https://doi.org/10.29298/rmcf.v9i45.138

Article

Effect of the change of land use on the contents of soil organic carbon and nitrogen

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Abstract:

Soils are the largest carbon reservoir, containing almost three times as much as aerial biomass. Changes in land use represent the second anthropogenic source of carbon into the atmosphere due to carbon emissions. Carbon and nitrogen content in four contrasting land-use systems were evaluated, Tamaulipan thornscrub, agricultural crop, grassland and eucalyptus plantation. Four soil samples at two depths were collected per site (0-5 and 5-30 cm) and the soil organic carbon content (COS), total nitrogen (Nt) were analyzed and the C/N ratio was estimated. The results for the COS and Nt content for the 0-5 cm depth were 1.4-0.16 %

(agricultural), 2.4-0.27 % (plantation), 3.41-0.33 % (pasture) and 4.1-0.43 % (Thornscrub land), respectively. Overall the contents of COS and Nt at depth 5-30 cm. decreased. The C/N ratio showed values between 8.7 and 10.4 at both depths, indicating effective humification and mineralization of organic matter. COS and Nt losses due to changes in the use of Thornscrub land to another land use system fluctuated between 2.4 % to 66 %, the COS decreased mainly at soil depth 0-5 cm, while Nt value decreased most at soil depth of 5-30 cm. The agricultural system experienced the greatest loss of COS and Nt, at both depths. The results indicated that changes in land use caused a decrease in soil fertility, which was reflected in the agricultural system, where the values of C and Nt were lower than those found with the Thornscrub vegetation.

Key words: Soil organic carbon, fertility, Tamaulipan thornscrub, nitrogen, land use system, Vertisol.

Fecha de recepción/Reception date: 4 de julio de 2017

Fecha de aceptación/Acceptance date: 27 de septiembre de 2017.

Introduction

Soils are a significant carbon reservoir, working as a source and sink of atmospheric carbon dioxide (CO_2) and therefore they play a crucial role in the global climate change (Llorente, 2004). According to Ordóñez and Masera (2001), CO_2 is one of the most important greenhouse gases, and its emission into the atmosphere due to changes in the land use occupies the second place globally. Thrice as much carbon is stored in the soils than in the aerial biomass and, approximately twice as much as in the atmosphere (Eswaran *et al.*, 1993).

Carbon is the basic chemical element of both CO_2 and CH_4; hence the relevance of analyzing the amount of carbon that is released with any change of land use. Its total content stored in the aerial part of the terrestrial biosphere (biomass) is estimated in 420 to 660 Gt (10^9 t, billions of tons), whereas the underground content (in the soil) can be 2 000 to 2 500 Gt. On the other hand, the amount of carbon absorbed each year by the plants ranges between 90 and 120 Gt, and the total carbon currently emitted into the atmosphere each year due to the use of fossil fuels is estimated to be between 5 and 6 Gt. The loss of carbon due to human agricultural activities as a consequence of the accelerated mineralization of organic matter ranges between 40 and 90 Gt (de la Rosa, 2008).

The change in land use may radically alter the vegetal cover even in short periods, which causes alterations in the physical, chemical and microbial properties of the soil. Continual inputs of organic matter in the form of humus reduce the apparent density and erosion, increase fertility, the infiltration rate and water retention; consequently, the vegetal biomass is maintained (Huang *et al.,* 2006; Jia *et al.,* 2011). They also lead to a loss of soil carbon as a result of various degrees of direct or indirect disturbance by humans, a significant factor in global change (Smith *et al.*, 2016).

Edaphic factors such as the pH, levels of nourishment and the quality and quantity of soil organic matter (SOM) change with depth (Rumpel and Kögel-Knabner, 2011; Eilers *et al.,* 2012). SOM is one of the main factors that affect other properties of the soil (Murray *et al.*, 2014) and its functions, including water retention (Carter, 2002), air infiltration, water infiltration (Nimmo, 2004), and the stability of aggregates (Six *et al.*, 2004). It modifies the porosity and the ability of available water to improve the development of the roots, directly or indirectly stimulating the growth of the plants and the yield of the crops by providing them with nutrients (Darwish *et al.*, 1995).

The soil organic matter is a key indicator of the quality of the soil in terms of both its agricultural (production and economy) and environmental functions; it is the main determinant of the biological activity of the soil (Llorente, 2004). It is made up of compounds that are rich mainly in carbon, nitrogen, phosphorus and water, and therefore it is a source of nutrients and energy required by the development and metabolism of microorganisms (Ferrera and Alarcón, 2001).

Soil microorganisms play an essential role in the volume of organic matter; they produce different sets of enzymes that degrade various molecules (Baumann *et al.*, 2013) by physically and chemically breaking up the detritus into various organic compounds and, eventually, into inorganic nutrients and CO_2 (Chapin *et al.*, 2013).

Carbon plays a crucial role in the control of the nitrogen cycling rate. Those soils in which the supply of carbon coincides closely with the input of nitrogen from cycling maintain nitrogen within the system. However, when the soils are saturated with nitrogen but deficient in carbon, they are more prone to release the nitrogen into the atmosphere (Goulding *et al.*, 2001).

Nitrogen is an essential element for the microbial growth and the degradation of organic matter. When this has a high nitrogen content, the microorganisms have sufficient substrate to induce an increase in the mineralization speed, as it fully satisfies their nitrogen requirements and therefore this element is not a limiting factor for them. Conversely, if the nitrogen content is low, the decomposition rate of the organic matter diminishes drastically, and the mineralization rate of organic carbon will depend on the addition of nitrogenous sources (Ferrera and Alarcón, 2001).

A certain amount of nitrogen is assimilated by the microbial biomass in proportion to the C/N ratio. Specifically, the amount of N required by the microorganisms is 20 times smaller than that of C. If there is a low concentration of easily degradable C compounds and a larger amount of N than the one required by the microbial biomass, there will be a net nitrogen mineralization with a release of the inorganic N available for the plants (Diacono and Montemurro, 2010). Furthermore, the C/N ratio is a parameter that indicates when the degradation of the organic matter has become stabilized (Isaza-Arias *et al.*, 2009).

Vertisols are very important soils in northeastern Mexico and, particularly, in the area of *Linares*, NL, since they occupy then largest part of the surface area subjected to agricultural or livestock productive activities and they sustain most of the native vegetation with a regional economic importance (Llorente, 2004).

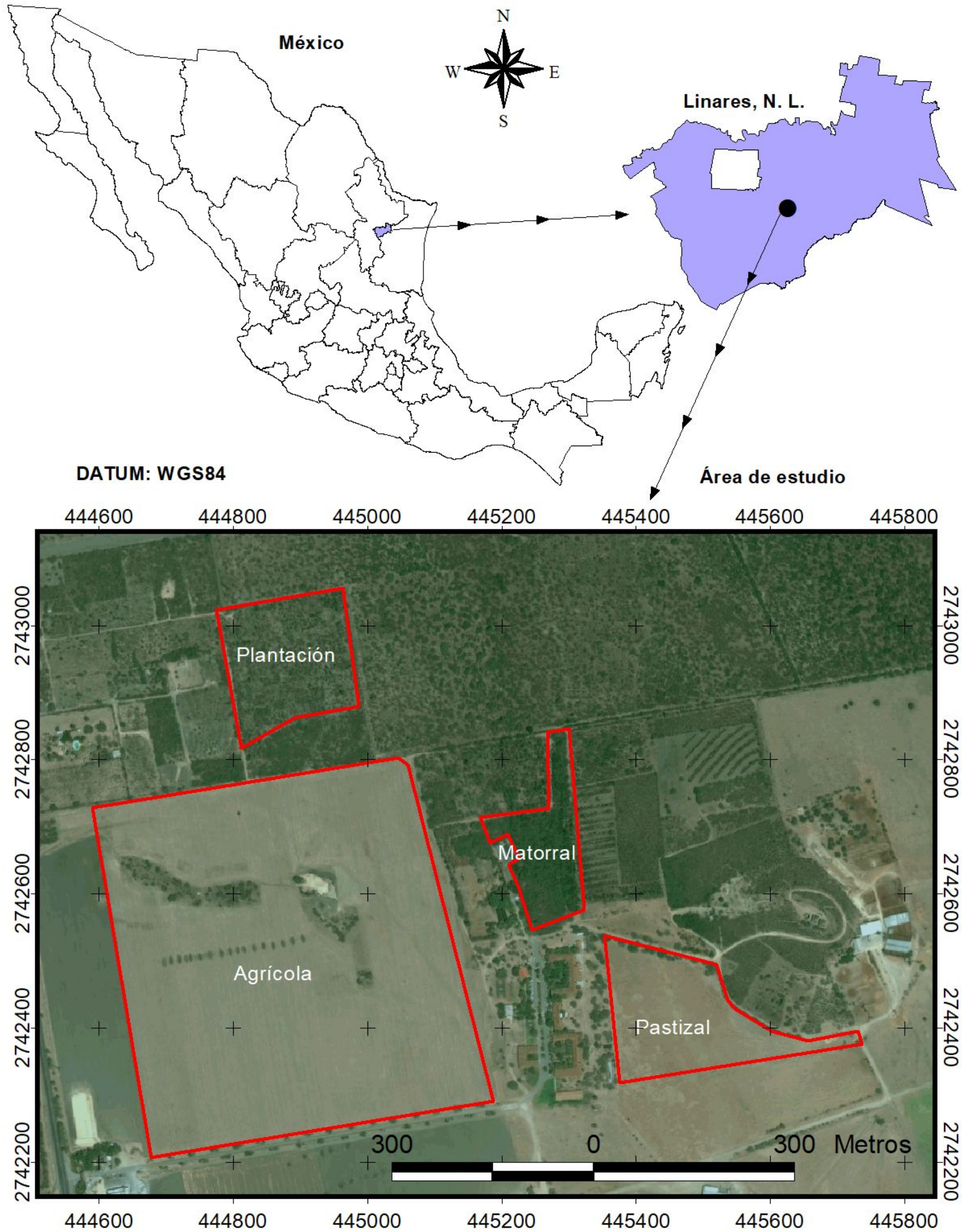
The name vertisols (from the Latin *vertere*, turn around) refers to the constant inner recycling of the edaphic material (IUSS, 2007). They are clayey, deep, extremely cracked when dry, or dark color, with a prismatic structure that is the result of the action of expansible clays (Woerner, 1991). Now, when a thornscrub land is cleared, significant modifications are produced in the structure and makeup of its vegetation; therefore, there is an impact on its agricultural, forest and ecological potential (Ruiz, 1990).

Based on the above considerations, the aim of the present study was to assess the effect of the changes in land use on the organic carbon and nitrogen contents and C/N ratio of a Vertisol under four different systems of land use.

Materials and Methods

The study area

It is located at the campus of the *Facultad de Ciencias Forestales* (Faculty of Forest Science) of the (Autonomous University of *Nuevo León*) U*niversidad Autónoma de Nuevo León*, at the geographical coordinates 24°47´51´´ N and 99°32´29´´ W and an altitude of 350 masl, 8 km south of *Linares* municipality, in *Nuevo León* State, Mexico (Figure 1). There is a subtropical and semiarid climate, with warm summers; the mean monthly temperature of the air ranges between 14.7 °C in January and 22.3 °C in August, with high daily temperatures of 45 °C during summer. The mean annual precipitation is 805 mm, with a bimodal distribution; the months with the most intense precipitations are May, June and September (González *et al.*, 2004).



Área de estudio = Study area; *Plantación* = Plantation; *Agrícola* = Agriculture; *Matorral* = Thornscrub; *Pastizal* = Pasture; *Metros* = Meters

Figure 1. Location of the study area.

Land use systems and experimental plots

Four experimental lots with various land uses were selected in the research state for the assessment of their soil organic carbon (SOC) and total nitrogen (TN) contents and their C/ N ratio. The first condition was a Tamaulipan thornscrub plot, native vegetation dominated by various dense and thorny shrubs, characterized by a broad range of growth patterns, various life stages of the leaves, and textures and growth dynamics with contrasting taxonomic and phonological developments. In terms of productivity, the average aerial biomass of the thornshrub and its annual production in dry weight have been determined to be 22 Mg ha^{-1} and 3.2 Mg ha^{-1} $year^{-1}$, respectively (Villalón, 1989). The second land use corresponds to a *Eucalyptus globulus* Labill. plantation and a *E. camaldulensis* Dehnh. plantation; both species were planted in 3 m × 3m squares, 33 years ago, for research purposes. The third land use was a plot with pasture, corresponding to a production system with intensive stockbreeding and pasture rotation. The perennial grass species established in the area is *Dichanthium annulatum* (Forssk.) Stapf (Bluestem), which forms bunches up to 60 cm tall. The fourth land use was a *Sorghum bicolor* (L.) Moench crop in a field under rain feeding conditions together with the implementation of conservation agricultural practices, where the protective layer of residues from each crop brings various environmental and soil management benefits, including the stabilization of the temperature and of the levels of soil moisture.

The soil type in all four systems is Pellic mazic vertisol, which has a deep gray color, a clayey-silty texture, with high montmorillonite contents that contract or swell perceptibly in response to changes in the soil moisture (González *et al.*, 2011).

In-field soil sampling

In April, 2016, 1 kg of soil was collected in four compound samples, with four subsamples each, at two different depths (0-5 and 5-30 cm). The sampling was carried out at random in each land use system. The samples (n=32) were taken to the Forest Soils and Nutrition laboratory of the Faculty of Forestry, U.A.N.L., where they were dried in the shade at room temperature, screened through a 0.2 mm mesh, and prepared for chemical analysis.

Organic matter and total nitrogen

The soil organic matter (SOM) was determined using the modified Walkley/Black method (Woerner, 1989). A wet digestion was performed with concentrated sulfuric acid (H_2SO_4); carbon was oxidized with potassium dichromate 0.07M ($K_2Cr_2O_7$), adding 25 mL of $K_2Cr_2O_7$ and 25 mL of H_2SO_4 to 0.5 g of soil, and the excess dichromate was titrated with ferrous sulphate 0.2 M ($FeSO_4 \cdot 7H_20$). The soil organic matter content and soil organic carbon (SOC) were estimated using this procedure under the assumption that the soil organic matter contains 58 % of carbon (Castellanos *et al.*, 2000).

Total nitrogen (TN) was determined by the semi-micro K method (Woerner, 1989), with a Micro Kjeldahl Rapid Still model, in which a digestion was produced by boiling 0.1 g of soil with 12 mL of H_2SO_4 and 0.3 g of mixture of catalyst of potassium sulphate and mercury oxide, subsequently distilled in an alkaline medium (NaOH) and collected using boric acid with an indicator, after which the TN was measured by means of titration with HCl 0.02 N. The C/N ratio was estimated with the data previously obtained for the SOC and TN.

Statistical analyses

The studied variables were analyzed statistically using a completely randomized design with a factorial arrangement by land uses (A, 4) and depth (B, 2), with four replications. The Kolmogorov-Smirnov normality test and Levene's homoscedasticity test were applied. The variables also underwent transformation of data of 1/x and a mean comparison with Tukey's test ($p \leq 0.05$) and Pearson correlations. All statistical analyses were carried out using the Statistical Package for the Social Sciences, version 17.0 for Windows (SPSS, 2009).

Results and Discussion

The results for the variables SOM, SOC, TN and C/N ratio, analyzed at the depths of 0-5 and 5-30 cm in the four types of land use, are shown in tables 1 and 2, respectively. In general, the soil depth of 0-5 cm, which belongs to the organic horizon, exhibited higher values for all variables in the various land uses, compared to the soil at a 5-30 cm depth.

The highest contents of SOM and SOC were registered in the thornscrub lands, at a 0-5 cm depth, with average values of 7.0 and 4.1 %, respectively, both of which are very high (Woerner, 1989). Conversely, the agriculture area had the lowest values of the four systems of land use, at the two depths: 2.46 and 2.1 for SOM, and 1.43 and 1.28 for SOC, respectively, that classifies it as of medium content. This decrease can be attributed to the processes associated with the agricultural practices. Typically, soils with crops contain about 1-3 % of SOC, while pastures and forest soils have higher values, according to the type of vegetation that they sustain (Jenkins, 1988).

The total content of nitrogen (TN) ranged between the average values of 0.14 % (agriculture, 5-30 cm) and 0.43 % (thornscrub, 0-5 cm). According to Fassbender (1987), the total N content in the soil has a broad range, but it is usually between 0.2 and 0.7 % for the so-called topsoil.

The order of content of SOM and TN for the different land uses at both depths was the following: Thornscrub > Pasture > Plantation > Agriculture.

The average values of C/N ratio ranged between 5.6 (thornscrub land 5-30 cm) and 10.4 (pasture 0-5 and 5-30 cm); in general, C/N ratio values between 4 and 12 indicate a well-balanced soil that is conducive to microbial activity (Kaye and Hart, 1997).

Table 1. Mean values (%) for the variables evaluated in the four systems of land use at a 0-5 cm soil depth (n=4).

Variable	Use	Mean	Median	Std Dev	Min	Max
SOM	Pasture	5.88	6.00	0.60	5.05	6.45
	Thornscrub	7.00	7.02	1.80	5.16	8.80
	Plantation	4.09	4.03	0.34	3.76	4.54
	Agriculture	2.46	2.53	0.19	2.18	2.61
SOC	Pasture	3.41	3.48	0.35	2.93	3.74
	Thornscrub	4.06	4.07	1.04	2.99	5.10
	Plantation	2.37	2.34	0.20	2.18	2.63
	Agriculture	1.43	1.47	0.11	1.26	1.51
TN	Pasture	0.33	0.33	0.03	0.30	0.35
	Thornscrub	0.43	0.40	0.12	0.31	0.59
	Plantation	0.27	0.26	0.02	0.25	0.29
	Agriculture	0.16	0.16	0.01	0.15	0.18
C/N	Pasture	10.37	10.42	0.58	9.66	10.96
	Thornscrub	9.59	9.52	0.78	8.72	10.61
	Plantation	8.91	8.83	0.49	8.47	9.53
	Agriculture	8.77	8.39	0.99	8.10	10.20

SOM = Soil organic matter; SOC = Soil organic carbon; TN = Total Nitrogen; C/N = Carbon/Nitrogen Ratio; Std Dev =Standard deviation; Min = Minimum; Max = Maximum.

Table 2. Mean values (%) for the variables evaluated in the four systems of land use at a 5-30 cm soil depth (n=4).

Variable	Use	Mean	Median	Std Dev	Min	Max
SOM	Pasture	3.31	3.36	0.54	2.61	3.92
	Thornscrub	3.39	3.44	1.46	1.75	4.94
	Plantation	2.91	3.01	0.27	2.52	3.12
	Agriculture	2.21	2.11	0.29	1.99	2.63
SOC	Pasture	1.92	1.95	0.31	1.51	2.27
	Thornscrub	1.97	2.00	0.84	1.01	2.87
	Plantation	1.69	1.75	0.16	1.46	1.81
	Agriculture	1.28	1.22	0.17	1.15	1.53
TN	Pasture	0.19	0.19	0.01	0.17	0.20
	Thornscrub	0.42	0.29	0.31	0.21	0.88
	Plantation	0.19	0.20	0.02	0.17	0.20
	Agriculture	0.14	0.15	0.02	0.12	0.16
C/N	Pasture	10.36	10.14	1.55	8.72	12.45
	Thornscrub	5.58	5.58	2.43	3.26	7.90
	Plantation	8.91	8.86	0.14	8.80	9.12
	Agriculture	9.13	9.11	1.56	7.45	10.86

SOM = Soil organic matter; SOC = Soil organic carbon; TN = Total Nitrogen; C/N = Carbon/Nitrogen Ratio; Std Dev =Standard deviation; Min = Minimum; Max = Maximum.

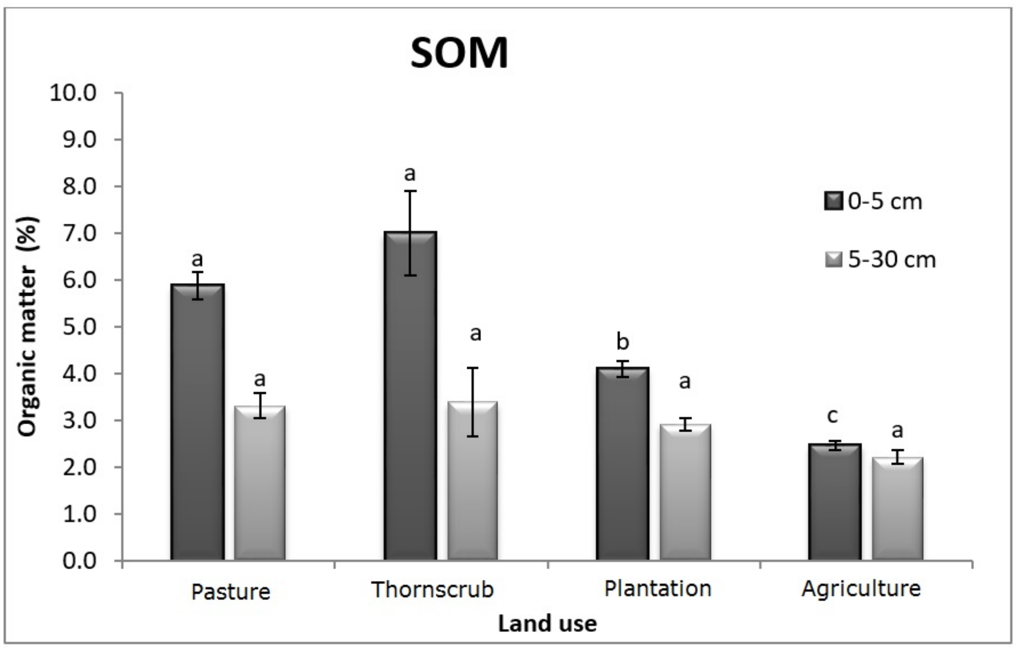
Based on the variance analysis, significant differences were obtained for the variables SOM, SOC, TN and C/N for the land use factor (FA), and for the depth factor (FB). Only the C/N ratio did not differ; instead, it was the only one that exhibited differences for the FA*FB interaction (Table 3).

Table 3. Results of the analysis of variance for the model with two criteria for classification (land use and soil depth) and the Levene's contrast.

Variable	Model $F_{(7, 24)}$	FA[a] $F_{(3,24)}$	FB[b] $F_{(1, 24)}$	FA*FB $F_{(3, 24)}$	*Levene's* Test[c] $F_{(7, 24)}$	Adjusted R^2
SOM [d]	9.772	13.191	24.077	1.584	4.474	0.665
	(0.000)	(0.000)	(.000)	(0.219)	(0.003)	
SOC[d]	9.649	23.745	18.92	1.566	4.459	0.661
	(0.000)	(0.000)	(0.000)	(0.223)	(0.003)	
TN [d]	19.069	33.788	26.858	1.754	1.978	0.803
	(0.000)	(0.000)	(0.000)	(0.183)	(0.101)	
C/N [d]	5.614	6.389	4.154	5.326	6.803	0.510
	(0.001)	(0.002)	(0.053)	(0.006)	(0.000)	

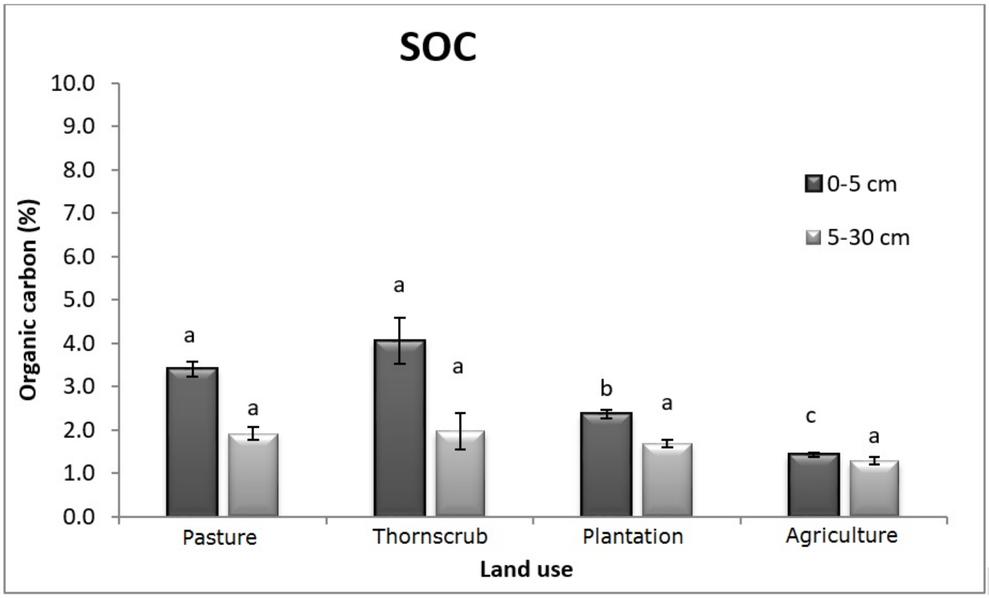
FA[a] = land use; FB[b] = Depth; [c] = For testing the null hypothesis of homogeneity of variances; [d] = In brackets provides the value of p; SOM = Soil organic matter; SOC = Soil organic carbon; TN = Total Nitrogen; C/N = Carbon/Nitrogen Ratio.

The Tukey's test for the SOM and SOC variables showed differences only for the depth 0-5 cm. The thornscrub lands and pasture were the systems with the highest contents of SOM and SOC. They were followed, in decreasing order, by the plantation and the agricultural system, the latter of which had the lowest values (figures 2 and 3). According to Llorente (2004), in a Vertisol under three land uses (agricultural, thornscrub and secondary vegetation), the SOC differed between the land uses only at the first 20 cm of depth, but were equal at the subsequent five depth levels, up to 70 cm. His results indicate that the thornscrub was the system with the highest content of SOC, while the agricultural lands had the lowest content.



Means with different letters at the same depth are statistically different (Tukey $p \leq 0.05$).

Figure 2. Mean values of the content of soil organic matter (%) at the 0-5 and 5-30 cm depths for the four types of land use.



Means with different letters at the same depth are statistically different (Tukey $p \leq 0.05$).

Figure 3. Mean values of the content of soil organic carbon (%) at the 0-5 and 5-30 cm depths for the four types of land use.

Soil carbon sequestration and the influence of management practices have been well documented (Nair *et al.*, 2015). In this regard, Diacono and Montemurro (2010) cite that the changes in land use cause effects on the biotic and abiotic properties of the soil as well as changes in the composition of the microbial communities. Thus, the use of the land during the last decades particularly for agriculture has caused a change in the quality of the soil and a reduction of its fertility (Anderson, 2003). SOC, through its effects on the physical, chemical and biological properties of the soil, has proved to be the main determinant of its productivity (Martínez *et al.*, 2008).

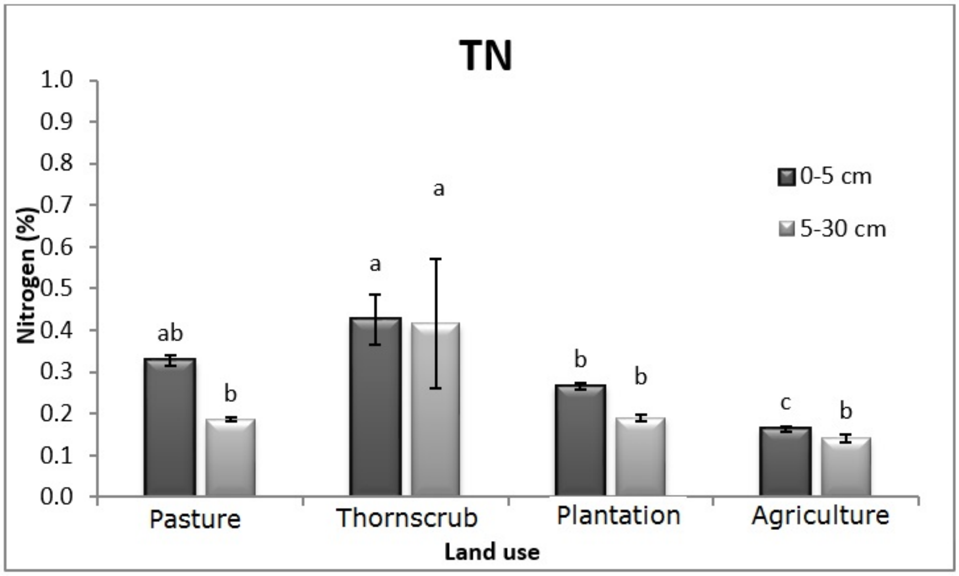
The results for SOC in the thornscrub lands and pastures contrast with those cited by Campo *et al.* (2016), who observed that the conversion of forest to pasture appears to increase carbon storage in the soils of the dry tropics of Mexico. However, according to Ross *et al.* (1999), the soils of New Zealand exhibited only small changes in their total carbon content after the conversion of pastures to pine forests. Mendham *et al.* (2003) documented that the change of land use from native vegetation to pasture or from pasture to plantations in south west Australia did not significantly affect the average carbon content at the surface horizon (0-5 cm) or at depths of more than 20 cm. However, Vela *et al.* (2012) reported similar results to those of the present research and point out that the natural sacred fir forests contain more SOC (145.6 Mg ha^{-1}) than the areas reforested with pine trees (119.4 Mg ha^{-1}), while these, in turn, have higher SOC contents than the pastures (90.0 Mg ha^{-1}) and the agriculture lands (46.1 Mg ha^{-1}).

On the other hand, Zabala and Gómez (2010) evaluated the microbial diversity in native savanna ecosystems converted to pine tree plantations and proved that ectomycorrhizal fungi can contribute to increase the carbon content of soil.

The results of the comparison of mean values for NT showed differences between the use of soil in the two depths under study. At the depth of 0-5 cm, the thornscrub lands and pastures exhibited the highest values, of 0.43 and 0.33 per cent, respectively, while the agricultural system had the lowest N content (0.14%).

Again, at a depth of 5-30, the thornscrub exhibited the highest N content (0.42%); the pasture, plantation and agriculture lands registered statistically lower and equal contents (Figure 4). These results are consistent with Carvajal (2008), who determined that the carbon and nitrogen contents vary according to the soil depths in such land uses as pastures, in the surface layer (0-10 cm) of which the largest amounts of these elements were stored, unlike what happened in a plantation of a Colombian variety of coffee, where these elements were distributed across the entire profile. Likewise, Lawal *et al.* (2009) observed that the TN in an Alfisol in Nigeria decreased when the native vegetation was replaced by a plantation of eucalyptus, but increased when it was changed to an agricultural system; furthermore, they point out that this was due to the effect of the fertilizers used in agriculture.

According to Gol (2009), in Turkey, the conversion of natural forest to continuous agriculture causes statistically significant decreases in SOM and TN.



Means with different letters at the same depth are statistically different (Tukey $p \leq 0.05$).

Figure 4. Mean values of the content of soil nitrogen (%) at the depths of 0-5 and 5-30 cm for the four types of land use.

Thornscrub appears to be the land use system that redistributes the TN at both soil depths, probably due to the presence of species of the Fabaceae family, which provide nitrogen via their dead leaves and which constitute 25 % of the total number of species (González *et al.*, 2011). Furthermore, they are associated with the potential ability to fixate the symbiotic nitrogen (Zitzer *et al.*, 1996).

Based on the classification by Woerner (1989) for the assessment of SOM and TN, the resulting values ranged between medium and very high in vertisols with a typical clayey texture. The category of very high content of organic matter and nitrogen corresponded to the thrornscrub site, while the agricultural area had a medium content of organic matter and an adequate nitrogen content. Although the organic matter content did not register differences for the 5-30 cm depth, it turned out to be medium for the pasture, the plantation and the agricultural use; only the thornscrub vegetation had a high content (Table 4).

Table 4. Assessment of the content of organic matter and nitrogen, according to the classification by Woerner (1989).

Land use	**SOM**		**TN**	
	0-5 cm	**5-30 cm**	**0-5 cm**	**5-30 cm**
Pasture	VH ^{c}	M ^{a}	H ^{ac}	AD ^{ab}
Thornscrub	VH ^{c}	M ^{a}	VH ^{c}	VH ^{b}
Plantation	H ^{b}	M ^{a}	H ^{b}	AD ^{ab}
Agriculture	M ^{a}	M ^{a}	AD ^{a}	AD ^{a}

Different letters within the column indicate differences between the land use systems (Tukey $p \leq 0.05$)

M = Medium; AD= Adequate; H= High; VH= Very High.

Soils are estimated to contain twice as much carbon dioxide from the atmosphere, and the amount stored in the soil depends on the balance between the input of C from the leaf litter and the detritus of the roots and the output of C due to the soil respiration (Sofi *et al.*, 2016). Thus, an indirect way to determine a sensitive response of the microbial activity is through the measurement of the basal respiration, because the flow of CO_2 represents an integrated measurement of the root respiration, the fauna, the soil micro-organisms and the carbon mineralization from different fractions of organic matter (Acuña *et al.*, 2006).

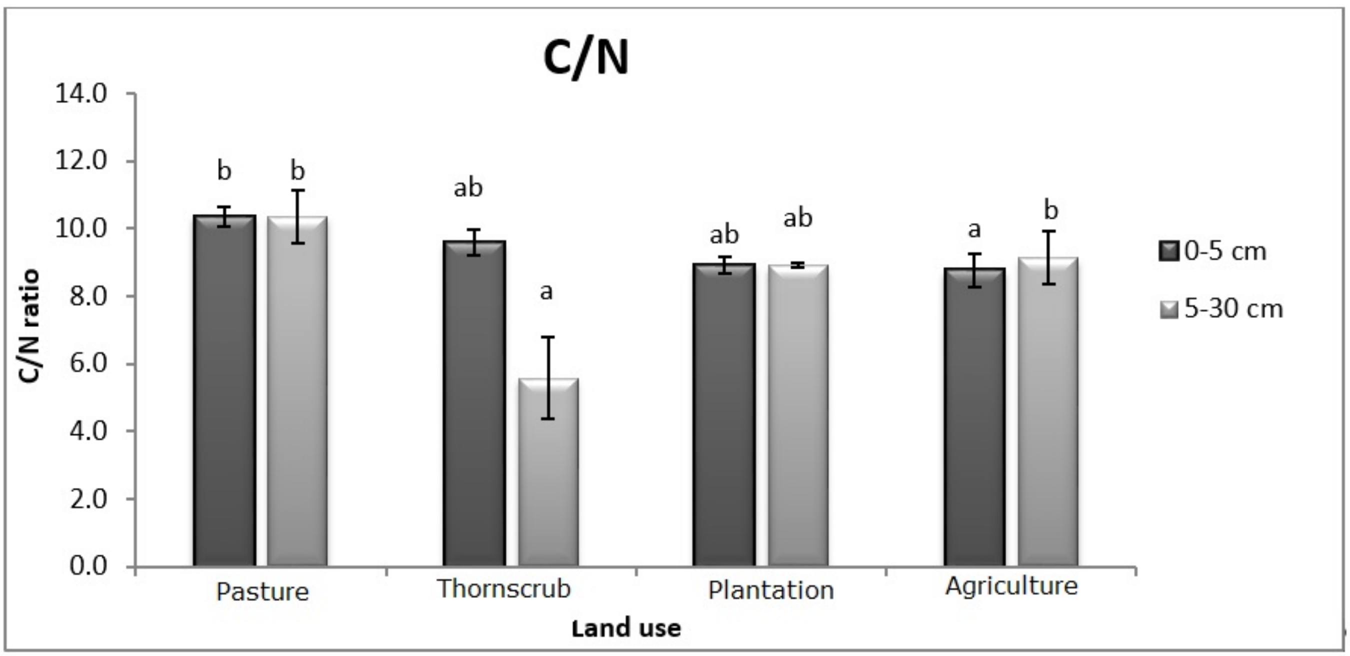
In the same study site in *Linares*, NL, Cantú *et al.* (2010) and Yáñez *et al.* (2017) measured CO_2 emissions of the Vertisol soils under different land use systems; these authors indicate a decrease in emissions of CO_2 in the agricultural system, unlike in the pasture and thornscrub systems. According to the results of the present research, the land use systems with the highest SOM and TN contents have a greater respiration and microbial activity.

The losses of SOC and TN attributable to changes of land use from thornscrub to some other system ranged between 2.4 % and 66 %, and the SOM was reduced mainly at the 0-5 cm depth, while the TN registered the largest reductions at the 5-30 cm depth. The agricultural system was the one with the greatest loss (Table 5). Very similar results were documented by Abera and Belachew (2011) in Bale, Ethiopia, when the SOC and TN contents were analyzed for different land use systems. Likewise, Vásquez and Macías (2017) determined an average loss of 26 % of the total carbon in agricultural soils with crops compared to forest soils. According to Llorente (2004), a submontane shrub on vertisols, when converted to an agricultural system, evidenced a loss of 37 % of SOC at the first 20 cm of depth, and the thornscrub was the land use system with the highest TN content.

Table 5. Loss of SOC and TN (%) at the depths of 0-5 and 5-30 cm by effect of the change of land use in relation to the thornscrub.

Land use	**SOC (%)**		**TN (%)**	
	0-5 cm	**5-30 cm**	**0-5 cm**	**5-30 cm**
Pasture	16	2.5	23	55
Plantation	42	14	37	55
Agricultural	65	35	63	66

The C/N ratio, in general, was low for all systems of land use, with variations between 5.6 (thornscrub) and 10.3 (pasture); this is considered to be a good proportion for the mineralization of the SOM. The Tukey's test indicated significance for the two depths. At the 0-5 cm depth, the agricultural use exhibited the highest C/N ratio (8.7), equal to that of the plantation and the thornscrub, but different from that of the pasture (10.3). Conversely, at the 5-30 cm depth, the thornscrub had the best C/N ratio (5.6), unlike the pastures and agricultural lands, which had 10.3 and 9.1, respectively (Figure 5).



Means with different letters at the same depth are statistically different. (Tukey $p \leq 0.05$).

Figure 5. Mean values of the C/N ratio at the 0-5 and 5-30 cm depths for the four types of land use.

The Pearson correlation between the SOC and nitrogen contents at the two depths was high, while correlation between the C/N ratio and the nitrogen content occurred only at the depth of 5-30 cm (Table 6).

Table 6. Pearson correlation matrix for the variables SOC, TN and C/N ratio, for the two soil depths.

Depth		**SOC**	**TN**	**C/N**
0-5 cm	SOC	1	0.000	0.018
	TN	0.973**	1	0.123
	C/N	-0.582*	-0.401	1
5-30 cm	SOC	1	0.032	0.480
	TN	0.536*	1	0.005
	C/N	-0.190	0.668**	1

* The correlation is significant at the level of ($p \leq 0.05$);** The correlation is significant at the level of ($p \leq 0.001$).

Conclusions

Results indicate that a Vertisol under different land use systems exhibits differences in contents of SOM, SOC and TN, and in the C/N ratio.

The perceptible changes in the fertility of the Vertisol soil as a result of the land-use practices, revealed a medium (agriculture) to very high (thornscrub and pasture) SOM content, while for the TN the content ranges between adequate (agriculture) and very high (thornscrub). The C/N ratio, in general, is low for all land use systems, ranging from 5.6 (thornscrub) to 10.3 (pasture), which is a good proportion for the humidification and mineralization of the SOM.

The losses of SOM and TN due to the changes in land use from the thornscrub to a different land use system varies from 2.4% to 66%. The SOM is reduced mainly at the depth of 0-5 cm, while the TN exhibits the greatest reductions in the depth of 5-30 cm. The agricultural system exhibited the loss of SOM and TN at both depths.

No differences were found between the SOM and the SOC at the depth of 5-30 cm for the different land uses. The SOM and TN contents at both depths for the different land uses follow this order: Thornscrub > Pasture > Plantation > Agriculture.

The land use systems influence the SOC and the TN contents in vertisols; as a result, agricultural soils exhibit lower levels than the rest of the land use systems, even when zero tillage is applied. This suggests the need for more sustainable agricultural systems, such as crop rotation and the addition of organic matter and crop residues to reverse the situation.

The variation in the SOC and TN contents between the different land use systems was minimal at the bottom layer of the soil compared to its superficial layer, which implies that the surface layer of the soil is the one most affected by management practices. Based on these conclusions, it is necessary to develop an appropriate policy of land use and a sustainable agricultural and soil management in order to fight land degradation and improve soil fertility in the study area.

Acknowledgments

The authors thank Conacyt (Doctoral Scholarship) and the U*niversidad Autónoma de Nuevo León* (project PAICYT CT263-15) for the support provided for the present research. They are also grateful to Rodolfo A. Martínez Soto for the technical assistance he provided both at the laboratory and in field. In addition, they wish to thank two anonymous reviewers who enriched and made critical comments to the present manuscript.

Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Israel Cantú Silva: design of the experiment, statistical analysis and interpretation of the results, design and editing of the manuscript; María Inés Yáñez Díaz: development of the research in field and at the laboratory, and structure, design and revision of the manuscript.