DOI: 10.29298/rmcf.v13i72.1055

Article

Reservorio de Nitrógeno y relación C:N de un Umbrisol bajo manejo forestal en Durango, México

Nitrogen storage and C:N ratio of an Umbrisol under forest management in *Durango,* Mexico

Israel Cantú Silva[1]*, Erik Orlando Luna Robles[1]

Fecha de recepción/Reception date: 1 de diciembre de 2021
Fecha de aceptación/Acceptance date: 1 de junio del 2022

[1]Facultad de Ciencias Forestales, Universidad Autónoma de Nuevo León. México.
*****Autor para correspondencia; correo-e: icantu59@gmail.com
*Corresponding author; e-mail: icantu59@gmail.com

Abstract

Forest activities exert a positive or negative influence on soil ecosystem properties and services, through changes in vegetation and microclimate. The removal of biomass alters the carbon (C) and nitrogen (N) cycles, which are important indicators of soil health. The objective of this study was to determine the reservoir of N and the C:N ratio at two different depths of an Umbrisol, considering three stands with forest management (Clearcutting, Parent Trees and Selection) and a post-fire regenerated area, all of them eight years after the intervention, and a control plot as reference stand in a *Pinus-Quercus* forest. Results indicate significant differences in the variables for both soil depths (Total N, organic C, C:N ratio, N reservoir Mg ha^{-1}). The observed contents of total nitrogen (>0.10 %) are considered very high, being ascribable to the nature of the Umbrisol and to the quality of the organic matter of this ecosystem, with the ensuing impact on the C:N ratio, which is slightly above the optimal ranges of mineralization, having an average value of 20.4 at both depths. On the other hand, the nitrogen reserve for the analyzed profile ranged between 5.03 (control) and 9.63 Mg ha^{-1} (Parent Trees). Particularly, the Clearcutting and Parent Trees treatments showed differences in regard to the Control, such treatments accelerated the incorporation of organic material to the soil (roots, branches, leaves), causing increases from 79 to 91 % in the nitrogen reservoir. The present research provides essential information to establish complementary pre- and post-management forestry practices to preserve and improve the condition of the soil (clearing, pruning, burning, etc.).

Keywords: Parent trees, soil organic matter, Clearcutting, post-fire, edaphic nitrogen reservoir, Selection.

Resumen

Las actividades forestales influyen positiva o negativamente sobre las propiedades y servicios ecosistémicos del suelo, mediante cambios en la vegetación y microclima. La remoción de biomasa altera los ciclos del Carbono (C) y Nitrógeno (N), indicadores importantes de la salud edáfica. El objetivo fue determinar el reservorio de N y la relación C:N en dos profundidades de un Umbrisol, en tres rodales con cortas de regeneración (Matarrasa, Árboles Padre y Selección), un área regenerada posincendio con antigüedad de ocho años de ser intervenidos y un rodal de referencia (control) en un bosque de pino-encino (*Pinus-Quercus*). Los resultados indicaron diferencias significativas para N total, C orgánico, relación C:N, y reservorio de N Mg ha^{-1} para ambas profundidades del suelo. Los contenidos de N total (>0.10 %) se consideran muy altos, atribuibles a la naturaleza del Umbrisol y calidad de su materia orgánica, lo que influye en la relación C:N, la cual está ligeramente por encima de los intervalos óptimos de mineralización, con un promedio para ambas profundidades de 20.4. La reserva de N para el perfil analizado varió entre 5.03 (Referencia) a 9.63 Mg ha^{-1} (Árboles Padre). Particularmente, las cortas de Matarrasa y Árboles Padre tuvieron diferencias con el control, estos tratamientos aceleraron la incorporación de material orgánico al suelo (raíces, ramas, hojas) que provocaron incrementos de 79 a 91 % en el reservorio de N. La información generada es fundamental para el establecimiento de prácticas complementarias pre y posmanejo forestal (limpias, podas, quemas) que conserven y mejoren la condición del suelo.

Palabras clave: Árboles Padre, materia orgánica del suelo, Matarrasa, posincendio, reservorio edáfico de nitrógeno, Selección.

Introduction

The world's soils have the capacity to store carbon (1 500 Pg) in the first meter of soil depth, three times more than the amount contained in terrestrial vegetation (550 Pg) and twice the amount in the atmosphere (750 Pg); therefore, they play a key role in climate change mitigation (Veni *et al.*, 2020). Also, soil total nitrogen (TN) stocks are estimated to vary between 133 and 140 Pg in the same depth interval (Batjes, 2014).

Carbon (C) and nitrogen (N) are important indicators of the quality of the soil organic matter because of their ability to improve soil structure, nutrient availability, water retention and microbial activity (Di Gerónimo *et al.*, 2018). Specifically, soil C is a component of the global C cycle, while N availability is the main limiting factor in productivity, since it is a macronutrient that determines vegetation growth (Cerón y Aristizábal, 2012; Yuan and Chen, 2012).

Nitrogen is part of the plant and animal residues deposited in the soil that go through a process of decomposition before it becomes available to plants; its stock is subject to environmental and topographic conditions, as well as to management practices, and it is related to the type of vegetation that defines the quality of organic matter (Suárez *et al.*, 2015; Cantú and Yáñez, 2018; Madrigal *et al.*, 2019; Ayala-Montejo *et al.*, 2020). In this sense, one of the indexes used to determine the quality of soil organic matter (SOM) is the C:N ratio, an indicator that reflects the rate of nitrogen mineralization for vegetation, high ratios indicate that the SOM decomposes slowly, as the nitrogen reserve is immobilized by microorganisms, so it cannot be used by plants; on the other hand, ratios between 10 and 14 correspond to rapid mineralization, which generates sufficient N for microorganisms and vegetation (Gamarra *et al.,* 2018).

However, in recent decades, greater pressure has been exerted on forest resources to meet human needs, this has led to changes in the ecology and biology of the soil resource, which in turn has affected the quality of its ecosystem services (food and biomass production, water storage and filtration, among others) (Murray and King, 2012; IPCC, 2014; Burbano-Orjuela, 2016).

Forest management practices can affect the stability and content of carbon and nitrogen reserves in the soil, as well as its properties, due to modifications in environmental conditions, vegetation structure, and composition (Zhou *et al*., 2015). Changes in soil properties are influenced by the degree of disturbance of the stand environment, which correlates with harvesting intensity and harvesting cut (Jurgensen *et al.*, 2012), determining to a large extent the soil nutrient availability, soil moisture and temperature, litter layer inputs, root distribution, and microbial community (Slesak *et al.*, 2011; Slesak, 2013; Wic *et al*., 2013; Mushinski *et al.*, 2017). In particular, forest harvesting with high cutting intensities greatly modifies the availability of soil organic matter, which affects site productivity over time (Binkley and Fisher, 2013; Kurth *et al*., 2014; Achat *et al*., 2015).

Zhang *et al*. (2016) indicate that any change in edaphic properties will affect the levels of nitrogen and carbon in the soil. As a result, activities related to forest management, such as road construction, heavy machinery traffic, logging, dragging, stacking and loading, cause multiple damages to the soil, including increased bulk density, rutting, changes in soil water dynamics, increased erosion and nutrient loss, threat of fungal infections and changes in the microclimate, aspects that, in general, greatly alter the biogeochemical cycles that develop in the soil (Cambi *et al*., 2015; Islam *et al.*, 2015, Luna-Robles *et al*., 2021).

Some studies have shown that the response of nitrogen in soils under forest management is considered to be highly dynamic, i.e., it can exhibit losses of nitrogen in the soil (Jones *et al*., 2011; Kellman *et al*., 2014), gains (Grand and Lavkulich, 2012), or no change, depending on the intensity of harvesting, vegetation type and soil type (Jerabkova *et al.*, 2011; Scott *et al.*, 2014). Nave *et al*. (2011) determined that, after 15 years of application of the forestry treatment, the total carbon concentrations did not show any variations. In this regard, Ruiz-Peinado *et al.* (2013) indicate that carbon is considerably reduced during the first years (post-harvest), with a tendency toward significant recovery in a 6 to 20 years-period after harvesting.

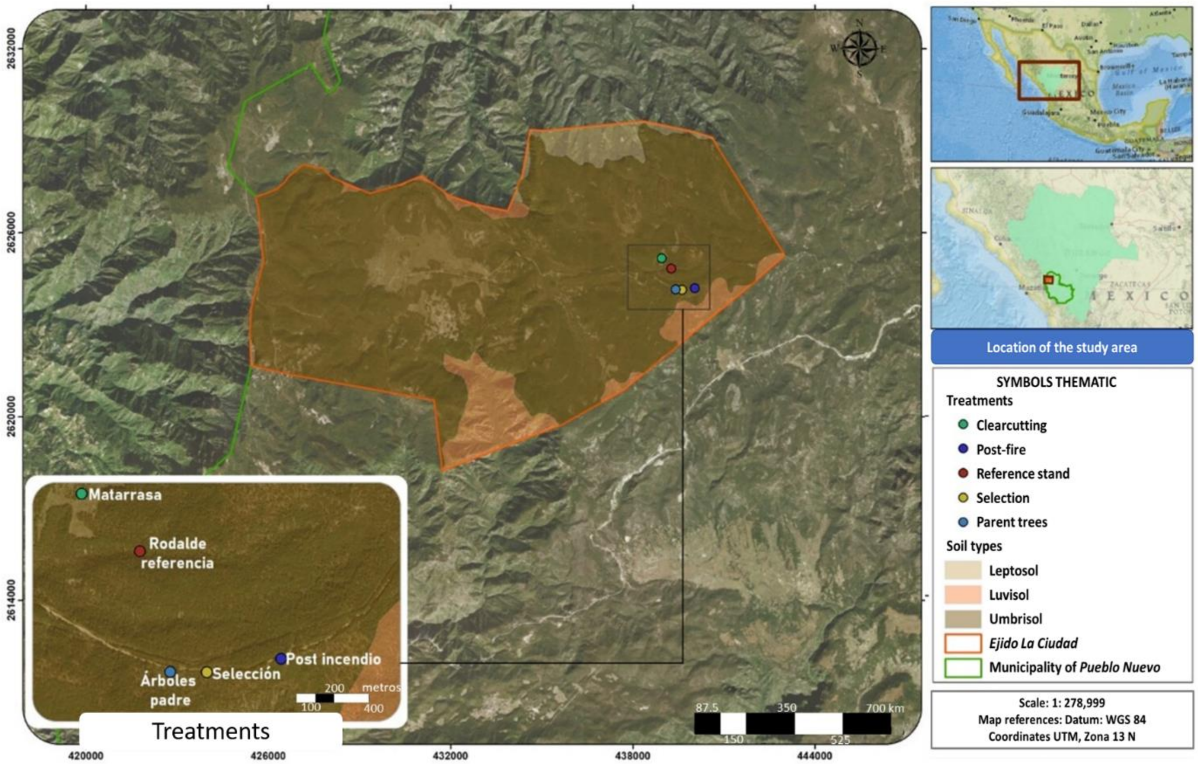
According to González-Rodríguez *et al.* (2019), the soil organic layer is an important nutrient pathway for forest ecosystems, therefore, the occurrence of forest fires represents a potential threat to carbon sequestration by biomass and soil resources. Likewise, Overby *et al.* (2002) cite that high severity fires cause high mortality in the tree layers, and high temperatures (675 °C) consume most of the organic layer. In addition, fires can cause changes in nutrient cycling and soil structure (Wohlgemuth *et al*., 2006), therefore, in the storage of SOC (North and Hurteau, 2011). Such alterations are related to the resilience of ecosystems to the effects of wildfires (Cadena-Zamudio *et al.*, 2020).

Umbrisol soils are characterized by a high content of organic matter within the first meter of depth, and highly acidic pH levels (<5.5), mainly distributed in temperate or cold areas, many umbrisols are covered with natural or near-natural vegetation and occupy around 100 million hectares worldwide (FAO, 2016). In Mexico, these soils cover less than 3 % of the country's surface, 2.91 % of the surface of the state of *Durango*, and specifically 3.3 % of *Pueblo Nuevo* municipality (INEGI, 2010; Inegi, 2017).

Based on the above, the objective of this study was to determine the N reservoir and the C:N ratio in two depths of an Umbrisol, in three stands with regeneration cuts as forestry management treatments (Clearcutting, Parent Trees, and Selection), and a post-fire regenerated area with eight years of intervention, in addition to a control called Reference stand.

Materials and Methods

The study was carried out in the forests of the *La Ciudad ejido* in the of *Pueblo Nuevo* municipality, *Durango* State, Mexico. The vegetation is mainly composed of *Pinus duranguensis* Martínez, *P. cooperi* C. E. Blanco, *P. ayacahuite* C. Ehrenb. ex Schltdl., *Juniperus deppeana* Steud. y *Quercus sideroxila* Bonpl. (González-Elizondo *et al.*, 2012). The average altitude is 2 583 masl. The dominant soil in the area belongs to the Umbrisol type (Figure 1). The average annual rainfall is 1 200 mm and the average annual temperature is 18 ºC (INEGI, 2010).



Matarrasa = Clearcutting; *Rodal de referencia* = Reference stand; *Posincendio* = Post-fire; *Selección* = Selection; *Árboles Padre* = Parent trees.

Figure 1. Location of the study area.

Five stands with different forestry management conditions corresponding to three regeneration cuts were evaluated: Clearcutting, Parent Trees, and Selection; A post-fire area regenerated in a natural way and a stand called Reference, considered as a control treatment, because it was assumed that it represents the original scenario of the soil before forest management and the occurrence of the fire (Table 1). The average time of the stands after the intervention is eight years, the same as for the post-fire stand.

Table 1. Description of stands and silvicultural treatments.

Stand	Surface area (ha)	Description
Clearcutting (C)	10.29	Total tree removal, currently in development stages between saplings and scrubland.
Parent tree (PT)	9	Cutting intensity of 80 %. Initial and subsequent volume of 206.8 and 41.3 m^3 ha^{-1}.
Selection (S)	20	Cutting intensity of 34 %. Initial and subsequent volume of 223.8 and 147.4 m^3 ha^{-1}.
Post-fire (P-I)	10	No data on the magnitude of the fire. Received a pre-thinning (year 2017) when it had a density of 10 000 individuals ha^{-1}.
Reference (R)	4.35	Tree mass closest to regeneration cutting considering that the forest rotation occurs approximately every 60 years, volume of 231 m^3 ha^{-1}.

Soil sampling

Based on the characteristics of the Umbrisol soil type, which include a deep superficial horizon and a high organic matter content, eight composite soil samples were collected from each stand (a combination of four individual subsamples, taken from the same stand, to obtain approximately 1 kg of soil) at two depths (four at 0-20 cm and four at 20-40 cm), for a total of 40 samples (Cantú and Yáñez, 2018). These were taken to the soil laboratory of the School of Forest Sciences *Universidad Autónoma de Nuevo León*, where they were air-dried, sieved through a 2 mm mesh, and stored for subsequent chemical analysis.

Determination of total nitrogen and soil organic carbon (SOC) (%)

The total nitrogen content of the soil was determined by the Kjeldahl method, with a Velp Scientifica™ UDK 159 distillation and titration equipment, based on Mamani *et al.* (2020). The SOC was determined from the organic matter content using the modified Walkley and Black method (Cantú and Yáñez, 2018), in which the soil is oxidized with a standardized solution of potassium dichromate; with the Van Bemmelen index, the organic carbon was estimated assuming that the organic matter has 58 % carbon.

Determination of nitrogen reserve in the soil

Table 2 shows the bulk density values (g cm^{-3}) of the soil of the different stands analyzed, determined by the gravimetric method (Luna *et al.*, 2021). The following equation was used to calculate the nitrogen reserve in Mg ha^{-1} (Madrigal *et al.*, 2019):

$$SN = T.N.*BD*SD$$

Where:

SN = Amount of soil nitrogen (Mg ha^{-1})

T.N. = Percentage of total nitrogen

BD = Bulk density (g cm^{-3})

SD = Sampling depth (cm)

Table 2. Mean values of soil bulk density for the analyzed stands.

Stand	**Bulk density (g cm^{-3})**	
	0-20 cm	20-40 cm
Clearcutting	0.80	0.77
Parent Trees	0.72	0.85
Selection	0.51	0.85
Post-fire	0.58	0.68
Reference	0.58	0.69

C:N ratio determination

The C:N ratio was calculated based on the percentages of carbon and nitrogen in the soil samples for both depth intervals; in this case, the result of the division is directly proportional to the availability of Nitrogen with respect to Carbon, such ratio provides an estimate of the degree of decomposition of soil organic matter (Kirkby *et al*., 2011; Castro *et al*., 2019); particularly, high proportions would indicate low nitrogen availability in the soil (Cantú and Yáñez, 2018).

$$\text{C:N Ratio} = \frac{O.C.}{T.N.}$$

Where*:*

O.C. = Organic carbon (%)

T.N. = Total nitrogen (%)

Statistical analysis

For the variables total nitrogen (%), carbon (%), C:N ratio and nitrogen reserve (Mg ha^{-1}), the Kolmogorov-Smirnov normality test and the Levene's test for homogeneity of variances were applied (Rubio and Berlanga, 2012).

In order to identify significant statistical differences ($P \leq 0.05$), the Kruskal-Wallis (*KW*) test with Bonferroni correction assuming non-normality (Berlanga and Rubio, 2012) was applied for both soil depths. The analysis was performed with the SPSS statistical package version 22 (International Business Machines, 2013).

Results

The N content for the 0-20 cm depth ranged from 0.28 to 0.46 %; the Parent Tree and Selection stands had the highest and lowest percentages, respectively. For the second depth interval (20-40 cm), it fluctuated between 0.11 and 0.27 %, and the Reference and Clearcutting stands were the areas with the lowest and highest content (Table 3).

Table 3. Mean values of the variables analyzed by depth interval.

Treatment	Soil depth range					
	0-20 cm			20-40 cm		
	TN (%)	OC (%)	C:N	TN (%)	OC (%)	C:N
Clearcutting	0.30 (0.30-0.31)	6.10 (5.62-6.40)	18.58 (17.9-19.5)	0.26 (0.25-0.27)	5.7 (5-6.4)	21.05 (18.3-21.4)
Parent Trees	0.46 (0.44-0.47)	8.58 (8.25-9.11)	18.8 (17.6-20)	0.18 (0.17-0.18)	2.63 (2.25-3.18)	14.5 (13.1-16.9)
Selection	0.28	6.63	24.7	0.18	6.63	20.0

	(0.18-0.31)	(5.92-7.90)	(19.1-34.4)	(0.16-0.20)	(3.19-4.36)	(18.5-21.9)
Post-fire	0.43	7.92	18.3	0.25	4.52	19.0
	(0.36-0.45)	(7.40-8.50)	(17.1-20.1)	(0.17-0.28)	(3.58-5-30)	(15.9 a 20.4)
Control	0.31	6.57	21.4	0.11	2.91	28.3
	(0.30-0.32)	(6.07-7.36)	(20-22.9)	(0.09-0.12)	(2.72-3.20)	(24.8-31.5)

The organic carbon for the first soil depth (0-20 cm) ranged between 6.10 and 8.58 %, with the following order among the analyzed stands: Parent trees > Post-fire > Selection > Reference > Clearcutting. For the depth of 20-40 cm, the carbon records corresponded to the interval of 2.64 and 5.72 %, at which the lowest and highest carbon content corresponded to the Parent Trees and Clearcutting stands. The average C:N ratio of the soil at both depths was 20.4. The Post-Fire and Parent Tree treatments had the lowest C:N ratio at both soil depths. The Selection and Reference stand exhibited a high C:N ratio at the depth of 0-20 cm, compared to the other analyzed stands, while the highest values at the depth of 20-40 cm were found in the Control and Clearcutting stands (Table 3).

Particularly, a decrease in Nitrogen and Carbon was determined as the soil depth increased in all the analyzed stands (Figure 2).

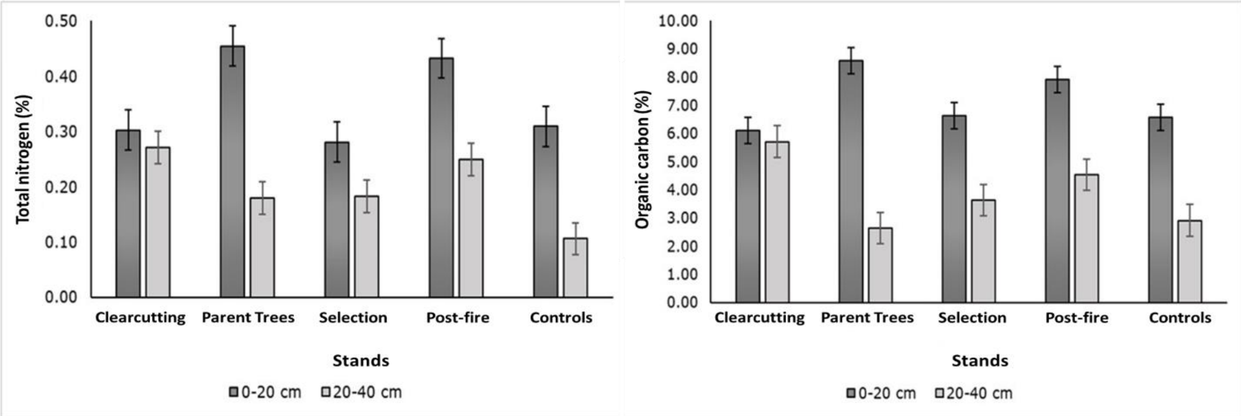


Figure 2. Average values of a) total nitrogen and b) organic carbon content by depth interval.

Soil nitrogen reservoir

The nitrogen pool in the Umbrisol soil for the 0-20 cm depth in the silvicultural treatments Clearcutting, Parent Trees, and Post-fire silvicultural treatments exhibited increases in the N pool of 35.65 %, 84.48 % and 40.92 % respectively, compared to the control stand (3.56 Mg ha^{-1}), while the Selection treatment registered the lowest nitrogen reserve in the first 20 cm of the stand (2.95 Mg ha^{-1}).

For the 20-40 cm depth, nitrogen decreased in all the stands, except for the Selection stand, which showed a slight increase with respect to the first depth, however, all four stands showed values above the control stand (1.47 Mg ha^{-1}) (Figure 3). When considering the whole profile from 0-40 cm, the nitrogen stock presented the following descending order: Parent Trees (9.63 Mg ha^{-1}) > Clearcutting (8.99 Mg ha^{-1}) > Post-fire (8.21 Mg ha^{-1}) > Selection (5.95 Mg ha^{-1}) > Control (5.03 Mg ha^{-1}).

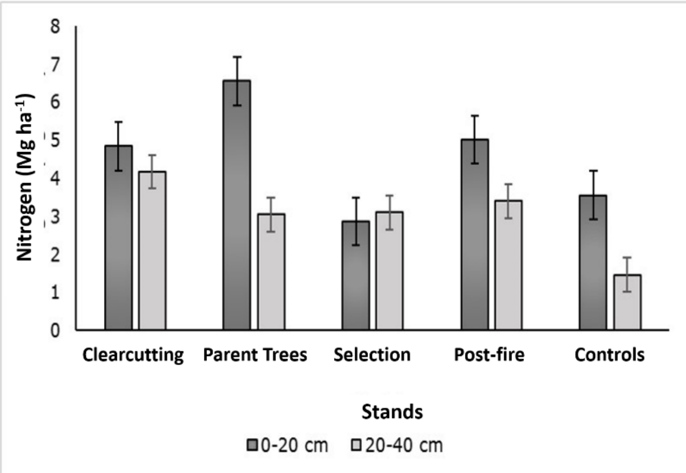


Figure 3. Mean nitrogen reserve values of the stands for both depths.

The results for total nitrogen (%), carbon (%), C:N ratio and nitrogen reserve (Mg ha^{-1}) showed significant statistical differences in all the variables (Table 4).

Table 4. Results of the Kruskal-Wallis test for the comparison between stands for both depth intervals.

KW test statistics	Carbon	Nitrogen	C:N	N (Mg h^{-1})
n (0-20 cm)	20	20	20	20
Degrees of freedom	4	4	4	4
Chi-square	14.80	14.50	12.10	11.92
Significance	0.005*	0.006*	0.018*	0.030*

n (20-40 cm)	20	20	20	20
Degrees of freedom	4	4	4	4
Chi-square	17.30	15.79	15.42	16.41
Significance	0.002*	0.002*	0.003*	0.002*

* Represents significant differences (P≤0.05).

Multiple comparisons with the Kruskal-Wallis post hoc test and the Bonferroni correction detected significant differences for the variables at both depths. At 0-20 cm, there were no significant differences in total nitrogen between stands for the organic carbon content, only the pairs of Clearcutting–Parent Trees obtained differences, the variable C:N had only one significant comparison (Post-fire–Selection), and Nitrogen reserve registered differences between Selection-Parent Trees and Reference–Parent Trees.

For the second depth interval (20-40 cm), the pairwise comparisons of Clearcutting–Control and Control–Post-fire were significant for total nitrogen; for organic carbon, Clearcutting–Control and Clearcutting–Parent Trees, the C:N ratio with the Reference–Parent Tree pair; and for Nitrogen reserve, differences were found only between the Clearcutting and Control stands (Table 5).

Table 5. Kruskal-Wallis post hoc test with Bonferroni correction for the variables analyzed.

Comparisons by pairs	Total nitrogen (%)		Organic carbon (%)		C:N		Nitrogen reserv (Mg ha^{-1})	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
Clearcutting-Selection	1.000	1.000	1.000	0.727	1.000	1.000	0.422	0.486
Clearcutting-Post-fire	1.000	1.000	0.155	1.000	0.943	1.000	1.000	0.730

Clearcutting-Control	0.214	0.008*	1.000	0.021*	1.000	1.000	1.000	0.001*
Clearcutting-Parent Trees	0.111	0.728	0.009*	0.003*	1.000	0.102	1.000	0.486
Selection-Control	1.000	0.828	1.000	1.000	1.000	0.558	1.000	0.639
Selection-Post-fire	0.231	1.000	1.000	1.000	0.050*	1.000	0.168	1.000
Selection-Parent Trees	0.120	1.000	0.101	0.680	0.314	0.639	0.003*	1.000
Control-Parent Trees	0.250	1.000	0.131	1.000	0.486	0.002*	0.023*	0.639
Control-Post-fire	0.131	0.034*	1.000	0.450	0.086	0.072	0.730	0.422
Post-fire-Parent Trees	1.000	1.000	1.000	0.110	1.000	1.000	1.000	1.000

* Significant differences at the significance level of α=0.05.

Discussion

According to the evaluation of the NOM-021-RECNAT-2000 (Semarnat, 2002), the total nitrogen contents (%) for the soil are very high, presumably as a consequence of the properties of the Umbrisol, which has acid pH levels below 5.5 and high organic matter contents, with very recalcitrant characteristics (resin, lignin and cellulose) (FAO, 2015), together, they favor the establishment of mycorrhizal fungi, which in forest soils are more resistant to acid pH than nitrifying bacteria (Paul, 2015; Kamble and Bååth, 2016; Zhang *et al.,* 2016). They are also responsible for the transformation of proteins from organic matter into nitrified substances (Havlin *et al.,* 1999).

Particularly, the contents of organic carbon and total nitrogen showed variability between the stands subjected to regeneration cuttings and the post-fire regenerated area in relation to the control stand at both depths. This agrees with Amundson *et al.* (2003), Thiffault *et al.* (2011), Achat *et al.* (2015) and Mushinski *et al.* (2017), who point out that, after regeneration and post-fire cuttings, various biogeochemical transformations —such as mineralization, humification, denitrification, etc.— usually occur in the soil and accelerate, potentially leading to alterations (gains or losses) in the nitrogen stocks. According to Steubing *et al.* (2002), regeneration and post-fire cuttings modify the soil cover and the vegetation structure, because they have an impact on several abiotic factors such as soil moisture, wind, radiation, interception and temperature, whose combined effect finally determines soil C, N and C:N balances.

The findings of the present study allow us to infer that, eight years after a silvicultural intervention and after the occurrence of the forest fire, the capacity of the nitrogen reservoir in the Umbrisol increased at the depth of 0-40 cm, consistently with the response of the carbon reservoir for these same stands, which exhibited an average sequestration of 149.89 Mg ha^{-1} after cuttings and forest fires (Luna *et al*., 2022).

According to the above, the Nitrogen reservoir increased by 79 and 91 % in the stands with the Clearcutting and Parent Trees treatment with respect to the Control stand. Such treatments modified the biotic and abiotic conditions that define the dynamics of Nitrogen, including the rates of incorporation of organic material into the soil (roots, branches, leaves) and the activity of nitrogen synthesizing microorganisms. Also, the opening of the canopy favored the establishment of grasses and shrubs with higher decomposition rates than the tree vegetation (Thiffault *et al.*, 2011; Zehetgruber *et al.*, 2017).

This contrasts with what has been cited in other studies on similar intensive forestry operations, in which low nitrogen concentrations have been found in stands a decade after the intervention (Achat *et al.*, 2015; Foote *et al.*, 2015; Mushinski *et al*., 2017).

The occurrence of the forest fire significantly influenced the total nitrogen content in the two soil depth intervals. Higher percentages were estimated for all the stands, except for the second depth in the stand with Clearcutting. These results are consistent with those reported by Johnson and Curtis (2001) and de la Rosa *et al.* (2014), who document that a wildfire increases the amount and rate of degradation of the SOM. The authors add that total nitrogen can result in subsequent gains due to the incorporation of unburned residues including charcoal, hydrophobic organic matter and the establishment of fast-growing post-fire vegetation, mainly herbs and shrubs.

Covington and Sackett (1992) and Certini (2005) point out that, in the superficial part of the soil, ammonium is the main inorganic form of nitrogen that originates during a fire; after weeks or months, nitrate is formed from ammonium; nitrification is immediate, if nitrifying bacteria (*Nitrosomonas* and *Nitrobacter*) are present. In the present study, this may have occurred to a lesser degree due to the acid pH of the Umbrisol, which inhibited bacterial activity, thereby reducing nitrogen availability; consequently, nitrate leaching may have occurred.

For the soil depth of 20-40 cm, it was determined that the nitrogen reserve decreased considerably for all stands; this coincides with Madrigal *et al.* (2019), who, in fir, pine and pine-aile forests, quantified decreases as the depth increased, an aspect that is mainly linked to the decrease in the amount of organic matter, as well as to processes such as assimilation by vegetation in the first centimeters, leaching, and volatilization of nitrogen.

According to Porta *et al.* (2014) in order to indicate that organic matter is in a dynamic state (mineralization), the C:N ratio must be within a range of 10 to 14. Galicia *et al.* (2016) state that, in pine-oak forests, C:N ratios ranging between 24 and 47 are considered optimal. The values of the present study are at an average ratio of 20.4 for both depths, which indicates that the rate of mineralization of the Umbrisol is slightly above optimal conditions.

Conclusions

Regeneration cuttings and the occurrence of forest fires after eight years contribute to increase the Nitrogen reservoir in the soil, compared to the Control stand; therefore, the forestry practices applied proved to favor the sustainability of the Umbrisol. Particularly, Clearcutting and Parent Trees stands show differences with regard to the Control stand. Due to their own management characteristics, these forestry treatments increase the incorporation of organic material into the soil (roots, branches, leaves), resulting in increases of 79 to 91 % in the N pool. The average C:N ratio of the Umbrisol soil (20.4) is below the optimal C:N range (24-47) for pine-oak forests.

These results will allow to establish pre- and post-management criteria, such as the planning of complementary silvicultural management treatments, with emphasis on thinning, clearing, pruning, controlled burning, site preparation, management of cutting residues, among others, to conserve and improve the variables soil C, N and C:N ratio.

Acknowledgments

The authors would like to thank the *Unidad de Prestación de Servicios Ejidales Núm. 6 El Salto, A. C.* and *Conacyt* for the doctoral scholarship granted for the development of this research.

Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Israel Cantú Silva: approach and conduction of the research, statistical analysis and drafting of the manuscript; Erik Orlando Luna Robles: field and laboratory work, data analysis, and drafting of the manuscript.

References

Achat, D. L., C. Deleuze, G. Landmann, N. Pousse and L. Augusto. 2015. Quantifying consequences of removing harvesting residues on forest soils and tree growth—A meta-analysis. Forest Ecology and Management 348:124-141. Doi: 10.1016/j.foreco.2015.03.042.

Amundson, R., A. T. Austin, E. A. G. Schuur, K. Yoo, … and W. T. Baisden. 2003. Global patterns of the isotopic composition of soil and plant nitrogen. Global Biogeochemical Cycles 17(1):1031. Doi: 10.1029/2002GB001903.

Ayala-Montejo, D., A. I. Monterroso-Rivas, J. Baca-Del Moral, E. Escamilla-Prado, … y E. Valdés-Velarde. 2020. Identificación de necesidades de investigación sobre la dinámica de carbono y nitrógeno en sistemas agroforestales de café en México. Tropical and Subtropical Agroecosystems 23(3):1-16. https://www.revista.ccba.uady.mx/ojs/index.php/TSA/article/view/3403/1499 (1 de enero de 2021).

Batjes, N. H. 2014. Total carbon and nitrogen in the soils of the world. European Journal of Soil Science 65(1):10-21. Doi: 10.1111/ejss.12114_2.

Berlanga S., V. y M. J. Rubio H. 2012. Clasificación de pruebas no paramétricas. Cómo aplicarlas en SPSS. REIRE Revista d'Innovació i Recerca en Educació 5(2):101-113. Doi: 10.1344/reire2012.5.2528.

Binkley, D. and R. F. Fisher. 2013. Ecology and management of forest soils. Wiley-Blackwell. Chichester, WS, UK. 456 p.

Burbano-Orjuela, H. 2016. El suelo y su relación con los servicios ecosistémicos y la seguridad alimentaria. Revista de Ciencias Agrícolas 33(2):117-124. Doi: 10.22267/rcia.163302.58.

Cadena-Zamudio, D. A., J. G. Flores-Garnica, A. G. Flores-Rodríguez y M. E. Lomelí-Zavala. 2020. Efecto de incendios en la vegetación de sotobosque y propiedades químicas de suelo de bosques templados. Agroproductividad 13(4):65–72. Doi: https://doi.org/10.32854/agrop.vi.1684.

Cambi, M., G. Certini, F. Neri and E. Marchi. 2015. The impact of heavy traffic on forest soils: A review. Forest Ecology and Management 338(1):124–138. Doi: 10.1016/j.foreco.2014.11.022.

Cantú S., I. y M. I. Yáñez D. 2018. Efecto del cambio de uso de suelo en el contenido del carbono orgánico y nitrógeno del suelo. Revista Mexicana de Ciencias Forestales 9(45):122-151. Doi: 10.29298/rmcf.v9i45.138.

Castro G., S. L., A. Aldrete, J. López U. y V. M. Ordaz C. 2019. Caracterización física y química de sustratos con base en corteza y aserrín de pino. Madera y Bosques, 25(2): 10.21829/myb.2019.2521520.

Cerón R., L. E. y F. A. Aristizábal G. 2012. Dinámica del ciclo del Nitrógeno y fósforo en suelos. Revista Colombiana de Biotecnología 14(1):285-295. http://www.redalyc.org/articulo.oa?id=77624081026. (1 de enero de 2021).

Certini, G. 2005. Effects of fire on properties of forest soils: a review. Oecologia 143(1):1-10. Doi: 10.1007/s00442-004-1788-8.

Covington, W. W. and S. S. Sackett. 1992. Soil mineral nitrogen changes following prescribed burning in ponderosa pine. Forest Ecology and Management 54(1-4):175-191. Doi: 10.1016/0378-1127(92)90011-W.

de la Rosa, J. M., H. Knicker, J. A. González-Pérez, F. J. González-Vila, N. T. Jiménez-Morillo y G. Almendros. 2014. Revisión de las investigaciones a nivel molecular sobre el impacto del fuego en la materia orgánica del suelo: Progresos en el siglo XXI. Cuadernos de investigación geográfica 40(2):387-402. https://dialnet.unirioja.es/servlet/articulo?codigo=4847437 (1 de enero de 2021).

Di Gerónimo, P. F., C. C. Videla y P. Laclau. 2018. Distribución de carbono y nitrógeno orgánico en fracciones granulométricas de suelos bajo pastizales, agricultura y forestaciones. Ciencia del Suelo 36(1):11-22. http://www.scielo.org.ar/pdf/cds/v36n1/v36n1a02.pdf. (5 de enero de 2021).

Foote, J. A., T. W. Boutton and D. A. Scott. 2015. Soil C and N storage and microbial biomass in US southern pine forests: Influence of forest management. Forest Ecology and Management 355:48-57. Doi: 10.1016/j.foreco.2015.03.036.

Galicia, L., A. M. Gamboa C., S. Cram, B. Chávez V., V. Peña R., V. Saynes y C. Siebe. 2016. Almacén y dinámica del carbono orgánico del suelo en bosques templados de México. Terra Latinoamericana 34(1):1-29. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-57792016000100001. (5 de enero de 2021).

Gamarra L., C. C., M. I. Díaz L., M. Vera de Ortíz, M. P. Galeano y A. J. N. Cabrera C. 2018. Relación carbono-nitrógeno en suelos de sistemas silvopastoriles del Chaco paraguayo. Revista Mexicana de Ciencias Forestales 9(46):4-25. Doi: 10.29298/rmcf.v9i46.134.

González-Elizondo, M. S., M. González-Elizondo, J. A. Tena-Flores, L. Ruacho-González e I. L. López-Enríquez. 2012. Vegetación de la Sierra Madre Occidental, México: Una síntesis. Acta Botánica Mexicana 100():351-403. Doi: 10.21829/abm100.2012.40.

González-Rodríguez, H., J. M. López-Hernández, R. G. Ramírez-Lozano, M. V. Gómez-Meza, I. Cantú-Silva, J. I. Sarquís-Ramírez and A. Mora-Olivo. 2019. Litterfall deposition and nutrient return in pine-oak forests and scrublands in northeastern Mexico. Madera y Bosques 25(3):1–16. Doi: 10.21829/myb.2019.2531514.

Grand, S. and L. M. Lavkulich. 2012. Effects of forest harvest on soil carbon and related variables in Canadian Spodosols. Soil Science Society of America Journal 76(5):1816-1827. Doi: 10.2136/sssaj2012.0103.

Havlin, J. L., J. D. Beaton, S. L. Tisdale and W. L. Nelson. 1999. Soil fertility and fertilizers: an introduction to nutrient management. Prentice-Hall Inc. Bergen, NJ, USA. 499 p.

Instituto Nacional de Estadística y Geografía (Inegi). 2017. Anuario estadístico y geográfico de Durango 2017. Instituto Nacional de Estadística y Geografía (Inegi). Aguascalientes, Ags., México. 501 p. https://datatur.sectur.gob.mx/ITxEF_Docs/DGO_ANUARIO_PDF.pdf. (22 de diciembre de 2020).

Instituto Nacional de Estadística, Geografía e Informática (INEGI). 2010. Compendio de información geográfica municipal 2010. Pueblo Nuevo, Durango. 10023. http://www3.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/10/10023.pdf. (4 de enero de 2021).

Intergovernmental Panel on Climate Change (IPCC). 2014. AR5 Climate change 2014: impacts, adaptation, and vulnerability. https://www.ipcc.ch/report/ar5/wg2/. (29 de diciembre de 2020).

International Business Machines (IBM). 2013. IBM SPSS Statistics for Windows, version 22.0. Armonk, NY, USA. IBM Corp. https://www.ibm.com/mx-es/analytics/spss-statistics-software (5 de enero de 2022).

Islam, M., A. Dey and M. Rahman. 2015. Effect of tree diversity on soil organic carbon content in the homegarden agroforestry system of North-Eastern Bangladesh. Small-scale Forestry 14(1):91–101. Doi: 10.1007/s11842-014-9275-5.

Jerabkova, L., C. E. Prescott, B. D. Titus, G. D. Hope and M. B. Walters. 2011. A metaanalysis of the effects of clearcut and variable-retention harvesting on soil nitrogen fluxes in boreal and temperate forests. Canadian Journal of Forest Research 41(9):1852-1870. Doi: 10.1139/x11-087.

Johnson, D. W. and P. S. Curtis. 2001. Effects of forest management on soil C and N storage: meta analysis. Forest Ecology and Management 140(2-3):227-238. Doi: 10.1016/S0378-1127(00)00282-6.

Jones, H. S., P. N. Beets, M. O. Kimberley and L. G. Garrett. 2011. Harvest residue management and fertilisation effects on soil carbon and nitrogen in a 15-year-old *Pinus radiata* plantation forest. Forest Ecology and Management 262(3):339-347. Doi: 10.1016/j.foreco.2011.03.040.

Jurgensen, M.; R. Tarpey, J. Pickens, R. Kolka and B. Palik. 2012. Long-term effect of silvicultural thinnings on soil carbon and nitrogen pools. Soil Science Society of America Journal 76(4):1418-1425. Doi: 10.2136/sssaj2011.0257.

Kamble, P. N. and E. Bååth. 2016. Comparison of fungal and bacterial growth after alleviating induced N-limitation in soil. Soil Biology and Biochemistry 103:97-105. Doi: 10.1016/j.soilbio.2016.08.015.

Kellman, L., S. Kumar and A. Diochon. 2014. Soil nitrogen dynamics within profiles of a managed moist temperate forest chronosequence consistent with long-term harvesting-induced losses. Journal of Geophysical Research: Biogeosciences 119(7):1309-1321. Doi: 10.1002/2013JG002469.

Kirkby, C. A., J. A. Kirkegaard, A. E. Richardson, L. J. Wade, C. Blanchard and G. Batten. 2011. Stable soil organic matter: A comparison of C:N:P:S ratios in Australian and other world soils. Geoderma 163(3-4):197-208. Doi: 10.1016/j.geoderma.2011.04.010.

Kurth, V. J., A. W. D’Amato, B. J. Palik and J. B. Bradford. 2014. Fifteen-year patterns of soil carbon and nitrogen following biomass harvesting. Soil Science Society of America Journal 78(2):624-633. Doi: 10.2136/sssaj2013.08.0360.

Luna-Robles, E. O., I. Cantú-Silva, H. González-Rodríguez, J. Marmolejo-Monsiváis, … and S. J. Béjar-Pulido. 2021. Effects of forest management on the physical and hydrological properties of an Umbrisol in the *Sierra Madre Occidental*. Revista Chapingo Serie Ciencias Forestales 27(1):19-32. Doi: 10.5154/r.rchscfa.2019.11.085.

Luna R., E. O., I. Cantú-Silva and S. J. Bejar P. 2022. Soil organic carbon changes in an umbrisol under different silvicultural treatments in a temperate forest in northwestern Mexico. Journal of Sustainable Forestry:1-16. Doi: 10.1080/10549811.2022.2043904.

Madrigal R., S., D. C. Acevedo, E. Hernández A. y J. L. Romo L. 2019. Influencia de la cobertura, pendiente y profundidad, sobre el Carbono y Nitrógeno del suelo. Revista Mexicana de Ciencias Forestales 10(51):201-223. Doi: 10.29298/rmcf.v10i51.113.

Mamani, M., R. Miranda, M. A. López, E. Yujra, M. López y A. Chuquimia. 2020. Validación del método Kjeldahl en la determinación del Nitrógeno Mineral, mediante el uso de Cloruro Potasio. Apthapi 6(2):1917-1925. http://apthapi.agro.umsa.bo/index.php/ATP/article/view/60/56. (29 de diciembre de 2020).

Murray, J. and D. King. 2012. Climate policy: Oil’s tipping point has passed. Nature (481):433-435. Doi: 10.1038/481433a.

Mushinski, R. M., T. J. Gentry, R. J. Dorosky and T. W. Boutton. 2017. Forest harvest intensity and soil depth alter inorganic nitrogen pool sizes and ammonia oxidizer community composition. Soil Biology and Biochemistry 112:216-227. Doi: 10.1016/j.soilbio.2017.05.015.

Mushinski, R. M., T. W. Boutton and D. A. Scott. 2017. Decadal-scale changes in forest soil carbon and nitrogen storage are influenced by organic matter removal during timber harvest. Journal of Geophysical Research: Biogeosciences 122(4), 846-862. Doi: 10.1002/2016JG003738.

Nave, L. E., E. D. Vance, C. W. Swanston and P. S. Curtis. 2010. Harvest impacts on soil carbon storage in temperate forests. Forest Ecology and Management 259(5):857–866. Doi: 10.1016/j.foreco.2009.12.009.

North, M. P. and M. D. Hurteau. 2011. High-severity wildfire effects on carbon stocks and emissions in fuels treated and untreated forest. Forest Ecology and Management 261(6):1115–1120. Doi: 10.1016/j.foreco.2010.12.039.

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). 2016. Base referencial mundial del recurso suelo 2014. Sistema internacional de clasificación de suelos para la nomenclatura de suelos y la creación de leyendas de mapas de suelos. Actualización 2015. Informes sobre recursos mundiales de suelos. FAO. Roma, Italia. 218 p. http://www.fao.org/3/i3794es/I3794es.pdf. (19 de diciembre de 2021).

Overby, S. T., S. C. Hart and D. G. Neary. 2002. Impacts of natural disturbance on soil carbon dynamics in forest ecosystems. In Kimble, J. M., L. S. Heath, R. A. Birdsey and R. Lal. (Eds.). The potential of U. S. forest soils to sequester carbon and mitigate the greenhouse effect. CRC Press. Boca Raton, FL, USA. pp. 159–172.

Paul, E. A. 2015. Soil microbiology, ecology and biochemistry. Academic Press. Waltham, MA, USA. 598 p.

Porta, J., M. López-Acevedo y R. M. Poch. y 2014. Edafología: uso y protección de suelos. Ediciones Mundi-Prensa Libros. Comunidad de Madrid, Mad., España. 624 p.

Rubio H., M. J. y V. Berlanga S. 2012. Cómo aplicar las pruebas paramétricas bivariadas *t* de Student y ANOVA en SPSS. Caso práctico. REIRE Revista d´Innovació i Recerca en Educació 5(2):83-100. Doi: 10.1344/reire2012.5.2527.

Ruiz-Peinado, R., A. Bravo-Oviedo, E. Lopez-Senespleda, G. Montero and M. Río. 2013. Do thinnings influence biomass and soil carbon stocks in Mediterranean maritime pinewoods? European Journal of Forest Research 132(2):253–262. Doi: 10.1007/s10342-012-0672-z.

Scott, D. A., R. J. Eaton, J. A. Foote, B. Vierra, T. W. Boutton, G. B. Blank and K. Johnsen. 2014. Soil ecosystem services in loblolly pine plantations 15 years after harvest, compaction, and vegetation control. Soil Science Society of America Journal 78(6):2032-2040. Doi: 10.2136/sssaj2014.02.0086.

Secretaria de Medio Ambiente y Recursos Naturales (Semarnat). 2002. NOM-021-RECNAT-2000 Que establece las especificaciones de fertilidad, salinidad y clasificación de suelos. Estudios, muestreo y análisis. Diario Oficial de la Federación. Segunda edición. 31 de diciembre de 2002. México, D. F. México. pp 1-73. http://www.ordenjuridico.gob.mx/Documentos/Federal/wo69255.pdf. (8 de enero de 2021).

Slesak, R. A., S. H. Schoenholtz, T. B. Harrington and N. A. Meehan. 2011. Initial response of soil carbon and nitrogen to harvest intensity and competing vegetation control in Douglas-fir (*Pseudotsuga menziesii*) plantations of the Pacific Northwest. Forest Science 57(1):26-35. Doi: 10.1093/forestscience/57.1.26.

Slesak, R. A. 2013. Soil temperature following logging-debris manipulation and aspen regrowth in Minnesota: Implications for sampling depth and alteration of soil processes. Soil Science Society of America Journal 77(5):1818-1824. Doi: 10.2136/sssaj2013.01.0022.

Steubing, L. 2002. Métodos de ecología vegetal. Universidad Austral de Chile. Valdivia, Chile. 345 p.

Suárez M., G., A. Campos C. y L. Cruz H. 2015. Dinámica del carbono y nitrógeno del suelo en ecosistemas de la costa tropical seca, en la mancha (CICOLMA), Veracruz, México. Tropical and Subtropical Agroecosystems 18(3):347-361. https://www.redalyc.org/pdf/939/93944043009.pdf. (1 de enero de 2021).

Thiffault, E., K. D. Hannam, D. Paré, B. D. Titus, … and S. Brais. 2011. Effects of forest biomass harvesting on soil productivity in boreal and temperate forests—A review. Environmental Reviews 19:278-309. Doi: 10.1139/a11-009.

Veni, V. G., Ch. Srinivasarao, K. S. Reddy, K. L. Sharma and A. Rai. 2020. Soil health and climate change. In: Vara P., M. N. and M. Pietrzykowski (eds.). Climate Change and Soil Interactions. Elsevier. Radarweg, Amsterdam, NH, Netherlands. pp 751-767.

Wic B., C., M. Andrés-Abellán, M. E. Lucas-Borja, E. Martínez-García, F. A. García-Morote, E. Rubio and F. R. López-Serrano. 2013. Thinning and recovery effects on soil properties in two sites of a Mediterranean forest, in Cuenca Mountain (South-eastern of Spain). Forest Ecology and Management 308:223-230. Doi: 10.1016/j.foreco.2013.06.065.

Wohlgemuth, P. M., K. Hubbert and M. J. Arbaugh. 2006. Fire and physical environment Interactions: soil, water, and air. In Sugihara, N. G., J. W. Van Wagtendonk, J. F. Kaufman, K. E. Shaffer and A. E. Thode (Eds.). Fire in California's Ecosystem. University of California Press. Berkeley, CA, USA. pp. 75–93

Yuan, Z. Y. and H. Y. H. Chen. 2012. A global analysis of fine root production as affected by soil nitrogen and phosphorus. Proceedings of the Royal Society B: Biological Sciences 279(1743):3796-3802. Doi: 10.1098/rspb.2012.0955.

Zehetgruber, B., J. Kobler, T. Dirnböck, R. Jandl, R. Seidl and A. Schindlbacher. 2017. Intensive ground vegetation growth mitigates the carbon loss after forest disturbance. Plant and soil 420(1):239-252. Doi: 10.1007/s11104-017-3384-9.

Zhang, Q., J. Wu, F. Yang, Y. Lei, Q. Zhang and X. Cheng. 2016. Alterations in soil microbial community composition and biomass following agricultural land use change. Scientific Reports 6:1-10. Doi: 10.1038/srep36587.

Zhou, X., Y. Zhou, C. Zhou, Z. Wu, … J. Gan. 2015. Effects of cutting intensity on soil physical and chemical properties in a mixed natural forest in southeastern China. Forests 2015 6(12):4495-4509. Doi: 10.3390/f6124383.