JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(5), 128–136
https://doi.org/10.12911/22998993/161616
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.02.15
Accepted: 2023.03.15
Published: 2023.04.01

Effect of plant Communities and Ecological Parameters on Soil Organic Carbon Stocks in the Mamora Forest, Morocco

Amal Boujraf[1], Youssef Dallahi[2*], Jamila Dahmani[1], Collins Ashianga Orlando[3], Allal Douira[1]

[1] Laboratoire des Productions Végétale, Animales et Agro-industrie, Equipe de Botanique, Biotechnologie et Protection des Plantes, Faculté des Sciences, Université Ibn Tofail, Kénitra, Morocco

[2] Laboratoire de Biotechnologie et Physiologie Végétales, Centre de Biotechnologie Végétale et Microbienne, Biodiversité et Environnement, Faculté des Sciences, Université Mohammed V de Rabat, Rabat 10000, Morocco

[3] Independent Researcher, Rabat, Morocco

* Corresponding author's e-mail: youssef.dallahi@fsr.um5.ac.ma

ABSTRACT

Several studies on the assessment of soil organic carbon (SOC) stocks have been carried out at the global level. However, reliable information on SOC stocks is not readily available at the regional level. In addition, very few studies have assessed the factors responsible for the variation of SOC stocks, in particular the effect of plant communities. For this purpose, the main objective was to analyze the effects of three plant communities and ecological parameters on the SOC stock in the Mamora forest. Specifically, the authors looked to examine the relationships between SOC stock and plant communities and to define the main parameters that directly influence SOC stock. Ten soil profiles with three replications were sampled at each plant community, from which SOC stock was determined. To assess the effect of plant communities on SOC stocks, phytosociological surveys were carried out according to the phytosociological stigma method developed by Braun-Blanquet. The results show that the SOC stocks in cork oak soils are characterized by high variability, with values ranging from 55 $t\cdot ha^{-1}$ to 95 $t\cdot ha^{-1}$. Indeed, the findings of this study showed that the SOC stocks fluctuated significantly with plant communities. In addition, SOC stocks were also affected by the interactions between plant communities, the amount of litter and the density of the cork oak stand. These outcomes of this study highlight the critical need to incorporate community-specific carbon values into future carbon sequestration modeling.

Keywords: SOC stocks, carbon sequestration, plant communities, ecological parameters, Mamora forest, Morocco.

INTRODUCTION

In the current context of climate change, increasing concentrations of greenhouse gases in the atmosphere, particularly carbon dioxide (CO_2), are recognized as the main cause of global warming. As such, the quantification of soil organic carbon (SOC) stocks in forest ecosystems is vital, given that forest soils represent an important carbon reservoir (Vanguelova et al., 2013). They contribute to about 70% of the CO_2 exchange between the atmosphere and the terrestrial biosphere (Jandl et al., 2007). The evaluation of the SOC stocks is essential in the assessment of greenhouse gas emissions, established in accordance with the recommendations of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and the Kyoto Protocol (1997). SOC sequestration is the process by which carbon is fixed from the atmosphere via plants and stored in the soil (Lefèvre et al., 2017). The variation of SOC stocks depends on several parameters including climate, vegetation type, physico-chemical properties of soils (Conant et al., 2003) and the extent as well as frequency of natural disturbances and forestry interventions. It is therefore difficult to estimate SOC stocks accurately at the regional scale and to obtain good empirical data that represent this heterogeneity well.

Several studies have been carried out worldwide on the assessment of SOC stocks. However, in most regions and countries, reliable information on SOC stocks remains limited. Indeed, much of the knowledge is concentrated on the quantification in a few specific forest ecosystems. Similarly, very few studies have focused on assessing the factors responsible for variation in SOC stocks; in particular, the effect of plant communities, which are homogeneous units, characterized by the same ecological conditions, and are considered determinants of soil carbon cycling and storage (Fry et al., 2018). The relationship between plant communities and SOC stocks is very complex, as plant communities themselves assemble according to climate and soil type, and a myriad of other factors (Fry et al., 2018). Thus, there remain huge gaps in the distribution of SOC stocks within the same ecosystem, depending on plant communities.

To study this relationship between plant communities and SOC stocks, this study focused on the plant communities present in cork oak (*Quercus suber* L.) stands. Cork oak is an endemic species of the Mediterranean basin and covers nearly 377000 ha in Morocco (HCEFLCD, 2021). The Mamora forest is one of the largest cork oak forests in the world. Phytosociologically, this forest is characterized by the presence of a single climax association referred to as *Telino linifoliae-Quercetum suberis* (Benabid, 2000), which, under the factors of deforestation and forest degradation, has given way to degradation-based associations of *Thymelaea lythroides* and *Chamaerops humilis* (Aafi, 2007). The soils that underlie the cork oak ecosystem of the Mamora Forest are a considerable organic carbon sink, retaining approximately 51% of SOC stocks, with the top 30 cm of soil containing up to 80% of SOC (Oubrahim et al., 2016). In addition, the soils under cork oak have been reported to store more carbon than any other land use in Mamora Forest (Oubrahim et al., 2016).

Given the importance of forest plant communities in carbon sequestration, the objective of this research project was to assess the SOC stocks in the upper soil layers (top 30 cm) of the forest soils of the cork oak ecosystem of the Mamora forest. This study also aimed to find the relationships between SOC stocks and plant communities as well as to define the main parameters that have a direct influence on SOC stocks.

MATERIAL AND METHODS

Study area

The study was carried out in the Mamora forest, which extends over 130000 ha and is located

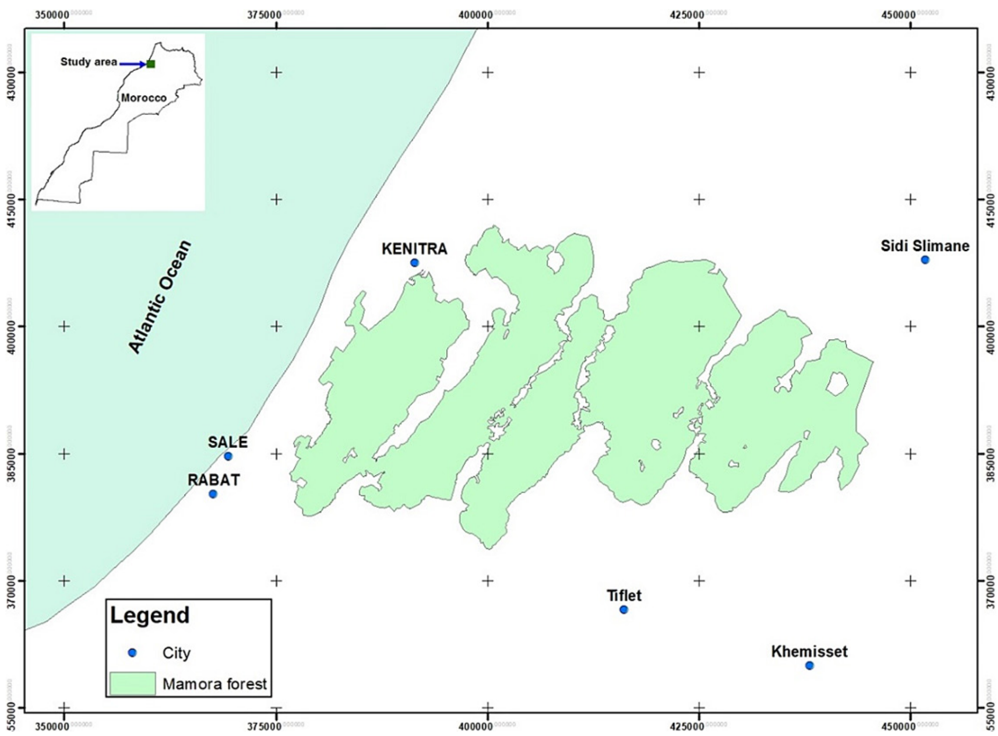

Figure 1. Geographic location of the study area

between 34° and 34°20’ North and 6° and 6°45’ West in the cities of Kénitra, Khémisset and Salé in Morocco (Figure 1). The soils are mainly of sandy over clay type, with pH values ranging from 4.8 to 6. The thickness of the sand layer is heterogeneous and can reach several meters in some places (Aafi, 2007). The climate type of this forest ranges from sub-humid to semi-arid, with mean annual precipitation ranging from 350 to 650 mm. The mean monthly temperature ranges from 12°C in January to 25°C during the summer months of July and August (Aafi, 2007). The vegetation type is dominated by cork oak (*Quercus suber* L.) which covers about 65487 ha, representing 51% of the study area. The remaining area is made up of pine, eucalyptus and Australian acacia plantations (HCEFLCD, 2021).

Sample collection

The choice of stratified sampling provided a basis for assessing the impact of plant communities and ecological parameters on the soil organic carbon (SOC) stock. This is an efficient sampling method recommended by several authors, including Roleček el al. (2007). Accordingly, ten soil profiles with three laboratory replications were sampled at each plant community (10 soil profiles × 3 plant communities × 3 replications). Uniform soil depths were considered (D: 0-30 cm) for comparison between the studied soils.

Sample preparation and analyses

The soil samples were first air-dried and crushed to pass through a 2 mm sieve. For each sample, the following properties were measured:

- soil bulk density (ρb) using the core (3 cm diameter; 10 cm height) method (Blake & Hartge, 1986);
- the particle size distribution by the international pipette method (Piper, 1966);
- soil pH by the glass electrode pH meter (Jackson, 1973);
- soil organic carbon (SOC) content by the Walkley and Black method (Walkley & Black, 1934).

The SOC stocks were quantified by collecting soil from the upper 30 cm. In each 20 × 20 m plot, the SOC stock was calculated by multiplying the corresponding values of fine bulk density and SOC content. To assess the effect of plant communities on the SOC stocks, a floristic survey was carried out on each 20 × 20 m plot at the peak of the growing season. Subsequently, abundance/dominance indices were assigned to each plant species in accordance with the phytosociological stigmatization method developed by Braun-Blanquet (1932). This method is widely used in Morocco and helps to describe plant communities (Dallahi et al., 2016). Using this method, the following arboreal plant communities were identified:

- *Quercus suber-Teline linifolia* plant community (PC-Qs-Tel)
- *Quercus suber-Thymelaea lythroides* plant community (PC-Qs-Thl)
- *Quercus suber-Chamaerops humilis* plant community (PC-Qs-Ch)

Overview of plant communities

Quercus suber-Teline linifolia (PC-Qs-Tel)

This plant community develops in the most stable and least disturbed areas of the Mamora forest. It is characterized by the strong presence cork oak and needle-leaved broom (*Teline linifolia*) species. The needle-leaved broom is a leguminous shrub known for its symbiotic nitrogen fixation estimated at 50% of the plant’s nitrogen content (Hracherrass et al., 2013). The PC-Qs-Tel plant community is species-rich, with an estimated 158 plant species. The floristic composition indicates a thermophilic forest environment, developed in a sub-humid and semi-arid temperate to warm bioclimate, whereas these species reflect the cork oak climax forest. This plant community exists between 140 and 203 m above sea level on sandy soils where humus is absent or rare and evolved. The most dominant aspect types are northwest, north and northeast. The average ground cover of trees, shrubs and herbaceous species is 30%, 60% and 35% respectively, while the corresponding heights are 11 m, 70 cm and 20 cm, respectively.

Quercus suber-Thymelaea lythroides (PC-Qs-Thl)

The PC-Qs-Thl plant community represents a sparsely populated matorral of cork oak at an advanced stage of degradation. It results from the decline of the PC-Qs-Tel climax and develops under less favorable ecological conditions. It is characterized by low species richness where the sand is typically brown to reddish and shallow to deep. This plant community is characterized by bioindicator species, such as *Thymelea* *lythroides, Urginea maritima, Chamaerops humilis, Quercus suber, Pyrus communis ssp. mamorensis* and *Teline linifolia*. The corresponding tree layer provides a ground cover of about 40% and has an average height of about 12.5 m, while the shrub layer accounts for about 45% of the cover and has an average height of about 85 cm. The herbaceous layer accounts for 45% of the ground cover and has an average height of 20 cm.

Quercus suber-Chamaerops humilis (PC-Qs-Ch)

The PC-Qs-Ch plant community is dominated by cork oak and the Mediterranean dwarf palm (*Chamaerops humilis*). It is widespread on the sands where the clay layer is closely adjacent to the soil surface. This soil feature results in high hydromorphy, which adversely affects the growth of cork oak. The PC-Qs-Ch community is similar to PC-Qs-Thl with regard to the plant composition, with the corresponding bioindicator species dominated by *Chamaerops humilis, Thymelea lythroïdes, Quercus suber, Pyrus communis ssp. mamorensis and Teline linifolia*. The tree stratum representing this plant community accounts for a ground cover of about 40%, with an average height of about 12 m, while the shrub stratum represents 45%, with an average height of about 70 cm. The herbaceous layer covers 45% and has an average height of 25 cm.

Overview of ecological descriptors

The ecological descriptors that could have an impact on the distribution of plant communities and SOC stocks were identified. These include altitude, distance to the sea, mean annual rainfall, stand density and litterfall (Table 1).

Statistical analyses

The data were presented as the mean value of the three replicate sites for each plant community. The means were compared using the ANOVA method and the Newman-Keuls test. Pearson's correlation index was used to test the significance ($p < 0.05$) of the relationships between the SOC stocks and elevation, stand density, distance to the Atlantic Ocean and amount of litterfall. In addition, the description of the relationships between plant communities, SOC stocks and other ecological parameters was carried out using hierarchical cluster analysis (HCA). HCA is a multivariate statistical tool used to identify the groups of samples that behave similarly or have similar characteristics (Roessner et al., 2011). XLSTAT was used to carry out the analyses.

RESULTS

SOC stocks at the Mamora forest

The results of the SOC stock assessment are presented in Table 2. The highest average SOC stocks were observed under the PC-Qs-Tel plant community with 86.67 ± 11.47 $t \cdot ha^{-1}$, while the lowest were observed under the PC-Qs-Ch community with 79.00 ± 10.37 $t \cdot ha^{-1}$. Interestingly, the relatively high average value of SOC stocks across all plant community types, which was recorded at 81.7 $t \cdot ha^{-1}$ (Figure 2), indicates a high carbon sequestration potential of Mamora forest soils. The area under cork oak in the Mamora forest is 65487 ha, making the contribution of carbon to the environment significant. Indeed, it has been estimated

Table 1. Modalities of the main ecological descriptors

Ecological descriptors	Classes	Modalities
Altitude (m)	Alt-1	Alt-1 ≤ 150
	Alt-2	Alt-2 ≥ 150
Distance from the sea (km)	Dis-1	Dis-1 ≤ 15
	Dis-2	Dis-2 > 15
Stand density (trees/ha)	Den-1: low density	Den-1 < 100
	Den-2: moderate density	100 ≤ Den-2 < 200
	Den-3: high density	Den-3 ≥ 200
Litter quantity	Lit-1	Litter quantity is low
	Lit-2	Litter is abundant
SOC stock	SOCs-1	SOC stock is low
	SOCs-2	SOC stock is abundant

Table 2. Descriptive statistics of the SOC stocks for the studied plant communities

Plant community	Samples	Mean	SD
PC-Qs-Tel	30	86.67	11.47
PC-Qs-Thl	30	79.33	7.28
PC-Qs-Ch	30	79.00	10.37

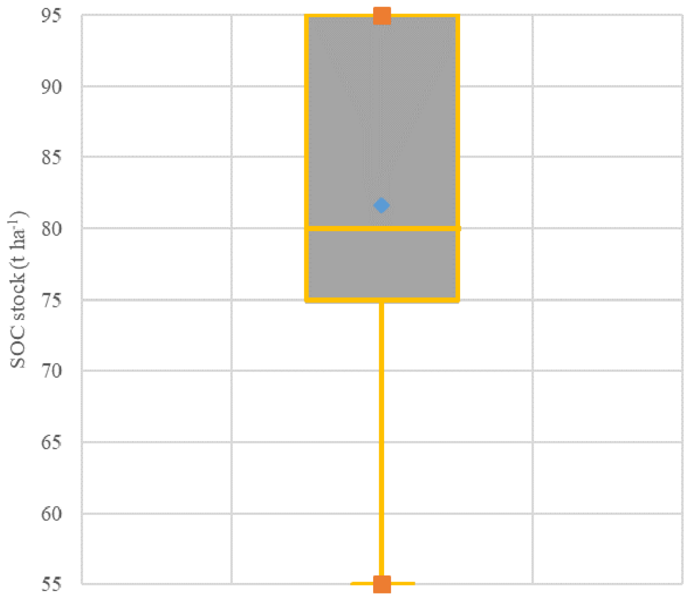

Figure 2. The SOC stocks at the Mamora Forest

that this area accounts for 3595236.3 – 6234362.4 t·ha^{-1} of soil organic carbon at a depth of 30 cm.

Influence of plant communities on SOC stocks

The results of the one-way ANOVA are presented in Table 3 and reveal that plant community types have a highly significant effect on the SOC stocks ($p < 0.005$). The multiple comparisons of the means using the Newman-Keuls test reveal two homogeneous groups (Table 4). These results show that the first plant community is markedly different from the other plant communities. Indeed, the PC-Qs-Tel community presents the highest SOC stocks.

Relationship between the SOC stocks and ecological parameters

The Pearson correlation coefficient was used to reflect the degree of linear correlation between the SOC stocks and the selected ecological parameters (Table 5).

Table 3. Analysis of variance (ANOVA): Effect of plant communities on the SOC stocks

Source	Degrees of freedom	Sum of square	Mean square	F	Prob > F
Model	2	1126.67	563.33	5.78	0.004
Error	87	8473.33	97.40		
Total	89	9600.00			

Table 4. The result of multiple comparisons of means using the Newman-Keuls test

Plant community	Mean (t ha^{-1})	Groups	
PC-Qs-Tel	86.67	A	
PC-Qs-Thl	79.33		B
PC-Qs-Ch	79.00		B

Table 5. The Person correlation between the SOC stocks and ecological parameters

	SOC	Den	Lit	Alt	Age
SOC	1.00				
Den	0.55**	1.00			
Lit	0.72**	0.40	1.00		
Alt	0.09	0.07	0.33	1.00	
Age	-0.11	-0.12	0.18	0.09	1.00

The results of the Pearson correlation test assessing the relationship between the SOC stocks and the selected parameters are presented in Table 5. The correlation coefficient ranged from -0.11 to 0.72. There was a strong relationship between the SOC stocks and the amount of litter and stand density, with correlation coefficients of 0.55 and 1.72, respectively. On the other hand, elevation had almost no effect on the distribution of the SOC stocks, with a correlation coefficient of 0.09. This was expected given its relatively low variation in the Mamora forest. As for the stand age factor, it was negatively correlated with the SOC stocks at -0.11, highlighting a decline in the SOC stocks under degraded old cork oak stands in the respective plant communities.

Characterization of the study plots

Hierarchical cluster analysis (HCA) was used to classify the study plots into clusters. The results are illustrated by the dendrogram in Figure 3. The first graphic revelation is that the sites can be divided into two distinct groups which differ in SOC stocks, plant community types, stand density and amount of litter. The first group is characterized by the SOC stocks above 80 t ha-1 and develops in the PC-Qs-Tel plant community. This group is marked by high densities (Den-1) of cork oak stands and an abundance of litter (Lit-2). Conversely, the second group features the SOC stocks under 80 t·ha^{-1}. It overlaps with the PC-Qs-Thl and PC-Qs-Ch plant communities. These communities are mainly composed of degraded cork oak stands and, consequently, are typically distinguished by low densities (Den-3) of cork oak stands and a low quantity of litter (Lit-1).

DISCUSSION

Forest soils are responsible for about 70% of carbon exchange between the atmosphere and the terrestrial biosphere. The main source of carbon exchange is the decomposition of organic matter and the root respiration of three plant species (Jandl et al., 2007). This process varies depending on several parameters, including vegetation type, amount of litter, stand density and soil physico-chemical properties (Conant et al., 2003).

This study shows that the soils of the Mamora forest have considerable potential for carbon sequestration. Indeed, the average SOC stocks ranged from 54.9 t·ha^{-1} to 95.2 t·ha^{-1}, with an average value of about 81.7 t·ha^{-1}. This is consistent with the value (78 t·ha^{-1}) reported by Oubrahim

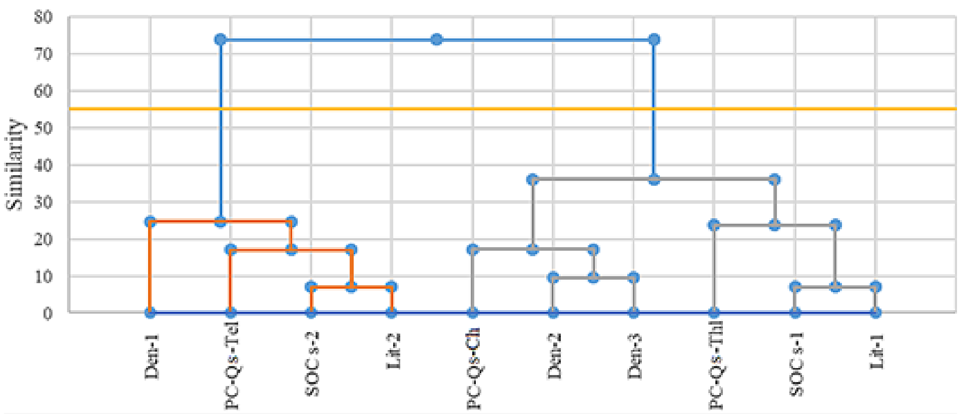

Figure 3. Dendrogram with groups identified in the cluster analysis

et al. (2016) in the same cork oak ecosystem in the Mamora forest. Nevertheless, it is much lower than the SOC stocks obtained in the Azrou forest (El Mderssa et al., 2018), composed mainly of *Cedrus atlantica, Quercus rotundifolia* and *Quercus canariensis*, under a basaltic substrate (231.45 t ha^{-1}). This superiority to the estimated stocks in the considered study area could be explained by the high stand densities, substrate type and the significant quantity of litter associated with those ecosystems.

The analysis of the relationship between the SOC stocks and plant communities also showed that there is a highly significant effect of plant communities on the SOC stocks. Multiple comparisons of means using the Newman-Keuls test showed the superiority of the Qs-Tel plant community. Indeed, this climax community presents the most favorable ecological conditions for the growth of cork oak (Aafi, 2007). Moreover, this association is marked by the strong presence of *Teline linifolia*, which is a leguminous shrub known for its symbiotic nitrogen fixation estimated at 50% of the plant's nitrogen content (Hracherrass et al., 2013). The PC-Qs-Tel plant community is also associated with a high species richness, which is estimated at 158 plant species (Aafi, 2007). By contrast, the lowest SOC stocks are observed in the PC-Qs-Ch and PC-Qs-Thl plant communities. These formations are the result of the degradation of the PC-Qs-Tel climax association, and develop in less favorable conditions and marked by low species richness (Aafi, 2007).

This study provides confirmation of the important relationship between biodiversity and soil carbon stock. Indeed, floristic biodiversity contributes to the formation of organic matter from organic litter, and thus to the improvement of the SOC stocks (Canedoli et al., 2020; Lefèvre et al., 2017; Thiele-Bruhn et al., 2012). These results also support the positive relationships between vegetation type and carbon stock and affirm the results obtained by Wang et al. (2020) who highlighted the negative impacts of plant diversity loss on carbon sequestration exacerbated over time in grasslands.

The results of this study indicate that the SOC stocks in the cork oak ecosystem increases in tandem with stand density. Indeed, the best SOC stocks were obtained at densities above 200 trees ha^{-1}. Similarly, Boulmane et al (2010) observed this effect under holm oak (*Quercus rotundifolia*) stands in the Middle Atlas region of Morocco in the Reggada (1584 trees/ha) and Tafchna (5192 trees/ha) forests where the SOC stocks were found to be 56 $t \cdot ha^{-1}$ and 80 $t \cdot ha^{-1}$, respectively. Dense forests often favor soil-forming processes and, therefore, are often characterized by deep and fertile soil, as well as high soil water content, which was shown by Zribi et al. (2016) to enhance the soil carbon sequestration potential under cork oak forests in Tunisia. Another important factor is the high carbon input from litter and plant roots incorporated in the soil. This corresponds to what was observed in the field, where the litter layer is considerably thick, which improves humification conditions and the formation of the very stable clay-humus complex in the soil (Duchaufour, 1970; Ono et al., 2011; Wei et al., 2018; Wei et al., 2020). As such, afforestation is still proposed as one of the most important climate change mitigation approaches, owing to its role in promoting the accumulation and concentration of SOC stocks, as well as being one of the most technically accessible and cost-effective climate engineering methods (Smith et al., 2016). Correspondingly, it is essential to ensure that the afforested areas are well managed, as their carbon sequestration potential has been shown to increase with age. Indeed, Varnagirytė-Kabašinskienė et al. (2021) found that the SOC concentrations in older afforestation sites were higher than in younger sites, particularly in the top 30 cm layer.

The important role of high density in humification and stability of soil organic matter, and subsequently in carbon stock accumulation was underlined in this study. Consistent with the findings, previous studies have indicated that SOC stocks increase with stand density (Wang et al., 2020; Chen et al., 2016) and higher stand densities can enhance soil carbon storage (Na et al., 2021). In addition, the role of litter as an important component of terrestrial ecosystems is highlighted in this study, as its production and accumulation contribute to carbon sequestration and soil fertility (Lee et al., 2020).

On the basis of the results of this study, stand age does not seem to have a direct influence on SOC stocks. Indeed, the correlation coefficient observed between the two variables was low, not exceeding 11%. The SOC stocks were found to not increase with age for the stands studied. However, some high carbon values are associated with older stands. The same results were reported by Peltoniemi et al. (2004) showed that soil carbon stock fluctuates significantly with stand age. This is in contrast to other authors, such as Cao et al. (2019), who showed that stand age has a significant influence on soil carbon storage in dragon spruce (*Picea asperata* Mast). The other parameters, including altitude and mean annual precipitation, showed little variation in the study area and therefore their effects were not significant on the SOC stocks.

CONCLUSIONS

The purpose of this study was to evaluate the effect of plant communities and ecological parameters on the soil organic stock in Mamora forest. The results obtained confirm the relationship between plant communities and SOC stocks. The more the plant community is at its climax and stable, the higher the SOC stocks. The PC-Qs-Tel plant community yielded the highest SOC stocks. Conversely, the PC-Qs-Ch plant community had the lowest SOC stocks. Additionally, the main ecological parameters that strongly influence the soil carbon stock and that vary between plant communities are stand density and amount of litter. These results demonstrate the critical importance of incorporating separate carbon values for each community in future carbon sequestration models.

REFERENCES

1. Aafi, A. 2007. Etude de la diversité floristique de l'écosystème de Chêne-liège de la forêt de la Maamora, Thèse de Doctorat D'Etat Es-Sc Agronomiques, Institut Agronomique et Vétérinaire Hassan II, Rabat, Maroc, 190. (http://www.agrimaroc.org/index.php/Actes_IA VH2/thesis/view/30)
2. Benabid, A. 2000. Flore et écosystème du Maroc : évaluation et préservation de la biodiversité, Ibis Press, Paris, 357.
3. Boulmane, M., Makhloufi, M., Bouillet, J.P., Saint-André, L., Satrani, B., Halim, M., El Antry, S. 2010. Estimation du stock de carbone organique dans la chênaie verte du Moyen Atlas marocain. Acta Bot. Gall., 157, 451. https://doi.org/10.1080/12538078.2010.10516222
4. Braun-Blanquet, J. 1932. Plant Sociology: The Study of Plant Communities, McGraw-Hill, New York, English translation of Pflanzensoziologie by G.D. Fuller and H.S. Conard. https://doi.org/10.5962/bhl.title.7161
5. Canedoli, C., Ferrè, C., Abu El Khair, D., Comolli, R., Liga, C., Mazzucchelli, F., Proietto, A., Rota, N., Colombo, G., Bassano, B., Viterbi, R., Padoa-Schioppa, E. 2020. Evaluation of ecosystem services in a protected mountain area: Soil organic carbon stock and biodiversity in alpine forests and grasslands, Ecosystem Services, 44, 101135. https://doi.org/10.1016/j.ecoser.2020.101135.
6. Cao, J., Gong, Y., Adamowski, J.F., Deo, R.C., Zhu, G., Dong, X., Xin, C. 2019. Effects of stand age on carbon storage in dragon spruce forest ecosystems in the upper reaches of the Bailongjiang River basin, China. Sci Rep, 9, 3005. https://doi.org/10.1038/s41598-019-39626-z
7. Chen, L.C., Liang, M.J., Wang, S.L. 2016. Carbon stock density in planted versus natural Pinus massoniana forests in sub-tropical China. Annals of Forest Science 73, 461–472. https://doi.org/10.1007/s13595-016-0539-4
8. Conant, R.T., Paustian, K., Elliott, E.T. 2001. Grassland management and conversion into grassland: Effects on soil carbon. Ecological Applications, 11, 343-355. https://doi.org/10.1890/1051-0761(2001)011[0343:GMACIG]2.0.CO;2
9. Dallahi, Y., El Aboudi, A., Aafi, A. 2016. The dynamics of natural regeneration of Tetraclinis articulata (Vahl) Masters in the Moroccan Central Plateau. Plant Sociol., 53, 41. http://www.scienzadellavegetazione.it/sisv/rivista/articoloCerca.do?idArticolo=609
10. Duchaufour, P. 1970. Précis de pédologie, Paris: Masson, 481, https://www.persee.fr/doc/rural_0014-2182_1963_num_9_1_1060_t1_0117_0000_1
11. Fry E.L., De Long J.R., Bardgett R.D. Plant Communities as Modulators of Soil Carbon Storage. Soil Carbon Storage, 2018. https://doi.org/10.1016/B978-0-12-812766-7.00002-0
12. El Mderssa, M., Benjelloun, H., Zennouhi, O., Nassiri, L., Ibijbijen, J. 2019. Pedogenetic characterization and classification of forest soils in the Central Middle Atlas (Morocco). Eurasian J. Soil Sci., 8, 152. https://doi.org/10.18393/ejss.544740
13. Blake G.R., Hartge K.H. 1986. Bulk Density. Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, Am. Soc. Agron. Madison, 101, USA 1986.
14. HCEFLCD. 2021. http://www.eauxetforets.gov.ma
15. Hracherrass, A., Berkat, O., Ismaili, M., De Montard, F.X. 2013. Fixation symbiotique de l'azote chez Teline linifolia (L.) Webb & Berth : influences de la profondeur du sol et du recouvrement arborescent dans la subéraie de la Mâamora (Maroc). Cahiers Agricultures, 22(2), 124–132(1). https://doi.org/10.1684/agr.2013.0614
16. Jackson, M.L 1973. Soil Chemical Analysis, Prentice Hall Grice, Englewood, New Delhi, India.

(https://doi.org/10.1002/jpln.19590850311)

17. Jandl, R., Lindner, M., Vesterdal, L., Bauwens, B., Baritz, R., Hagedorn, F., Byrne, K.A. 2007. How strongly can forest management influence soil carbon sequestration?, Geoderma, 137(3–4), 253–268. https://doi.org/10.1016/j.geoderma.2006.09.003
18. Lee, S., Lee, S., Shin, J., Yim, J., Kang, J. 2020. Assessing the Carbon Storage of Soil and Litter from National Forest Inventory Data in South Korea. Forests, 11(12), 1318. MDPI AG. Retrieved from http://dx.doi.org/10.3390/f11121318
19. Lefèvre, C., Rekik, F., Alcantara, V., Wiese, L. 2017. Soil organic carbon: the hidden potential, Food and Agriculture Organization of the United Nations (FAO).
20. Na, M., Sun, X., Zhang, Y., Rousk, J. 2020. Higher stand densities can promote soil carbon storage after conversion of temperate mixed natural forests to larch plantations. Eur J Forest Res, 140, 373–386. https://doi.org/10.1007/s10342-020-01346-9
21. Ono, K., Hiradate, S., Morita, S., Ohse, K., Hirai, K. 2011. Humification processes of needle litters on forest floors in Japanese cedar (Cryptomeria japonica) and Hinoki cypress (Chamaecyparis obtusa) plantations in Japan. Plant Soil, 338, 171–181. https://doi.org/10.1007/s11104-010-0397-z
22. Oubrahim, H., Boulmane, M., Bakker, M.R., Augusto, L., Halim, M. 2016. Carbon storage in degraded cork oak (Quercus suber) forests on flat lowlands in Morocco. iForest., 9, 169. https:// doi: 10.3832/ifor1364-008
23. Peltoniemi, M., Mäkipää, R., Liski, J., Tamminen, P. 2004. Changes in soil carbon with stand age – an evaluation of a modelling method with empirical data. Global Change Biology, 10, 2078–2091. https://doi.org/10.1111/j.1365-2486.2004.00881.x
24. Piper, C.S. 1966. Soil and plant analysis. Hans Publishers, Bombay, India, 14.
25. Roessner, U., Nahid, A., Chapman, B., Hunter, A., Bellgard, M. 2011. Metabolomics – The Combination of Analytical Biochemistry, Biology, and Informatics. Comprehensive Biotechnology, Academic Press, Editors: Murray Moo-Young, 13. https://doi.org/10.1016/B978-0-08-088504-9.00052-0
26. Roleček, J., Chytrý, M., Hájek, M., Lvončík, S., Tichý, L. 2007. Sampling design in large-scale vegetation studies: Do not sacrifice ecological thinking to statistical purism!. Folia Geobot 42, 199. https://doi.org/10.1007/BF02893886
27. Smith, P., Davis, S. J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., Kato, E., Jackson, R. B., Cowie, A., Kriegler, E., van Vuuren, D. P., Rogelj, J., Ciais, P., Milne, J., Canadell, J. G., McCollum, D., Peters, G., Andrew, R., Krey, V. … Yongsung, C. 2016. Biophysical and economic limits to negative CO2 emissions. Nature Clim Change, 6, 42–50. https://doi.org/10.1038/nclimate2870
28. Thiele-Bruhn, S., Bloem, J., de Vries, F.T., Kalbitz, K., Wagg, C. 2012. Linking soil biodiversity and agricultural soil management, Current Opinion in Environmental Sustainability, 4(5), 523–528. https://doi.org/10.1016/j.cosust.2012.06.004
29. Vanguelova, E.I., Nisbet, T.R., Moffat, A.J., Broadmeadow, S., Sanders, T.G.M., Morison, J.I.L. 2013. A new evaluation of carbon stocks in British forest soils. Soil Use Manag., 29, 169. https://doi.org/10.1111/sum.12025
30. Varnagirytė-Kabašinskienė, I., Žemaitis, P., Armolaitis, K., Stakėnas, V., Urbaitis, G. 2021. Soil Organic Carbon Stocks in Afforested Agricultural Land in Lithuanian Hemiboreal Forest Zone. Forests., 12(11), 1562. https://doi.org/10.3390/f12111562
31. Walkley, A., Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29–38.
32. Wang, C., Tang, Y., Li, X., Zhang, W., Zhao, C., Li, C. 2020. Negative impacts of plant diversity loss on carbon sequestration exacerbate over time in grasslands. Environ. Res. Lett., 15, 1. https://doi.org/10.1088/1748-9326/abaf88
33. Wang, X., He, C.,Liu, B., Zhao, X., Liu, Y., Wang, Q., Zhang, H. 2020. Effects of Residue Returning on Soil Organic Carbon Storage and Sequestration Rate in China's Croplands: A Meta-Analysis Agronomy, 10. https://doi.org/10.3390/agronomy10050691
34. Wei, X.Y., Yang, W.Q., Zhang, L., Tan, B., Chen, Y., Dong, Y.L., et al. 2018. Effects of litter addition on soil humification during freeze-thaw cycles in a subalpine forest. Acta Ecol. Sin., 38, 6521–6529. https://doi.org/10.5846/stxb201802060311
35. Wei, X., Yulian, Y., Shen, Y., Chen, Z., Dong, Y., Wu, F., Zhang, L. 2020. Effects of Litterfall on the Accumulation of Extracted Soil Humic Substances in Subalpine Forests. Frontiers in Plant Science, 11. https://doi.org/10.3389/fpls.2020.00254
36. Zribi, L., Chaar, H., Khaldi, A., Hanchi, B., Mouillot, F., Gharbi, F. 2016. Estimate of biomass and carbon pools in disturbed and undisturbed oak forests in Tunisia. Forest Systems., 25, e060. https://doi.org/10.5424/fs/2016252-08062