and the second application during the fruit growth stage (July). Fertilization treatments are applied every year of study.

Yield

During the harvest (beginning of November 2016, 2017 and 2018), trees were vibrated mechanically. The nut was collected and the weight (kg) was estimated for each tree. The yield was extrapolated in tons per hectare multiplying the yield per tree by the number of trees per hectare, corrected by a 0.95 factor due to the heterogeneity in the individual yield of the trees.

Pecan nut quality

Number of nuts per kilogram. The number of nuts from a 300 g sample was counted and the value was extrapolated to the weight unit (kg). Based on Mexican Standard FF-084-SCFI-2009, the classification by size depends on the number of nuts per kilogram (giant size 122 nuts or less per kilogram, extra-large 123-139, large 140-170, medium 140-170, medium 171 to 210 and small 211 or more nuts per kilogram).

Edible nut percentage. A 300 g sample was selected to measure the edible nut content. The shell was separated from the edible part, weighed separately and the edible percentage was determined. This value was used to determine the fraction of edible product regarding the total. Mexican Standard FF-084-SCFI-2009 set 2 classifications for the edible nut percentage: when it is higher than 54% it is classified as quality I, and when it is within the range of 54 to 50% it is classified as quality II.

The three previous variables were obtained in accordance with the Mexican Standard NMX-FF-084-SCFI-2009.

Alternate bearing intensity

To calculate the alternate bearing intensity, the formula reported by Medina *et al.* (2004) with slight modifications was used:

Alternate bearing intensity = (standard deviation of yield (years analyzed) / average yield (years analyzed)) * 100

Long-term yield index

The long-term yield index was calculated using the following formula:

Long-term yield index = (average yield of the years analyzed / alternate bearing intensity) * 100

Statistical analysis

Given the Taguchi L25 factor structure for the treatment generation, the statistical analysis was conducted using a linear and quadratic response surface by adjusting the surface to determine the factor levels for an optimal response. This technique is used when each factor has three or more levels. A response surface is estimated by regression using the least-squares method. For this, the statistical package SAS (SAS Institute Inc., SAS/STAT Software: Usage and Reference, Version 6, First Edition, Cary, NC: SAS Institute Inc., 1989) was used.

The analysis for each response variable included three stages: 1) analysis of regression and contribution of each factor to the adjustment of regression; 2) canonical analysis of the response surface to determine the curve shape of those factors that had a significant linear response, quadratic and factor interaction; and 3) predicted values as the minimum or maximum response were selected according to the original data range. The increase or decrease percentage of the response variable and each of the factors to reach the required maximum or minimum value was also determined.

The behavior of all the response variables (pooled or not by categories) is summarized in a table where factors and the simple average are specified for each of them. The resulting eigenvalues expressed as percentages of the mean are taken- positive or negative as appropriate. The contribution of the eigenvectors is expressed with rounded signs from 0.25 (a part of the first quartile or greater) such that $0.2501 \leq + \leq 0.3749$, $0.3750 \leq + \leq 0.6249$, $0.6250 \leq +++ \leq 0.8749$, $++ ++ > 0.8750$. The same procedure was applied to negative eigenvectors. In this way, factors were weighted to determine which ones have more influence on the variable.

The data were analyzed for each of the years evaluated, as well as the set of the 3 years evaluated.

Results

Table 3 shows a summary of the statistical analysis results.

Yield

Table 3 shows that the average production was 2.39 t ha^{-1} . However, the range of data varied from 0.94 to 5.20 t ha^{-1} . Figure 1a shows that yield increased by 13.84% from 2016 to 2018. The factors that had the greatest impact on the production variable were N, P_2O_5 , K_2O , and liquid humus. The results indicate that there is an interaction among liquid humus, P_2O_5 and K_2O , and P_2O_5 with K_2O . Figure 2a shows the interaction between liquid Humus and P_2O_5 , which indicates that both factors contributed to increase yield.

Table 3. Overview of Yield, quality, alternate bearing and Long-term yield index in pecan tree treated with macronutrients and organic amendments

Eigenvalues	Year	MgO	N	P_2O_5	K_2O	CaO	Liq - Hu	Sol - Hu	Eigenvectors	
	2	10.0 ^T	120.0	60.0	50.0	200.0	1800.0	4000.0	Total	Ratio. +/-
Production μ 2.39 (0.94 – 5.20 t ha^{-1}) ^V										
99.2 ^U			+++ ^W	+			++		6	6 / 0
71.1			-		++		+++		6	5 / 1
-70.0				+++	++			+	6	6 / 0
Freq.	0	0	4	4	4	0	5	1	18 ^Y	
Response ^R			L,C				L,C			
Interaction ^S				K, HL	HL					
Kg ha^{-1}		9.8	181.4	66.8	56.3	239.5	3271.9	3868.9	Selection ≥ 4	
Nuts per kilogram μ 157 (166 – 134)										
16.8				+++	+			++	6	6 / 0
5.2			+		+	++	--	-	7	4 / 3
-11.3	++++								4	4 / 0
-19.4			+		+	+	+++		6	6 / 0
Freq.	4	0	2	3	3	3	5	3	23	
Response	L,C			L,C			L,C	L		
Interaction	Mg, P,K		K, HL	Ca	HL	HL				
Kg ha^{-1}		9.7	139.5	52.2	59.9	240.5	2659.4	3867.4	Selection ≥ 5	
Edible nut percentage μ 58.9 (56.5 – 59.7%)										
3.1	+		--	+++	+	+			8	6 / 2
2.4	++++			-					5	4 / 1
-1.1		+++	+	+	-				6	5 / 1
-3.0			++			+	+++		6	6 / 0
Freq.	5	3	5	5	2	2	3	0	25	
Response	L,C	C								
Interaction	Mg,K	N								
Kg ha^{-1}	2	9.3	140.1	28.1	35.7	116.4	1258.9	3251.0	Selection ≥ 5	
Alternate bearing intensity μ 31.58 % (15.6 – 54.8)										
81.2			--	+++	++	+			8	6 / 2

21.5		++		--	++	+			7	5 / 2
-43.8			+		++	---	-		7	3 / 4
-100.3			++		+		+++		6	6 / 0
Freq.	2	<u>5</u>	<u>5</u>	<u>7</u>	<u>5</u>		4	0	28	
Response ^R										
Interaction ^S			K							
Kg ha ⁻¹	10	120.0	60.0	50.0	200.0	1800.0	4000.0		Selection ≥ 5	
Long-term yield index μ 9.59% (1.64 – 31.29)										
168.9			++	++			+++		7	7 / 0
104.4			+++				--		5	3 / 2
-97.6				++	++	++			6	6 / 0
Freq.	0	<u>5</u>	<u>4</u>	2	2	<u>5</u>		0	18	
Response		L,C				L				
Interaction				HL	Ca					
Kg ha ⁻¹	9.8	164.5	84.1	51.8	181.2	3287.2	4359.9		Selection ≥ 4	
Overview										
Subtotal	9	5	<u>21</u>	<u>21</u>	18	12	<u>22</u>	4	112	112
Selection	1 / 5	0 / 5	4 / 1	4 / 5	2 / 5	1 / 5	3 / 5	0 / 5	Ratio + / -	
Prop. +/-	9 / 0	5 / 0	16 / 5	18 / 3	17 / 1	9 / 3	17 / 5	3 / 1	94 ^Z / 18	
Promotor %			76.2	85.7			77.3			
Depressor %			23.8	14.3			22.7			
Maximum			181.4	93.5			3287.2		Selection ≥ 19	

^RType of response (L) linear, (C) Quadratic. ^S interaction between factors (N) nitrogen, (P) phosphorus, (K) potassium, (Ca) Calcium, (HL) liquid humus, (HS) solid humus ^TSimple average of factor levels; ^UEigenvalues expressed as a percentage of the media of response variable; ^VRange in parentheses corresponds to the predicted values from the simple average in bold, below the optimal range, underlined above; otherwise optimal values are considered (Soto *et al.*, 2008); ^WEach sign corresponds to multiples of 0.25 rounded to the nearest quarter; ^YTotal frequency observed for that variable, multiplied by 20% to select the factors of greater weight; ^ZTotal frequency for the set of variables, those factors with a subtotal equal to or greater than 20% are selected.

Pecan nut quality

The average number of nuts per kilogram was 157. Table 3 shows that the ranges for this variable was 166 - 134 nuts per kilogram. The factors that had the greatest impact were N and liquid humus (Table 3). Likewise, Figure 1b shows the averages during the three years of studies showing a 12.73% increase in the number of nuts per kilogram. Among the analyzed factors, only liquid humus was the factor that had an influence on this parameter. Figure 2b shows the interaction between liquid humus and K₂O₅. This interaction indicates that if the doses of these factors increase, the number of nuts per kilogram will increase, which would not favor nut quality.

The edible nut percentage presented an average of 58.9% and the ranges in this variable did not show considerable variation. Thus, the minimum value was 56.5%, while the maximum value was 59.7% (Table 3). Figure 1c shows that over the three years the edible nut percentage decreased by 3.85%. Likewise, the factors that had the greatest influence on this variable were the year, N and P₂O₅. Simultaneously, an interaction was observed between N and Mg (Figure 2c) because a higher N application combined with an intermediate dose of Mg increased the edible nut percentage.

Alternate bearing intensity

In this research, the average of alternate bearing intensity was 31.58%, differing in a range of 15.6% to 54.8% (Table 3). The factors that showed an impact on this variable were N, P₂O₅, K₂O, and Ca. On the other hand, Figure 2d shows that N presented an interaction with K₂O₅. Therefore, an increase in the application of N and a deficiency of K₂O₅ increases the intensity of the alternative bearing.

Long-term yield index (IRLP) and optimum application rates

In this research the average IRLP was 9.59%, differing in a range of 1.64 to 31.29% (Table 2). The factors that showed influence on the IRLP were N, P₂O₅ and liquid humus. In addition, P showed an interaction with liquid humus, and K₂O₅ with CaO.

The factors that showed influence for the set of variables evaluated in this investigation were N, P₂O₅ and liquid humus however, K₂O is a factor that should not be neglected.

Taking into account all the results obtained in the present study, it can be defined optimum application rates of mineral and organic fertilization. Thus, these optimum application rates defined for optimum production, nut quality and reduction of the alternate bearing index were: 181.4 Kg ha⁻¹ of N, 93.5 Kg ha⁻¹ of P₂O₅, and 3287.2 Kg ha⁻¹ of liquid humus.

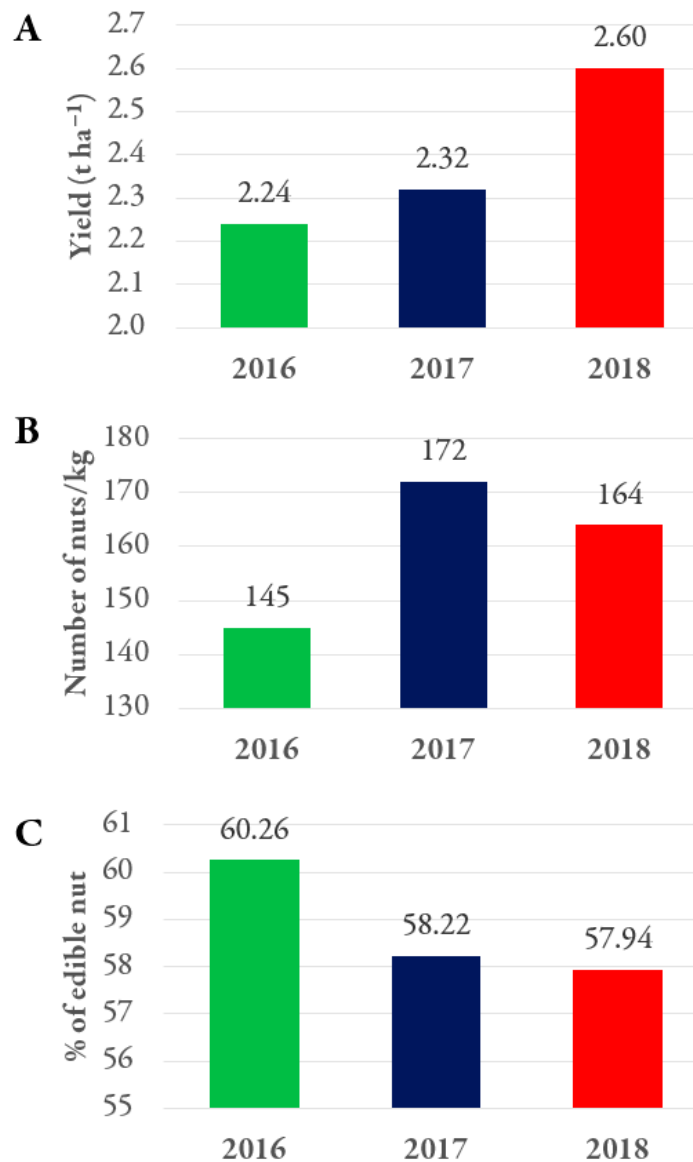


Figure 1. Average yield per year (a). Average nuts per kilogram per year (b). Average edible nut percentage (c)

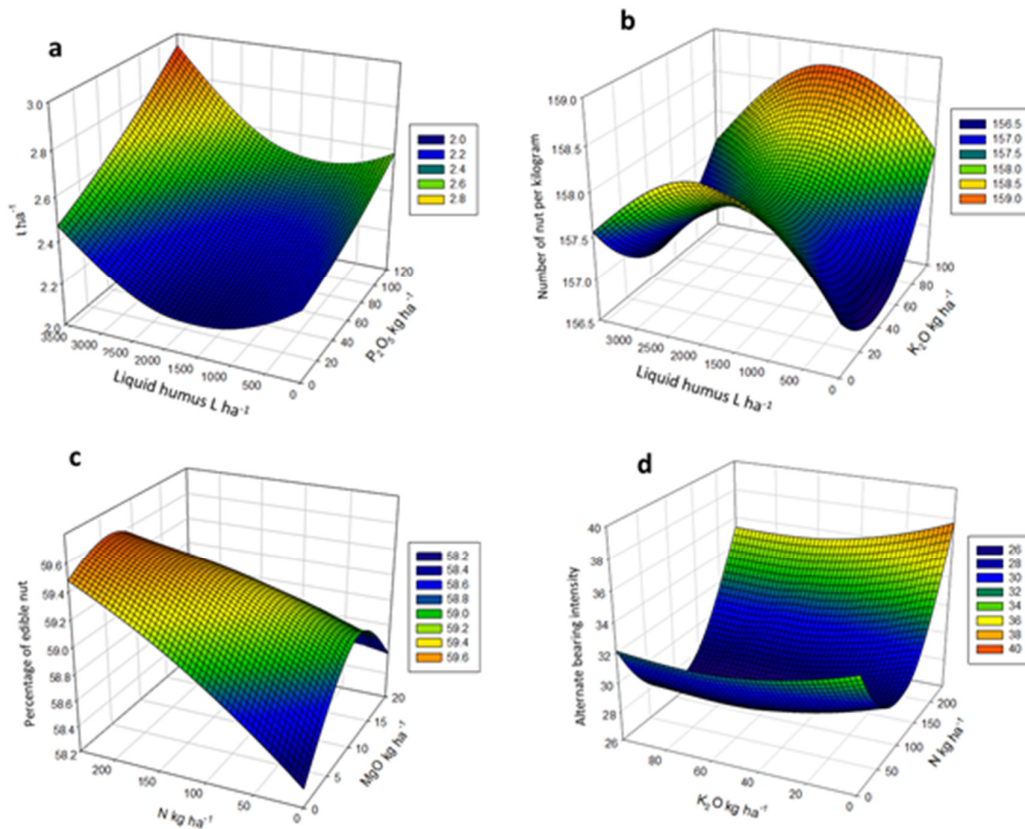


Figure 2. Response surface plots showing the interaction between liquid humus and P_2O_5 on yield (a), the interaction between liquid humus and K_2O in the number of nuts per kilogram (b), the interaction between N and MgO on the edible nut percentage, and the interaction between K_2O and P_2O_5 on alternate bearing intensity (d)

Discussion

Yield

Yield is the main parameter related to the alternate bearing index. In this research, the yield was higher than previously reported. Thus, SAGARPA reported that the national average yield in 2017 was 1.7 t ha^{-1} (SAGARPA, 2018). Vázquez *et al.*, (2018) also reported that during the years 2001-2013 the average yield in the Comarca Lagunera region in Mexico was 1.73 t ha^{-1} . On the other hand, in studies where mineral and organic fertilization was tested on pecan trees for two years, the average yield was 1.34 t ha^{-1} (Flores *et al.*, 2018). The yield increased during the three years of this research, the N, P_2O_5 , K_2O and liquid humus, showed a direct impact this because the N and K are closely related to the yield of pecans (Wells and Wood, 2007). At the same time, the increase in the weight of the pecan nut is assigned to P fertilization (Aguilar *et al.*, 2003). On the other hand, the interaction between liquid humus and P_2O_5 contributes to increased performance. Thus, the application of organic amendments such as liquid humus allows reducing mineral fertilization without diminishing yield (Soto-Parra *et al.*, 2016; Flores *et al.*, 2018). This could be due to the fact that organic fertilization facilitates the uptake and assimilation of nutrients (Labrador, 2001). Therefore, in our study, organic fertilization is probably positive to improve the uptake of minerals by pecan trees and thus increase yield.

Pecan nut quality

To determine nut quality, parameters such as fruit size, number of nuts per kilogram, nut color, edible nut percentage, as well as nut damages are taken into account (Sánchez *et al.*, 2009). Regarding the number of nuts per kilogram, the smaller this parameter is, the greater is the classification by size. The results of this research indicate that they are higher than those reported in studies that applied mineral and organic fertilization in Western Schley pecan trees. Thus, Flores *et al.* (2018) reported 171 nuts per kilogram, whereas Soto-Parra *et al.* (2016) reported 163 nuts per kilogram. The averages during the three years of studies increased, although this increase did not affect the nut classification based on the Mexican Standard FF-084-SCFI-2009. On the other hand, the edible nut percentage is an important parameter because it is the basis for nut commercialization (Castillo *et al.*, 2013). The higher the edible nut percentage, the greater is price in the market. Recent researches showed similar values. Soto-Parra *et al.* (2016) reported 58.2% of edible nut, whereas Flores *et al.* (2018) obtained 58.4% of edible nut. Therefore, in the present study, the edible nut percentage is similar but higher than previously reported. During the three years the percentage of edible nuts decreased. This decrease could be due to the fact that increased yields usually produce lower quality nuts (Conner and Worley, 2000; Flores *et al.*, 2016). However, even with this decrease in edible nut percentage, the nut classification is quality I, being well accepted in the market. Likewise, the factors that had the greatest influence on this variable were the year, N and P₂O₅. Concerning the year, this indicates that the climatic conditions during the study had an impact on the edible nut percentage. Thus, 2017 was the year with the maximum temperatures, although in this year the highest rainfall was presented, favoring the crop. Alternatively, N is present in crucial molecules such as chlorophylls, amino acids, proteins, DNA, becoming in a limiting factor for development and production in pecan (Yáñez-Muñoz *et al.*, 2015). In addition, P is related to the increase in nut weight (Aguilar *et al.*, 2003). Simultaneously, an interaction was observed between N and Mg. This positive interaction could be due to these two elements are present in chlorophyll molecules, which are fundamental for the synthesis of compounds in plants (De Castro *et al.*, 2014; Huang, *et al.*, 2019).

Alternate bearing intensity

Alternate bearing is one of the main biological problems that impact pecan yield (Wood *et al.*, 2003). In this research, the average of alternate bearing intensity was lower than that reported in two previous studies, which were carried out in the Comarca Lagunera region in Mexico, presenting 52% of average alternate bearing intensity, with a range of 23% to 94% (Medina-Morales *et al.*, 2000; Santamaria *et al.*, 2002). The factors that showed an impact on this variable were N, P₂O₅, K₂O, and Ca. Regarding N, its impact could be because N is the most demanded nutrient by plants, and is important in the synthesis of key compounds (Yáñez-Muñoz *et al.*, 2015). Regarding P, its application tends to increase the weight of the nut (Aguilar *et al.*, 2003). Likewise, K is an essential element in photosynthesis, the synthesis of carbohydrates and proteins, as well as an enzyme activator. Finally, Ca prevent Na toxicity, easing K and nitrates uptake, even in the presence of Na (Yáñez *et al.*, 2010). In addition, Ca application corrects the problem of nut-cracking, which contributes to greater production (Sparks, 1986). On the other hand, N showed an interaction with K₂O₅. This could be due to N excess in pecan causes excessive vegetative growth, which directly affects the nut quality and yield, principally because nut germination is triggered (Sparks, 1994). It was also observed that a low K₂O supply increased the alternate bearing intensity and this was probably caused by K deficiency in the pecan tree. This deficiency leads to early defoliation, affecting the following year's production (Yáñez *et al.*, 2010). Moreover, in Figure 2d it is observed that when the balance between N and K is broken, the alternate bearing intensity increases. This could be due to when the N supply is excessive, a deficiency of K is produced, resulting in a flowering delay. On the other hand, an excessive K supply cause toxicity symptom such as burn leaves and defoliation. In addition, a K excess in pecan reduces Mg and Zn uptake (Yáñez *et al.*, 2010). Therefore, it is recommended to maintain an adequate balance between N and K.

Long-term yield index (IRLP) and optimum application rates

IRLP is defined as the increasing percentage in productivity over time. In this research the average IRLP was 9.59%, agreeing this result with those reported by Flores *et al.* (2018). These authors suggested that the nut production and quality can be ensured from a year earlier through an adequate N and P fertilization and using organic amendments. It is important to highlight that these factors (N, P₂O₅ and liquid humus) also have influence in production and the alternate bearing percentage which are parameters directly related to the IRLP (Table 2).

Conclusions

The results in this research suggest that an adequate system of mineral and organic fertilization reduces the alternate bearing intensity and simultaneously enhances the yield and the long-term yield index in pecan cultivation. Likewise, it is important to mention that the main factors that showed an impact on the evaluated parameters were N, P₂O₅ and liquid humus, although K₂O is also an important factor to take into account. Thus, in this research, the optimum application rates of mineral and organic fertilization were defined which would be very useful for pecan nut producers to increase yield and quality and to reduce alternate bearing at the same time.

Acknowledgements

Thank Consejo Nacional de Ciencia y Tecnologia (CONACYT) for the scholarship of the Ph.D. for Linda Citlalli Noperi Mosqueda.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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