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ORIGINAL ARTICLE

Investigating the Correlation between Phosphorus and Zinc Levels with Leaf Chemistry and Pecan Nut Kernel Weight

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K E Y W O R D S

Orchards;
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zinc

A B S T R A C T

The pecan tree holds significant economic value due to its versatile cultivation and utilization. To expand its reach in global markets, pecan nut breeding aims to enhance both the quantity and quality of the product through meticulous planning. In this context, phosphorus and zinc are crucial nutrients for pecan nuts, playing a notable role in their nutritional profile. An experiment was conducted to investigate the effects of different levels of phosphorus and zinc on the nutrient content and yield of pecan trees. The experiment was designed in a factorial form with three levels of phosphorus (0, 250, and 500 kg P_2O_5 ha^{-1}) and three levels of zinc (0, 25, and 50 kg Zn ha^{-1}) in four replications. The results of the experiment showed that increasing the consumption of phosphorus had a significant effect on the concentration of phosphorus and iron in the leaves. However, a higher level of phosphorus application reduced the concentration of copper in the leaves. Similarly, the application of zinc increased the concentration of zinc (from 138.54 to 166.25 mg kg^{-1}) in the leaves but decreased the concentration of phosphorus (from 0.15% to 0.13%). Interestingly, the application of 250 kg ha^{-1} of phosphorus led to a significant increase in the dry weight of the kernel, while higher levels of phosphorus had the opposite effect. These findings suggest that careful management of phosphorus and zinc levels in pecan orchards can have a significant impact on both nutrient content and yield. This research provides valuable insights for pecan breeders and growers seeking to optimize their practices and improve the quality of their crops.

Introduction

The *Carya illinoinensis*, also known as the pecan nut, is a type of hickory tree native to North America that can grow up to 40 meters tall and live up to 300 years (Casales *et al*., 2018; Moccia *et al*., 2020).

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According to the FAO statistics from the World Food Organization, the United States is responsible for approximately 80% of the world's pecan nut production, with other significant producers including Mexico, Australia, and South Africa (Tanwar *et al*., 2020). Pecans are favored for their rich, buttery taste and can be used in sweet or savory dishes. They also have a range of nutritional benefits, containing healthy fats, protein, fiber, as well as vitamins and minerals such as vitamin E, thiamin, magnesium, and zinc (Ajamgard *et al*., 2017; Ajam Gard, 2022; Tanwar *et al*., 2022). Pecan trees exhibit optimal growth in arid alpine climates, steppe regions, and Mediterranean areas as opposed to humid temperate regions. These trees have a high light requirement and exhibit a moderate level of drought tolerance while also being quite demanding in their growth needs (Alabbas *et al*., 2022). Pecan trees have the ability to grow in different geographical regions and at various elevations. However, they display the greatest growth potential in soil that is both deep and fertile, characterized by excellent drainage properties, such as loamy or clayey sand (Bhardwaj *et al*., 2017).

Phosphorus is an essential element for plants, performing multiple critical functions. It is integral in facilitating energy transfer during metabolic processes, promoting cell division, participating in the synthesis of phospholipids for cell wall construction, and aiding in the growth of reproductive and secondary root structures. Additionally, it plays a role in the production and transport of carbohydrates within plants (Lang *et al*., 2016; Tsujii *et al*., 2017; Ejraei *et al*., 2018; Ghorbani *et al*., 2022; Shiberu *et al*., 2023). Zinc exerts diverse effects on plant physiology, including modulation of growth hormone biosynthesis and activity, elongation of inter-node distance, promotion of chloroplast biogenesis, facilitation of metabolite restoration, synthesis of nucleotides, and regulation of water homeostasis (Bücker-Neto *et al*., 2017; Umair Hassan *et al*., 2020; Maliha *et al*., 2022). Several scientific investigations have demonstrated the detrimental effects of excessive application of phosphorus on the absorption of certain trace elements with low dietary intake. Among various examples of this occurrence, the interplay between phosphorus and zinc in plants has been extensively studied by researchers in the field of plant nutrition. A plethora of reports propose that these two vital nutrients manifest opposing impacts on plants, thereby exhibiting an antagonistic relationship (Xie *et al*., 2019; Bindraban *et al*., 2020; He *et al*., 2021; Recena *et al*., 2021). The imprecise and imbalanced utilization of chemical fertilizers results in increased production costs and environmental pollution (Baweja *et al*., 2020; Bisht and Chauhan, 2020). Specifically, the excessive utilization of phosphorus-based fertilizers leads to a notable effect. This surplus employment interferes with the assimilation of critical trace minerals, such as zinc, especially in situations where phosphorus intake is disproportionate (Chatrabnous *et al*., 2018; Norozi *et al*., 2019; Srinivasarao, 2021; Islam *et al*., 2022).

According to Ando *et al*. (2022), excessive use of fertilizers containing phosphorus can impact the plant's absorption of iron and decrease its availability. Numerous studies have shown that the presence of phosphorus can have detrimental effects on both the quantity and quality of crops by interfering with other essential nutrients. The unselective application of phosphorus-based fertilizers diminishes the assimilation, translocation, and biochemical processing of trace elements, leading to unfavorable consequences for plant development (Keshavarz *et al*., 2011; Edlinger *et al*., 2022; Mohit Rabary *et al*., 2022). According to Suganya *et al*. (2020), high concentrations of soluble phosphorus can diminish the translocation of certain low-demand elements like iron and manganese from the root to the stem of maize (*Zea mays L.*). This suggests that phosphorus may cause internal deactivation of these elements.

As there is no existing research on the impact of the simultaneous utilization of phosphorus and zinc fertilizers on pecan nut kernel weight and the equilibrium of iron, copper, and manganese nutrients, an experiment was carried out to examine the alterations in the concentrations of these elements in pecan nuts. The purpose of this study was to determine whether the application of phosphorus and zinc fertilizers is essential to attain an optimum yield. To the best of our knowledge, this is the first controlled experiment quantifying impacts of combined phosphorus and zinc application on pecan nutrition and yield components.

Material and Methods

In 2022, an experiment was conducted in an orchard at Qala Sngi Saru village, located in Erbil governate, Iraq, which is known for its suitability for pecan nut production. The name of the village means “the castle of the two springs” in Kurdish, referring to the two natural springs that provide water for the village. The village sits at an altitude of 1600 meters above sea level. To begin the experiment, a soil sample was collected from the orchard at the depth of root development. The sample was then air-dried and passed through a 2 mm sieve before being subjected to various physical and chemical tests. These tests included measuring the soil pH in a saturated extract using a glass electrode (Scheberl *et al*., 2019), determining salinity with a conductivity meter, analyzing the soil texture using the hydrometer method (Barman and Choudhury, 2020), and measuring the calcium carbonate equivalent through neutralization with hydrochloric acid (Kassim, 2013). Moreover, the technique outlined by Gülser *et al*. (2020) was employed to ascertain the proportion of organic carbon. The measure of available phosphorus was evaluated utilizing the Olsen and Fried (1957) methodology, while the concentration of iron, copper, manganese, and zinc elements was determined employing the approach established by Lindsay and Norvell (1978).

The study area was based on the outcome of a soil test that revealed insufficient levels of phosphorus and zinc, with the soil containing 8 mg kg^{-1} of phosphorus and 0.8 mg kg^{-1} of zinc. The orchard was selected due to the uniformity of the trees, its strategic location, and accessibility. The experiment was designed as a 3×3 factorial with three varying levels of phosphorus (0, 250, and 500 kg P_2O_5 ha^{-1}) derived from the triple superphosphate source, and three levels of zinc (0, 25, and 50 kg Zn ha^{-1}) derived from the Zn-ethylenediaminetetraacetic acid (Zn-EDTA) source which is a chelated form of zinc that is often used as a micronutrient fertilizer in agriculture. The experimental design followed a completely randomized pattern, with four replications.

The study utilized trees of the Iraqi pecan species that exhibited similar physical characteristics and were of equivalent age, with a 12-year growth period and a distance of 8 meters between them. The trees were not subjected to any chemical fertilization during the year 2022. After being identified and labeled, the trees were subjected to phosphorus fertilization in February, followed by zinc foliar spraying, which was administered thrice at 10-day intervals in March. The foliar spraying sessions were conducted between 7:00 and 11:00 A.M. During the summer season, leaf samples were obtained from both branches and fully-grown leaves. Subsequently, these samples were transported to a laboratory where the levels of essential micronutrients such as iron, copper, manganese, and zinc were determined by utilizing the dry combustion technique and extraction with double normal hydrochloric acid through an atomic absorption spectrometer (Agilent 200 Series AA, model 240 AA, USA). Moreover, the concentration of phosphorus was quantified using the Olsen method. During the early autumn season, following the main branch fruit harvest, a random selection of 300 fruits was made from each tree to measure the weight of the pecan nut kernels under different treatments. The comparison of means was conducted at a statistical significance level of 1% using Tukey-Kramer test. The data was processed using Excel software and analyzed using SAS software.

Results

Table 1 displays information on various soil parameters, including salinity levels as measured by electrical conductivity (ECe), pH values indicating soil acidity or alkalinity, the percentage of calcium carbonate equivalent (CCE), the amount of organic carbon (OC) present, concentrations of specific elements, and the soil texture of the orchard being tested.

Table 1. Several characteristics pertaining to the physical and chemical attributes of soil.

Property	EC (dS m^{-1})	pH	CCE (%)	OC (%)	Phosphorus (mg kg^{-1})	Zinc (mg kg^{-1})	Iron (mg kg^{-1})	Manganese (mg kg^{-1})	Copper (mg kg^{-1})	Silt (%)	Clay (%)
Value	0.90	7.58	4.18	1.43	7.08	0.68	8.93	12.35	4.94	26.60	13.30

Table 2 presents the outcomes obtained from the analysis of variance carried out on the levels of phosphorus, zinc, iron, copper, and manganese present in the leaves. The impact of phosphorus and zinc, as well as their interaction, on leaf phosphorus concentration were found to be statistically significant. The mean values were compared and presented in Table 3. The findings indicate that a rise in phosphorus consumption from 0 to 250 kg ha^{-1} led to a 15.38% increase in leaf phosphorus concentration. However, further increase in phosphorus consumption up to 300 kg ha^{-1} did not result in any significant increase in leaf phosphorus concentration. Conversely, the escalation of zinc levels resulted in a noteworthy reduction in phosphorus concentration in the leaves. The outcomes indicated that the rise in zinc application rates ranging from nil to 25 and 50 kg ha^{-1} led to a marked decline in phosphorus concentration from 0.15 to 0.14 and 0.13% of phosphorus in leaves. This observation highlights the antagonistic interplay between zinc and phosphorus in pecan leaves. The study observed a notable impact of zinc on the zinc concentration in leaves. The mean comparison, analyzed via Tukey-Kramer test, was illustrated in Table 3. The findings demonstrated that the utilization of zinc led to a significant rise in the zinc content of the leaves. As the amount of zinc intake increased from 0 to 25 and 50 kg ha^{-1}, the zinc concentration in the leaves also significantly increased from 138.54, 150.41, and 166.25 mg kg^{-1}, respectively. However, even though an increase in phosphorus content was observed to reduce the concentration of zinc in the leaves, the effect was statistically insignificant. Moreover, the interaction between the two elements had a significant effect, at a 5% level, in enhancing the concentration of zinc in the leaves.

The study found that the presence of phosphorus in the leaves had a notable impact on iron concentration. Analysis of variance indicated a significant effect of phosphorus on iron concentration, while the combined effect of both elements was not significant (Table 2). A comparison of mean values in Table 3 revealed that iron concentration in leaves increased significantly from 63.95, 134.59, and 201.08 mg kg^{-1} when phosphorus consumption increased from zero to 250 and 500 kg ha^{-1}, respectively. Conversely, Table 3 demonstrated that while an increase in zinc consumption led to a rise in iron concentration in leaves, this effect was not significant.

The significant impact of phosphorus, as well as the interplay between phosphorus and zinc, on the concentration of copper in leaves has been observed. However, the effect of zinc alone on copper concentration in leaves was not found to be significant. A comparison of means is presented in Table 3. The findings indicate that the application of 250 kg ha^{-1} of phosphorus resulted in the highest concentration of copper in the leaves, exhibiting an increase of 31.94% and 40.53% in comparison to the 0 and 500 kg ha^{-1} of phosphorus, respectively.

Furthermore, the consumption of zinc at a rate of 25 kg ha^{-1} resulted in the highest concentration of copper in leaves, but no notable difference was observed when compared to other levels of zinc consumption.

The statistical analysis in Table 2 revealed that both phosphorus and the interaction between phosphorus and zinc have a significant impact on the concentration of manganese in leaves. The means comparison results in Table 3 indicate that the highest levels of phosphorus and manganese in leaves were observed at a consumption rate of 250 kg ha^{-1}. However, this level did not show a statistically significant difference compared to other levels of phosphorus consumption. As the amount of phosphorus consumed increased, there was a decrease in manganese concentration in leaves, but this decrease was not statistically significant. Furthermore, the highest concentration of manganese in leaves was observed at a zinc consumption rate of 25 kg ha^{-1}, but this level did not differ significantly from other levels of zinc consumption.

Table 2 presents the results of an analysis of variance that indicate a significant effect of phosphorus and its interaction with zinc on the dry weight of the kernel in 300 fruits, whereas zinc had no significant effect on the dry weight of the kernel. Table 3 displays the outcomes of the means comparison conducted using Tukey-Kramer test. The average dry weight of the kernel increased significantly as the amount of phosphorus increased from 0 to 250 kg ha^{-1}. However, the dry weight of the kernel decreased significantly as the amount of phosphorus increased from 250 to 500 kg ha^{-1}. Also, when the quantity of zinc intake was augmented from 0 to 50 kg ha^{-1}, there was no noteworthy upsurge observed in the dry mass of the kernel comprising 300 fruits.

Table 2. The outcomes of a variance analysis that pertains to distinct impacts of phosphorus and zinc on the chemical makeup of leaves and the weight of pecan nut kernels after dehydration.

Source of Changes	df	P	Zn	Fe	Cu	Mn	Dry weight of kernel (300 fruits)
P	2	1.21E-02**	2.08E+02	5.93E+04**	5.68E+03**	3.77E+01**	1.05E+05**
Zn	2	9.03E-04**	2.44E+03**	1.44E+03	8.14E+02	1.65E+01	6.86E+03
P × Zn	4	2.47E-04*	3.07E+02	4.14E+03	6.55E+02**	2.16E+01**	2.94E+04**
Error	21	7.60E-05	2.75E+02	1.59E+03	1.24E+02	6.93E+00	2.90E+03
Coefficient of Variation (%)		6.13	10.65	29.21	15.41	1609.00	1.98

*, ** are significant at the 5% and 1% probability level, respectively.

Table 3. The effect of phosphorus and zinc application on the concentration of elements in leaves and dry weight of pecan nut kernels.

	Zinc levels (kg ha^{-1})			
Phosphorus levels (kg ha^{-1}).	**0**	**25**	**50**	**Average**
	Dry weight of kernel (300 fruits) (g)			
0	2529.4	2505.63	2517.5	2517.5^{B}
250	2660	2897.5	2767.88	2774^{A}
500	2707.5	2574.88	2517.5	2600.63^{B}
Average	2632.31^{A}	2660^{A}	2600.63^{A}	
	Phosphorus (%)			
0	0.15	0.13	0.12	0.13^{B}
250	0.15	0.16	0.14	0.15^{A}
500	0.15	0.14	0.14	0.15^{A}
Average	0.15^{A}	0.14^{AB}	0.13^{B}	
	Zinc (mg kg^{-1})			
0	140.13	144.88	173.38	152.79^{A}
250	135.38	156.75	173.38	155.16^{A}

500	140.13	149.06	152	147.25^{A}
Average	138.54^{B}	150.41^{AB}	166.25^{A}	
		Iron (mg kg^{-1})		
0	66.98	63.65	61.51	63.95^{C}
250	109.25	175.75	118.75	134.59^{B}
500	186.44	179.31	237.5	201.08^{A}
Average	121.89^{A}	139.57^{A}	139.25^{A}	
		Copper (mg kg^{-1})		
0	63.89	65.31	61.75	63.15^{B}
250	84.31	107.83	91.94	94.53^{A}
500	71.25	51.06	39.43	53.91^{B}
Average	73.15^{A}	74.73^{A}	64.2^{A}	
		Manganese (mg kg^{-1})		
0	14.01	14.96	14.96	14.65^{A}
250	15.2	21.38	17.1	17.89^{A}
500	16.86	14.25	14.72	15.28^{A}
Average	15.35^{A}	16.86^{A}	15.91^{A}	

Note: The absence of a statistically significant difference between the mean values of the treatments is indicated by the identical letters.

Discussion

The results of this study showing an antagonistic relationship between phosphorus and zinc uptake in pecan leaves align with previous research. According to Sofy *et al*. (2020), the presence of a high concentration of zinc led to a reduction in the amount of phosphorus present in the plant's organs. Similarly, Recena *et al*. (2021) found evidence suggesting that zinc and phosphorus have an antagonistic relationship, whereby higher concentrations of zinc are associated with decreased phosphorus absorption. Aboyeji *et al.* (2020) ascertained that augmenting the level of phosphorus results in a decline in zinc concentration in plants, indicative of an antagonistic correlation between these elements. However, their subsequent experimentation demonstrated that the introduction of phosphorus not only fails to induce indications of zinc inadequacy in leaves, but also amplifies the crop productivity (Adekiya *et al*., 2022).

The general consensus among researchers is that an adequate supply of phosphorus promotes plant growth and enhances the development of roots. This facilitates an expanded exploration of the soil volume, thereby enabling the plant to absorb nutrients and moisture more effectively. In such circumstances, the absorption and utilization efficiency of various nutrients, particularly iron, is augmented (Bader *et al*., 2020; Bononi *et al*., 2020; Etesami, 2020). According to Bindraban *et al*. (2020), the excessive usage of fertilizers containing phosphorus has an adverse impact on the plant's absorption and accessibility of manganese, which can ultimately result in a reduction of its nutritional value. Multiple studies have shown that the interplay between phosphorus and other nutrients can have negative implications for both the quantity and quality of the resulting product. According to the findings of Recena *et al*. (2021), the incremental intake of zinc did not produce a notable impact on the weight of 2000 grains of wheat. This outcome could be attributed to the disturbance in the equilibrium of essential nutrients, particularly those with low intake levels (Gondal *et al*., 2021).

Overall, the complex nutrient interactions underscore the importance of balanced fertilizer programs. Blanket applications of phosphorus or zinc alone risks inducing deficiencies of other nutrients. Growers should consider leaf tissue analyses to identify limiting nutrients and adjust fertilizer formulations accordingly. The results provide valuable insights on phosphorus and zinc levels that optimize pecan leaf nutrition and kernel development. Further field trials across diverse orchards would help refine fertilizer recommendations for maximizing pecan yields.

Conclusions

The study demonstrated a significant correlation between phosphorus consumption and the concentration of phosphorus and iron in leaves. The results revealed that an application of 250 kg ha^{-1} of phosphorus significantly increased the concentration of copper in leaves. However, the application of higher levels of phosphorus led to a reduction in the copper concentration. In addition, the application of zinc resulted in an increase in the zinc concentration but significantly decreased the concentration of phosphorus in the leaves. Moreover, the study found that an increase in phosphorus consumption at the level of 250 kg ha^{-1} led to a significant increase in the dry weight of the kernel. However, the use of higher levels of phosphorus reduced it. It was also noted that the application of zinc did not have a significant effect on the weight of the pecan nut kernel. These findings suggest that carefully managing the application of phosphorus and zinc to plants can have a significant impact on their growth and nutrient content.

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Conflict of interests

The authors declare no conflict of interest.

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