DOI: 10.29298/rmcf.v14i79.1359

Research article

Efecto en las propiedades fisicoquímicas de un Regosol con cambios de uso de suelo

Effect on the physicochemical properties of a Regosol from land use change

María Inés Yáñez Díaz[1]*, Israel Cantú Silva[1], Fortunato Garza Ocañas[1]

Fecha de recepción/Reception date: 14 de marzo de 2023.
Fecha de aceptación/Acceptance date: 11 de agosto de 2023.

[1]Universidad Autónoma de Nuevo León. Facultad de Ciencias Forestales. México.

*Autor para correspondencia; correo-e: maria.yanezdz@uanl.edu.mx; inesyd@gmail.com.
*Corresponding author; e-mail: maria.yanezdz@uanl.edu.mx; inesyd@gmail.com.

Abstract

Soils provide ecosystem goods and services that are affected by the loss of their fertility; land use changes aimed at recovering areas or reducing degradation have a positive influence on their properties. This study was conducted in a Regosol soil in *Galeana*, *Nuevo León*, where physical (texture, bulk density, and mechanical resistance to penetration) and chemical properties (pH, electrical conductivity, and organic matter) were evaluated at two depths (0-5 and 5-30 cm) in a pine forest, reforestation area, agricultural use, and grassland. The results showed no significant differences in most of the properties evaluated between soil uses and depths. Mechanical resistance to soil penetration was one of the most susceptible variables for agricultural use (8.25 kg cm^{-2}), as opposed to forest (22.5 kg cm^{-2}). The pH did not show changes between soil uses, while it increased and showed differences between depths with a mean of 7.75 (0-5 cm) and 7.81 (5-30 cm), and there were no salinity issues (0.17 dS m^{-1}). The organic matter (*OM*) content showed a recovery trend in the order of grassland>pine forest>reforestation>agriculture. Texture was classified as loam, with differences in sand content for the depth factor and silt content in the 5-30 cm stratum between the different land uses. It is concluded that land use changes focused on reclamation can improve the quality of Regosol.

Key words: Pine forest, compaction, soil degradation, organic matter, grassland, reforestation.

Resumen

Los suelos proporcionan bienes y servicios ecosistémicos que son afectados por la pérdida de su fertilidad; los cambios de uso de suelo orientados a la recuperación de áreas o a reducir la degradación influyen positivamente en sus propiedades. Este estudio se realizó en un suelo Regosol en Galeana, Nuevo León, donde se evaluaron propiedades físicas (textura, densidad aparente y resistencia mecánica a la penetración) y químicas (pH, conductividad eléctrica y materia orgánica) a dos profundidades (0-5 y 5-30 cm) en un bosque de pino, área de reforestación, uso agrícola y pastizal. Los resultados no mostraron diferencias significativas en la mayoría de las propiedades evaluadas entre usos de suelo y profundidad. La resistencia mecánica a la penetración del suelo fue una de las variables más susceptible para el uso agrícola (8.25 kg cm^{-2}), a diferencia del bosque (22.5 kg cm^{-2}). El pH no evidenció cambios entre los usos del suelo, mientras que entre profundidades se incrementó y presentó diferencias con una media de 7.75 (0-5 cm) y 7.81 (5-30 cm); y no hubo problemas de salinidad (0.17 dS m^{-1}). El contenido de materia orgánica (*MO*) registró una tendencia de recuperación en el orden de pastizal>bosque de pino>reforestación>agrícola. La textura se clasificó como franca, con diferencias en el contenido de arena para el factor profundidad y en el de limo en el estrato de 5-30 cm entre los diferentes usos. Se concluye que los cambios de uso de suelo enfocados hacia la recuperación de áreas pueden mejorar la calidad del Regosol.

Palabras clave: Bosque de pino, compactación, degradación de suelos, materia orgánica, pastizal, reforestación.

Introduction

Soil is a natural resource on which civilizations depend. Population growth and the pressure exerted on it, mainly for food production, leads to its degradation when recovery strategies are not applied. This decrease in the capacity to produce goods and services is known as degradation, which is a limiting factor with severe negative impacts, as a result of the periodic change in the use that is made of the product (Yinka *et al.*, 2022).

Land use change is the modification of natural vegetation cover to an induced ecosystem, such as cropland and grassland, which usually leads to a loss of soil fertility (Gong *et al.*, 2022), as their physical, chemical, and biological properties are affected (Yinka *et al.*, 2022). However, when these changes are focused on land cover recovery or conversion, such as with reforestation following the abandonment of cropland, they can increase fertility over time (Smith *et al.*, 2016), in addition to the positive effects due to the increase in the number of fauna species (Nardi and Marini, 2021).

Soil properties, as indicators of soil quality, reflect its ability to function within the limits of the ecosystem of which it is a part (Bautista *et al.*, 2004); although they can be studied in isolation, they are all interrelated (López and Estrada, 2015). The physical, chemical and biological properties indicate the behavior, constitution, and fertility of the soil and are an inherent product of the soil formation process.

In Mexico, the National Institute of Statistics and Geography (Inegi) cites 25 of the 32 soil units classified by the World Reference Base for Soil Resources (WRB), in which shallow soils such as Leptosol and Regosol predominate, covering 41.5 % of the national territory

(Semarnat, 2016). Regosols are a type of soil that develops on unconsolidated materials poor in organic matter; they are widely distributed worldwide and at all altitudes, mainly in arid areas, in the dry tropics and in mountain regions (Semarnat, 2016) and are used in agricultural and livestock activities.

In Mexico, soil deterioration affects many components of the social and natural environment; its management involves different agencies, international organizations and academic and civil institutions (Semarnat, 2000). Environmental restoration programs are focused on vegetation, which involves actions for the recovery of the natural capacity and potential of forest soils, depending on their structure, the management practices applied, and the time they have been under disturbance conditions (de Andrade *et al.*, 2017); it should be noted that organic matter is one of the most useful properties as an indicator of fertility (Salehi *et al.*, 2011; Cantú and Yáñez, 2018).

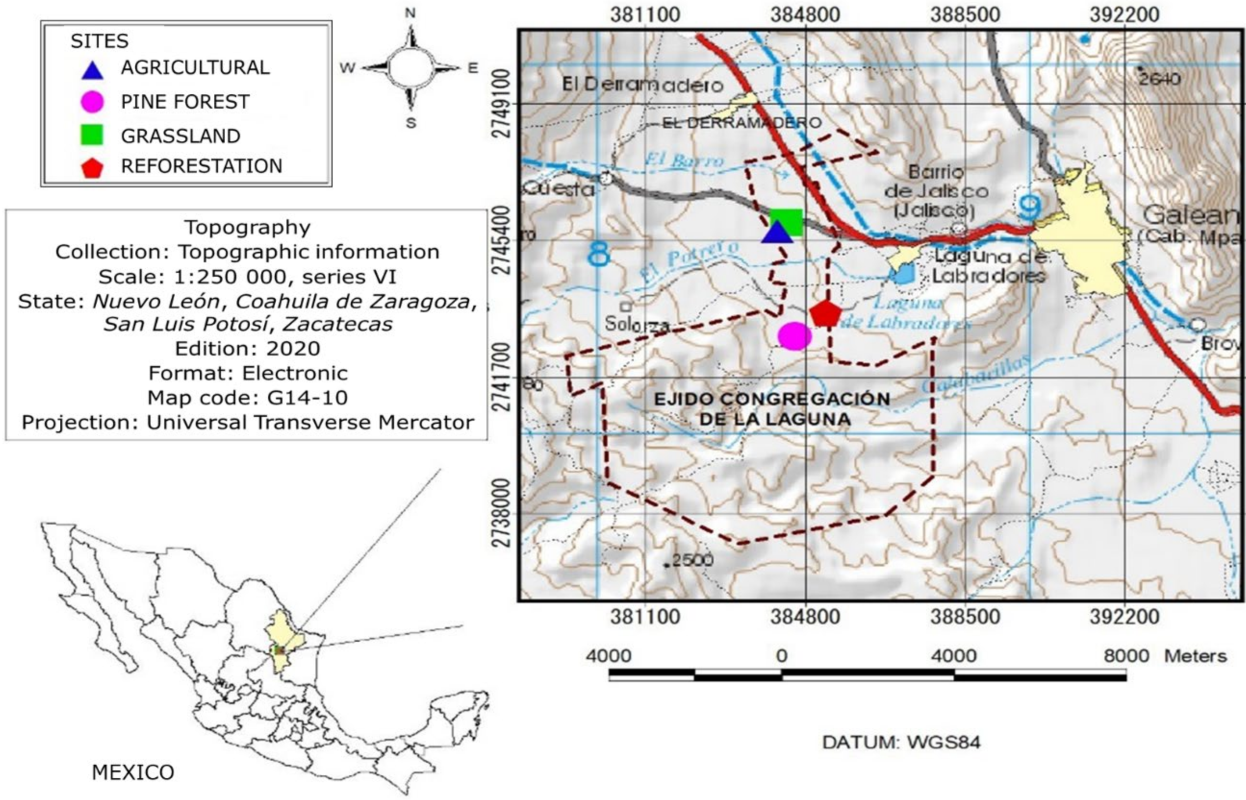
The objective of this research was to evaluate the physical (texture, bulk density, mechanical resistance to penetration) and chemical properties (pH, electrical conductivity, and organic matter) of a Regosol with pine forest vegetation and to compare it with areas of reforested forest, agricultural use and grassland.

Materials and Methods

Study area

The study area was located in the *Congregación de la Laguna ejido*, in *Galena* municipality, *Nuevo León*, Mexico, at 24°49’59.88” N and 100°04’01” W. The dominant climate is temperate sub-humid with summer rains, total annual precipitation fluctuates between 600 and 800 mm, and the average annual temperature between 12 and 18 °C (INEGI, 2008). The dominant soils in the area belong to the Leptosol (38.8 %) and Regosol (20 %) calcareous types. The vegetation in the valleys and lower areas is a desert rosette scrub and in the higher areas pines cover considerable areas (INEGI, 2007).

Within the area, four 100 m^2 sites were randomly selected. S1: Pine forest (PF) dominated by *Pinus cembroides* Zucc. and *P. greggii* Engelm., S2: A reforestation area (REF) with pine (*P. cembroides*) with level edges established in 2008, S3: A rainfed agricultural area (AGRI) with corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) crops, and S4: An abandoned grassland area (PAST) with the presence of grasses, approximately 10 years of abandonment, previously used for rainfed agriculture (Figure 1).



Ejido Congregación de la Laguna = *Congregación de la Laguna ejido*.

Figure 1. Location of sampling sites in the *Congregación de la Laguna ejido*, *Galeana* municipality, *Nuevo León*, Mexico.

Materials and methods

Sampling was carried out according to a randomized experimental design with a bifactorial arrangement (land use by depth). At each site, four areas of 100 m^2 were randomly selected to obtain composite samples derived from five subsamples at two depths (0-5 cm and 5-30 cm) (*n*=32) in order to evaluate the effect from the superficial part of the soil (5 cm) to the depth at which root development occurs (30 cm).

The samples were processed at the Soil and Forest Nutrition Laboratory of the Graduate School of Forest Sciences of the *Universidad Autónoma de Nuevo León*, where they were dried at room temperature and sieved with a 2 mm mesh in order to determine the Hydrogen potential (pH) in a 1:2 ratio of soil-calcium chloride 0.01 M, measured through a glass electrode (model 8172BNWP, Thermo Scientific®), according to method AS-23 of the Mexican Official Standard NOM-021-RECNAT-2000 (Semarnat, 2002). Electrical conductivity (*EC*) from a 1:5 soil-water suspension, after 2 hours of rest (Woerner, 1989). Both the pH and the *EC* were measured in a model 542 Corning® pH/conductivity meter. The organic matter (*OM*) content was determined by the Walkley and Black (1934) wet combustion method; the granulometric composition (texture), with the Bouyoucos type density meter, method AS-09, according to the methodology of the Mexican Official Standard NOM-021-RECNAT-2000 (Semarnat, 2002).

The cylinder method was utilized to evaluate the bulk density (*BD*) content (Woerner, 1989). Unaltered samples were collected using metal cylinders of 5 cm in diameter and 5 cm in length (volume 98.175 cm^3). Five samples were obtained per site in the top layer of soil, after 48 hours, they were weighed and brought to constant weight after drying at 105 °C in model HCF-102-D Riossa® a forced-air oven. At the selected sites, mechanical penetration resistance (*MPR*) was evaluated using a Yamanaka type portable penetrometer (22110 Orion®, MKK Co. Japan); five measurements were made on the soil surface within each sampling point.

Statistical analyses

The data of the physical and chemical properties evaluated were analyzed with a Shapiro-Wilk normality test and Levene's homoscedasticity of variances test with the SPSS statistical package (IBM, 2016). The properties of pH, electrical conductivity (*EC*), bulk density (*BD*), and mechanical resistance to penetration (*MRP*) complied with these assumptions; a square root transformation of the proportion of each component was applied to the variables corresponding to sand, silt and clay contents ($\sqrt{\times}$), and to the organic matter (*OM*) content a transformation of the inverse of the ratio (1/x) (Sokal and Rohlf, 2012).

A two-way analysis of variance (ANOVA) was performed for soil use (Factor A), depth (Factor B) and their interaction (Factor A×Factor B). In addition, a one-factor ANOVA was segmented by depth for the purpose of comparing the means between the land uses with the Tukey test ($p \leq 0.05$) (Sokal and Rohlf, 2012).

Results and Discussion

The chemical properties indicative of the quality and the results for the four types of use (Table 1) evidenced the effect of the changes in soil use leading to changes in fertility. The pH values correspond to a slightly alkaline soil (Semarnat, 2002), with an average of 7.70 pH units in a range of 7.71 (agricultural 0-5 cm) to 7.84 (grassland 5-30 cm); the highest values were registered for the second depth, with differences between the two depths. This is in agreement with Martínez *et al.* (2008), who reported that after four years of soil management by tillage, there was a decrease in the pH on the surface of the soil. The *EC* registered low salinity values within a range of 0.159 dS m^{-1} (agricultural 0-5 cm) to 0.187 dS m^{-1} (grassland 5-30 cm) and without significant differences between soil uses for each depth (Table 1). Generally, coarse-textured soils have macropores that hinder the accumulation of salt (Encina and Valinotti, 2000).

Table 1. Descriptive statistics of the chemical soil properties evaluated in the four land uses and the two depths (0-5 and 5-30 cm).

Chemical properties	Land use	Depth (cm)	Average values	*Std. Dev.*	Min. value	Max. value
pH	PF	0-5	7.72	0.04	7.67	7.76
		5-30	7.79	0.09	7.69	7.90
	REF	0-5	7.80	0.06	7.73	7.87
		5-30	7.82	0.06	7.77	7.91
	AGRI	0-5	7.72	0.02	7.70	7.74
		5-30	7.80	0.09	7.72	7.90
	PAST	0-5	7.76	0.05	7.72	7.82
		5-30	7.84	0.06	7.77	7.92
EC (dS m^{-1})	PF	0-5	0.18	0.06	0.10	0.23
		5-30	0.17	0.05	0.11	0.24
	REF	0-5	0.16	0.02	0.15	0.19
		5-30	0.17	0.02	0.15	0.20
	AGRI	0-5	0.16	0.04	0.10	0.19
		5-30	0.14	0.04	0.10	0.19
	PAST	0-5	0.17	0.04	0.12	0.22

		5-30	0.19	0.02	0.15	0.21
OM (%)	PF	0-5	4.34	2.12	2.28	7.28
		5-30	3.22	0.86	2.00	4.03
	REF	0-5	3.63	1.37	2.74	5.67
		5-30	3.49	0.47	2.90	4.06
	AGRI	0-5	2.57	0.47	2.18	3.17
		5-30	2.94	0.81	2.04	4.00
	PAST	0-5	4.43	2.02	2.61	7.28
		5-30	3.39	0.64	2.69	4.24

pH = Soil reaction; *EC* = Electrical conductivity; *OM* = Organic matter; PF = Pine forest; REF = Reforestation; AGRI = Agricultural; PAST = Grassland.

Organic matter represents the fertility of soils —an important product of the combination of physical and chemical properties—, in addition to the contribution of organic residues in the process of decay, and constitutes 5 % of the composition of an ideal soil (Porta *et al.*, 2003).

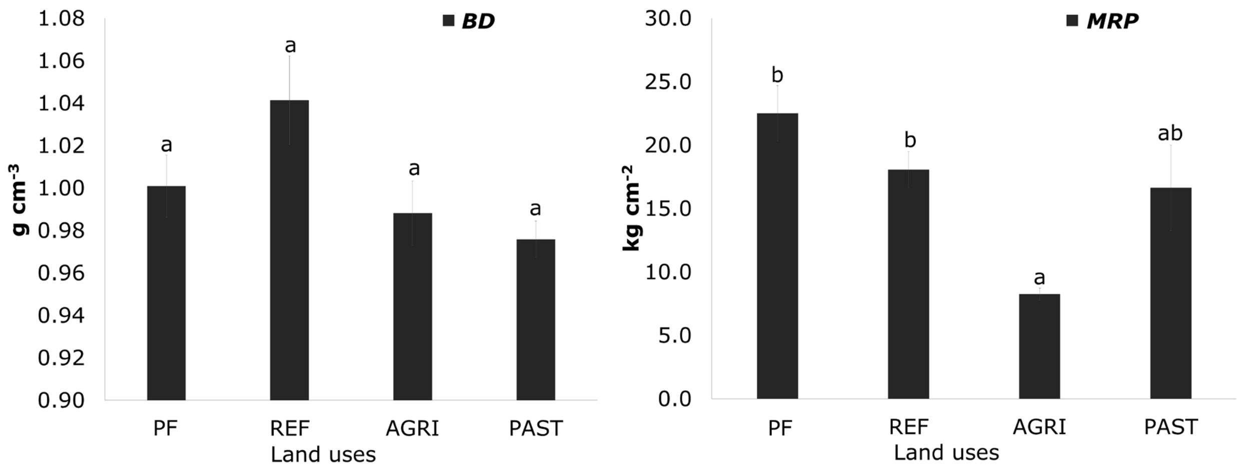
In the analyzed Regosol, the *OM* values at depth 0-5 cm ranged from 2.56 % for the agricultural area to 4.43 % for the grassland. For the 5-30 cm depth, pine forest and grassland decreased about 1 % in relation to the total content; in the reforestation site it remained similar (with a difference of 0.1 %), while in the agricultural use it increased slightly (0.5 %). Higher values in the first depth indicate a higher content of active carbon and nitrogen, due to the accumulation of plant residues (Gong *et al.*, 2022).

Soil is an active reservoir of organic carbon and can act as a source or reservoir of carbon (C) for release into the atmosphere, depending on the management applied (Lal, 1997). Soils with agricultural systems generally have lower carbon stocks than soils with natural vegetation (Kátai *et al.*, 2022); in grasslands, 70 Mg ha^{-1} are estimated, this is a value similar to that documented for forest soils (Céspedes *et al.*, 2012).

In this study, the increase in *OM* in the abandoned grassland, as opposed to the agricultural area, involves a greater potential for carbon sequestration, and evidences the effect of good land use management practices (rest); in this regard, Sahoo *et al.* (2019) note that a decrease in the *OM* stock in land uses other than forests, implies C depletion, a situation that is ameliorated only when better management practices are applied that include addition of plant residues and lower disturbance.

Ordóñez *et al.* (2022) compared the effect of land use changes in forests; these authors reported a lower impact in the conversion to natural grasslands compared to that observed in crops, due to the differences between the two uses in the time required for soil microbial communities to recover; good management practices and the effect of climatic conditions, such as humidity, influence nutrient content and soil microbial processes (Kátai *et al.*, 2022). According to Martínez *et al.* (2008), the *OM* content not only depends on local environmental conditions but also is affected by the management.

Physical soil properties are the way in which the soil behaves in processes that do not involve chemical modifications and have a direct or indirect influence on all the functions it performs (Narro, 1994); this influence is expressed by the structural organization, *i. e.*, its aggregation status characterized by the shape, stability, and resilience of the structure (Álvarez *et al.*, 2006) and is determined by the activities carried out on its surface that affect the reduction of the porous system and its continuity (González *et al.*, 2008). Bulk density (*BD*) and mechanical resistance to penetration (*MRP*) are two of the physical properties that reflect the affectation of the porosity of the soil as a result of changes in land use. In this research, the *BD* was maintained at an average of 1.00 g cm^{-3}, with no significant differences between land uses in relation to the pine forest (Figure 2).



Different values for each property indicate significant differences ($p \leq 0.05$) between the land uses. PF = Pine forest; REF = Reforestation; AGRI = Agricultural; PAST = Grassland.

Figure 2. Average values for bulk density (*BD*) and mechanical resistance to penetration (*MRP*) for shallow depths.

In the grassland, the presence of grasses covering most of the area stood out; the *BD* registered low values, with no significant differences between uses, however, the grassland had the lowest value with 0.97 g cm^{-3} compared to the other sites, where the reforestation area had values of up to 1.04 g cm^{-3}. In areas with 25 years of conversion to buffel grass, Celaya *et al.* (2015) observed an impact on the physical properties and on the nitrogen and water reservoirs in the spaces between soil particles, which they related to cattle trampling. Mongil-Manso *et al.* (2022) point out that the recovery time on some properties is slow after reforestation and long periods are required for significant changes in soil properties, even in 20-year-old reforestation. Conversely, Hernández-Vigoa *et al.* (2018) point out that biological variables, and certain physical and chemical ones, such as bulk density and total organic carbon, are very susceptible to change in the very short term due to land use intensity.

The *MRP* was the property most sensitive to land use change. There were significant differences between land uses in the surface layer; the pine forest had the highest *MRP* with an average value of 22.5 kg cm^{-2}, in contrast to the agricultural area where the effect of tillage breaks the surface layer, reducing its compaction to only 8.25 kg cm^{-2} on average (Figure 2). This is in agreement with the findings of Navarro *et al.* (2000), who assessed the effect of five tillage treatments on sandy loam and clay loam soils; according to them, the *BD* and *MRP* were modified independently of the type of tillage and remain unaltered only with a no-tillage system.

Texture is one of the most stable physical properties. Regosols are unconsolidated, fine-grained, little-evolved mineral soils (FAO, 2016), with high silt and sand contents. In the present study, texture was classified as loamy for all soil uses, with mean values of 40.9 % sand, 40.3 % silt, and 18.8 % clay for depth 0-5 cm, while at the second depth, the values for sand, silt, and clay were 38.3 %, 42.1 %, and 19.6 %, respectively.

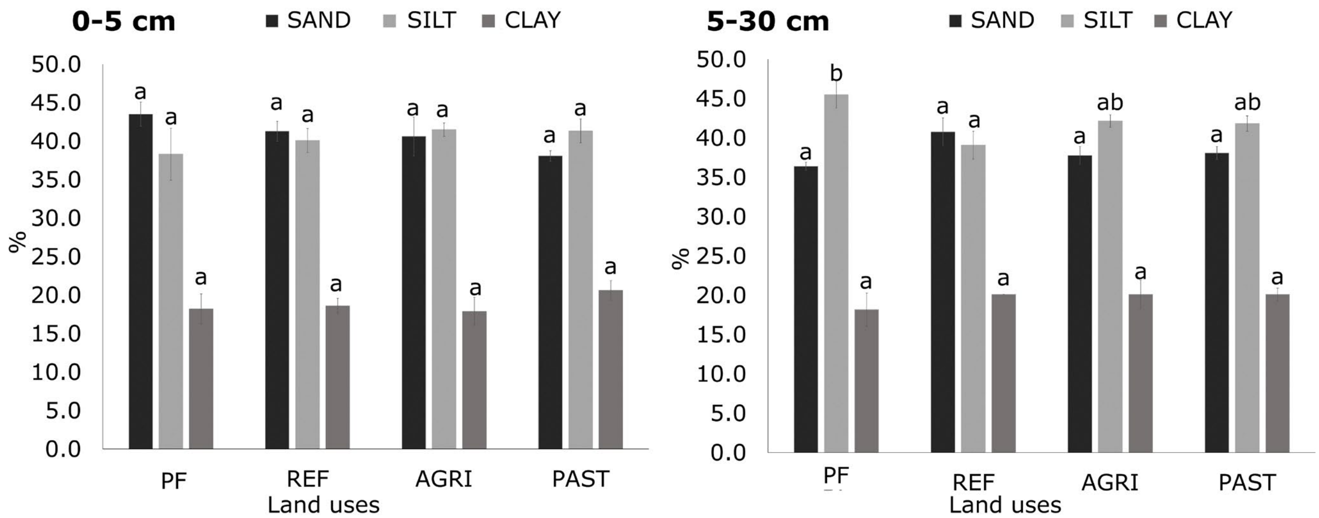
Nevertheless, differences in sand content were obtained according to the analysis of variance between the two depths (Table 2), the comparison of means between land uses for each of the depths showed differences for the percentage of silt in the 5-30 cm depth; in this respect, reforestation had contents of 39 % and pine forest 45.5 %. In the grassland and agricultural sites, there were no differences between them, their values were 41.8 and 42.2 %, respectively (Figure 3). Novillo *et al.* (2018) obtained differences in physical and chemical properties with the change from native forest to monocultures, mainly in texture, which affects the properties that contribute to the decrease of aggregates, thereby influencing the vertical movement of water.

Table 2. ANOVA of the physical and chemical properties evaluated in the four land uses (Factor A), two depths (Factor B), and their interaction (Factor A×Factor B) in the Regosol soil.

Soil properties	Units	Factor A (3.31)	Factor B (1.31)	Factor A×B (3.31)

pH	-	1.711 NS	7.416 *	0.348 NS
EC	dS m^{-1}	0.827 NS	0.001 NS	0.261 NS
OM	%	1.909 NS	0.187 NS	0.519 NS
Sand	%	0.229 NS	0.325 *	0.353 NS
Silt	%	0.173 NS	0.158 NS	0.440 NS
Clay	%	0.267 NS	0.063 NS	0.131 NS
BD	g cm^{-3}	3.484 NS		
MRP	kg cm^{-2}	6.997 *		

EC = Electrical conductivity; *OM* = Organic matter; *BD* = Bulk density; *MRP* = Mechanical resistance to penetration. * Significant differences ($p \leq 0.05$). NS No significant differences ($p > 0.05$).



Different letters for the same component indicate significant differences based on Tukey's test ($p \leq 0.05$) between the land uses. PF = Pine forest; REF = Reforestation; AGRI = Agricultural; PAST = Grassland.

Figure 3. Graphs of average texture values (sand, silt, and clay) for the two depths (0-5 and 5-30 cm).

High silt contents do not favor stable aggregation (Rollán and Bachmeier, 2015), however, in the presence of low clay contents, the silt fraction plays a key role in *OM* stabilization, especially when clays are saturated with carbon (Matus *et al.*, 2016).

It should be noted that among the four land uses: edged reforestation, abandoned grassland, agricultural areas, and pine forest, there were no significant differences in the physical and chemical properties evaluated, with the exception of the *MRP*. Table 2 summarizes the results of the two-way analysis of variance: land use (Factor A) only had significant differences for mechanical resistance to surface layer penetration, where land use change mainly affected the porous system, which is correlated with water infiltration, root growth, and crop productivity (Cerana *et al.*, 2005).

The depth factor (Factor B), which evaluates the effect on soil properties at the two depths, showed significant differences in pH and sand content. Domínguez-Calleros *et al.* (2017) explain that the surface layer of the soil presents a greater release of nutrients due to the accumulation of organic residues, with a reduction of soil properties at greater depths.

The soil properties evaluated in the interaction between land use factors by depth (Factor A×Factor B) exhibited no significant differences (Table 2). However, some authors report that changes in soil properties vary according to the use to which the land is subjected (Dieckow *et al*., 2009; Ordóñez *et al*., 2022). Others, such as Mongil-Manso *et al.* (2022) indicate the opposite; they report the same organic matter content and bulk density for the various uses (shrubland, oak woodland, grassland). Geissen *et al.* (2009) evaluated the effect of changes in soil use on physical and chemical properties with different conversion times; their results showed that the evaluated grasslands, with up to 15 years of change, had lower pH, increased *BD* and *MRP*, but maintained fertility due to their high clay content and the influence of water, due to the high precipitation that promotes the inhibition of organic matter mineralization processes.

The deterioration and absence of forest cover cause loss of soil fertility, which is why actions are taken to protect ecosystems and contribute to their conservation, protection, restoration, and sustainable use (Conafor, 2010); thus, the evaluated reforestation area was created for the purpose of protecting forest areas. The improvement of its properties unlike in the agricultural area evidences the environmental importance of recovering and improving the soil properties; however, the joint effect takes time to manifest itself. Although the results did not show significant differences, the improvement of physical properties such as bulk density, in addition to the increase in organic matter content, indicated that is in the process of recovery.

On the other hand, although no information was obtained regarding the type of management applied to the pine forest, it is likely that because it is a common area of the *ejido*, it is used for grazing or forestry; this is reflected in the high values of *MRP* compared to other uses, or simply in the fact that the physical and chemical properties of the soil of this forest correspond to the intrinsic and dynamic properties of the Regosol.

Conclusions

Most of the physical and chemical properties of the analyzed soil show no significant differences between the evaluated land uses. The most susceptible property to land use change is *MRP*, for which agricultural use has the lowest value due to the effect of tillage, as the tools utilized for this purpose disperse the soil and reduce compaction. Sand content shows differences when only depths are compared; significant differences in silt content between uses are observed at the 5-30 cm depth, and although the *OM* content does not exhibit significant differences, it does show a higher accumulation at both depths, in the following order: grassland>pine forest>reforestation>agricultural.

Finally, fallow grasslands after years of agricultural use and reforestation with edges favor the recovery of the properties of Regosol and eventually improve the soil quality, which is maintained in the natural forests due to the intrinsic properties of the Regosol.

Acknowledgments

The authors would like to thank engineer Rodrigo Solís Castro for his support and intervention with the *Congregación de a Laguna ejido*, in *Galeana* municipality, *Nuevo León*, and engineers Aylin Danae Díaz Zarate and Anastasio Sandoval Martínez, who were part of this research during their academic training, for their collaboration in the field and laboratory work.

Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

María Inés Yáñez Díaz: conduct of research, data analysis and drafting of the manuscript; Israel Cantú Silva: experimental design and manuscript review; Fortunato Garza Ocañas: statistical analysis and manuscript review.

References

Álvarez, C. R., M. Á. Taboada, C. Bustingorri y F. H. Gutiérrez B. 2006. Descompactación de suelos en siembra directa: efectos sobre las propiedades físicas y el cultivo de maíz. Ciencia del Suelo 24(1):1–10. https://doaj.org/article/e64f18b2dd35497c9f5f0e08130afd75. (21 de enero de 2023).

Bautista C., A., J. Etchevers B., R. F. del Castillo y C. Gutiérrez. 2004. La calidad del suelo y sus indicadores. Ecosistemas 13(2):90-97. https://www.revistaecosistemas.net/index.php/ecosistemas/article/view/572. (21 de enero de 2023).

Cantú S., I. y M. I. Yáñez D. 2018. Efecto del cambio de uso de suelo en el contenido del carbono orgánico y nitrógeno del suelo. Revista Mexicana de Ciencias Forestales 9(45):122-150. Doi: 10.29298/rmcf.v9i45.138.

Celaya M., H., F. García O., J. C. Rodríguez y A. E. Castellanos V. 2015. Cambios en el almacenamiento de nitrógeno y agua en el suelo de un matorral desértico transformado a sabana de buffel (*Pennisetum ciliare* (L.) Link). Terra Latinoamericana 33:79-93. http://www.redalyc.org/articulo.oa?id=57335800007. (23 de enero de 2023).

Cerana, J., M. Wilson, O. Pozzolo, J. J. De Battista, S. Rivarola y E. Díaz. 2005. Relaciones matemáticas entre la resistencia mecánica a la penetración y el contenido hídrico en un Vertisol. In: Samper C., J. y A. Paz G. (Edits.). VII Jornadas de Investigación en la Zona no Saturada del Suelo ZNS'05. Xunta de Galicia, Universidade Da Coruña y Diputación Da Coruña. La Coruña, GA, España. pp. 159-163.

Céspedes F., F. E., J. A. Fernández, J. A. Gobbi y A. C. Bernardis. 2012. Reservorio de carbono en suelo y raíces de un pastizal y una pradera bajo pastoreo. Revista Fitotecnia Mexicana 35(1):79-86. https://www.redalyc.org/articulo.oa?id=61023295009. (26 de enero de 2023).

Comisión Nacional Forestal (Conafor). 2010. Programas y acciones en reforestación, conservación y restauración de suelos, incendios forestales y sanidad forestal de ecosistemas forestales. Conafor. Zapopan, Jal., México. 108 p.

http://www.conafor.gob.mx:8080/documentos/ver.aspx?articulo=1359&grupo=7. (10 de enero de 2023).
de Andrade B., J., I. Anghinoni, M. T. de Moraes and J. R. Fink. 2017. Resilience of soils with different texture, mineralogy and organic matter under long-term conservation systems. Soil and Tillage Research 174:104-112. Doi: 10.1016/j.still.2017.06.008.
Dieckow, J., C. Bayer, P. C. Conceição, J. A. Zanatta, … and L. C. Hernani. 2009. Land use, tillage, texture and organic matter stock and composition in tropical and subtropical Brazilian soils. European Journal of Soil Science 60(2):240-249. Doi: 10.1111/j.1365-2389.2008.01101.x.
Domínguez-Calleros, P. A., R. Rodríguez-Laguna, J. Capulín-Grande, R. Razo-Zárate y M. A. Díaz-Vásquez. 2017. Influencia de factores edáficos en el crecimiento de una plantación de *Pinus greggii* Engelm. en Santiago de Anaya, Hidalgo, México. Madera y Bosques 23(2):145-154. Doi: 10.21829/myb.2017.2321522.
Encina R., A. y P. Valinotti. 2000. Comportamiento de la conductividad eléctrica a diferentes profundidades en suelos bajo cobertura de espartillares o paleocauces colmatados–Chaco Paraguayo. Investigación Agraria 3(1):9-12. https://www.agr.una.py/revista/index.php/ria/article/view/183. (21 de enero de 2023).
Geissen, V., R. Sánchez-Hernández, C. Kampichler, R. Ramos-Reyes, … and S. Hernández-Daumas. 2009. Effects of land-use change on some properties of tropical soils–An example from Southeast Mexico. Geoderma 151(3-4):87-97. Doi: 10.1016/j.geoderma.2009.03.011.
Gong, S., Z. Feng, A. Qu, J. Sun, … and Y. Kong. 2022. Effects of land-use types on the temporal dynamics of soil active carbon and nitrogen in the rocky mountainous of North China. Soil Science and Plant Nutrition 68(1):72-80. Doi: 10.1080/00380768.2021.1985383.
González C., O., C. E. Iglesias C., M. Herrera S., E. López B. y Á. Sánchez I. 2008. Efecto de la humedad y la presión sobre el suelo en la porosidad total de un Rhodic Ferralsol. Revista Ciencias Técnicas Agropecuarias 17(2):50-54. www.redalyc.org/articulo.oa?id=93217211. (13 de febrero de 2023).
Hernández-Vigoa, G., G. de la C. Cabrera-Dávila, I. Izquierdo-Brito, A. A. Socarrás-Rivero, L. Hernández-Martínez y J. A. Sánchez-Rendón. 2018. Indicadores edáficos después de la

conversión de un pastizal a sistemas agroecológicos. Pastos y Forrajes 41(1):3-12. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-03942018000100001&lng=es&tlng=es. (21 de febrero de 2023).

Instituto Nacional de Estadística, Geografía e Informática (INEGI). 2007. *Geografía y Medio Ambiente: Edafología.* Serie II. INEGI. México. https://www.inegi.org.mx/temas/edafologia/. (10 de noviembre de 2022).

Instituto Nacional de Estadística, Geografía e Informática (INEGI). 2008. Geografía y Medio Ambiente: Climatología. INEGI. https://www.inegi.org.mx/temas/climatologia/#mapas. (10 de noviembre de 2022).

International Business Machines (IBM). 2016. Statistical Package for the Social Sciences (SPSS) V22.0. IBM Inc. Chicago, IL, United States of America.

Kátai, J., A. Z. Olah, M. Tállai, I. Vágó, … and K. Inubushi. 2022. Comparison of soil characteristics related to C and N processes in Eastern Hungarian and Central Japanese soils under different land use and nutrient supply. Soil Science and Plant Nutrition 68(1):88-98. Doi: 10.1080/00380768.2022.2031283.

Lal, R. 1997. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO_2–enrichment. Soil and Tillage Research 43(1-2):81-107. Doi: 10.1016/S0167-1987(97)00036-6.

López D., M. y H. Estrada M. 2015. Propiedades físicas, químicas y biológicas del suelo. Bioagrociencias 8(1):3-11. https://xdoc.mx/preview/ropiedades-fisicas-quimicas-y-biologicas-5e77ca8cb1966. (27 de febrero de 2023).

Martínez H., E., J. P. Fuentes E. y E. Acevedo H. 2008. Carbono orgánico y propiedades del suelo. Revista de la Ciencia del Suelo y Nutrición Vegetal 8(1):68-96. https://www.scielo.cl/pdf/rcsuelo/v8n1/art06.pdf. (13 de enero de 2023).

Matus, F., E. Garrido, C. Hidalgo, F. Paz, … and A. Báez. 2016. Carbon saturation in the silt and clay particles in soils with contrasting mineralogy. Terra Latinoamericana 34:311-319. http://www.redalyc.org/articulo.oa?id=57346617005. (23 de febrero de 2023).

Mongil-Manso, J., J. Navarro-Hevia and R. San Martín. 2022. Impact of land use change and afforestation on soil properties in a Mediterranean Mountain Area of Central Spain. Land 11(7):1043. Doi: 10.3390/land11071043.

Nardi, D. and L. Marini. 2021. Role of abandoned grasslands in the conservation of spider communities across heterogeneous mountain landscapes. Agriculture, Ecosystems & Enviroment 319:1-9. Doi: 10.1016/j.agee.2021.107526.

Narro F., E. 1994. Física de suelos con enfoque agrícola. Trillas y Universidad Autónoma Agraria Antonio Narro. Benito Juárez, México D. F., México. 195 p.

Navarro B., A., B. Figueroa S., V. M. Ordaz C. y F. V. González C. 2000. Efecto de la labranza sobre la estructura del suelo, la germinación y el desarrollo del maíz y frijol. Terra Latinoamericana 18(1):61-69. www.redalyc.org/articulo.oa?id=57318107. (22 de febrero de 2023).

Novillo E., I. D., M. D. Carrillo Z., J. E. Cargua C., V. Nabel M., K. E. Albán S. y F. L. Morales I. 2018. Propiedades físicas del suelo en diferentes sistemas agrícolas en la provincia de Los Ríos, Ecuador. Temas Agrarios 23(2):177-187. Doi: 10.21897/rta.v23i2.1301.

Ordoñez, M. C., L. Galicia and J. F. Casanova O. 2022. Evaluation of land use change on an andosol through physicochemical and biological indicators. Tropical Grasslands-Forrajes Tropicales 10(1):52-62. Doi: 10.17138/TGFT(10)52-62.

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). 2016. Base referencial mundial del recurso suelo 2014. Sistema internacional de clasificación de suelos para la nomenclatura de suelos y la creación de leyendas de mapas de suelos. Actualización 2015. FAO. Roma, RM, Italia. 205 p. https://www.fao.org/3/i3794es/I3794es.pdf. (21 de enero de 2022).

Porta C., J., M. López-Acevedo R. y C. Roquero de L. 2003. Edafología para la agricultura y el medio ambiente. Ediciones Mundi-Prensa. Madrid, MD, España. 960 p.

Rollán, A. A. del C. y O. A. Bachmeier. 2015. Efecto de la siembra directa continua sobre el comportamiento físico-funcional de los suelos francos limosos de la región semiárida central de la provincia de Córdoba (Argentina). Terra Latinoamericana 33(4):275-284. http://www.redalyc.org/articulo.oa?id=57343335002. (20 de enero de 2023).

Sahoo, U. K., S. L. Singh, A. Gogoi, A. Kenye and S. S. Sahoo. 2019. Active and passive soil organic carbon pools as affected by different land use types in Mizoram, Northeast India. PLoS ONE 14(7):e0219969. Doi: 10.1371/journal.pone.0219969.

Salehi, M. H., O. H. Beni, H. B. Harchegani, I. E. Borujeni and H. R. Motaghian. 2011. Refining soil organic matter determination by loss–on–ignition. Pedosphere 21(4):473-482. Doi: 10.1016/S1002-0160(11)60149-5.

Secretaria de Medio Ambiente y Recursos Naturales (Semarnat). 2000. *Capítulo 3. Los suelos de México*. https://paot.org.mx/centro/ine-semarnat/informe02/estadisticas_2000/informe_2000/03_Suelos/3.1_Suelos/index.htm. (17 de febrero de 2023).

Secretaria de Medio Ambiente y Recursos Naturales (Semarnat). 2002. Norma Oficial Mexicana NOM-021-RECNAT-2000, que establece las especificaciones de fertilidad, salinidad y clasificación de suelos. Estudios, muestreo y análisis. Diario Oficial de la Federación. 31 de diciembre de 2002. México, D. F., México. 73 p. https://www.dof.gob.mx/nota_detalle_popup.php?codigo=717582. (10 de noviembre de 2021).

Secretaria de Medio Ambiente y Recursos Naturales (Semarnat). 2016. Informe de la Situación del Medio Ambiente en México 2015. Compendio de estadísticas ambientales, Indicadores Clave, de desempeño ambiental y de crecimiento verde. Edición 2015. Semarnat. Miguel Hidalgo, Cd. Mx., México. 470 p. https://apps1.semarnat.gob.mx:8443/dgeia/informe15/tema/pdf/Informe15_completo.pdf. (10 de enero 2023).

Smith, P., J. I. House, M. Bustamante, J. Sobocká, … and T. A. M. Pugh. 2016. Global change pressures on soils from land use and management. Global Change Biology 22(3):1008-1028. Doi: 10.1111/gcb.13068.

Sokal, R. R. and F. J. Rohlf. 2012. Biometry the principles and practice of statistics in biological research. W. H. Freeman and company. New York, NY, United States of America. 915 p.

Walkley, A. and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science 37(1):29-38. Doi: 10.1097/00010694-193401000-00003.

Woerner P., M. 1989. Métodos químicos para el análisis de suelos calizos de zonas áridas y semiáridas. Facultad de Ciencias Forestales de la Universidad Autónoma de Nuevo León. Linares, NL, México. 105 p.

Yinka O., K., O. Aliku and S. Oshunsanya. 2022. Land degradation rating under different land use types. International Journal of Life Science Research Archive 3(2):75-85. Doi: 10.53771/ijlsra.2022.3.2.0093.