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Research article

Reservorio de carbono y nitrógeno en un suelo Cambisol bajo dos usos de suelo en Linares, Nuevo León, México

Carbon and nitrogen stock in a Cambisol soil under two land uses in *Linares*, *Nuevo Leon*, Mexico

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Abstract

The organic Carbon of the soil is related to the physical, chemical, and biological properties of the soil, while Nitrogen is an essential macroelement in plant growth. To know the Carbon and Nitrogen stock in a Cambisol, a study was carried out in *Linares*, *Nuevo León*, Mexico. Four composite samples (*n*=4) (individual subsamples) were collected at five depths (0-5, 5-15, 15-30, 30-60 and 60-100 cm), in two land uses: Tamaulipan Thorny Scrub (MET) and Induced Grassland for livestock use, obtaining 40 samples in total (20 each land use); the chemical variables analyzed were soil organic Carbon percentage (*COS*), total Nitrogen (*Nt*) and the ratio C:N was estimated. Likewise, bulk density (*Da*) was determined to calculate the *COS* and *Nt* storage (Mg ha^{-1}). The mean percentage of *COS* and *Nt* for the MET were 2.87 and 0.28 %, and Grassland were 2.21 and 0.21 %. Statistical analyses showed that there are differences in the *COS* and *Nt* reservoirs between land uses and depths. The *COS* and *Nt* reservoirs in the entire profile analyzed (0-100 cm) for the MET were 164.99 and 19.83 Mg ha^{-1}, and for Grassland 146.07 and 17.81 Mg ha^{-1}, respectively. While the average C:N ratio for the MET was 9.28 and Grassland was 10.73. Change in land use from MET to Grassland caused a decrease in the *COS* and *Nt* reservoirs of 11.47 and 10.17 %, respectively.

Key words: *Storage, strata, Tamaulipan Thornscrub, Grassland, soil profile, C:N ratio.*

Resumen

El Carbono orgánico del suelo está relacionado con las propiedades físicas, químicas y biológicas del suelo, y el Nitrógeno es un macroelemento esencial en el crecimiento de las plantas. Con el fin de conocer los reservorios de Carbono y Nitrógeno en un Cambisol, se realizó un estudio en Linares, Nuevo León, México. Se recolectaron cuatro muestras compuestas (*n*=4) (submuestras individuales) a cinco profundidades (0-5, 5-15, 15-30, 30-60 y 60-100 cm), en dos usos del suelo: Matorral Espinoso Tamaulipeco (MET) y Pastizal inducido de uso pecuario, para un total de 40 muestras (20 por uso de suelo). Las variables químicas analizadas fueron porcentaje de Carbono orgánico del suelo (*COS*), Nitrógeno total (*Nt*), y se estimó la relación C:N. Asimismo, se determinó la densidad aparente (*Da*) para estimar el almacén de *COS* y *Nt* (Mg ha^{-1}). Las concentraciones medias de *COS* y *Nt* para el MET fueron de 2.87 y 0.28 %, y para el Pastizal de 2.21 y 0.21 %, respectivamente. Los análisis estadísticos mostraron diferencias en los reservorios de *COS* y *Nt* entre usos del suelo y profundidades. Los almacenes en el perfil analizado (0-100 cm) fueron de 164.99 y 19.83 Mg ha^{-1} para el MET, y para Pastizal de 146.07 y 17.81 Mg ha^{-1}, respectivamente. El promedio de la relación C:N para el MET fue de 9.28 y en Pastizal de 10.73. El cambio de uso de suelo del MET a Pastizal provocó una disminución en las reservas de *COS* y *Nt* de 11.47 y 10.17 %, respectivamente.

Palabras clave: Almacén, estratos, Matorral Espinoso Tamaulipeco, Pastizal, perfil de suelo, relación C:N.

Introduction

Soil is an essential resource for environmental sustainability as it is directly related to the hydrological cycle and biogeochemical cycles. However, its deterioration is increasing, due to the pressure exerted by the increase in agricultural and livestock production to satisfy food demand (Burbano-Orjuela, 2016).

One of the ecosystem services that the soil provides is Carbon capture which makes it a key factor for the mitigation of climate change (Wagner-Riddle *et al.,* 2007). Burbano (2016) points out that soils have the ability to store up to 1 500 Pg C at 1 m deep. On the other hand, Batjes (2014) mentions that the C and N contents in the soil are a function of land use, and it is estimated that the availability of soil organic Carbon (*SOC*) and total Nitrogen (*tN*) in the first 100 cm of soil varies from 1 462 to 1 548 Pg of C and 133 to 140 Pg of *tN*, respectively. However, worldwide the soil is subjected to different anthropogenic activities, which are related to soil degradation and alter its capacity as a reservoir.

Land use change affects *SOC* reservoir and the availability of Nitrogen; these elements are essential to maintain the quality and health of the soil (Cantú and Yáñez, 2018).

It is estimated that 80 % of the Carbon that vegetation and soils exchange with the atmosphere corresponds to forests (Galicia *et al.*, 2016). When the Carbon is incorporated in the growth of the trees, they act as sinks (2.30 Gt C yr^{-1}) and play an important role in the Carbon balance, which contributes to reducing the carbon dioxide (CO_2) content in the atmosphere from anthropogenic emissions (Pardos, 2010).

Soil Carbon and Nitrogen reserves fluctuate according to the type of soil, climatic and geographic conditions, types of ecosystems and land uses (Hume *et al*., 2018). In addition, they are indicators of the quality of organic matter (Luna *et al.*, 2023). In particular, C is a key component in biogeochemical cycles, and N is in charge of defining ecosystem productivity (Di Gerónimo *et al.*, 2018).

On the other hand, the C:N ratio is a good indicator of the quality of soil organic matter, and is associated with the speed of Nitrogen mineralization. Gamarra *et al.* (2018) point out that ratios between 10 and 14 are generated from rapid mineralization, which produces enough N for microorganisms, while high ratios (>20) indicate slow decomposition.

The most arid places in Mexico are covered by scrublands and grasslands, which is most of the plain of the state of *Nuevo León* and providing ecosystem services to more than half of the Mexican population (Briones *et al.*, 2020). On the other hand, it is considered that the grasslands and natural habitats have a high potential of Carbon and Nitrogen reservoirs. However, most studies are focused on analyzing the superficial layers (0-40 cm), which leads to uncertainty about the behavior of Carbon and Nitrogen in deeper strata (Ward *et al.*, 2016).

Jurado-Guerra *et al.* (2021) mention that pastures in Mexico occupy an approximate area of 9 million hectares, and that with a system of moderate grazing use, which on average present *SOC* reservoirs of 24 to 34 Mg ha^{-1} in the first few years 30 cm from the ground.

Based on the above, the objective of this study was to determine the effect of land use change on *SOC* and *tN* reservoirs and their distribution in different depth strata in a Cambisol.

Materials and Methods

Study area

The study area is located in the *San Rafael Ejido*, *Linares* Municipality, *Nuevo León*, UTM coordinates zone 14: 430500 E and 2737400 N, with 989.4 mm average annual rainfall, 21.3 °C average annual temperature and an altitude of 441 m (García, 2004). Such area belongs to the coastal plain of the North Gulf made up of gentle hills and plains (INEGI, 1986) (Figure 1).

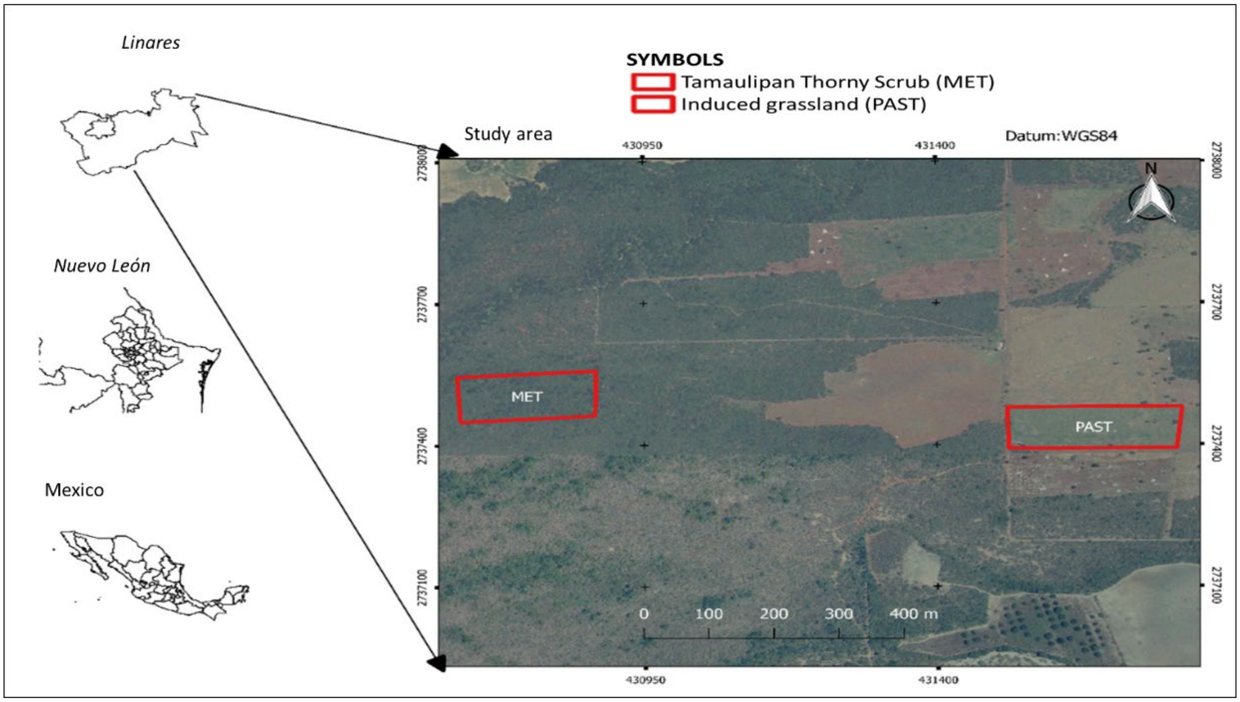

Figure 1. Study area location.

Land uses

Tamaulipan Thorny Scrub: native vegetation of the area, made up of more than 50 tree and shrub species (1 to 5 m high), without intervention, among which prevail *Havardia pallens* (Benth.) Britton & Rose, *Leucaena leucocephala* (Lam.) de Wit, *Vachellia farnesiana* (L.) Wight & Arn., *Yucca filifera* Chabaud, *Ebenopsis ebano* (Berland.) Barneby & J. W. Grimes, *Prosopis laevigata* (Humb. & Bonpl. ex Willd.) M. C. Johnst., *Cordia boissieri A. DC.*, among others (Patiño-Flores *et al.*, 2022).

Induced grassland: it is an intensive grazing system, 20 years old, with rotation in pastures and a stocking rate of 8 AU ha^{-1}, with rest periods of 8 and 5 weeks in the dry and rainy seasons, respectively.

Cambisol soil

A Cambisol soil was selected, whose name comes from the Latin *Cambiare*, which means to change. They are young soils in which changes in the clays between the horizons are perceived, it does not show a specific distribution in any particular type of climate, it presents moderate accumulations of iron, manganese and clay, it is characterized by good structural stability, high porosity and retention moisture, medium texture and good drainage, neutral to slightly acidic pH, with good fertility and biological activity (INEGI, 2015; IUSS, 2015).

Sample collection

Sampling was carried out in June 2021. Two 400 m^2 plots were selected for each land use (MET and Grassland). Four composite samples (n=4) (individual subsamples) of 1.5 kg were collected at five depths (0-5, 5-15, 15-30, 30-60 and 60-100 cm) (Ward *et al.*, 2016; Conafor, 2017; Lefèvre *et al.*, 2017), which added up to 40 samples in total (20 for land use). Simultaneously, 4 undisturbed samples were extracted for the calculation of bulk density (*Da*, for its acronym in Spanish) at each depth, for which a 5 cm×5 cm metal cylinder was inserted (model 0200, Soilmoisture®), dried at 105 °C for 48 hours (drying oven model CE5F, Shel lab®), and subsequently weighing was carried out to determine its mass (scale model cp2202S, Sartorius®) (Blake and Hartge, 1986). Bulk density is the mass per unit volume including its pore space (Gabriels and Lobo, 2006). In this study, the bulk density was used to calculate the amount of Carbon and Nitrogen stored in the Cambisol soil.

All the samples were taken to the *Laboratorio de Suelos y Nutrición de Bosques del Departamento Agroforestal* (Soil and Forest Nutrition Laboratory of the Agroforestry Department) which belongs to the *Facultad de Ciencias Forestales de la Universidad Autónoma de Nuevo León* (Faculty of Forest Sciences of the Autonomous University of *Nuevo León*) for their analysis.

Analysis of chemical properties

The analysis of the organic Carbon content of the soil was determined with the wet combustion method according to Walkley-Black to obtain organic matter and applying the Van Bemmelen correction factor (Semarnat, 2002; Ramos-Hernández and Martínez-Sánchez, 2020). While the total Nitrogen was obtained by the Kjeldahl digestion method (Bremner and Mulvaney, 1982), using the model UDK159 Velp Scientifica® equipment. The C:N ratio was estimated from the *SOC* and *tN* values (Semarnat, 2002).

SOC and *tN* reservoir

For counting with the *SOC* (Mg ha^{-1}) and *tN* (Mg ha^{-1}) reservoir, the percentage of both, the bulk density (*Da*, g cm^{-3}) and the soil depth stratum (*Eps*, cm), with the application of the following equations (González *et al.,* 2008):

$$SOC\ (Mg\ ha^{-1}) = SOC\ \% \times Da \times Eps \qquad (1)$$

$$tN\ (Mg\ ha^{-1}) = tN\ \% \times Da \times Eps \qquad (2)$$

Where:

SOC = Soil organic Carbon

Da = Bulk density

Eps = Soil depth stratum

tN = Total Nitrogen

In addition, the accumulated reservoir of both variables in the entire profile (0-100 cm) was calculated from the sum of the 5 strata in each land use.

Statistical analysis

With the collected data, Kolmogorov-Smirnov normality tests and Levene homoscedasticity tests were performed (Flores and Flores*,* 2021). The accumulated reservoir of *tN* (Mg ha^{-1}) in the 0-100 cm profile did not comply with the normality assumption, Non-parametric tests were used to compare between land uses (Mann-Whitney U) (Steel and Torrie, 1980). On the other hand, the *SOC* accumulated reservoir variable (Mg ha^{-1}) in the 0-100 cm profile was analyzed with the t-Student test to detect differences between land uses (Sánchez, 2015).

Likewise, the *SOC* variable (Mg ha^{-1}) by depth strata, did not meet both assumptions of normality and homogeneity of variances, so the Kruskal-Wallis test was applied to detect differences in each land use (Sánchez-López *et al.*, 2015). While for the *tN* variable (Mg ha^{-1}) by strata, an analysis of variance and its respective Tukey test were used (Gómez *et al.*, 2019).

Regarding the C:N ratio, a t-Student test was used to compare between land uses, as well as an analysis of variance and its respective Tukey test for strata (Berlanga and Rubio, 2012). All analyzes were performed with the SPSS® program (Statistical Package for Social Sciences, SPSS), standard version 22 for Windows (IBM, 2013).

Results

The average values of the percentage of *SOC* and *tN*, as well as the bulk density for each land use (*MET* and Grassland) recorded in general, a decrease in the Carbon and Nitrogen percentages as the depth of the soil increases, where the strata with the highest and lowest values were observed in the 0-5 cm and 60-100 cm depths, respectively, in *MET* and Grassland. Bulk density showed variations between depths in each land use, in which an increase was detected in the MET and Grassland as the depth of the soil increases, with the exception of the 60-100 cm stratum in Grassland where a slight decrease is outlined (Table 1).

Table 1. Mean values of *SOC*, *tN* and bulk density for the two land uses and depth strata.

Variable	**Land use**	**Mean (cm)**					**Depth**
		0-5	**5-15**	**15-30**	**30-60**	**60-100**	
SOC (%)	*MET**	5.99	5.17	1.53	0.88	0.78	2.87
	Grassland**	5.09	2.57	1.46	1.05	0.90	2.21
tN (%)	*MET**	0.61	0.30	0.21	0.15	0.13	0.28
	Grassland**	0.42	0.18	0.15	0.17	0.12	0.21
Da (g cm^{-3})	*MET**	0.87	0.97	1.07	1.12	1.15	1.04
	Grassland**	1.13	1.14	1.16	1.17	1.06	1.13

**MET* = Tamaulipan Thorny Scrub; ** Induced Grassland of livestock use

SOC reservoir (Mg ha^{-1})

The findings obtained through the t-Student test ($p \leq 0.05$) indicated that there are significant differences in the *SOC* reservoir between the different land uses in the profile analyzed from 0 to 100 cm deep.

The *MET* land use registered an average reserve of 164.99 Mg ha^{-1} of *SOC*, while the Grassland use, an average reserve of 146.07 Mg ha^{-1}, which represents a 18.93 Mg ha^{-1} difference between both uses, as can be seen in Figure 2.

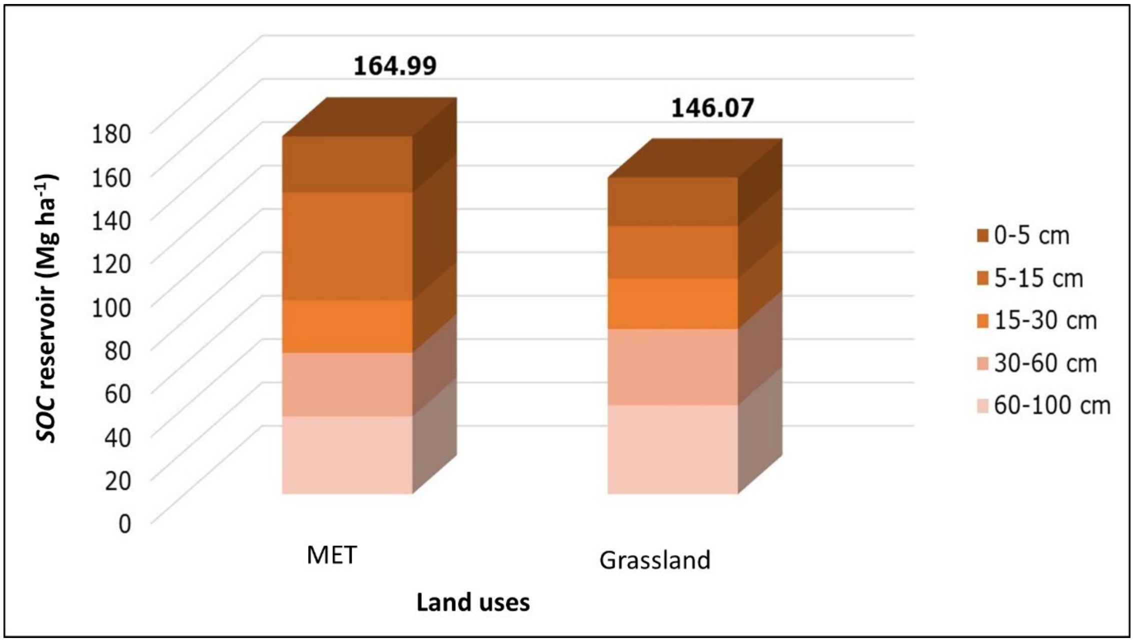

Figure 2. Accumulated Carbon reservoir in the 0-100 cm profile for two land uses: Tamaulipan Thorny Scrub and Induced Grassland for livestock use.

The Kruskal-Wallis test revealed that there are significant differences between the different depth strata for each of the land uses. In addition, it was identified that the *SOC* reservoir varied between 24.22 and 49.72 Mg ha^{-1} in different depth strata for the use of *MET* soil, while in the Grassland this variable fluctuated between 22.26 and 41.07 Mg ha^{-1} (Table 2).

Table 2. Average *SOC* reservoirs (Mg ha^{-1}) in the different depth strata in two land uses.

Land use	Depth (cm)					Square chi	*P* value
	0-5	**5-15**	**15-30**	**30-60**	**60-100**		
*MET**	25.89	49.72	24.22	29.26	35.91	12.75	0.013***
Grassland**	22.36	24.31	23.21	35.12	41.07	14.47	0.006***

**MET* = Tamaulipan Thorny Scrub; **Induced Grassland of livestock use.

***Significant differences among depths (Kruskal-Wallis $p \leq 0.05$).

tN reservoir (Mg ha^{-1})

The Mann-Whitney U test ($p \leq 0.05$) yielded results that indicate that there are significant differences in the accumulated *tN* reservoir between the different land uses. The *MET* land use registered an average reserve of 19.83 Mg ha^{-1}, while that of Grassland had an average reserve of 17.81 Mg ha^{-1}, which represents a difference of 2.02 Mg ha^{-1} between both uses (Figure 3).

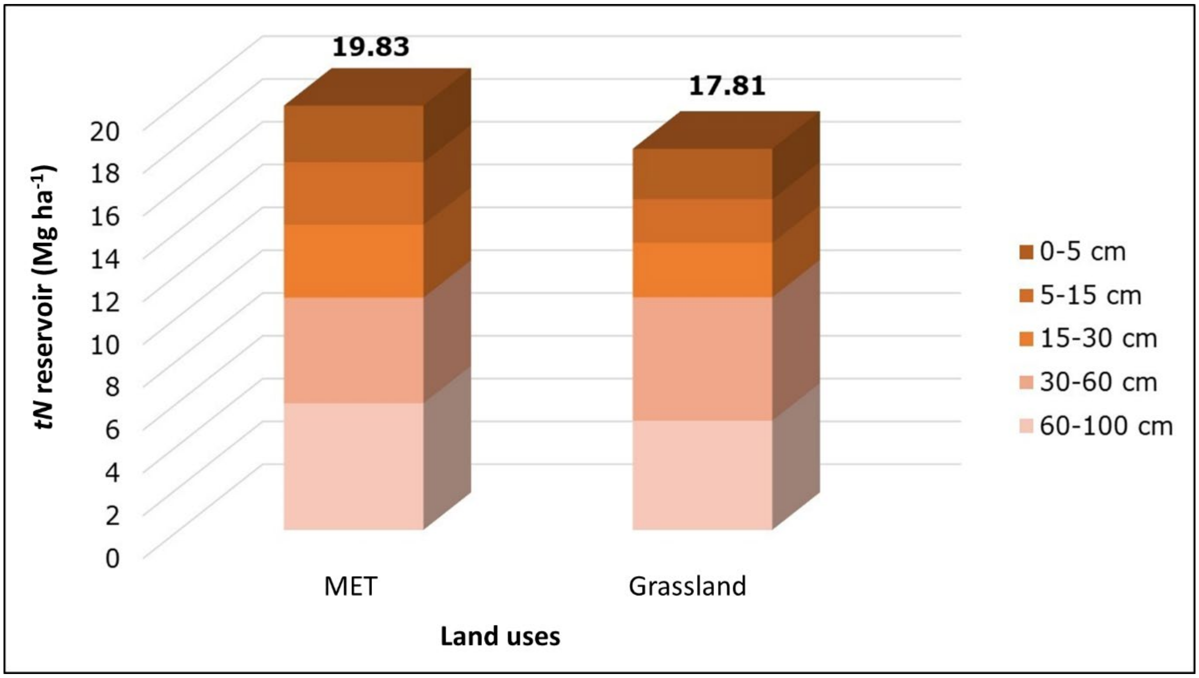

Figure 3. Accumulated Nitrogen reservoir in the 0-100 cm profile for two land uses: Tamaulipan Thorny Scrub (*MET*) and Induced Grassland for livestock use.

The analysis of variance for the *tN* reservoir indicated that there are differences between the depth strata in both land uses. Tukey's test revealed that the first three strata of the profile, where the lowest Nitrogen reserves are located, do not show significant differences between them in both land uses. In addition, the *tN* reservoir in the *MET* varied between 2.64 and 5.92 Mg ha^{-1} in the different depth strata, while for the Grassland, between 2.03 and 5.76 Mg ha^{-1} (Table 3).

Table 3. Average *tN* (Mg ha^{-1}) reservoirs in different depth strata by land use.

Land use	**Depth (cm)**				
	0-5	**5-15**	**15-30**	**30-60**	**60-100**
*MET**	2.64^{b}	2.92^{b}	3.41^{b}	4.93^{a}	5.92^{a}

Grassland**	2.36[b]	2.03[b]	2.55[b]	5.76[a]	5.11[a]

**MET* = Tamaulipan Thorny Scrub; ** Induced Grassland of livestock use. Means with different letters are statistically different (Tukey p≤0.05).

C:N ratio

The C:N ratio did not show significant differences between land uses; the averages of the C:N ratio for *MET* was 9.28 and for Grassland it was 10.73. However, differences were detected in the analysis of variance between the different depth strata for each land use. Tukey's test indicated that the C:N ratio is statistically the same in the last three strata in both *MET* and Grassland. According to Figure 4, the highest and lowest C:N ratios occurred in the same depth strata (5-15 cm and 30-60 cm) in the two land uses: in the *MET* it was 17.2 and 5.9, and in the Grassland of 16.3 and 7.0, respectively.

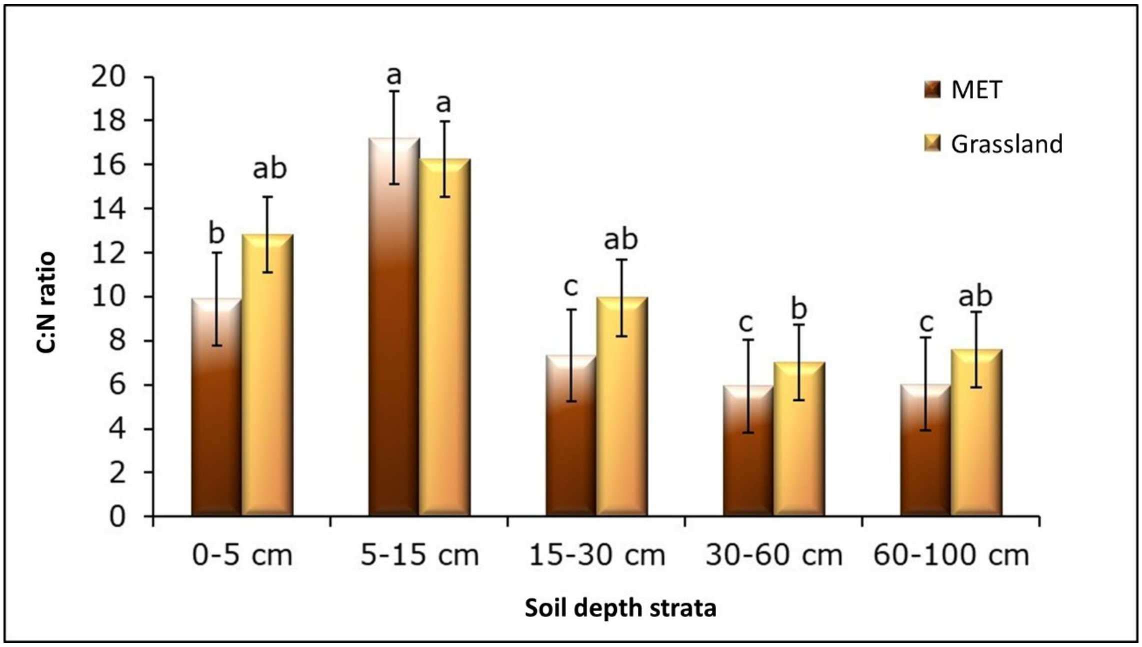

Figure 4. Mean values of the C:N ratio in different depth strata, by land use (Tukey $p \leq 0.05$).

Discussion

Carbon and Nitrogen reservoirs are affected by changes in land use due to the different practices implemented, as well as changes in biogeochemical cycles (Cocotle *et al*., 2022). In this sense, Franco *et al.* (2015) stated that the change in land use from native vegetation to grasslands entails a 37 % decrease in *SOC* and 43 % in *tN*. However, the results of this investigation indicate that the reduction of these variables was 23 and 26 %, respectively. Likewise, Piñeiro (2009) points out that grazing interrupts the nutrient cycle due to the consumption of the biomass area, which results in decreases in C and N in the soil. Although there are differences between land uses, they are not so noticeable since the accumulation of feces and urine from cattle are a secondary source of C and N deposits (Ortiz, 2021). According to Ward *et al.* (2016), intensive grazing has a direct effect on *SOC* contents, and indicates that *SOC* decreases as depth increases; the highest concentrations are verified in the first 7.5 cm, which agrees with this investigation in which the highest concentration of *SOC* was recorded in the 0-5 cm depth.

Muñoz-Rojas *et al.* (2015) point out that the change in land use can generate *SOC* losses of up to 84 %. In particular, the conversion from MET to Grassland produces a loss of 50 %, mainly in the first 30 cm (Montaño *et al*., 2016). Results with a similar trend (31 %) were obtained in the present study. However, Campo *et al.* (2016) point out that said conversion can increase the *SOC* reservoir in the grasslands, depending on management, a situation that was observed in this study for the last two strata, where the Grassland accumulated 14.4 % more Carbon than the *MET*. For this reason, Conant *et al.* (2001) mention that the inclusion of management practices such as fertilization, type of grazing, addition of native vegetation, introduction of legumes and grasses, macro and decomposing microorganisms, and irrigation can increase said reservoir. This can be attributed to the fact that the Scrub presents a greater capacity to accumulate Carbon in the upper layer of the soil due to the greater density of vegetation. However, the Grassland has a greater capacity to store Carbon due to the structure and constant renewal of its roots that can reach deeper layers of the soil.

The depth of the soil plays a very important role in the *tN* percentages, since the largest number of microorganisms responsible for Nitrogen fixation and decomposition of organic matter, have their greatest activity in the superficial layer and the *tN* content is greater in depth decreases (Madrigal *et al.*, 2019). As observed in each land use in this study, the 0-5 cm depth presented the highest percentages of *tN*, while the 60-100 cm depth had the lowest percentages. Likewise, the vegetation cover has a strong influence with high *tN* percentages, mainly in the first centimeters (Díaz *et al.*, 2021).

These results coincide with those observed in the present investigation when finding a higher percentage of *tN* in the *MET* and lower in the Pastizal. These data suggest that the change in land use from Scrub to Pasture had a different effect on nitrogen content throughout the soil profile. In the strata analyzed, the percentage of Nitrogen was higher in *MET* than in the Grassland, except for the 30-60 cm stratum.

Bulk density has a direct effect on the percentages of *SOC* and *tN*, since it can limit the penetration of roots in deeper zones (de Moraes *et al.*, 2020), and therefore, reduces the sources of organic matter. This coincides with the tendency of the percentage of Carbon and Nitrogen in both land uses in the present study, in which bulk density increases as the depth of the soil increases.

The ratio (C:N) in the 1 m profile in the two land uses (MET and Grassland) resulted in average values of 9.3 and 10.73, respectively. According to Porta *et al.* (2014), Gamarra *et al.* (2018) and Cantu and Luna (2022), C:N ratios between 10 and 14 show optimal mineralization of organic matter. In this study, the calculated values are above the optimal conditions (10-14) for the right activity of soil microorganisms. In this regard, Yáñez *et al.* (2017) recorded different soil respiration rates between *MET* and Grassland in a Vertisol -soil respiration is an indicator of the activity of microorganisms-. The land use with the highest CO_2 emission was *MET* (6.17 μmol CO_2 m^{-2} s^{-1}) compared to Grassland (4.61 μmol CO_2 m^{-2} s^{-1}), which are the most common land uses in northeastern Mexico.

The MET showed a greater capacity to store Nitrogen, which can be attributed to the fall of leaf litter from the trees and the presence of legumes in symbiotic association with microorganisms that fix Nitrogen to the soil, while the roots of the pivot trees cross deeper layers and contribute to the nutrient cycle (Díaz *et al.*, 2021).

If the soils at the National level store 56.1 Mg ha^{-1} and at the state level in *Nuevo León* 36.9 Mg ha^{-1} in a depth stratum of 0-20 cm, the average capacity of the Cambisol Carbon reservoir between both land uses (70 Mg ha^{-1}) can be valued as high (Segura-Castruita *et al*., 2005).

In general, Cambisol offers a good *SOC* and *tN* reservoir capacity, if an average of both land uses is calculated, and a total of 155.53 and 18.82 Mg ha^{-1} is obtained at 1 m deep, respectively. Based on the above, the 30-100 cm stratum of Cambisol accumulated 39.5 % of the total *SOC* in *MET* and 52.2 % in Grassland. Likewise, in the case of the *tN* reservoir, the importance of the 30-100 cm stratum is even greater, since it accumulated 54.8 % in *MET* and 61 % in Grassland. This confirms the importance of investigating the entire soil profile in studies of Carbon and *tN* reservoirs and not only concentrating on the 0-30 cm stratum, where most of the *SOC* and *tN* are believed to be found.

Conclusions

The change in land use due to the conversion of the Tamaulipan Thorny Scrub to Grassland significantly affects the Carbon and Nitrogen reservoirs in Cambisol, which causes a decrease of 11.47 and 10.17 %, respectively.
The Cambisol has a good reservoir capacity of *SOC* and *tN* in the 1 m deep profile. The *tN* (Mg ha^{-1}) reserves increase as the depth increases, and are mainly

concentrated in the last two depth strata. The 30-100 cm layer is as important, or more, than the 0-30 cm layer with respect to the capacity to store *SOC* and *tN*.

The C:N ratio was maintained in an optimal interval of mineralization between the land uses and depth strata and was not affected by the land use change. The above described indicates that the *MET* and the Grassland have an important influence on the dynamics of Carbon and Nitrogen of Cambisol and, therefore, it is important to consider this in planning and sustainable soil management.

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Conflict of interests

The authors declare no conflict of interest.

Contribution by author

Rodolfo Alejandro Martínez Soto: field and, laboratory work and writing of the manuscript; Israel Cantú Silva: experimental design, conducting of the research study and writing of the manuscript; María Inés Yáñez Díaz: statistical analysis and writing of the manuscript; Humberto González Rodríguez: laboratory work and review of the manuscript; Silvia Janeth Béjar Pulido: statistical analysis and writing of the manuscript.

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