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AMENDMENTS, PLANT GROWTH-PROMOTING MICROORGANISMS, AND BIOSTIMULANTS ON PECAN TREE YIELD

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Abstract: The state of Chihuahua is the leading producer of walnuts, with a planted area of 87,657 hectares and a production of 105,767 tons, accounting for 85% of national production and generating an economic impact of 8.736 billion pesos. As walnut trees are a crop of great economic importance in the state, it is important to study all the nutritional aspects of this crop, where organic matter is one of the main characteristics of the soil, associated with the release of nitrogen, phosphorus, and sulfur; with the availability of iron, manganese, copper, and zinc, due to its chelating action, and is a source of humic and fulvic acids. Biostimulants can increase nutrient absorption, improve resistance to disease and stress, and increase nut yield. In this sense, the right combination of organic amendments and biostimulants can have a positive impact on yield parameters. The work was carried out during the 2016-2018 growing season in Aldama, Chihuahua, at the Huerta el Edén orchard, on the 'Western Schley' variety, with 34-year-old trees. There were seven treatments, distributed in two applications based on the phenological stages of greatest demand: 1) beginning of fruit set and 2) Watery state; with four replicates: 1) Control, 2) Humus 231.88 kg, 3) Leachate 115.94 L, 4) Mycorrhizae 579.71 g, 5) Biocop B+A 289.86 mL, 6) Algaenzyms 289.86 mL, 7) Al Zinc 289.86 mL, in relation to all treatments, did not have a significant effect on nut weight (g) and number of nuts per (kg), nor on the nutritional content of N, P, Cu, and Zn; while Algaenzims (T6) and Mycorrhizae (T4) showed a significant response in the percentage of almonds and in production t.ha-1respectively, Azospirillus (T5) for K, Ca, and Mn; AlZinc (T7) for Fe. This can be interpreted as a positive addition of nu-

trients in the treatment, satisfying requirements, as it offers a favorable margin of maneuver. Research has shown that the right combination of organic amendments, plant growth-promoting microorganisms, and biostimulants can have a positive impact on plant performance parameters.

Keywords: Carya illinoienensis (Wangenh.) K Koch, 'Western Schley', growth regulators, amendments, yield t.ha-1 , number of nuts per kg, and percentage of edible kernel.

INTRODUCTION

In Mexico, the main producer of pecan trees (*Carya illinoinensis*) is the state of Chihuahua, accounting for 70.0% of the national area. This crop is considered to be extremely profitable as a result of the high prices paid to producers for the harvest, which is why pecan plantations have grown substantially in Mexico (Gutiérrez *et al.,* 2022). The pecan tree is a highly valued tree species in agriculture, both for its nut production and its high profitability, which is why the area dedicated to its cultivation increases annually. However, at the national level, the average yield is only 1.5 t ^{ha} ^{1}(SIAP-SAGARPA, 2014), due, among other factors, to nutritional deficiencies and imbalances, which make its management more expensive, given the increase in fertilizer prices. To achieve adequate yields, it is important to provide the essential nutrients that walnut trees require, which means it is necessary to understand and improve the physical and chemical properties of the soil (Wood, 2009).

This tree is of great economic importance in the southern United States and northern Mexico, where both countries stand out as the world's leading producers, consumers, and exporters/importers of pecans. It is crucial to maximize their yield and health, for which it is necessary to carefully consider the influence of organic matter and biostimulants, fundamental elements that significantly affect their development and production. This provides an opportunity to make more rational use of fertilizers and transition to sustainable fruit growing that allows for a better nutritional balance of the pecan tree. To achieve this, proper nutrition management is required, as it is an important part of the production process that promotes an excellent quality harvest (Sánchez, *et al.*, 2009). The objective of this study is to evaluate the application of organic amendments, microorganisms, and biostimulants on the foliar nutritional content and yield of pecan trees.

MATERIALS AND METHODS

The study was conducted in the municipality of Aldama, Chihuahua, Mexico, during the 2016, 2017, and 2018 production cycles. In the "El Edén" orchard. The 'Western Schley' pecan variety was used, with 34-year-old trees and a planting density of 69 trees per hectare, with a distance of 12 x 12 meters between them. The region has a dry climate, with an average maximum temperature of 28.35 °C and an average minimum temperature of 11.92 °C during the three years of the study. Annual rainfall is low, with an average of 1.2 mm, with the heaviest rains concentrated in the months of July, August, and September (INIFAP, 2018). Table 1 shows the treatments to be used, in two applications with four replicates, which are: 1) Control, 2) Earthworm humus with a total of 231.88 kg, 3) Leachate with a total of 115.94 L, 4) Mycorrhizae with a total of 579.71 g, 5) Biocop B+A

(Azospirillus) with a total of 289.84 mL, 6) Alga Enzims with a total of 289.84 mL, 7) Al Zinc with a total of 289.84 mL.

RESULTS AND DISCUSSION

Biostimulants are compounds that, although not nutrients, promote plant growth and development by stimulating natural physiological processes. Table 1 shows the results over three years (2016 to 2018) of yield, where a significant response is observed both in the percentage of almonds and in production in tons per hectare, for treatments with algaenzims (T6) of 60.4% and mycorrhizae (T4) of 2.61 t ha^{-1} , respectively. González (2009) mentions that the use of mycorrhizae increases the surface area of the walnut tree's root system, which is relevant for water and nutrient absorption. Therefore, this indicates that the application of mycorrhizae and algaenzims could be an effective strategy for increasing walnut production. On the other hand, Pedroza *et al.* (2015) state that algaenzims are important in the bioprocessing of products that are vital for plant development, so they can play an important role in improving soil quality, which in turn can benefit walnut cultivation. Noperi (2019) mentions that liquid humus is one of the main factors that has an impact on mineral content, creating a balance between factors, preventing antagonistic interactions, and thus contributing to nutrient availability. On the other hand, not all treatments seem to have a significant effect on nut weight (expressed in g) and number of nuts (expressed in kg).

Tables 2 and 3 show the foliar nutritional content for macronutrients (%) and micronutrients (ppm) during 2016, 2017, and 2018. The treatments had a significant impact on the nutrient levels in walnut leaves. However, in the specific case of nitrogen (N), phosphorus (P), copper (Cu), and zinc (Zn), no significant response was observed in the foliar nutrient content of pecan trees treated with amendments, plant growth-promoting microorganisms, and biostimulants, so they were not a determining factor in the plant's response to the treatments applied.

Treatment with Biocop B+A (T5), in relation to potassium (K, Ca, and Mn), reached a significant value of 1.29 in K, with a suggested range of (0.87-1.23), 2.14 in Ca, with a suggested range of (1.45-2.06), and 1011.5 in Mn, with a suggested range of (146.8-208.0), exceeding the suggested range for these elements. García *et al.* (2007) state that the positive effects of Azospirillum on various crops have been attributed mainly to improved root development and the subsequent increase in the rate of water assimilation and soil mineral utilization, as well as increased resistance to adverse conditions. In addition, it can reduce the need for chemical fertilizers and promote more sustainable agricultural practices.

According to Yáñez, *et* al. (2010), K is the second most required macronutrient for walnut trees, as it is necessary for higher production. Therefore, its proper administration is important to ensure good production. According to Andrade (2019), Azospirillum is a plant growth-promoting bacterium due to its ability to stimulate plant growth ( ). Therefore, it is essential to apply them appropriately to obtain the maximum benefit from their advantages.

		Dosis ha^{-1}	Mat árbol	Total a Usar
Humus Lomb (T2)	Enmiendas	4000	57.97 Kg	231.88 Kg
Lixiviado (T3)		2000	28.99 L	115.94 L
Biocop B+A (T4)	MPDV	5	72.46 mL	289.84 mL
Micorrizas (T5)		10	144.93 g	579.72 g
Algas Enzims (T6)	Bioestimulantes	5	72.46 mL	289.84 mL
Al Zinc (T7)		5	72.46 mL	289.84 mL

Table 1.- Organic amendments, plant growth-promoting microorganisms (PGPM), and biostimulants in pecan trees. 2016-2017-2018.

	Nuts kg	% kernel	Production t ha^{-1}
Treatments	0.8942[w]	0.0763	0.3710
1 Control	153 a	59.2 abc	2.02 ab
2 HumSol	155 a	58.2 c	1.88 b
3 HumLiq	157 a	58.8 bc	2.44
4 Mycorrhizae	160.a	59.4	2.61 a
5 Biocop B+A	156 a	60.0 ab	2.30 ab
6 Algaenzims	159 a	60.4 a	2.27 ab
7 AlZinc	158.a	59.1	2.04 ab
DMS[X]	10	1.4	0.70
μ	157	59.3	2.23
CV	6.78	2.51	32.85
R^2	0.5057	0.6088	0.4363

[W]Probability of analysis of variance Pr > 0.05 not significant, 0.05 ≤ Pr ≤ 0.01, significant, Pr < 0.01 highly significant; XMinimum Significant Difference (t α 0.05); Y means with the same letter are statistically equal; μ overall mean, CV coefficient of variation, R2 coefficient of determination; HumSol, Optihumus solid humusMR 8.14% organic matter, ash 82.41%, total carbon 9.44% C/N ratio 5.82, N 1.62%, P 0.49%, K 1.04%, Ca 2.26%, Mg 1.35%, N-NO3 836.3 ppm, Na 0.045%, Cu 20.0 ppm, Fe 54.5 ppm, Mn 376.5 ppm, Zn 92.0 ppm, free CO3, % moisture 13.08, pH 7.83, C.E. 3.00 mS/cm; HumLiq, Optihumus liquid humus MR 11.33% organic matter, ash 82.10%, total carbon 6.57%, C/N ratio 6.68, N 0.98%, P 0.58%, K 2.77%, Ca 5.10%, Mg 0.66%, Na 0.069%, Cu 13.5 ppm, Fe 717.5 ppm, Mn 123.5 ppm, Zn 17.0 ppm, pH 9.21, C.E. 4.06 mS/cm; mycorrhizae Acaulospora scobiculata, Gigaspora margarita, Glomus fasciculatum, G. constrictum, G. tortuosum, G. geosporum with 20,000 viable spores kg-1, Biocop B+A, AZospirillum lipoferum 1x107 cfu mL-1 ; AlgaEnzims, M.O. 4.15%, Protein 1.14%, crude fiber 0.43%, ash 0.28%, sugars 0.13%, fats 0.03; Al Zinc, Zn 10.0%, B 0.5%, auxins 492 ppm, gibberellins 201 ppm, cytokinins 498 ppm.

Table 1. Production parameters in pecan trees treated with amendments, plant growth-promoting microorganisms, and biostimulants

For magnesium (Mg), the overall average was 0.55, indicating a level below the sufficiency range (1.09-1.55). This indicated that the plant may be experiencing a deficiency of this nutrient. Yáñez *et al.* (2010) mention that magnesium deficiency in walnut trees is relatively rare, as deficiency of this nutrient is related to low soil pH, because excess Ca tends to replace Mg. However, a significant response was found in the liquid humus treatment (T3), which reached a value of 0.63. Compared to the control, this response is remarkable, as the control had an even lower value of 0.49, suggesting a possible Mg deficiency in the soil. Therefore, Huang *et al.* (2019) mention that it is important to correct magnesium deficiency through proper fertilization practices to ensure healthy walnut tree growth and optimal production . Arenas (2013) states that liquid humus increases the reabsorption of minerals found in the soil, such as phosphorus, nitrogen, potassium, iron, magnesium, among others. This treatment is therefore very appropriate for improving the availability of Mg in the crop.

In the case of iron (Fe), the overall average was 137.7, indicating a level slightly above the sufficiency range, which is between 67.2 and 92.2. This indicates that the plant could be experiencing an excess of this nutrient, but it is not available to the plant. Aguilar *et al.* (2003) mention that it is essential for chlorophyll formation, therefore, it is essential to ensure that the plant receives the adequate amount of iron for optimal growth and development. AlZinc (T7) reached a significant value of 162.3 compared to the control, which had a value of 148.8, indicating that it was above the suggested range (67.2-95.2). This can be interpreted as a positive addition of nutrients in the AlZinc treatment (T7). According to Morales *et al.* (2009), the proper use of seaweed-based biostimulants could increase crop production by 40% to 60%. Therefore, it is essential to apply them correctly to maximize their benefits.

Manganese (Mn) was observed to have an overall average of 889.4, indicating a level well above the sufficiency range (146.8-208.0). This suggests that the plant could be experiencing an excess of this nutrient, so it is crucial to ensure that the plant receives a sufficient amount of manganese to promote optimal growth and development. In (T4) Mycorrhizae, a significant value of 1083.1 was reached, compared to the control, which had a value of 709.0, which is above the suggested range.

CONCLUSIONS

No significant effects were observed in nut weight (g), number of nuts per (kg), N, P, and Zn in any treatment; while mycorrhizae (T4) and algaenzims (T6) showed a significant response in production t/ha^{-1} and in the percentage of almonds, respectively. The treatments that showed significant responses in macro- and micronutrients were: (Biocop B+A) (T5) for K, Ca, and Zn; (Mycorrhizae) (T4) for Mn; and (AlZinc) (T7) for Fe. This can be interpreted as a positive addition of nutrients in the treatments with plant growth-promoting microorganisms and biostimulants, satisfying requirements, as it offers a favorable margin of maneuver; increasing nutrient absorption, improving resistance to disease and stress, as well as increasing nut yield. It is important to correct magnesium deficiency through proper fertilization practices to ensure healthy walnut tree growth and optimal production. Rese-

	Nt	P	K	Ca	Mg	Na
Treatments	0.0196[W]	0.5202	0.0021	0.1237	0.0075	0.0738
1 Control	2.35 ab	0.213 a	0.93 c	1.85	0.49 b	0.0135 abc
2 HumSol	2.21 b	0.185 a	1.00 BC	2.14 a	0.58 ab	0.0125 c
3 HumLiq	2.42 a	0.176 a	0.94 c	2.12 abc	0.63 a	0.0165 abc
4 Mycorrhizae	2.44 a	0.186 a	1.12 ab	1.85 bcd	0.60 ab	0.0131 bc
5 Biocop B+A	2.49 a	0.201 a	1.29 a	2.14 a	0.56 ab	0.0135
6 Algaenzims	2.39 a	0.210 a	0.95 bc	1.78 cd	0.51 ab	0.0173 a
7 AlZinc	2.50 a	0.209 a	1.04 bc	1.91 bcd	0.50 b	0.0169 ab
DMS[X]	0.17	0.044	0.18	0.33	0.12	0.0040
μ	2.40	0.197	1.04	1.97	0.55	0.0148
CV	7.29	23.72	18.01	17.63	23.45	28.44
R^2	0.5493	0.5645	0.8907	0.8023	0.8409	0.8389

[W] Probability of analysis of variance Pr > 0.05 not significant, 0.05 ≤ Pr ≤ 0.01, significant, Pr < 0.01 highly significant; X Minimum Significant Difference (t α 0.05); Y means with the same letter are statistically equal; μ overall mean, CV coefficient of variation, R2 coefficient of determination; HumSol, Optihumus solid humusMR 8.14% organic matter, ash 82.41%, total carbon 9.44% C/N ratio 5.82, N 1.62%, P 0.49%, K 1.04%, Ca 2.26%, Mg 1.35%, N-NO3 836.3 ppm, Na 0.045%, Cu 20.0 ppm, Fe 54.5 ppm, Mn 376.5 ppm, Zn 92.0 ppm, free CO3, % moisture 13.08, pH 7.83, C.E. 3.00 mS/cm; HumLiq, Optihumus liquid humus MR 11.33% organic matter, ash 82.10%, total carbon 6.57%, C/N ratio 6.68, N 0.98%, P 0.58%, K 2.77%, Ca 5.10%, Mg 0.66%, Na 0.069%, Cu 13.5 ppm, Fe 717.5 ppm, Mn 123.5 ppm, Zn 17.0 ppm, pH 9.21, C.E. 4.06 mS/cm; mycorrhizae Acaulospora scobiculata, Gigaspora margarita, Glomus fasciculatum, G. constrictum, G. tortuosum, G. geosporum with 20,000 viable spores kg-1, Biocop B+A, AZospirillum lipoferum 1x107 cfu mL-1 ; AlgaEnzims, M.O. 4.15%, Protein 1.14%, crude fiber 0.43%, ash 0.28%, sugars 0.13%, fats 0.03; Al Zinc, Zn 10.0%, B 0.5%, auxins 492 ppm, gibberellins 201 ppm, cytokinins 498 ppm.

Table 2. Foliar nutritional content for macronutrients (%) in pecan trees treated with amendments, plant growth-promoting microorganisms, and biostimulants

	Fe	Mn	Zn	Cu
Treatments	0.2553W	0.0235	0.6870	0.0096
1 Control	148.8 ab	709.0 b	58.0 a	5.9 ab
2 HumSol	128.7	916.1 ab	44.0 a	5.5 bc
3 HumLiq	151.8 ab	879.9 ab	54.3 a	5.8 bc
4 Mycorrhizae	121.2 b	1083.1 a	51.4 a	5.9 b
5 Biocop B+A	126.5 ab	1011.5 a	53.8 a	6.6 a
6 Algaenzims	124.5 ab	692.4 b	53.5	6.0 ab
7 AlZinc	162.3	933.6 ab	49.3 to	5.1 c
DMSX	39.9	248.0	15.7	0.8
µ	137.7	889.4	52.0	6.0
CV	30.31	29.17	31.62	15.77
R^2	0.6244	0.6647	0.4388	0.4398

[W] Probability of analysis of variance Pr > 0.05 not significant, 0.05 ≤ Pr ≤ 0.01, significant, Pr < 0.01 highly significant; [X] Minimum Significant Difference (t α 0.05); [Y] means with the same letter are statistically equal; µ overall mean, CV coefficient of variation, R^2 coefficient of determination; HumSol, Optihumus solid humus[MR] 8.14% organic matter, ash 82.41%, total carbon 9.44% C/N ratio 5.82, N 1.62%, P 0.49%, K 1.04%, Ca 2.26%, Mg 1.35%, N-NO3 836.3 ppm, Na 0.045%, Cu 20.0 ppm, Fe 54.5 ppm, Mn 376.5 ppm, Zn 92.0 ppm, free CO3, % moisture 13.08, pH 7.83, C.E. 3.00 mS/cm; HumLiq, Optihumus liquid humus [MR] 11.33% organic matter, ash 82.10%, total carbon 6.57%, C/N ratio 6.68, N 0.98%, P 0.58%, K 2.77%, Ca 5.10%, Mg 0.66%, Na 0.069%, Cu 13.5 ppm, Fe 717.5 ppm, Mn 123.5 ppm, Zn 17.0 ppm, pH 9.21, C.E. 4.06 mS/cm; mycorrhizae *Acaulospora scobiculata, Gigaspora margarita, Glomus fasciculatum, G. constrictum, G. tortuosum, G. geosporum* with 20,000 viable spores kg^{-1}, Biocop B+A, AZospirillum lipoferum $1x10^7$ cfu mL^{-1} ; AlgaEnzims, M.O. 4.15%, Protein 1.14%, crude fiber 0.43%, ash 0.28%, sugars 0.13%, fats 0.03; Al Zinc, Zn 10.0%, B 0.5%, auxins 492 ppm, gibberellins 201 ppm, cytokinins 498 ppm.

Table 3. Foliar nutritional content for micronutrients (ppm) in pecan trees treated with amendments, plant growth-promoting microorganisms, and biostimulants

arch has shown that the right combination of organic amendments, plant growth-promoting microorganisms (PGPM), and biostimulants can complement a macro- and micronutrient-based fertilization program and have a positive impact on plant yield parameters.

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