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

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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 with the greatest impact on the analyzed variables were N and P₂O₅. In addition, it was found 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 illinoiensis; 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 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 | 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% P\(_2\)O\(_5\), D 1.61), K (potassium thiosulfate 12.63% K\(_2\)O, S 17.0%, D 1.46), Ca (calcium sulphate Solugyp\textsuperscript{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, 7.35 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:

\[
\text{Alternate bearing intensity} = \left( \frac{\text{standard deviation of yield (years analyzed)}}{\text{average yield (years analyzed)}} \right) \times 100
\]

**Long-term yield index**

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

\[
\text{Long-term yield index} = \left( \frac{\text{average yield of the years analyzed}}{\text{alternate bearing intensity}} \right) \times 100
\]

**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$_2$O$_5$, K$_2$O, and liquid humus. The results indicate that there is an interaction among liquid humus, P$_2$O$_5$ and K$_2$O, and P$_2$O$_5$ with K$_2$O. Figure 2a shows the interaction between liquid humus and P$_2$O$_5$, 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$_2$O$_5$ | K$_2$O | CaO | Liq - Hu | Sol - Hu | Eigenvectors |
|-------------|------|-----|---|----------|-------|-----|---------|---------|-------------|
| 99.2 | 2 | 10.0$^T$ | 120.0 | 60.0 | 50.0 | 200.0 | 1800.0 | 4000.0 | 6 | 6 / 0 |
| 71.1 | - | ++ | +++ | + | 6 | 5 / 1 |
| -70.0 | - | +++ | ++ | + | 6 | 6 / 0 |
| Freq. | 0 | 0 | 4 | 4 | 4 | 0 | 5 | 1 | 6 / 0 |
| Response | L.C | L.C | L.C | L.C | L.C | L.C | L.C | L.C | L.C |
| Interaction | K, HL | K, 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 | ++++ | | | | | | | |
| -19.4 | + | + | + | +++ | 6 | 6 / 0 |
| Freq. | 4 | 0 | 2 | 3 | 3 | 5 | 3 | 6 / 0 |
| Response | L.C | L.C | L.C |
| Interaction | Mg, P, K |
| 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 | ++++ | | | | | | | |
| -1.1 | ++++ | + | + | - | 6 | 5 / 1 |
| -3.0 | ++ | + | +++ | | 6 | 6 / 0 |
| Freq. | 5 | 3 | 5 | 5 | 2 | 2 | 2 | 2 | 6 / 0 |
| Response | L.C | C |
| Interaction | Mg, K |
| 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 |
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, K2O5, 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 K₂O 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 K2O. 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.

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Conflict of Interests

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

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