Colegio de Postgraduados

Changes in soil properties with the establishment of *Pinus greggii* Engelm. ex Parl. forest plantations, on marginal lands in Durango, Mexico

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ABSTRACT

Objective: Evaluate the changes in the physicochemical properties of the soil and organic carbon in a *P. greggii* plantation on marginal land with previous agricultural use.

Methodology: Two plots were compared: agricultural use vs. forest use, in La Soledad, Canatlán, Durango, analyzing various physicochemical soil properties and organic carbon on two dates (2023 and 2024). The effects of land use, time, and their interaction were determined using a mixed linear model ($\alpha=0.05$), with the plot considered as a random factor. A multivariate principal component analysis was performed to identify patterns of association between the variables and determine their sensitivity to the type of land use.

Results: There were significant differences ($p<0.05$) between the two land uses in phosphorus, potassium, organic matter (SOM), and total organic carbon (TOC), with interactions with the evaluation time. The plantation increased phosphorus, SOM, and TOC levels by 58%, 27%, and 29%, respectively, compared to agricultural soil. Cation exchange capacity, calcium, and magnesium explained the greatest variation in both land uses, but in the plantation, in addition to these three variables, the response was also associated with SOM and COT.

Limitations on study: Further studies are needed to examine the rate of nutrient recycling in litter.

Conclusions: The plantation improved soil fertility and favored the accumulation of organic matter and carbon, highlighting its potential for the recovery of degraded soils.

Keywords: soil quality, fertility, productivity, soil recovery.

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INTRODUCTION

Soil degradation is a widespread issue in various regions of Mexico, affecting approximately 64% of the national territory, according to CONAFOR-UACH (2013). Over half of this degradation (38%) is attributed to land-use changes driven by agricultural and livestock activities. This process compromises soil health and quality, diminishing its

capacity to deliver essential ecosystem goods and services. Furthermore, the interplay between climate change and soil degradation exacerbates the severity of the problem.

Over the past decade, Mexico has promoted several strategies aimed at soil conservation and restoration, such as the National Soil Strategy for Sustainable Agriculture (ENASAS) (Secretariat of Agriculture and Rural Development [AGRICULTURA], 2022) and the establishment of forest plantations on abandoned lands. However, in states like Durango where the establishment of fast-growing coniferous commercial plantations has been encouraged since 2008 as a productive reconversion strategy on low-yielding soils many of these initiatives have failed due to restrictive environmental conditions. These plantations were established on marginal soils characterized by shallow depth, limited moisture, and low fertility (Rosales *et al.*, 2022). Despite their limited growth performance, forest plantations may contribute to soil restoration (López-Upton, 2017), enhancing physical, chemical, and biological properties by depositing organic matter (OM). Once incorporated and mineralized in the soil, OM supports nutrient cycling within this complex system (Haase & Jacobs, 2013). For instance, Gageler *et al.* (2014) demonstrated that reforestations in riparian zones reduce bulk density and improve soil infiltration rates, largely due to OM's role in aggregate stability. Another study by Hou *et al.* (2020) highlighted the benefits of plantations composed of forest species from diverse functional groups in increasing soil organic carbon (SOC) storage and mitigating degradation. Conversely, Koryś *et al.* (2021) found no significant differences in OM content or in key macronutrients such as nitrogen, phosphorus, and potassium in abandoned lands subjected to active tree-based restoration practices. While the aforementioned scientific evidence supports the role of forest plantations in soil recovery or rehabilitation, the contrasting findings reported by Koryś *et al.* (2021) underscore the need for further research to deepen our understanding of how plantations influence soil restoration particularly at local and regional scales. Species selection and site-specific conditions are crucial variables in this dynamic (Xu *et al.*, 2024). Additionally, historical land use such as recurrent tillage or overgrazing affects restoration outcomes, especially with regard to SOC, as these practices accelerate its depletion (Haddaway *et al.*, 2017). This perspective is essential for assessing the impact of forest plantations on degraded soil recovery, especially in the case of commercial *Pinus greggii* Engelm. ex Parl. plantations in Durango. Although these plantations have not achieved the expected productivity, they may still serve as valuable tools for improving soil quality in marginal lands. Therefore, the aim of this study is to evaluate changes in the physicochemical properties and organic carbon content of soil under a *P. greggii* plantation established on marginal land previously used for agriculture. The research questions guiding this study are: Do soil physicochemical properties and organic carbon content change following the establishment of the plantation? If so, which properties are affected and to what extent?

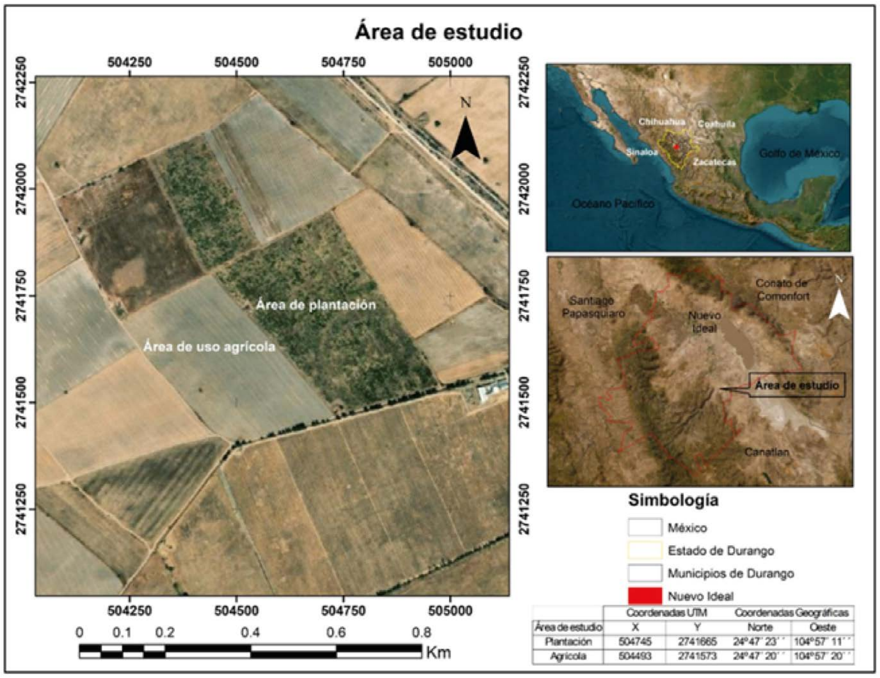
MATERIALS AND METHODS

Study area

The study was conducted in the locality of La Soledad, in the municipality of Canatlán, Durango. Two adjacent plots were selected, both sharing a common history of agricultural use. However, in one of the plots, a commercial *Pinus greggii* plantation was established in 2015 as a strategy for the productive reconversion of marginal soils (Rosales *et al.*, 2022) (Figure 1). The plantation was initially established at a density of 1,258 trees per hectare, with a spacing of 3 meters between rows and 2.65 meters between trees. The adjacent plot continues to be used for rainfed bean cultivation. The predominant soils in the area are Phaeozems and Vertisols with a loam -clay -sand texture. The terrain is characterized as an alluvial plain. The regional climate is classified as semi-arid temperate with summer rainfall (BS1 kw) (INEGI, 2010). The mean annual temperature is 15.8 °C, and the average annual precipitation is 535.8 mm. Rainfall is concentrated between June and September, with July being the wettest month, receiving up to 140 mm (Medina *et al.*, 2005).

Soil sampling and analysis

Two soil samplings were conducted during the summer (July), the first in 2023 and the second in 2024. The "five-of-diamonds" method was used, collecting three subsamples of approximately 0.4 kg each per sampling point using a manual auger, to form five composite samples of 1 kg each per site at a depth of 0-20 cm. The soil samples were transported in plastic bags for immediate drying, first air-dried in a greenhouse, and then oven-dried at 105 °C in a forced-air oven until constant weight. Each site's samples underwent a physicochemical analysis in the laboratory, following the guidelines of NOM-021-RECNAT-2000 (SEMARNAT, 2002), to determine bulk density (g/cm^3), pH, electrical conductivity (EC; dS/m), cation exchange capacity (CEC; mEq/100 g), and concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and boron (B), all expressed in mg kg^{-1}.



	Coordenadas UTM		Coordenadas Geográficas	
Área de estudio	X	Y	Norte	Oeste
Plantación	504745	2741665	24°47' 23''	104°57' 11''
Agrícola	504493	2741573	24°47' 20''	104°57' 20''

Figure 1. Geographical location of the study area. La Soledad, Canatlán, Durango.

Additionally, soil organic matter (SOM; %) and total organic carbon (TOC; %) contents were measured. Bulk density was determined using the core method, while pH and EC were measured using an electrode in a 1:2 soil-to-water solution. CEC was analyzed via the 1 N ammonium acetate method at pH 7. Nitrate nitrogen ($N\text{-}NO_3^-$) was determined using the micro-Kjeldahl method, phosphorus using the Bray-Kurtz 1 method, and exchangeable bases (K^+, Ca^{2+}, Mg^{2+}) were extracted with ammonium acetate and measured by ICP-Plasma. Micronutrients Fe, Zn, Mn, Cu, and B were extracted with DTPA-sorbitol and also quantified by ICP-Plasma. SOM content was determined using the Walkley and Black method (Walkley & Black, 1934), while TOC was quantified using an elemental analyzer by combustion (Elementar Vario Micro Cube, Elementar Analysensysteme GmbH, Langenselbold, Germany). Prior to TOC analysis, the samples were homogenized using an agate mortar and pestle, and three independent weighings (3-4 mg each) were conducted using a microbalance. Samples were prepared in tin capsules with a maximum volume of 25 μL. Analyses were performed at a combustion temperature of 1115 °C and a reduction temperature of 850 °C.

Statistical analysis

A repeated-measures experimental design was implemented (2023 and 2024) to compare soil physicochemical properties under two land-use conditions: *P. greggii* forest plantation and agricultural use. To evaluate the effects of land use, time, and their interaction on soil variables, linear mixed models (LMMs) were applied (α=0.05), with the plot considered a random factor. Before applying the LMMs, assumptions of normality and homoscedasticity of residuals were tested using the Shapiro-Wilk and Bartlett tests, respectively. Variables not meeting the normality assumption were log-transformed (natural logarithm, ln). Interactions between land use and time in the LMMs were analyzed via mean comparisons by year using Student's t-test (α=0.05). For pH and Cu, which did not meet normality assumptions even after transformation, the non-parametric Kruskal-Wallis test was used to compare medians between land uses in each year. A principal component analysis (PCA) was also performed using data from both years to identify patterns of association among soil variables and determine which were most sensitive to treatments reflected in the components explaining the highest proportion of total variance (>80%) (Härdle *et al.*, 2024). All statistical analyses were carried out using IBM SPSS Statistics, version 26 (IBM Corp., 2019).

RESULTS AND DISCUSSION

Most of the variables analyzed exhibited significant differences between the evaluation years, regardless of land-use condition (treatments) (Table 1). Specifically, the properties pH (p=0.008), electrical conductivity (EC) (p=0.002), cation exchange capacity (CEC) (p=0.000), as well as nitrogen (N) (p=0.002), calcium (Ca) (p=0.002), magnesium (Mg) (p=0.000), and manganese (Mn) (p=0.002) levels were significantly affected by time (Table 1). From 2023 to 2024, for instance, pH decreased by 7%, from 6.13±0.05 (mean ± standard error) to 5.69±0.11, while CEC declined by 18%, from 7.68±0.24 to 6.29±0.13. In contrast, EC increased markedly by 121%, from 0.13±0.01 dS/m in 2023 to 0.30±0.04

Table 1. Statistical significance values from the analysis of variance using linear mixed models to evaluate the effects of land use, time, and their interaction on soil variables in the study area ($\alpha=0.05$).

Response Variable	Factor	p-value	Response Variable	Factor	p-value
Bulk Density (BD)	Treatment	0.428	Magnesium (Mg)	Treatment	0.237
	Year	0.505		Year	0.000
	Treatment×Year	0.955		Treatment×Year	0.369
pH	Treatment	0.364	Iron (Fe)	Treatment	0.339
	Year	0.008		Year	0.273
	Treatment×Year	0.954		Treatment×Year	0.398
Electrical Conductivity (EC)	Treatment	0.795	Zinc (Zn)	Treatment	1.000
	Year	0.002		Year	0.076
	Treatment×Year	0.942		Treatment×Year	0.207
Cation Exchange Capacity (CEC)	Treatment	0.300	Manganese (Mn)	Treatment	0.223
	Year	0.000		Year	0.002
	Treatment×Year	0.206		Treatment×Year	0.674
Nitrogen (N)	Treatment	0.276	Copper (Cu)	Treatment	0.544
	Year	0.002		Year	0.105
	Treatment×Year	0.474		Treatment×Year	0.285
Phosphorus (P)	Treatment	0.950	Boron (B)	Treatment	0.615
	Year	0.505		Year	0.420
	Treatment×Year	0.011		Treatment×Year	0.193
Potassium (K)	Treatment	0.267	Soil Organic Matter (SOM)	Treatment	0.492
	Year	0.956		Year	0.631
	Treatment×Year	0.038		Treatment×Year	0.028
Calcium (Ca)	Treatment	0.258	Total Organic Carbon (TOC)	Treatment	0.492
	Year	0.002		Year	0.631
	Treatment×Year	0.701		Treatment×Year	0.028

Note: CEC=Cation Exchange Capacity; SOM=Soil Organic Matter; TOC=Total Organic Carbon. p-values in bold indicate statistical significance. *, **, *** denote significance at the 0.1, 0.05, and 0.01 probability levels, respectively.

dS/m in 2024. Regarding nutrient concentrations, N increased by 203%, from 6.40±1.54 to 19.40±3.59 mg kg^{-1}, and Mn rose by 62%, from 36.43±3.89 to 59.01±4.67 mg kg^{-1}. Conversely, Ca and Mg concentrations decreased by approximately 20%; Ca levels dropped from 1141.87±50.46 mg kg^{-1} in 2023 to 909±29.47 mg kg^{-1} in 2024, and Mg declined from 121.62±3.38 to 96.42±1.85 mg kg^{-1} over the same period. Additionally, the analysis revealed significant interaction effects between land use and time for phosphorus (P), potassium (K), soil organic matter (SOM), and total organic carbon (TOC), with respective p-values of 0.011, 0.038, 0.028, and 0.028 (Table 1).

The interaction analysis revealed that phosphorus (P) levels were higher in the agricultural land (14.45±1.41 mg kg^{-1}) during the first evaluation year (2023); however, in the following year (2024), the plantation exhibited the highest concentration of this nutrient (15.52±1.25 mg kg^{-1}), reflecting a 58% increase relative to the 9.15±2.42 mg kg^{-1} recorded in the plantation in 2023.

In contrast, the response pattern for potassium (K) was different. In 2023, the plantation had the highest levels of this element (360±43.09 mg kg^{-1}) compared to the agricultural soil (344.24±21.39 mg kg^{-1}). By 2024, however, the agricultural land recorded 425.75±30.79 mg kg^{-1} of K, while the plantation showed only 274.50±43.06 mg kg^{-1} representing a significant decline of 85.5% in K concentration in the plantation.

For the variables soil organic matter (SOM) and total organic carbon (TOC), the trend mirrored that of phosphorus. In 2023, the agricultural site presented the highest values (2.0±0.07% for SOM and 3.45±0.13% for TOC), but by 2024, the plantation experienced increases of 27% in SOM and 29% in TOC. These increases were based on the 2023 values of 1.74±0.13% for SOM and 2.96±0.26% for TOC, which rose to 2.22±0.25% and 3.82±0.44%, respectively, in 2024. In contrast, the agricultural soil exhibited a 17% decrease in both SOM and TOC over the same period.

According to the principal component analysis (PCA), two main components (PCs) were identified that together explained over 80% of the variation in the evaluated soil properties. In the agricultural land, cation exchange capacity (CEC), calcium (Ca), and magnesium (Mg) formed PC1, which accounted for the majority of the variation (79.93%) in soil properties under that land use. In the plantation, SOM and TOC, along with CEC, Ca, and Mg, comprised PC1, explaining a substantial portion of the observed variation (90.43%).

The analysis of changes in soil properties over time and under different land-use conditions provides a foundation for generating indicators of soil quality loss or recovery. Soil is a dynamic system whose properties fluctuate due to both natural and anthropogenic processes. Berhe (2019) notes the existence of various direct and indirect drivers of soil change that operate across spatial and temporal scales. Land conversion, intensive use,

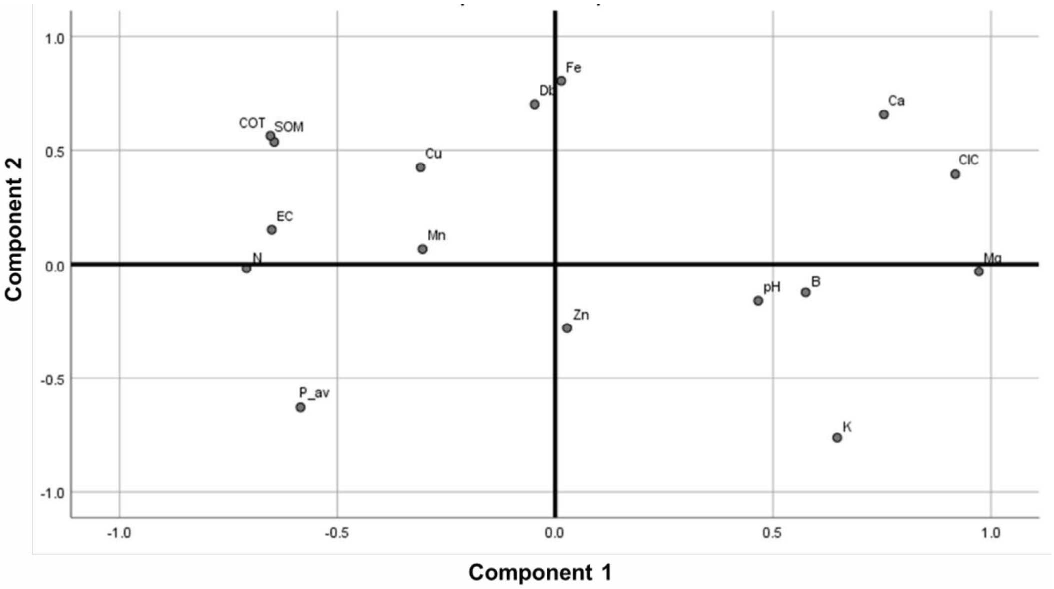


Figure 2. Rotated graph of the principal components for the soil properties evaluated in the agriculturally used land.

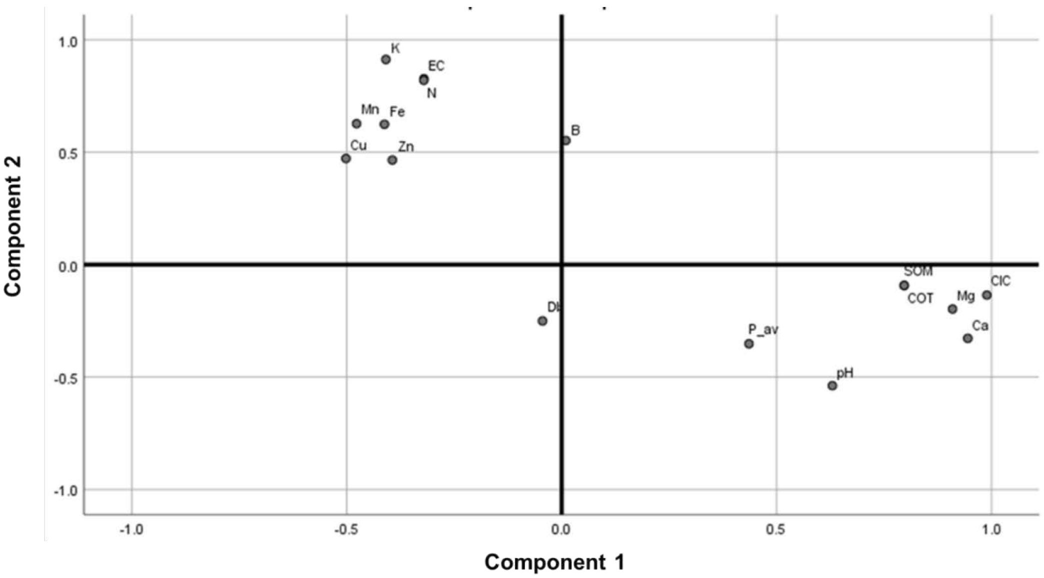


Figure 3. Rotated graph of the principal components for the soil properties evaluated in the *P. greggii* plantation.

climate variability, and biological invasions are identified as direct drivers of soil change, significantly influencing its physical, chemical, and biological characteristics.

According to Berhe, some soil properties are more responsive and can undergo rapid changes, altering the chemical composition, structure, function, and services provided by the soil. In this context, the year-to-year variations in pH, electrical conductivity (EC), cation exchange capacity (CEC), nitrogen (N), calcium (Ca), magnesium (Mg), and manganese (Mn) observed in this study clearly illustrate the dynamic nature of soil properties. For instance, pH can shift in less than a year, as observed in the evaluated sites. Other properties such as CEC, base cation concentrations, or soil organic matter (SOM) may require a longer period (1-10 years) to exhibit noticeable changes. In the present study, the response of several variables within the evaluation period aligns with the timeframes reported in the literature (Berhe, 2019). Moreover, the behavior of variables affected by the interaction between land use and year provides meaningful insights for the core question of this study. It demonstrates that changes in soil physicochemical properties and total organic carbon (TOC) do occur following plantation establishment, albeit to varying degrees. For example, the increase in phosphorus (P) concentration, and especially the higher levels of SOM and TOC recorded, confirm the plantation's contribution to improving soil quality. Both SOM and TOC are key indicators closely associated with numerous soil properties and functions (Li *et al.*, 2021; Xu *et al.*, 2024). Conversely, the decline in SOM and TOC in the agricultural soil highlights the negative impacts of poor land management particularly when organic residues are not returned to the soil and large quantities of essential nutrients are removed due to crop demands. This issue is exacerbated in semi-arid environments like the one studied here, where decomposition rates are presumed to be slow due to limited moisture availability, with mean annual precipitation not exceeding 550 mm. Changes in SOM both in the agricultural land and in the plantation are explained by its high sensitivity to management practices. Unlike inherent properties such as texture or mineral composition, which are relatively immutable (Weil & Brady, 2017), SOM can be readily influenced by land use. Therefore, increasing SOM is a favorable condition for restoring degraded soils, as emphasized by Ceccon *et al.* (2014) and Xu *et al.* (2024).

The biological potential of forest cover to incorporate organic matter into the soil is well recognized (Xu *et al.*, 2024), even though the rates of litter production and accumulation vary depending on species and environmental conditions (Ceccon *et al.*, 2014; González-Rodríguez *et al.*, 2019). Although generally lower than broadleaf or deciduous species, conifers significantly contribute organic inputs which are the main sources of essential nutrients such as N, P, and sulfur (S) and play a vital role in nutrient cycling, including that of Ca, Mg, and K (González-Rodríguez *et al.*, 2019). In the plantation, only P and K showed significant changes among the analyzed nutrients, contrasting with the findings of Koryś *et al.* (2021), who reported no significant differences in macronutrient content (N, P, K) after evaluating their availability in abandoned lands with tree plantations. In this study, P levels in the *Pinus greggii* plantation exceeded those reported for other pine and eucalyptus plantations located in humid and tropical regions (García *et al.*, 2024; Yáñez *et al.*, 2018). García *et al.* (2024) argue that extractable P is generally lower in tropical humid soils than in arid and semi-arid regions. The increase in phosphorus in the plantation soil supports the role of organic matter as a source of this nutrient, in addition to the ability of trees to extract nutrients from deeper soil horizons via their root systems (Weil & Brady, 2017). Deeper horizons often contain larger reserves of inorganic phosphorus, especially in arid and semi-arid soils. Moreover, it is plausible that the higher P levels in the plantation, compared to agricultural soils, result from greater losses due to erosion in the latter, owing to insufficient vegetative cover. According to Weil & Brady (2017), erosion is one of the main pathways through which phosphorus is lost from the soil system. In contrast, potassium declined significantly in the plantation from one year to the next. This reduction may be attributed to the nutrient demands of trees particularly since K , once it reaches a certain saturation level, becomes readily available for plant uptake. Plants are known to absorb potassium in amounts five to ten times greater than phosphorus, and this nutrient is more prone to leaching under acidic conditions (Weil & Brady, 2017), which were present in the plantation, where pH dropped from 6.2 in 2023 to 5.77 in 2024. The higher K concentration in the agricultural soil could be attributed to fertilization practices, which are common in rainfed bean cultivation (Rico-Alderete *et al.*, 2020). Although litterfall quantity was not measured, a visible layer of litter was observed on the plantation soil surface during both sampling periods. Forest soils typically exhibit this feature in the O horizon, with material in various stages of decomposition (Weil & Brady, 2017). Needle decomposition is known to be slow due to its chemical composition. While this study did not quantify litter accumulation or decomposition rates which is recommended for future research the observed presence of litter in the plantation, unlike in the agricultural land (where organic crop residues are seldom left or amendments added), suggests that the plantation is actively contributing organic matter to the soil. This is further supported by the increases in P, SOM, and TOC variables that are naturally linked and serve as key indicators of soil health and quality (Li *et al.*, 2021). Litter contributes organic acids that lower soil pH and promote mineralization (Coleman *et al.*, 2017), which could partly explain the discussed decline in potassium, even though the observed pH reduction was attributed to the year rather than land use. Nevertheless, it is likely that more pronounced chemical changes will occur in the plantation soil over time. Organic matter accumulation tends to acidify soil by forming soluble complexes with non-acidic nutrient cations (Ca^{2+} and Mg^{2+}), facilitating their leaching. Additionally, organic matter is a significant source of H ions (Coleman *et al.*, 2017; Weil & Brady, 2017). Finally, according to PCA, the strong association between CEC, Ca, and Mg under both land uses reflects the sensitivity of these variables to shifts in soil properties driven by management practices, supporting Berhe's (2019) assertion that soil chemical composition is susceptible to land-use change. Naturally, CEC, Ca, and Mg are closely correlated, as illustrated in Figures 2 and 3. CEC determines the availability of these base cations, which dominate soils in low-precipitation regions. Furthermore, the variation observed in SOM and TOC, and their correlation with CEC, Ca, and Mg in the plantation, underscores the contribution and potential of this silvicultural system to restore fertility, organic matter, and carbon stocks in degraded soils under the specific edaphoclimatic conditions of the study area.

CONCLUSIONS

The *Pinus greggii* plantation enhances soil fertility and increases both organic matter and organic carbon reserves, indicating its biological potential for restoring degraded lands.

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REFERENCES

Berhe, A. A. (2019). Drivers of soil change. Developments in Soil Science 36, 27-42. Elsevier.

CONAFOR-UACh. (2013). Línea Base Nacional de Degradación de Tierras y Desertificación. Informe final. Comisión Nacional Forestal y Universidad Autónoma Chapingo. Zapopan, Jalisco.

Coleman, D., Callaham, M., & Crossley, D. Jr. (2017). Fundamentals of Soil Ecology (3rd Edn). London: Academic Press.

García Martínez, R., Hernández Soto, F. N., Emeterio Moreno, J., & Colín Velázquez, M. K. (2024). Diferencias en la fertilidad del suelo en cuatro plantaciones forestales comerciales de pino en Amanalco, Estado de México. *Revista Mexicana de Ciencias Forestales, 15*(85), 150-170. https://doi.org/10.29298/rmcf.v15i85.1462

Gageler, R., Bonner, M., Kirchhof, G., Amos, M., Robinson, N., Schmidt, S., & Shoo, L. P. (2014). Early response of soil properties and function to riparian rainforest restoration. *PloS one, 9*(8), e104198. https://doi.org/10.1371/journal.pone.0104198

González-Rodríguez, H., López-Hernández, J. M., Ramírez-Lozano, R. G., Gómez-Meza, M. V., Cantú-Silva, I., Sarquís-Ramírez, J. I., & Mora-Olivo, A.. (2019). Litterfall deposition and nutrient return in pine-oak forests and scrublands in northeastern Mexico. *Madera y Bosques, 25*(3), e2531514.

Haase, D. L., & Jacobs, D. F. (2013). Nutrient dynamics of planted forests. *New Forests, 44*(5), 629-633.

Hou, G., Delang, C.O., Lu, X., & Gao, L. (2020). A meta-analysis of changes in soil organic carbon stocks after afforestation with deciduous broadleaved, sempervirent broadleaved, and conifer tree species. *Annals of Forest Science* 77, 92. https://doi.org/10.1007/s13595-020-00997-3

Härdle, W. K., Simar, L., & Fengler, M. R. (2024). Applied Multivariate Statistical Analysis. Alemania: Springer International Publishing.

Haddaway, N. R., Hedlund, K., Jackson, L. E., Kätterer, T., Lugato, E., Thomsen, I. K., Jørgensen, H. B. and Isberg, P.-E. (2017). How does tillage intensity affect soil organic carbon? A systematic review. *Environmental Evidence, 6*(1). https://doi.org/10.1186/s13750-017-0108-9

INEGI. 2010. Compendio de información geográfica municipal 2010, Canatlán, Durango. Instituto Nacional de Geografia y Estadística.

IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp

Koryś, K. A., Latawiec, A. E., Mendes, M. S., Sansevero, J. B. B., Rodrigues, A. F., Iribarrem, A. S., Dib, V., Jakovac, C. C., Allek, A., Pena, I. A. B., Lino, E., & Strassburg, B. B. N. (2021). Early Response of Soil Properties under Different Restoration Strategies in Tropical Hotspot. *Land, 10*(8), 768. https://doi.org/10.3390/land10080768

Li, Q., Gu, F., Zhou, Y., Xu, T., Wang, L., Zuo, Q., Xiao, L., Liu, J., & Tian, Y. (2021). Changes in the Impacts of Topographic Factors, Soil Texture, and Cropping Systems on Topsoil Chemical Properties in the Mountainous Areas of the Subtropical Monsoon Region from 2007 to 2017: A Case Study in Hefeng, China. *International Journal of Environmental Research and Public Health, 18*(2), 832. https://doi.org/10.3390/ijerph18020832

López-Upton, J. (2017). Oportunidades de conservación del bosque de niebla a través del manejo alternativo: plantaciones forestales comerciales. *Agro Productividad, 10*(1). 50-55. https://revista-agroproductividad.org/index.php/agroproductividad/article/view/938

Medina García., G., Díaz Padilla, G., López Hernández, J., Ruíz Corral, J. A., & Marín Silva M. (2005). Estadísticas climatológicas del estado de Durango (Periodo 1961-2003). Libro Técnico No. 1. SAGARPA-INIFAP-CIRNOC-Campo Experimental Valle del Guadiana. Durango, Dgo., México.

Rosales Serna, R., Basave Villalobos, E., Ríos Saucedo, J. C., Santana Espinoza, S., Domínguez Martínez, P. A., & Sierra Zurita, D. (2022). Pruning and fertilization in young *Pinus greggii* plantations established at Durango, Mexico. *Agro Productividad, 14*(12), 173-180.

Rico-Alderete, I. A., Sánchez-Chávez, E., Soto-Parra, J. M., Antillón-Leyva, R., Salas-Salazar, N. A., Ojeda-Barrios, D. L., & Flores-Córdova, M. A. (2020). Manejo de fertilización en frijol 'Pinto Centauro' y su impacto en el rendimiento, calidad nutricional e índice de rentabilidad. *Revista Chapingo. Serie Horticultura, 26*(3), 207-222.https://doi.org/10.5154/r.rchsh.2020.03.005

SEMARNAT. (2002). NOM-021-RECNAT-2000-. Norma oficial mexicanaNOM-021-RECNAT-2000 que establece las especificacionesde fertilidad, salinidad y clasificación de suelos. Estudios, muestreos y análisis. Diario Oficial de la Nación. México, D.F. 73 p.

Secretaría de Agricultura y Desarrollo Rural (AGRICULTURA). (2022). Estrategia Nacional de Suelo para la Agricultura Sostenible (ENASAS), 2022. Secretaría de Agricultura y Desarrollo Rural, México.

Walkley, A & Black, I. A. (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37, 29-38.

Weil, R.R., & Brady, N.C. (2017). The Nature and Properties of Soils, 15th ed.; Pearson Education Limited: London, UK.

Xu, S., Eisenhauer, N., Zeng, Z., Mo, X., Ding, Y., Lai, D. Y. F., & Wang, J. (2024). Drivers of soil organic carbon recovery under forest restoration: a global meta-analysis. *Carbon Research, 3*(80). https://doi.org/10.1007/s44246-024-00165-6

Yáñez Díaz, M. I., Cantú Silva, I., & González Rodríguez, H. (2018). Efecto del cambio de uso de suelo en las propiedades químicas de un vertisol. *Terra Latinoamericana, 36*(4), 369-379. https://doi.org/10.28940/terra.v36i4.349