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Cost-benefit analysis of the best combination of organic and inorganic sources to supply zinc deficiency in pecan (*Carya illinoinensis* [wangenh] k. Koch)

Análisis costo-beneficio de la mejor combinación de fuentes orgánicas e inorgánicas para suplir la deficiencia de zinc en el nogal pecanero (*Carya illinoinensis* [Wangenh] K. Koch)

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Abstract

Zinc (Zn) is considered a trace element; however, this element is scarce in calcareous soils, so it is necessary to make applications to optimize performance. The objective of this study was to analyze the cost-benefit relationship of the best combination of applying organic and inorganic sources of zinc in the cultivation of walnut (*Carya illinoinensis* [Wangenh] K. Koch) that maximizes the yield of pecan nut. Prior to the cost-benefit analysis, five Zn application treatments were evaluated; a control treatment (T1-no application); T2 was the application of 4.5 L H_2SO_4 + 3 kg $ZnSO_4$ in 100 L H_2O; T3 consisted of the application of 3 Kg $ZnSO_4$ in 20 L of worm leachate measured at 100 L of H_2O; T_4 was with the addition of 3 kg $ZnSO_4$ mixed in 25 kg of solid vermicompost; and T5 was the addition of 3 Kg $ZnSO_4$ in 25 kg of compost. A total of two applications per treatment were made. The parameters evaluated were the concentration of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) in the leaf tissue and the yield in kilograms of walnut (kg ha^{-1}). The highest nut yield was obtained with T2 with 1,400 kg ha-1 compared to 933 kg ha^{-1} that were harvested in the control treatment; that is to say, a differential of 467 kg of walnut. A b/c ratio of 1.2861 was calculated for the best biological treatment, which was T2.

Analysis, Yield, Inorganic, Optimize

Resumen

El zinc (Zn) es considerado un elemento traza; sin embargo, este elemento es escaso en suelos calcáreos por lo que es necesario realizar aplicaciones para optimizar rendimiento. El objetivo de este estudio fue analizar la relación costo-beneficio de la mejor combinación de aplicar fuentes orgánicas e inorgánicas de zinc en el cultivo del nogal (*Carya illinoinensis* [Wangenh] K. Koch) que maximice el rendimiento de nuez pecanera. Previo al análisis costo-beneficio se evaluaron cinco tratamientos de aplicación de Zn; un tratamiento testigo (T1-sin aplicación); el T2 fue la aplicación de 4.5 L H_2SO_4 + 3 kg $ZnSO_4$ en 100 L H_2O; el T3 consistió en la aplicación de 3 Kg $ZnSO_4$ en 20 L de lixiviado de lombriz aforado a 100 L de H_2O; el T4 fue con la adición de 3 Kg $ZnSO_4$ mezclados en 25 kg de lombricomposta sólida; y el T5 fue la adición de 3 Kg $ZnSO_4$ en 25 kg de composta. Se realizaron un total de dos aplicaciones por tratamiento. Los parámetros evaluados fueron la concentración de nitrógeno (N), fósforo (P), potasio (K), calcio (Ca), magnesio (Mg), sodio (Na), fierro (Fe), cobre (Cu), manganeso (Mn) y zinc (Zn) en el tejido foliar y el rendimiento en kilogramos de nuez (kg ha-1). El mayor rendimiento de nuez se obtuvo con el T2 con 1,400 kg ha-1 en comparación con 933 kg ha^{-1} que se cosecharon en el tratamiento testigo; es decir, un diferencial de 467 kg de nuez. Se calculó una relación de b/c de 1.2861 para el mejor tratamiento biológico que fue el T2.

Análisis, Rendimiento, Inorgánicas, Optimización

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Introduction

The United States of America, with 75% of the world's pecan nut (*Carya illinoinensis* [Wangenh] K. Koch) production, is considered the world's largest producer (USDA, 2020). Mexico ranks second in the world with approximately 20% of the production. Thus, the production in 2009 was 74,226 tons, where the state of Chihuahua with 65% is considered the first producer of this nut. The cultivation area has grown exponentially in Mexico; thus, SAGARPA (2013) specified that, only in a period of 10 years (2003-2013), 20,000 ha of walnut trees were established. By 2016, Mexico was harvesting 280,000 tons of walnut in an area of 112,156 ha with a production value of 622 million dollars (PAN-SAGARPA, 2017).

In the particular case of Mexico, pecan nuts are harvested in arid and semi-arid soils; which are classified in the soil taxonomy order as Aridisols and cover about 60% of the country's surface (Montaño et al., 2016). These soils cover about 1/3 of the world's surface and present unique characteristics such as high levels of CaCo3 in their profile (calcareous-caliche soils), alkaline, presence of salts and low levels of organic matter. These characteristics are the result of low rainfall and high temperatures that further potentiate the desertification process (IPCC, 2007). The tree that produces the pecan nut belongs to the Juglandaceae family and is native to northern Mexico and southern United States of America (Hal, 2000).

Zinc (Zn) is considered a trace element and essential for plants because it plays an important role in physiological metabolism and hormone regulation (Ojeda-Barrios et al., 2014) as well as being involved as a cofactor in enzyme regulation and cell division (Hajiboland and Amirazad, 2010). However, Zn deficiency in plants growing on calcareous soils is common and, in particular, the pecan tree requires adequate Zn inputs to achieve good yields. It is clear that a Zn deficiency can lead to reduced photosynthesis and lower yields in the crop of interest. Consequently, it is necessary to evaluate cheap and easily accessible sources of this trace element to guarantee a good pecan nut production and to know its benefit-cost ratio.

The purpose of a benefit-cost (b/c) analysis, particularly in the agricultural sector, is to identify the rate of return on an investment and to identify a potential negative effect, if any. Ultimately, the aim is to increase the profitability of farmers in the agricultural sector, who are willing to incur additional expenditure in their production processes. It is important to mention that growth in the agricultural sector plays an important role in poverty reduction, as some estimates have determined that such growth is three to four times more effective than growth in other non-agricultural sectors (Christiansen and Martin, 2018). The objective of this study was to conduct a cost-benefit analysis of the best combination resulting from analysing various organic and inorganic sources to supply the element Zn in walnut (*Carya illinoinensis* [Wangenh] K. Koch) cultivation to obtain the best pecan nut yield.

Methodology to be developed

An experiment was conducted in 2018 in the walnut orchard owned by the Faculty of Agricultural and Forestry Sciences (FCAyF) of the Autonomous University of Chihuahua (UACH). The orchard is located near the city of Delicias, in the state of Chihuahua, Mexico, and belongs to Irrigation District 005. The area is located at 28°11" North Latitude and 105°30" West Longitude and is at an altitude of 1,415 m above sea level. The area is considered to be semi-arid extreme, with an average annual temperature of 18.6º C, a maximum temperature of 42º C in summer (July-August) and a minimum of -13º C in winter (December-February). The average annual rainfall is 294.7 millimetres which occurs in the summer (June-August) and a relative humidity of 45%. The number of frost days is 110 and there are potentially 3 days of early frost in October and 4 days of late frost in April. The prevailing winds come from the southwest.The walnut trees are irrigated with a gravity irrigation system and one walnut tree was considered as experimental unit with four replications. A total of four treatments were evaluated, which were prepared with different sources of organic matter (OM) and sulphuric acid (H_2SO_4) plus the control treatment (T1). The second treatment was the application of 4.5 L H_2SO_4 + 3 kg Zn SO_4 in 100 L H_2O (T2); the third treatment consisted of the application of 3 kg $ZnSO_4$ in 20 L of worm leachate gauged to 100 L H_2O (T3); the fourth treatment was the addition of 3 kg $ZnSO_4$ mixed in 25 kg of solid vermicompost (T4); and the fifth treatment was the addition of 3 kg ZnSO4 in 25 kg of compost (T5).

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A total of two applications of each of the treatments were carried out; the first one was done on 5 April and the second one on 12 May. For the application of the treatments, a trench of approximately 30 cm depth was constructed. This trench was constructed in each experimental unit at a distance of 2m. In this trench, the amount of product corresponding to each treatment was applied, then the trench was covered and irrigation was applied. All other tasks in the orchard (irrigation, weed control, pest control, soil and foliar fertiliser application) were carried out according to the schedule of activities established by the institution. The parameters evaluated were the concentration of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) in the foliar tissue and the yield in kilograms of nut. In the first week of August, a first sampling was carried out to determine these concentrations in the leaf tissue. These determinations were carried out in the soil fertility laboratory of the FCAyF. In November, the harvest was carried out to determine the nut yield by transforming the harvested nut into kilograms per hectare.

Statistical analysis of biological response

To determine differences between treatments, an analysis of variance (ANOVA) was carried out considering an arrangement of treatments without structure (Rubio and Jiménez, 2012). The analysis was carried out using the statistical package SAS (Statistical Analysis System) and when the ANOVA showed significant effects, i.e., when the F value was significant, we proceeded to use a comparison of means test with Tukey's method. In all cases the statistical analyses considered a significance value of 95%, i.e., $\alpha=0.05$.

Cost-benefit análisis

Once the best treatment evaluated in the Zn application treatments from the biological point of view had been determined, a cost-benefit analysis was carried out. To carry out this analysis, the simplest formula was used, i.e., the b/c ratio was calculated, where b represents the benefit and c the cost.

The benefit of each treatment is determined as a percentage, and its interpretation is: if the result is greater than 1 it is acceptable or profitable, if its result is equal to 1 it has no profit benefit or loss and if its result is less than 1 it is not profitable, therefore the treatment or project is rejected. Its formula: Profit Cost = Net Profit/Net Cost × 100.

Results and discussion

The ANOVA results for nutrient concentration in walnut leaf tissue showed differences between treatments for the elements P, Fe, Cu, Mn and Zn ($P<0.05$) while no statistical difference was detected for N, K, Ca, Mg, Na and B ($P>0.05$). A detailed analysis of these results is not carried out as it is not the objective of this study. Of the treatments evaluated, the highest nut yield was obtained with T2, i.e., with the application of 4.5 L H2SO4 + 3 kg Zn SO_4 in 100 L H_2O (T2). The higher concentration obtained in this treatment is attributed to the effect of the sulphuric acid in lowering the soil pH, increasing the availability of Zn. In this regard, the researchers Miyamoto et al. (1975) mentioned that acidification of calcareous soil can temporarily lower the soil pH and, consequently, reactivate the solubility of Zn and other nutrients that were not available to the plant. In fact, this treatment had a positive effect on the availability of other elements (i.e., the elements P, Fe, Cu and Mn) which would favour better tree development. This assertion is confirmed by Lindsay and Norvell (1978) and Wallace and Mueller (1978) who indicated that acidification of small, banded soil areas with H_2SO_4 applications near the roots eliminated micronutrient deficiencies.

The highest nut yield was obtained with T2 with 1,400 kg ha^{-1} compared to 933 kg ha^{-1} harvested in the control treatment, i.e., a differential of 467 kg nut, in this treatment was obtained as a b/c ratio of 1.2861 and is the one that generated the highest return per invested weight and without any visible risk. Researchers Hosseinpour *et al.* (2022) conducted a study where they performed a b/c analysis in an urban agriculture design project in a sustainable environment. They found a value of 0.86 in the traditional system, which was not considered economically profitable. However, in their project proposal they found a value of 4.08 which tremendously outperformed the traditional project.

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Most c/b ratio analyses around the world have focused on irrigation water use (Szott and Motamed, 2023). However, c/b analyses are indispensable for any activity that aims to increase crop yields. Ultimately, it is desired that the farmer adopts an innovation that will increase his yield in the field and, consequently, increase his income. In addition, the adoption of a certain practice can lead to the adoption of that practice by other farmers. For example, when a producer in Canada adopted strip grazing in a short period of time, this new technology (practice) supported other producers, who adopted it, increasing all their profits (Agriculture and Agri-Food Canada, 2016). Other advantages observed as a result of adopting this innovation were that producers did not fall into arrears, better understood the advantages of more extensive grazing, improved their grazing areas due to the organic manure left by livestock and reduced certain cultivation work.

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