

# Soil NPK fertilization in pecan [*Carya illinoensis* (Wangenh) K. Koch]: effect on yield, quality and mineral content

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## ABSTRACT

**Objective:** To evaluate edaphic NPK fertilization doses in pecan nut [*Carya illinoensis* (Wangenh) K. Koch]: effect on yield, quality and mineral content.

**Design/methodology/approach:** The experiment was conducted in a pecan nut orchard in the community of Nuevo San Lucas, municipality of Meoqui, Chihuahua. The trees were of the “Western Schley”, 45 years old, with a real frame type distribution at a distance of 12 meters between trees. A completely randomized experimental design was used, using three treatments: control (T1) 123-126-6, medium dose (T2) 148-98-54 and high dose (T3) 200-119-96, composed of 6 replicates. The variables to be evaluated were fruit size, dry weight, fresh weight, yield, quality and mineral content in kernels.

**Results:** Significant differences were obtained for the yield variable in treatment 3 with an increase of 65.15% in relation to the almond percentage and a lower moisture content of 27.42%. In the mineral concentration, total N was higher in treatment 3 with 33% in contrast to treatment 2, the percentage of potassium in the control obtained an increase of 13.04% compared to treatment 3, zinc obtained an increase of 36.59% in treatment 3 with respect to the control.

**Limitations on study/implications:** The fertilization doses evaluated pose desirable traits for producers. However, replication of the experiment in future years is crucial to corroborate results, as well as to learn new behaviors in response to fertilization.

**Findings/conclusions:** Treatment 3 is positioned as a fertilization alternative to increase yield, mineral content of N and Zn, in addition to decreasing the percentage of moisture in kernels, despite this, it did not obtain favorable results with respect to quality and K concentration in kernels.

**Keywords:** Pecan tree, Fertilization, Dosage, Quality, Yield.

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## INTRODUCTION

Pecan [*Carya illinoensis* (Wangenh.) K. Koch] is a fruit tree of significant global importance (Gutiérrez-González *et al.*, 2022). In Mexico, approximately 166,839 hectares (ha) are cultivated with pecan, distributed across various states, with the state of Chihuahua



being the leading national producer, accounting for around 104,088 ha (SIAP, 2023). In Chihuahua, pecan cultivation represents a major source of income, generating an annual economic impact of nearly 6 billion pesos. Therefore, it is essential to improve production practices and techniques related to this crop to maintain profitability. Currently, several challenges affect pecan production, one of which is the general increase in fertilization costs across many crops. In the case of pecan, fertilization accounts for approximately 42.5% of the total annual production investment. This highlights the need for efficient strategies regarding the timing and amount of fertilizer applied, without compromising nut yield or quality (SIAP, 2025; Díaz-Aguirre, 2025). In the south-central region of Chihuahua, the most commonly applied fertilizers in pecan orchards are nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn), due to the tree's high nutrient demand (INIFAP, 2013). However, 68% of the region's soils have low nitrate ( $\text{NO}_3$ ) levels ( $<10$  ppm). Phosphorus, the third most demanded element, is also deficient, with 70% of soils registering less than 7 ppm. While potassium is found at high concentrations in 94% of soils, its availability is limited due to its fixation in the soil matrix, which restricts the amount accessible to plants. Finally, zinc is typically unavailable in these soils due to their alkaline pH (Gutiérrez-González *et al.*, 2022; Hargreaves, 2015). Therefore, proper fertilization with these nutrients is essential for achieving high yields and quality production. Fertilizer dosages must be tailored to the edaphic conditions of each site to avoid toxicity or deficiency. It is thus crucial to define sufficiency ranges and determine specific regional requirements (Flores-Córdova *et al.*, 2018; Sánchez *et al.*, 2009). Based on this, the aim of the present research was to evaluate different soil fertilization rates with N, P, and K to improve yield and nut quality of pecan trees in the south-central region of Chihuahua.

## MATERIALS AND METHODS

This study was conducted in a commercial pecan orchard located in the community of Nuevo San Lucas, municipality of Meoqui, Chihuahua, Mexico ( $28^{\circ} 20' 46.4''$  N,  $105^{\circ} 34' 00.0''$  W), at an elevation of 1,160 meters above sea level. The region has a semi-arid climate. The orchard is planted with 45-year-old *Carya illinoensis* 'Western' variety trees, arranged in a square planting design with 12 m spacing between trees. The soil is sandy loam in texture, with a pH of 8.3, a cation exchange capacity (CEC) of 24.8 meq/100 g, and a bulk density of  $1.48 \text{ g/cm}^3$ . Irrigation is provided by surface gravity using floodwater.

### Experimental design and treatments

A completely randomized experimental design was used using three treatments, each consisting of six replicates per treatment, for a total of 18 experimental units across the three treatments. It should be noted that each experimental unit represented a Western variety tree. Three fertilization rates were evaluated. The first was a fertilization used in the region managed as a control with a dose per hectare of N-P-K of 123-126-6 respectively, a medium dose of 148 units of N, 98 units of P, and 54 units of K per hectare, and a high dose of 200 units of N, 119 units of P, and 96 units of K. These fertilizations were supplied with the following fertilizers: Blaukorn<sup>®</sup> Classic (12-08-16 + 3% MgO); Monoammonium Phosphate (MAP) (11-52-00); Ammonium Sulfate (21-00-00) and Hakaphos<sup>®</sup> Violet (13-40-13).

Fertilization dates were scheduled according to the most demanding phenological stages of the pecan tree. In addition, the orchard was managed using traditional practices by the grower, supplemented with seven foliar applications of zinc at a concentration of 0.4% zinc nitrate.

### Fruit size measurement

According to the stipulations of the NMX-FF-084-SCFI-2009 standard (Secretaría de Economía, 2009), various physical and quality characteristics of the fruit were evaluated. Firstly, fruit size was determined by measuring the equatorial thickness and total length of the fruit. A sample of 120 fruits per experimental unit was measured using a Vernier caliper, and the results were expressed in mm.

### Fresh weight

Furthermore, the fresh weight of the fruit was analyzed. In this case, 20 fruits per replication were weighed on an analytical balance (CHIO-JL200<sup>®</sup>), and results were expressed as g per fruit.

**Table 1.** Fertilization doses for the different treatments per experimental unit.

Treatment	Application Stage	Fertilizer	Amount (kg/tree)
1 (Control)	Basal	Ammonium sulfate	4.3
		Monoammonium phosphate (MAP)	2.9
	Flowering	Ammonium sulfate	2.1
	Fruit set	Hakaphos <sup>®</sup> Violet	0.7
2 (Medium)	Basal	Blaukorn <sup>®</sup> Classic	2.9
		MAP	1.4
		Ammonium sulfate	3.6
	Flowering	Ammonium sulfate	2.9
	Fruit set	Hakaphos <sup>®</sup> Violet	0.7
		Blaukorn <sup>®</sup> Classic	1.4
3 (High)	Basal	Blaukorn <sup>®</sup> Classic	4.3
		MAP	1.4
		Ammonium sulfate	3.6
	Flowering	Ammonium sulfate	2.9
	Fruit set	Hakaphos <sup>®</sup> Violet	0.7
		Blaukorn <sup>®</sup> Classic	3.7
		Ammonium sulfate	1.4

**Table 2.** Application dates and fertilizer doses per hectare for each treatment.

Application No.	Scheduled Date	Actual Date	Dose (NPK, kg/ha)
Fertilization 1	20032024	25032024	T1 8510400 · T2 876832 · T3 987648
Fertilization 2	25052024	25052024	T1 320000 · T2 420000 · T3 420000
Fertilization 3	12072024	25062024	T1 062206 · T2 183022 · T3 584348

**Table 3.** Sampling dates in leaves, fruits and harvest.

Sampling	Scheduled date	Actual date
1	May 1, 2024	May 1, 2024
2	June 1, 2024	June 7, 2024
3	July 7, 2024	July 6, 2024
4	August 7, 2024	August 19, 2024
5	First fruit harvest	October 18, 2024
6	Second fruit harvest	November 7, 2024

### Dry weight

In turn, the dry weight of the fruits was determined. The same 20 nuts per replication were subjected to drying in an oven at 70 °C for 48 hours.

### Yield

Crop yield was calculated as the average weight of fruit per tree for each treatment. Individual weights were summed and adjusted using the moisture percentage obtained from the corresponding dried sample.

### Kernel percentage

The kernel percentage was evaluated following the methodology of NMX-FF-084-SCFI-2009. A 300 g sample of nuts in shell was taken; the number of nuts and germinated kernels were counted. After shelling, the kernel weight was determined separately. The following formula was applied:

$$\text{Kernel percentage} = (\text{Weight of kernels} / \text{Weight of nuts in shell}) \times 100$$

### Determination of macro and micronutrients in nuts

#### Total nitrogen determination

Total nitrogen ( $N_t$ ) was determined using the Kjeldahl method, following the protocol described by Goyal *et al.* (2022). Briefly, 0.1 g of finely ground pecan kernel was placed in a Kjeldahl flask, followed by the addition of 0.3 g selenium catalyst and 3 mL of concentrated sulfuric acid. The mixture was allowed to rest for two hours before being digested on a heating block under a fume hood until the solution turned greenish. After cooling, 20 mL of deionized water and three drops of phenolphthalein were added. A receiving solution was prepared by mixing 30 mL of 4% boric acid with six drops of methyl red and six drops of bromocresol green. To the digested mixture, 40% sodium hydroxide was added until a purple coloration appeared. Distillation was carried out until the receiving solution turned turquoise green. Finally, the distillate was titrated with 0.2 N hydrochloric acid.

The total nitrogen (N) content was interpreted as follows:

$$\text{Total nitrogen (\%)} = \left[ (\text{mL HCl}) \times (\text{HCl Normality}) \times 0.014 \times 100 \right] / \text{Sample weight (g)}$$

### Mineralization (stock solution)

One gram of the ground sample was placed in a 250 mL beaker, to which 25 mL of a triacid digestion mixture (nitric acid, perchloric acid, and sulfuric acid) was added. The mixture was left to rest under a fume hood for 24 hours. It was then heated on a hot plate until it turned a yellowish oily color. The resulting solution was filtered into a 50 mL volumetric flask and brought to volume with deionized water (Wolf, 1982).

### Phosphorus determination

Phosphorus quantification followed the method proposed by Van der Heiden and Desplanque (1971). From the stock solution, 0.5 mL was taken and mixed with 1 mL of ammonium metavanadate reagent and 3.5 mL of deionized water. The solution was allowed to stand for 30 minutes, then the absorbance was read using a UV spectrophotometer. A blank was prepared using 10 mL of ammonium metavanadate reagent:

$$P(\%) = \text{Absorbance}(\text{from standard curve}) \times 0.05$$

### Determination of Ca, Mg, and K

Following the methodology of Wolf (1982), the content of calcium (Ca), magnesium (Mg), and potassium (K) was determined using 1 mL of the stock solution. This aliquot was transferred into a 100 mL volumetric flask, brought to volume with deionized water, and thoroughly mixed. A 20 mL subsample was used for analysis via atomic absorption spectrophotometry (AAS). The concentration was calculated using the following formula:

$$\text{Ca, Mg, K}(\%) = \text{Instrument reading}(\text{ppm}) \times 0.5$$

### Determination of Cu, Fe, Mn, Zn, and Na

From the same stock solution, a 20 mL aliquot was used to quantify copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), and sodium (Na) via atomic absorption spectrophotometry, following Wolf (1982). The nutrient concentrations were calculated using the formulas below:

$$\text{Cu, Fe, Mn, Zn}(\text{ppm}) = \text{Instrument reading}(\text{ppm}) \times 50$$

$$\text{Na}(\%) = \text{Instrument reading}(\text{ppm}) \times 0.005$$

## RESULTS AND DISCUSSION

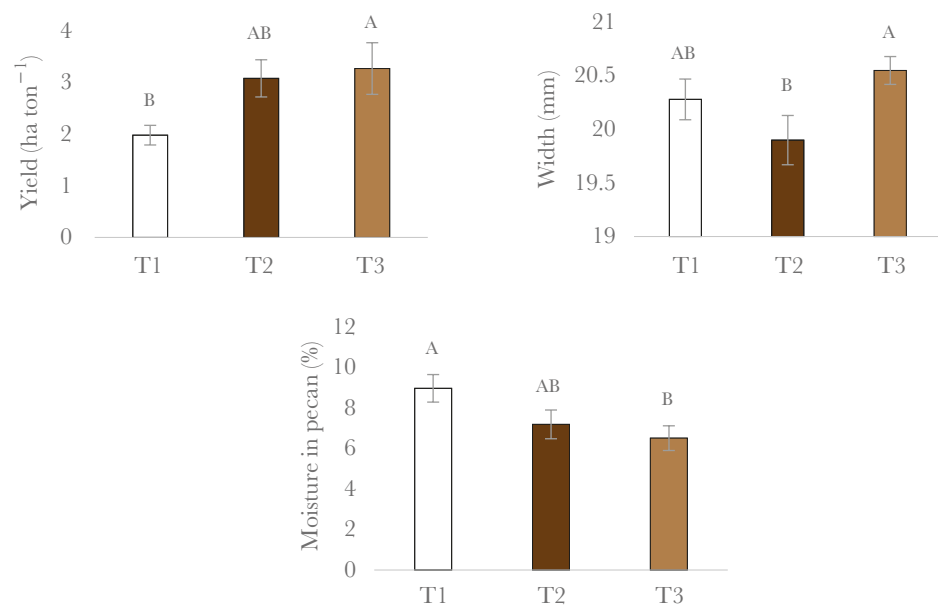
### Yield, size, and moisture content of the fruit

Fertilization in pecan (*Carya illinoensis*) cultivation is a crucial factor for ensuring grower profitability, as achieving a proper nutritional balance translates into higher yields and improved fruit quality and size (Estrada-Arellano *et al.*, 2023). The results obtained in this study revealed a statistically significant difference ( $p < 0.05$ ) for the variables of yield, equatorial fruit diameter, and kernel moisture content. Regarding yield, a significant difference was observed in Treatment 3, which showed a 65.15% increase compared to

Treatment 1, used as the control (Figure 1a). This suggests a clear correlation between the supplied nutrient doses and yield enhancement, particularly with the application of potassium (K). Potassium was notably increased in the fertilization scheme of Treatment 3 relative to the control, which received only a minimal dose of this nutrient. Additionally, an increase in equatorial fruit diameter was identified, with Treatment 3 exhibiting a 3.27% growth compared to Treatment 2, reflecting an increase in fruit weight (Figure 1b). As for kernel moisture content, Treatment 3 exhibited a 27.42% reduction compared to the control (Figure 1c), indicating an earlier harvest relative to the other treatments. This presents a competitive commercial advantage in terms of both yield and time to market.

The national average pecan yield is  $1.4 \text{ t ha}^{-1}$ ; thus, the treatments evaluated in this study achieved yields exceeding this benchmark (SIAP, 2025). These findings align with those reported by Soto-Parra *et al.* (2016), who, in a study conducted during the 2010-2012 cycles on ‘Western Schley’ pecan trees, recorded yields of  $2.9 \text{ t ha}^{-1}$ , with 153 nuts per kg and a kernel percentage of 59.4%. This required a nitrogen application of  $305 \text{ kg N ha}^{-1}$ , a dosage considered high for this nutrient. Similarly, Tong *et al.* (2024) found that high potassium application significantly increased yield during the first year of their study compared to lower doses or alternative nutrient sources.

Proper fertilization with nitrogen (N), phosphorus (P), and potassium (K) is directly associated with enhanced yield, as each nutrient independently contributes to various physiological processes vital to the tree’s growth and development. When applied synergistically and in the correct order, these macronutrients significantly boost productivity. Along these lines, Madero *et al.* (2017) recommend applying  $160\text{-}200 \text{ kg N ha}^{-1}$  for orchards with a density of 100 trees per hectare, which fulfills the crop’s



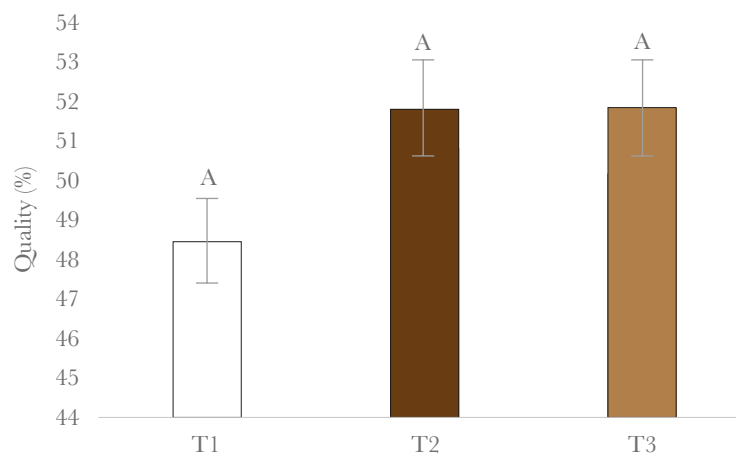
**Figure 1.** a) Yield per hectare in tons, b) equatorial fruit diameter in millimeters, and c) kernel moisture percentage in pecan (*Carya illinoensis*) fruits subjected to different fertilization levels in Meoqui, Chihuahua. Different letters indicate significant differences according to LSD ( $p < 0.05$ ). Vertical bars represent standard error.

productive demands and enhances the accumulation of photoassimilates. These assimilates, depending on the phenological stage, are directed to sink organs, promoting kernel filling. Furthermore, phosphorus and potassium applications are essential for sugar transport, directly influencing fruit growth and kernel development. Accordingly, the application of 80 kg P and 100 kg K per hectare per expected ton of yield is recommended.

### Kernel percentage

An essential factor in the commercialization of pecan nuts is the kernel percentage, which plays a key role in determining product quality and directly contributes to its commercial value (Rodríguez-González *et al.*, 2022). In the present study, no statistically significant differences were observed among treatments ( $p < 0.05$ ); however, a slight quality increase of 6.91% was noted in Treatment 2 compared to the control.

Improving pecan nut production quality depends on several contributing factors, including the number of nuts per tree, individual nut weight, fertilization, water availability, and effective pest and disease control. Among these, kernel percentage is considered a key indicator of quality (Cruz-Álvarez *et al.*, 2020; Rodríguez-González *et al.*, 2022). The results observed in Treatments 2 and 3 align with the quality standards established in NMX-FF-084-SCFI-2009, placing them within Quality Grade II, which is considered acceptable for older trees under traditional management practices (Secretaría de Economía, 2009). Flores-Córdova *et al.* (2018) reported a production yield of 1.94 t ha<sup>-1</sup> with an average of 149 nuts per kilogram after implementing a soil management regime that included 226 kg N, 121 kg P<sub>2</sub>O<sub>5</sub>, 94 kg K<sub>2</sub>O, 3,111 kg compost, 1,905 kg vermicompost, and 13 kg mycorrhizae per hectare. This approach resulted in a kernel percentage of 59%, demonstrating that a high fertilization dose, when supplemented with organic amendments, not only meets market quality demands but also contributes to soil improvement. These findings are consistent with the current study, indicating that increased fertilization tends to enhance kernel percentage. Conversely, a nitrogen fertilization strategy proposed by Cruz-Álvarez *et al.* (2020), involving applications of 100, 150, and 200 kg N ha<sup>-1</sup> both as a single application



**Figure 2.** Kernel percentage in pecan (*Carya illinoensis*) fruits subjected to different fertilization levels in Meoqui, Chihuahua. Different letters indicate significant differences according to LSD ( $p < 0.05$ ). Vertical bars represent standard error.

and in split doses alongside  $100 \text{ kg ha}^{-1}$  of PK, showed no significant differences in quality parameters across treatments or repeated years. This suggests that nitrogen dosage alone may not influence kernel filling.

### Macronutrient and micronutrient mineral content in pecan kernels

Fertilization meets the physiological demands of the crop throughout its developmental stages from bud break and flowering to fruit development and growth. Nutrient uptake varies depending on the stage, as each nutrient serves specific physiological functions (Rengel *et al.*, 2022). In the present study, statistically significant differences were observed in the nitrogen (N) and potassium (K) content. Nitrogen levels increased by 16% and 33% compared to the control and Treatment 2, respectively, while potassium content was highest in the control treatment, showing a 13.04% increase relative to Treatment 3 (Table 1).

Micronutrients play a crucial role in ensuring fruit uniformity and quality, and are essential for the optimal development of the crop (Rengel *et al.*, 2022). In the present study, statistically significant differences were observed for iron (Fe), zinc (Zn), manganese (Mn), and sodium (Na). Notably, zinc content increased by 36.59% in Treatment 3 compared to the control, while Treatment 2 showed increases of 33.3% in both iron and manganese content relative to the control (Table 2).

Fertilization management ranges from soil-based (edaphic) applications to foliar supplementation, driven by the mobility of various nutrients and the specific soil conditions of the orchard. This approach ensures optimal nutrient absorption (Mitra, 2015). In a similar study, Frusso (2013) evaluated the effects of different nitrogen, phosphorus, and zinc fertilization doses in a pecan orchard, observing significant improvements in yield, quality, and nitrogen concentration compared to the control. However, phosphorus and zinc did not show statistically significant differences across treatments. The study concluded that while increased fertilization doses can enhance yield and quality, nutrient concentration may not always reflect statistically significant variations for certain minerals.

**Table 1.** Macronutrient mineral content in pecan (*Carya illinoensis*) kernels in Delicias, Chihuahua. Different letters indicate significant differences according to LSD ( $p < 0.05$ ).

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T1	$2.29 \pm 0.14$ ab	$0.16 \pm 0.01$ a	$2.60 \pm 0.04$ a	$0.83 \pm 0.10$ a	$0.22 \pm 0.01$ a
T2	$2.00 \pm 0.12$ b	$0.16 \pm 0.01$ a	$2.51 \pm 0.07$ ab	$0.78 \pm 0.20$ ab	$0.22 \pm 0.03$ a
T3	$2.66 \pm 0.14$ a	$0.17 \pm 0.01$ a	$2.30 \pm 0.13$ b	$0.35 \pm 0.20$ b	$0.20 \pm 0.02$ a

**Table 2.** Micronutrient mineral content ( $\text{mg kg}^{-1}$ ) in pecan (*Carya illinoensis*) kernels under different fertilization treatments in Delicias, Chihuahua. Different letters within each column indicate significant differences according to LSD ( $p < 0.05$ ).

Treatment	Cu	Fe	Zn	Mn	B	Na
T1	$5.73 \pm 0.37$ a	$129.68 \pm 9.6$ b	$20.8 \pm 2.3$ b	$128.69 \pm 6.3$ ab	$76.43 \pm 4.6$ a	$4.2\text{E}-0.3 \pm 3.1\text{E}-04$ b
T2	$6.46 \pm 0.35$ a	$172.89 \pm 8.1$ a	$24.26 \pm 1.9$ ab	$152.56 \pm 12.7$ a	$59.76 \pm 11.2$ a	$0.01 \pm 3.3\text{E}-04$ a
T3	$6.76 \pm 0.34$ a	$142.5 \pm 7.1$ b	$28.41 \pm 1.7$ a	$125.7 \pm 4.6$ b	$64.29 \pm 5.5$ a	$0.01 \pm 5.6\text{E}-04$ a

Similarly, Noperi-Mosqueda (2019) assessed ‘Western Schley’ pecan trees under progressive fertilization rates of 0 to 240 kg ha<sup>-1</sup> N, 0 to 240 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 0 to 100 kg ha<sup>-1</sup> K<sub>2</sub>O, 0 to 400 kg ha<sup>-1</sup> CaO, and 0 to 3600 L ha<sup>-1</sup> of liquid humus. Significant differences were observed in nitrogen and potassium content, along with increases in yield and kernel percentage. However, no significant variation was found in phosphorus content. These findings suggest that high levels of nitrogen and potassium fertilization can improve kernel filling and edible nut yield, although not all nutrients necessarily show significant differences in tissue concentration. In pecan production, nitrogen is the most critical nutrient for increasing yield, followed by phosphorus and potassium. Therefore, a combination of mineral fertilization with organic amendments and adequate zinc supplementation enhances yield, kernel percentage, and the antioxidant capacity of the nuts (Ojeda-Barrios *et al.*, 2023; Noperi-Mosqueda *et al.*, 2019).

## CONCLUSIONS

Fertilization had a clear influence on yield, fruit diameter, kernel moisture content, and mineral concentration in pecan kernels. Among macronutrients, nitrogen emerged as the most influential element, while zinc stood out among the micronutrients. Treatment 3 was particularly notable, as it achieved the highest yield per hectare and increased equatorial fruit diameter, thereby improving fruit uniformity. Moreover, it reduced kernel moisture content, facilitating better storage and transport conditions, and lowering postharvest risks such as pest, fungal, and disease infestations. This treatment also resulted in higher nitrogen and zinc concentrations. While no significant differences were detected in kernel percentage, a positive trend was observed with increased fertilization, suggesting that long-term application of these treatments may yield further improvements in fertilization response.

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