Egypt. J. Soil Sci. **Vol. 64**, No. 3, pp: 1305 - 1314 (2024)

Egyptian Journal of Soil Science

http://ejss.journals.ekb.eg/

Impacts of land use change on carbon and nitrogen stocks in an Andosol in Michoacan, Mexico

Israel Cantú Silva[1] and **Silvia Janeth Bejar Pulido***[2]

[1] *Faculty of Forestry Sciences, Autonomous University of Nuevo Leon, Linares, México*
[2] *TECNM/ Instituto Tecnologico de El Salto, Durango, Mexico*

Changes in vegetation and land use alter the biogeochemical cycles of soil C and N, as a result of agricultural practices that alter soil quality and function. Adopting sustainable agricultural practices improves soil health by increasing its capacity to store C in the long term. The objective of this study was to evaluate the content and stocks of C and N and the C:N ratio, under different land uses in an Andosol. Four composite soil samples were collected in a pine-oak forest, conventional avocado, organic avocado and organic macadamia soil uses at 0-20 and 20-40 cm soil depths (n=32). The total C content was determined by the Walkley and Black method (Woerner, 1989), the total N by the Kjeldahl method with the Velp Scientifica's UDK159 model equipment (Bremner and Mulvaney 1982). In order to detect significant differences, a two factor analysis of variance (ANOVA) was applied C (%), N (%), SOC (Mg ha^{-1}), Nt (Mg ha^{-1}) and C:N ratio variables. When applied, a Tukey comparison of means ($p \leq 0.05$) was performed. The results indicate that conventional avocado land use presented the highest C and N content at both soil depths (C: 9.22 and 7.32%, N: 0.70 and 0.40%), while the C:N ratio was higher in the forest land use in the first depth (14.5) and higher in the organic avocado land use in the second soil depth (25.8). The stock of SOC varied from 65.27 to 267.30 (Mg ha^{-1}) and the Nitrogen from 4.61 to 14.61 (Mg ha^{-1}). The C:N ratio showed significant variations between land uses, specifically in the first depth it ranged from 10.33 (O. Macadamia) to 14.51 (Forest), while in the second depth it varied from 13.09 (Conventional) to 25.83 (O avocado). The pine-oak forest, organic avocado and organic macadamia systems, with the smallest reseivors, were statistically similar only in C content, while the conventional system, with the largest stocks, was differente in C and N content. The change in land use from forest to agricultural caused a significant effect on the carbon and nitrogen content and the stocks in the Andosol soil, which may be attributes to the different agricultural applied practices such as pruning, pesticides and fertilization used in the organic and conventional regimes, respectively.

The C:N ratio indicates that mineralization rates decrease as depth increases because the quantity and quality of soil organic matter also decreases. Specifically, the conventional avocado practice compared to organic avocado and macadamia practices maximized crop yields.

Keywords: avocado orchard, C:N ratio, conventional management, forest use, *Persea americana*, SOC, Uruapan.

1. Introduction

Soil Carbon (C) and Nitrogen (N), as responsible for vegetation growth, are considered as indicators of soil quality and sustainable management (Gamarra et al., 2018). Di Gerónimo et al. (2018) point out that both elements in the soil can define soil structure, nutrient availability, water retention, and microbial activity. Specifically, C and N stocks are subject to environmental conditions, topographical conditions, management practices and the type of vegetation that defines the quality and quantity of organic matter deposited on the soil (Suárez et al., 2015; Cantú & Luna 2022). In this sense, the amount of carbon stored in the first meter of soil depth double and triple that stored by the atmosphere and vegetation, respectively, being important for climate change mitigation. On the other hand, the availability of N is the main limitation in many ecosystems (Cerón and Aristizábal, 2012). Batjes

*Corresponding author e-mail: siljan2411@gmail.com
Received: 26/04/2024; Accepted: 25/06/2024
DOI: 10.21608/EJSS.2024.285526.1757

(2014) estimated between 133 and 140 Pg in the same depth interval.

In addition to the above, the relationship between soil C:N is a key indicator of soil quality, health and productivity: In particular, this indicator defines the rate of nitrogen mineralization for plants, where high values indicate that the decomposition of soil organic matter is slow (>14), since the available nitrogen is immobilized by microorganisms, so it cannot be assimilated by plants. On the other hand, ratios ranging from 10 to 14 reflect a rate of rapid mineralization that generates enough N for microorganisms and vegetation (Gamarra et al., 2018).

However, worldwide, changes in land use are considered as one of the main actions that alter the condition of the soil; for example, agriculture is one of the main activities that exert the greatest pressure on the soil due to the excessive use of chemicals, intensive tillage, use of heavy machinery, among others, which affect their management and productivity in the short-term (Cristóbal-Acevedo et al., 2019; Somoza and Vázquez, 2023;). The agriculture is commonly based on organic and conventional management practices that causes changes in soil physics, chemistry and biology propierties. Conventional practices can cause soil degradation, as a result of the accumulation of soluble salts, compaction, loss of soil structure, and nutritional deficit (Mogollón et al., 2014). Meanwhile, organic practices have a positive effect on soil properties, increasing the amount of carbon and organic matter in the soil, as well as nitrogen. They improve cation exchange capacity and electrical conductivity and decrease pH, although nutrient availability is reduced (Sihi et al., 2017). However, Timsina (2018) points out that chemical fertilization is strongly criticized because it is assumed that it does not allow the accumulation of MOS, but some evidence has shown that the appropriate dosage of inorganic fertilizers maximizes the capacity to accumulate MOS and increase microbial biomass growth (Akinnifesi et al., 2010; Bijay-Singh, 2018).

In Mexico, the production of avocado trrought the conventional management contribute with the 97% (2.4 million tons), while organic management contributes with the 3% (84,952 tons) (SIAP, 2022). Avocado (*Persea americana* Mill) is one of the most sought-after food products worldwide (Agri-Food and Fisheries Information Service [SIAP], 2022). This triggered the change and use of land for the establishment of this crop. In addition to the above, avocado production is strongly criticized for environmental problems, mainly deforestation and water use (Rindermann et al., 2021). However, this crop is considered the main economic activity of the state.

Considering that agriculture is carried out through organic and conventional practices, the objectives of the present estudy were to determine the carbon and nitrogen stocks as well as the C:N ratio of an Andosol volcanic soil that has been subjected for more than 40 years to avocado production and was later compared with a forest area and to define the effect of land use change on these edaphic variables assuming that before being used for agricultural purposes they were representative forests of the region.

The application of organic amendments and inorganic fertilizers can cause a differential response in the C, N, C:N ratio variables of soil in agricultural uses with respect to forestry.

2. Materials and Methods

2.1. Description of the study area

The study was carried out in the Ejido "Toreo El Alto", located east of the municipality of Uruapan, Michoacán, at an altitude of 1890 m at the coordinates 19° 28' 22.2" N and 102° 00' 19.7" W, presenting a humid temperate climate with rains in the summer (Cw) (García, 2004) and a temperature between 10 and 27 °C, with an average annual rainfall of 1500 mm. The predominant soil is Andosol of volcanic origin formed mainly of volcanic glass (Fig. 1).

2.2. Land use systems

Pine-Oak Forest (Forest): This system, considered as the control treatment, is the natural vegetation of the region without management, represented by a mixture of species of the genus *Pinus* and *Quercus*.

Organic Management: Cultivation of *Macadamia integrifolia* Maiden & Betche (O. macadamia) and *Persea americana* Mill var. Hass (O. avocado) 40 years old. Using livestock compost ($N-P_2O_5-K_2O$ [39-37-29] + S [18.4%] + Mg [13.6] + Ca [74%]) in doses of 50 Mg ha^{-1}, applied for a period of three years.

Conventional management (C. avocado): *Persea americana* Mill var. Hass, 60 years old, which has been managed under a conventional system, using inorganic fertilizers and pesticides. The chemical fertilizers used are copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) 600 ml ha^{-1} as a preventive fungicide and bactericide and a foliar fertilizer $CO(NH_2)_2$, (20-30-10) at a dose of 3 kg ha^{-1} every two months and a granular extended-release fertilizer (15-00-00 + 26.6 [CaO] + 0.3 [B]).

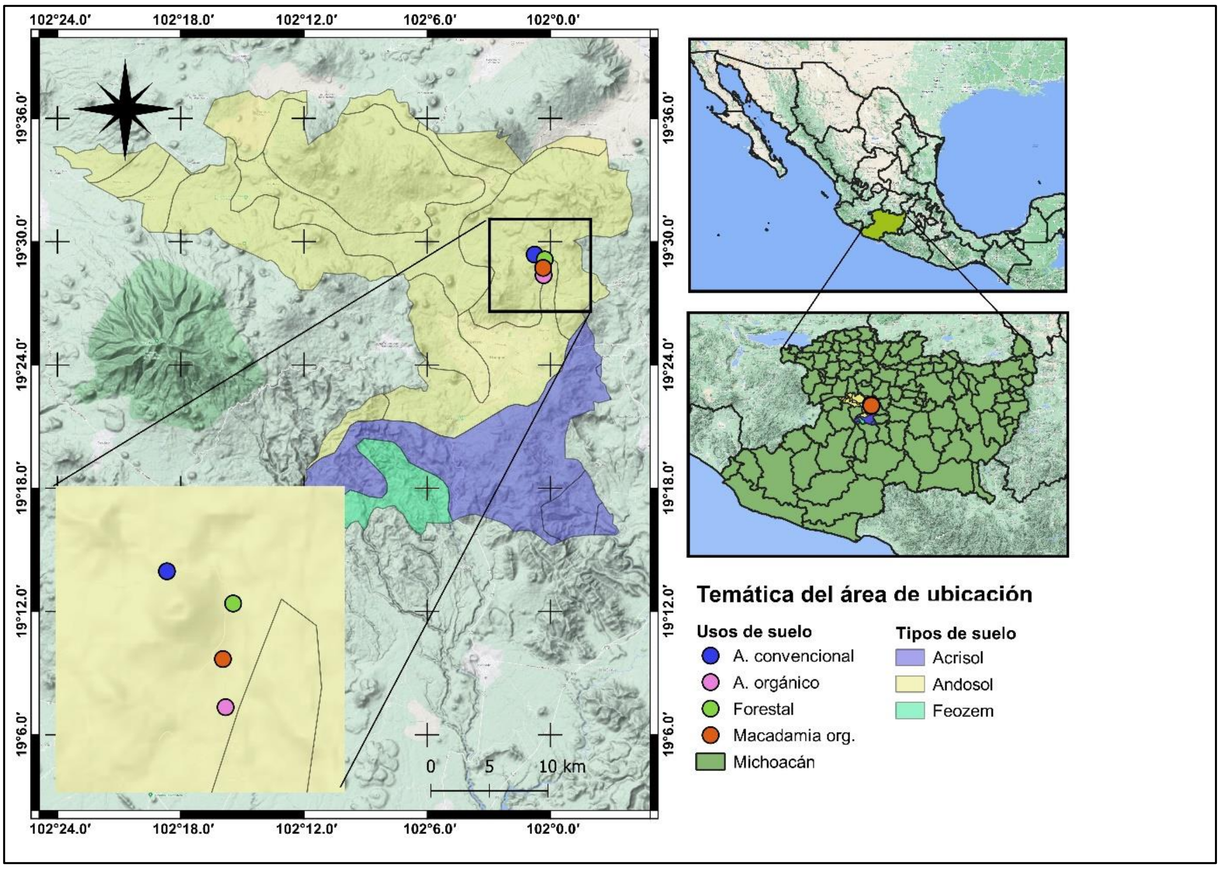

Fig. 1. Location of the study area Ejido "Toreo El Alto", Uruapan, Michoacan, Mexico.

2.3. Soil sampling

Based on the soil characteristics of Andosol that include a deep surface horizon and high organic matter contents, eight composite soil samples (combination of four individual subsamples, taken in the same land use, to obtain approximately 1 kg of soil) were collected at two depths (four of 0-20 cm and four of 20-40 cm) at each of the sites for a total of 32 samples (Luna et al., 2024). The samples were packaged and classified to be taken to the Soil Laboratory of the Faculty of Forestry Sciences, where they were air-dried and later sieved with a 2 mm metal mesh and stored for later analysis.

2.4. Carbon and Nitrogen soil contents

The organic carbon content in the soil was determined through the Walkley and Black method modified by Woerner (1989) and the total nitrogen was determined by the Kjeldahl digestion method, using a Velp Scientifica model UDK159 distiller-titrator equipment (Bremner and Mulvaney 1982).

2.5. Carbon and nitrogen stocks

To determine the stock of Carbon and Nitrogen, the following equations were used:

$$SOC = (Mg\ ha^{-1}) = C\ (\%) * Bd\ (g\ cm^{-3}) * D\ (cm)$$

$$Nitrogen = (Mg\ ha^{-1}) = N\ (\%) * Bd\ (g\ cm^{-3}) * D\ (cm)$$

Where: C (%) and N (%) is the percentage of Carbon and Nitrogen in the soil, respectively. Bd is the bulk density (g cm^{-3}) and D the depth of the sample (cm) (Cantú & Luna, 2022).

2.6. Statistical analyses

All variables were tested for normality and homogeneity of variance (*n=32*). In order to detect significant differences, a two-way variance analysis (ANOVA) was applied to the variables C (%), N (%) C:N ratio, COS y Nt were land use and soil depth were the factors. After of analysis of variance procedure a Tukey comparison test of means was performed ($p \leq 0.05$). The analysis were done with the SPSS statistical package (SPSS Inc., Chicago, IL) (International Business Machines [IBM, 2013]).

Also, the relationship between C, N, C:N ratio, COS y Nt was analyzed using the Pearson correlation method con el software Rstudio (Rstudio Team, 2015).

3. Results

3.1. C and N soil contents

The analysis of variance showed highly significant differences ($p \leq 0.01$) in the content of C, N and the

C:N ratio, for the factor of land use and depth, as well as in their interaction (Table 1).

Table 1. Two-way ANOVA for the C, N, C:N variables of an Andosol under different land use (FA) and soil depth (FB).

Variables	Units	FA $F_{(3,24)}$	FB $F_{(1,24)}$	FA*FB $F_{(3,24)}$	Levene (*P* value)	R^2
C	%	33.406	75.530	5.082	0.368	0.81
		(0.000)	(0.000)	(0.000)		
N	%	18.963	140.642	3.054	0.857	0.92
		(0.000)	(0.000)	(0.003)		
C:N		13.357	64.106	12.622	0.59	0.82
		(0.000)	(0.000)	(0.005)		

The value of p (p≤0.05) is presented in parentheses, C=Carbon, N=Nitrogen, C:N=Carbon/Nitrogen ratio.

In Tukey's test (p≤0.05) it can be identified that the C averages are statistically different between land uses: C. avocado showed the highest C content, while the O. macadamia, O. avocado and forest systems were similar for both soil depths (Table 2).

The results of the present study suggest that the application of organic amendments did not cause a significant change in the contents of C and N in the soil with respect to the natural (forest) ecosystem, which may be attributed to a poor quality of the organic materials used for the preparation of the amendments.

In general, N contents ranged from 0.47 to 0.70% and from 0.17 to 0.40%, for the first and second depths, respectively (Table 2). Of the land uses studied, C. avocado presented the highest values of N at both depths.

On the other hand, a decrease in N could be observed as the depth of the soil increases for all areas.

The C:N ratio showed significant variations between land uses, specifically in the first depth it ranged from 10.33 (O. Macadamia) to 14.51 (Forest), while in the second depth it varied from 13.09 (Conventional) to 25.83 (O avocado) (Table 2).

The values of the present study are in an average relationship of 12.2 and 18.1 for the first and second depths. This indicates that the rate of mineralization for Andosol with and without agricultural practices (organic and conventional) can be considered as moderately optimal.

Table 2. Minimum (Min.), maximum (Max.), mean (n = 4) and standard deviation (SD) of the contents of C, N and C:N ratio in the plots under different land uses.

Variable	Soil management	Depth (0-20 cm)				Depth 20-40 (cm)			
		Min	Max	Media	SD	Min	Max	Media	SD
C (%)	Forest	6.00	8.38	7.55a	1.12	4.29	4.83	4.54a	0.22
	C. avocado	8.84	9.70	9.22b	0.38	6.66	7.68	7.32b	0.45
	O. avocado	4.68	6.23	5.25c	0.69	4.01	4.95	4.48a	0.66
	O. macadamia	6.74	7.75	7.12a	0.43	3.74	4.91	4.25a	0.60
N (%)	Forest	0.44	0.59	0.52a	0.06	0.26	0.35	0.30a	0.04
	C. avocado	0.65	0.78	0.70b	0.06	0.32	0.47	0.40a	0.06
	O. avocado	0.41	0.61	0.47a	0.09	0.15	0.19	0.17b	0.03
	O. macadamia	0.54	0.88	0.69b	0.17	0.32	0.33	0.32a	0.01
C:N	Forest	13.57	16.54	14.51a	1.37	13.76	16.26	14.88a	1.26
	C. avocado	11.96	13.74	13.09a	0.81	16.38	20.69	18.54b	1.80
	O. avocado	10.27	12.64	11.17b	1.05	25.44	26.23	25.83c	0.55
	O. macadamia	8.00	12.52	10.33b	2.00	11.40	15.13	13.07a	1.89

Table 3 shows the data on crop yields, indicating a significant increase in yields resulting from the application of conventional agricultural practices in comparison to those achieved through organic management.

Table 3. Effect of organic management and convention on the yield of avocado and macadamia crops.

Land use	Management	Density (Trees/ha^{-1})	Yields (Mg ha^{-1})	Manipulation time (Years)
Forest	N.A.	600	N.A.	N.A.
C. avocado	Conventional	100	15	60
O. avocado	Organic	100	6.2	40
O. macadamia	Organic	100	3.2	40

N.A. Not applicable

3.2. Soil organic carbon and total nitrogen stocks

The analysis of variance showed highly significant differences (p≤0.01) in the SOC and Nt stocks between land uses and depth, in their interaction, only SOC showed significant differences (p≥0.05), while Nt was statistically the same (Table 4).

Table 4. Two-way ANOVA for SOC and Nitrogen stock in an Andosol under different land use (FA) and soil depth (FB).

Variables	Units	FA $F_{(3,24)}$	FB $F_{(1,24)}$	FA*FB $F_{(3,24)}$	Levene (*P* value)	R^2
SOC	Mg ha^{-1}	91.773	15.965	25.623	0.057	0.92
		(0.000)	(0.001)	(0.000)		
Nt	Mg ha^{-1}	24.084	68.281	2.570	0.079	0.82
		(0.000)	(0.000)	(0.078)		

Regarding the SOC and Nt reservoir, the use of conventional C. and O. avocado presented the highest and lowest values in both depth ranges (Table 5). Particularly, the Forestal and O. avocado uses presented a similar behavior at the two depths. In contrast, the organic management of macadamia where there is an increase compared to the aforementioned ones. The increase in the use of C. aguacate may be the result of adequate fertilization, which favored crop productivity.

Table 5. Minimum (Min.), maximum (Max.), mean (n = 4) and standard deviation (SD) of the SOC and Nt stocks in the plots under different land uses.

Variable	Soil management	Depth (0-20 cm)				Depth 20-40 (cm)			
		Min	Max	Media	SD	Min	Max	Media	SD
SOC (Mg ha^{-1})	Forest	57.67	76.85	68.98a	8.12	108.02	119.86	116.08b	6.14
	C. avocado	163.78	186.95	173.50c	9.75	110.91	147.10	133.65b	16.77
	O. avocado	56.14	83.68	65.37a	12.65	23.02	64.52	42.81a	19.83
	O. macadamia	94.38	107.91	101.96b	6.18	28.28	60.73	45.358a	15.19
Nt (Mg ha^{-1})	Forest	4.25	5.06	4.75a	0.38	1.39	4.24	3.26a	1.39
	C. avocado	12.04	14.29	13.28b	1.15	5.36	8.88	7.30b	1.46
	O. avocado	4.44	8.15	5.95a	1.60	1.66	2.54	2.11a	0.36
	O. macadamia	7.54	13.25	10.28b	2.66	2.19	4.35	3.45a	0.95

Means with different letters indicate the presence of significant differences according to Tukey's mean comparison test at P ≤ 0.05.

3.3. Cumulative SOC and nitrogen stock in the profile 0-40 cm

The analysis of variance for carbon and nitrogen stocks in the analyzed profile (0-40 cm) showed significant differences between land uses ($p \leq 0.01$) in Andosol (Table 6).

Table 6. One-way analysis of variance for the Carbon and Nitrogen reservoir in an Andosol.

Variable	Units	F value	Sig.	Levene *(P value)*
SOC	Mg ha^{-1}	65.124	0.000	0.438
Nt	Mg ha^{-1}	31.541	0.000	0.055

The SOC and Nt reservoir of Andosol were estimated in the 0-40 cm profile for each land use, adding the values for each depth. In particular, the C. avocado crop had the highest stocks for both SOC and Nt (Fig. 2). On average for the depth analyzed by land use, the organic carbon reservoir ranged from 108.18 to 307.16 Mg ha^{-1}.

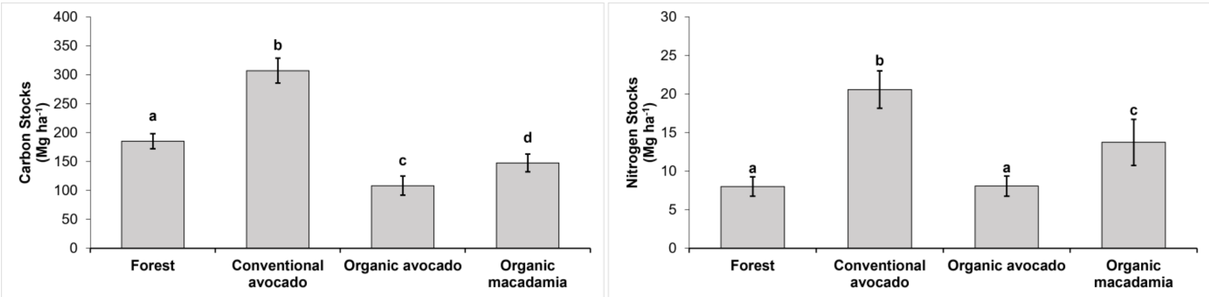

Fig. 2. Comparison of means for SOC and nitrogen stock between land uses. Tukey (p≤0.05).

The results of the present research showed that the avocado plantation with conventional management presented the highest N contents for both soil depths, trend may be influenced by fertilization and the type of crops, factors that alter the N cycle.

Although agricultural use with conventional management showed a high reserve of SOC, it cannot be assumed that it is an ideal practice for climate change mitigation, since if its application is not carried out properly it can have an impact on other ecosystem services such as water quality, food, and human health, it cannot be pointed out as a practice of high environmental impact. since there is no scientific evidence to show that chemical fertilizers, when applied in optimal doses, affect the structure and biology of the soil or reduce its water retention capacity, and highlight.

Pearson's correlation analysis reveals a strong positive association between C and N, COS, and Nt, alongside a moderate correlation with the C ratio. Similarly, Nt exhibits a strong positive correlation with COS, N, and C, but no correlation with the C ratio. Conversely, the C ratio demonstrates only a moderate positive correlation with C, without showing significant associations with the other variables (Fig. 3).

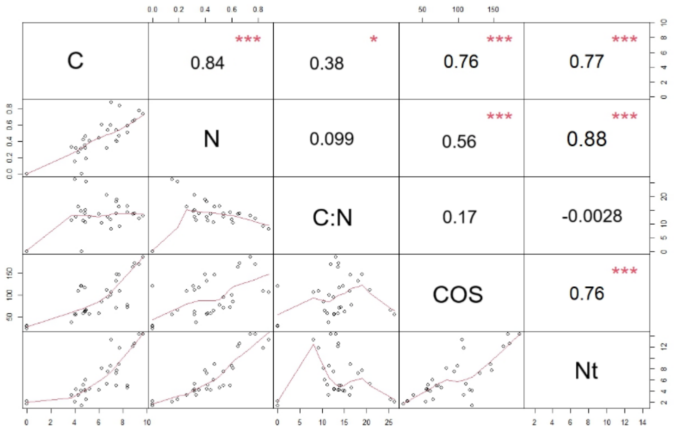

Fig. 3. Pearson correlation matrix for the variables C, N, C:N ratio, COS y Nt. Level of significance *** = p≤0.001; ** p≤0.01; * p≤0.05.

4. Discussion

The amount of carbon stored depends on the soil cover from aboveground biomass in addition to the agricultural practices that are implemented, for example, the additions of chemical and organic fertilizers can significantly modify the biomass and therefore the contributions of organic material on the soil (Porwollik et al., 2022). However, the use of organic amendments did not have such an effect on soil C and N contents compared to forest land use. on the other hand, the observed increase in conventional use may be associated with the effects of nitrogen fertilizers which are essential for plant growth, in addition to increasing the biomass and vegetative growth of plants significantly, which over time become substantial amounts of organic residues and exudates on the soil (El-Naqma et al., 2023).

Zhang et al. (2021) point out that the amounts of N in the soil are usually very low, except in those cases in which it has been fertilized with nitrogen fertilizers, where the constant accumulation of N exceeds the heterotrophic mineralization rate of the soil, immobilizing it for a medium term, the above coincides with the results of the present study where the land use of C. avocado was the one that obtained the highest contents. high N with respect to forestry and organic uses (Córdova et al., 2020).

Gaafar et al. (2021), suggest that the decrease in N is a function of depth and can decrease by up to 80%, because the surface layer is the most influenced by the additions of N from the organic waste that is Incorporate. This coincides with the results of the present study where there was a decrease in N contents as the depth of the soil increased in all the land uses analyzed.

The C:N ratio showed little variation in the first depth, finding values of 10 to 15, while in the second depth the variations increased or finding values from 13 to 26, and according to Zajícová and Chuman (2019) mineralization rates decrease as depth increases because the quantity and quality of soil organic matter also decreases.

According to Cantú & Luna et al. (2022) to define that the mineralization rate is optimal, the C:N ratio must correspond to an interval of 10 to 14. However, Batjes (1995) and Córdova et al. (202) determined that the rate of mineralization in Andosoles is higher compared to other soil types.

The implementation of inorganic fertilizers had a significant effect on the yield of avocado crops, on the contrary the application of organic amendments in which a low productivity of the O. avocado agroecosystem is observed. This coincides with Oliveira et al. (2021) who point out that the addition of nitrogen fertilizers improves crop growth and yields, in addition to influencing the growth of microbial populations, soil structure, and nutrient cycloping (Cui et al., 2021).

According to the results, the land use C. avocado presented the highest SOC and Nt reservoirs unlike the O. avocado with the lowest reservoirs as well as the forest land use that behaved similarly at both depths, this trend may be due to the quality of the organic matter of the forest and the quality of the organic amendment and the leaf litter of the crop (Lehmann et al., 2020). On the other hand, O. macadamia had an increase in its reservoirs , which suggests that the quality of organic matter is less recalcitrant (Ochoa et al., 2019). The increase in COS and Nt reservoirs in C. aguacate may be associated with the use of adequate fertilization, which in addition to favoring crop productivity is a secondary source of nitrogen supply for soil organisms; therefore, carbon compounds are available more immediately (Ruiz et al., 2000), directly reflected in SOC reserves in soil (Reyes et al., 2019).

The COS reservoirs ranged from 108.18 a 307.16 Mg ha^{-1} a value that corresponds to a soil with high carbon storage capacity, considering that soils at the national level and in the state of Michoacán store an average of 56 and 63.4 Mg ha^{-1}. respectively (Segura et al., 2005).

Regarding the N reserve, Cristóbal-Acevedo et al. (2011) mention that fertilizers generate a cumulative effect of N in the soil. In addition, they stimulate the growth of crops (biomass) from which a greater amount of residues accumulate due to pruning and leaf fall on the soil, increasing biological activity and therefore COS and Nt stocks (He et al., 2015).

According to Baldotto et al. (2015), forest soils can have a significant carbon stock due to constant litter production. However, Prescott and Vesterdal (2021) point out that its mineralization rate is very slow due to the quality of the organic matter, which has very recalcitrant characteristics (resin, lignin and cellulose). Similarly, several authors point out that ecosystems with native vegetation fix a greater amount of N in the soil (Wang et al., 2016), however, the land use C. avocado presented the largest reserves of Nt.

Timsina (2018) and Elbasiouny et al. (2019) point out that the use of inorganic fertilizers in the Americas is too low compared to other countries, however, the use of inorganic products has been strongly criticized for the long-term impacts it can generate on agroecosystems, despite the fact that conventional C. presented the largest reserves of SOC, It cannot be proposed as a model management, since its impact depends on the dosage of fertilizers. There are other alternatives such as the combination of organic and inorganic materials in different proportions that could result in a greater accumulation of MOS and therefore improve the reservoirs of COS and Nt in the cultivated soil (Bijay-Singh, 2018)

The correlations revealed a strong and positive association between all variables (C, N, COS, and Nt) with the exception of the C:N elation, which according to Forero et al. (2021), the low correlation between the content of C and N and the C:N ratio is influenced by other nutrients (Na, S, NO_3, NH_4, pH, Mg, Fe, Cu, Zn and B) that have a positive impact on the concentrations of Nt and SOC, highlighting their role as a source and store of these elements.

5. Conclusions

The change of land use from forest to agricultural caused a significant effect on the content and stocks of SOC and Nt in the Andosol type soil, which may be related to the different agricultural practices used by both organic and conventional regimes (pruning, pesticides, fertilization, among others).

Conventional practices maximized crop yields, compared to organic uses (O. avocado and O. macadamia), due to the implementation of inorganic fertilizers and the immediate availability of nutrients, maintaining soil health.

In general, despite the implementation of organic and conventional practices, Andosol has a high SOC reservoir capacity. Likewise, the C/N ratio can be considered as optimal in the different land uses.

The evaluation of carbon and nitrogen contents in the Andosol can establish diagnostic criteria to evaluate the impacts due to the change of land use from forest plantations to avocado and macadamia plantations, organic or conventional crop management, as well as pine-oak vegetation.

List of abbreviations:
C %: Carbon content
SOC: Soil Organic Carbon
N % Nitrogen content
Nt: Nitrogen
C:N: Ratio Carbon and nitrogen
$CuSO_4 \cdot 5H_2O$: Copper sulfate pentahydrate
$CO(NH_2)_2$: Urea
CaO: Calcium oxide
B: Boron

Declarations

Ethics approval and consent to participate

Consent for publication: The article contains no such material that may be unlawful, defamatory, or which would, if published, in any way whatsoever, violate the terms and conditions as laid down in the agreement.

Availability of data and material: Not applicable.

Competing interests: The authors declare that they have no conflict of interest in the publication.

Funding: Not applicable.

Authors' contributions: Authors ICS and SJBP They wrote, edited, and finalized the manuscript. All authors read and agree for submission of manuscript to the journal. as well as read and accept the submission of the manuscript to the journal.

Acknowledgments: The authors thank Ejido "Toreo el Alto" for facilities to obtain field information and CONAHCYT for its support in the development of this research.

References

Akinnifesi, FK, Ajayi, OC, Sileshi, G, Chirwa, PW, Chianu, J (2010). Fertiliser trees for sustainable food security in the maize-based production systems of East and Southern Africa. A review. Agronomy for sustainable development, 30, 615-629. https://doi.org/10.1051/agro/2009058

Baldotto MA, Vieira EM, Souza DDO, Baldotto LEB (2015). Estoque e frações de carbono orgânico e fertilidade de solo sob floresta, agricultura e pecuária. Rev. Ceres, 62, 301-309. https://doi.org/10.1590/0034-737X201562030010

Batjes NH (1995). Total carbon and nitrogen in the soils of the world. Eu. J. of Soil Sci.. 47 (2), 151-163. https://doi.org/10.1111/j.1365-2389.1996.tb01386.x

Bijay-Singh, B. (2018). Are nitrogen fertilizers deleterious to soil health?. Agronomy, 8(4), 48. https://doi.org/10.3390/agronomy8040048

Bremner JM, Mulvaney CS (1982). Nitrogen-Total. In: Page AL, Miller RH, Keeney KD (ed.). Methods of soil analysis part 2: chemical and microbiological properties. Agronomy Monograph Num. 9. 2nd ed. American Society of Agronomy and Academic Press. Madison, WI, USA. pp. 595-624.

Cantú SI, Luna REO (2022). Nitrogen storage and C:N ratio of an Umbrisol under forest management in Durango, Mexico. Mex. J.of For. Sci., 13(72), 82-111. https://doi.org/10.29298/rmcf.v13i72.1055

Cerón, RLE, Aristizábal, GF (2012). Nitrogen and phosphorus cycles dynamics in Soils. Revista colombiana de Biotecnología, 14(1), 285-295. http://www.scielo.org.co/scielo.php?pid=S0123-34752012000100026&script=sci_arttext

Cristóbal-Acevedo D, Tinoco-Rueda JÁ, Prado-Hernández JV, Hernández-Acosta E (2019). Soil carbon and nitrogen in tropical montane cloud forest, agroforestry and coffee monoculture systems. Rev. Chap. S. Cienc. For., 25(2).http://dx.doi.org/10.5154/r.rchscfa.2018.09.070

Cristóbal-Acevedo, D, Álvarez-Sánchez, ME, Hernández-Acosta, E, Améndola-Massiotti, R (2011). Concentración de nitrógeno en suelo por efecto de manejo orgánico y convencional. Terra Latinoamericana, 29(3), 325-332. https://www.scielo.org.mx/scielo.php?pid=S0187-57792011000300325&script=sci_arttext

Cui, J, Yuan, X, Zhang, Q, Zhou, J, Lin, K, Xu, J, ... Chen, Y (2021). Nutrient availability is a dominant predictor of soil bacterial and fungal community composition after nitrogen addition in subtropical acidic forests. *PLoS One*, *16*(2), e0246263. https://doi.org/10.1371/journal.pone.0246263

Di Gerónimo, PF, Videla, CDC, Laclau, P (2018). Distribution of carbon and organic nitrogen in particle size fractions of soils under grasslands, agriculture and afforestation. Ciencia del suelo, 36(1), 11-22. http://www.scielo.org.ar/scielo.php?pid=S1850-20672018000100002&script=sci_arttext&tlng=en

Elbasiouny, H, Elbehiry, F (2019). Soil carbon and nitrogen stocks and fractions for improving soil quality and mitigating climate change. Egyptian Journal of Soil Science, 59(2), 131-144. 10.21608/EJSS.2019.9984.1251

El-Naqma, Ramadan MSA and El-Sherpiny M.A. (2023). Effect of organic amendments and synthetic substances on copper availability, absorption, and wheat productivity. Egyptian Journal of Soil Science, 63(3), 429-442. 10.21608/EJSS.2023.220516.1614

Forero, SEA, Gambasica, NVP, Cruz, RK (2022). Relationship between nutrients and carbon, nitrogen and organic matter in soils of the banana zone of Colombia. *RIAA*, *3*(2), 7. https://doi.org/10.22490/21456453.5186

Gaafar, DE Baka, ZA, Abou-Dobara, MI, Shehata, HS, El-Tapey, HM (2021). Microbial impact on growth and yield of Hibiscus sabdariffa L. and sandy soil fertility. Egyptian Journal of Soil Science, 61(2), 259-274. 10.21608/EJSS.2021.84433.1457

Gamarra LC, Díaz LMI, Vera DOM, Galeano MDP, Cabrera CAJ (2018). Carbon-nitrogen relationship in soils of silvopastoral systems of the Paraguayan Chaco. Mex. J.For. Sci. 9(46), 4-26. https://doi.org/10.29298/rmcf.v9i46.134

García E (2004). *Modifications to the Köppen Climate Classification System.* Mexico DF.

He, YT, Zhang, WJ, Xu, MG, Tong, XG, Sun, FX, Wang, JZ, .. He, XH (2015). Long-term combined chemical and manure fertilizations increase soil organic carbon and total nitrogen in aggregate fractions at three typical cropland soils in China. *Science of the Total Environment*, *532*, 635-644. https://doi.org/10.1016/j.scitotenv.2015.06.011

International Business Machines (IBM) (2013). IBM SPSS Statistics for Windows, Version 22.0. IBM Corp. Armonk, New York. E.U.A. n/p.

Lehmann, J, Hansel, CM, Kaiser, C, Kleber, M, Maher, K, Manzoni, S, ... Kögel-Knabner, I (2020). Persistence of soil organic carbon caused by functional complexity. *Nature Geoscience*, *13*(8), 529-534. https://doi.org/10.1038/s41561-020-0612-3

Luna, REO, Hernandez, FJ, Cantu, SI, Bejar, PSJ, Dominguez, GTG (2024). Sequence of Soil Organic Carbon through the Silvicultural Development Method (MDS) in temperate forests of Durango, Mexico. Egyptian Journal of Soil Science, 64(3). doi: 10.21608/ejss.2024.271685.1729

Mogollón, JP, Vera, MC, Martínez, A (2015). Efecto de los plaguicidas sobre la calidad química y biológica del suelo en sistemas de producción de hortalizas del semiárido venezolano. Química Viva, 14(1), 69-89. https://www.redalyc.org/articulo.oa?id=8634067200

Oliveira, VA, Brasil, EPF, Teixeira, WG, Santos, FCVD, Silva, ARD (2021). Effects of Enhanced-Efficiency Nitrogen Fertilizers on Soil Microbial Biomass and Respiration in Tropical Soil Under Upland Rice Cultivation. *Journal of Agricultural Science*, *13*(6), 31. https://doi.org/10.5539/jas.v13n6p31

Porwollik, V, Rolinski, S, Heinke, J, von Bloh, W, Schaphoff, S, Müller, C (2022). The role of cover crops for cropland soil carbon, nitrogen leaching, and agricultural yields–a global simulation study with LPJmL (V. 5.0-tillage-cc). *Biogeosciences*, *19*(3), 957-977. https://doi.org/10.5194/bg-19-957-2022

Prescott, CE, Vesterdal, L (2021). Decomposition and transformations along the continuum from litter to soil organic matter in forest soils. For Ecol Manag 498: 119522. https://doi.org/10.1016/j.foreco.2021.119522

Reyes, PJL, León, LMA, Herrero, EG (2019). Influence of mineral fertilization on carbon sequestration in a pine plantation. *Revista mexicana de ciencias forestales*, *10*(51), 4-22. https://doi.org/10.29298/rmcf.v10i51.147

Rindermann, RS, Vázquez, RLE, Ayala, GAV, Rodríguez, NF, Gómez, TL and Cruz, RJA (2021). *Comparison of organic and conventional avocado production in Ario de Rodales, Michoacán*. *In:* Pérez, S., Figueroa, H., Jiménez, G., Godínez, M. and García N. (2021) Production and marketing. Mexican Association of Interdisciplinary Research A.C. (ASMIIA, A.C.) Mexico.

RStudio Team (2015). RStudio: Integrated Development Environment for R. Boston, MA. Retrieved from http://www.rstudio.com/

Ruiz, O, Aciego, J, Rivero, C, Ampueda, J (2000). Efecto de residuos de cultivo y fertilizantes químicos sobre el carbono y el nitrógeno de la biomasa microbiana en dos suelos venezolanos. *Venesuelos*, *8*(1 y 2), 2-9.

Segura-Castruita MA, Ortiz-Solorio CA, Sánchez-Guzmán P, Gutiérrez-Castorena M (2005) Organic carbon of the soils of Mexico. Latin American Terra, 23(1), 21-28. Avalaible at: https://www.redalyc.org/pdf/573/57323103.pdf

[Accessed february 11, 2024]

SIAP (Agri-Food and Fisheries Information Service) (2022). Statistical Yearbook of Agricultural Production. Avalaible at: https://nube.siap.gob.mx/cierreagricola/ [Accessed march 06, 2024]

Sihi, D, Dari, B, Sharma, DK, Pathak, H, Nain, L, Sharma, OP (2017). Evaluation of soil health in organic vs. conventional farming of basmati rice in North India. Journal of Plant Nutrition and Soil Science, 180(3), 389-406. https://doi.org/10.1002/jpln.201700128

Somoza, A, Vázquez, P (2023). Spatiotemporal variation of organic carbon stock and its relationship with changes in land use. Tandil District, Austral Pampas Region, Argentina. Geog. J. of Cent. Ame., (70), 476-513. http://dx.doi.org/10.15359/rgac.70-1.18

Suárez, G, Campos, A, Cruz, L (2015). Soil Carbon and Nitrogen Dynamics in Dry Tropical Coastal Ecosystems (CICOLMA), Veracruz, Mexico. Tropical and Subtropical Agroecosystems, 18(3), 347-361. https://www.redalyc.org/pdf/939/93944043009.pdf

Timsina, J (2018). Can organic sources of nutrients increase crop yields to meet global food demand?. *Agronomy*, *8*(10), 214. https://doi.org/10.3390/agronomy8100214

Woerner M (1989) *Chemical methods for the analysis of limestone soils in arid and semi-arid areas*. Linares, Nuevo León, México.

Zajícová K, Chuman T (2019) Effect of land use on soil chemical properties after 190 years of forest to agricultural land conversion. Soil and Wat. Res. 14: 121-131. https://doi.org/10.17221/5/2018-SWR

Zhang, X, Zhu, B, Yu, F, Cheng, W (2021). Plant inputs mediate the linkage between soil carbon and net nitrogen mineralization. *Science of the Total Environment*, *790*, 148208. https://doi.org/10.1016/j.scitotenv.2021.148208