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Agroforestry olive orchards for soil organic carbon storage: Case of Saiss, Morocco

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A B S T R A C T

Soil supports numerous ecosystem services and contributes to climate change mitigation. Several publications have appeared in recent years considering soil as a persistent carbon sink and reported that agroforestry systems have a potential for soil organic carbon storage. However, there is still little knowledge about the soil organic carbon storage in olive orchards and its role in climate change mitigation. Therefore, soil samples collected from topsoil (0–30 cm) and subsoil (30–60 cm) in 57 different olive orchards provide an excellent opportunity to investigate the role of several factors (tree ages, planting density, farming system type and soil depth) in driving soil organic carbon storage variability in agroforestry olive orchards compared to olive trees in monoculture system across the Saiss region (Morocco). The difference was significant between the two types of plantation systems studied (agroforestry and monoculture) and between the two soil layers studied (topsoil and subsoil). Agroforestry olive orchard systems stored approximately 1.2 times the organic carbon in the soil compared to monoculture systems. In addition, topsoil stores 1.5 times compared to subsoil. The correlation results showed a positive relationship between the organic carbon stock of the topsoil and the subsoil, indicating that an increase in the topsoil is accompanied by an increase in the organic carbon stock of the subsoil. These results can provide a better understanding of the effect of agroforestry on deep soil organic carbon stock in Moroccan olive orchards. Furthermore, it can provide a valuable reference for future research on the soil organic carbon storage variability in Morocco and from an international perspective.

1. Introduction

Over the past century, the Earth's climate has undergone significant changes, including rising temperatures, changing precipitation patterns, and increasing frequency and intensity of extreme weather events. According to the sixth assessment report of IPCC, the global average surface temperature increased by 1.09 °C between 1850 and 2020, and almost all regions in the world have experienced surface warming [1]. Human activities have become the primary driving force influencing the biotic and abiotic processes, systems and cycles of the Earth's environment [2,3]. Agriculture is a significant contributor to greenhouse gas emissions, accounting for approximately one-third of global emissions [4]. However, balancing anthropogenic greenhouse gas emissions with ecosystem

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sequestration of CO_2 is currently required in most national and international climate policies [5]. Soil organic carbon is the largest terrestrial carbon pool, estimated at 1550 Pg to a depth of 1 m in the soil. It represents about 70 % of total terrestrial carbon, accounting for three times the carbon stored in the aboveground biomass (610 Pg) and twice that in the atmosphere (770 Pg). A reduction in soil carbon by 1 Pg is equivalent to an atmospheric enrichment of CO_2 by 0.47 ppmv. As a result, any changes in the soil carbon stock would have a notable impact on the global carbon cycle [6–8].

Orchards are considered important land-use type across the globe and, are valued for their economic, ecological, and cultural importance across the world [9]. Previous studies have shown that fruit tree ecosystems, including orchards, possess soil carbon sequestration potential equivalent to forests, with a range of 240–1250 g C m^{-2} $year^{-1}$ [4]. In the Mediterranean region, olive groves are a key crop, providing a major source of income for farmers and a crucial ingredient in the Mediterranean diet. The Mediterranean basin accounts for approximately 97 % of the world's olive cultivation area, with Spain, Tunisia, Italy, Greece, Turkey, and Morocco being the top olive-producing countries [10–12]. In Morocco, the implementation of the Green Morocco Plan has led to the establishment of new olive tree plantations, as well as the improvement and restoration of existing national olive orchards. As a result, the surface area occupied by olive trees has steadily expanded, encompassing a cultivated land area of 1,220,000 ha by 2020. The total production of olives has also increased, reaching 500,000 tons [13]. The olive sector has become a significant contributor to the national agricultural Gross Domestic Product (GDP), accounting for up to 5 %, and has generated approximately 100,000 permanent job opportunities [14].

The olive tree (*Olea europaea* L.) is considered a xerophyte and able to adapt to diverse bioclimatic zones, ranging from mountain areas to hyper aridic zones [13,15]. The areas suited to olive cultivation have mild winters, with temperatures rarely falling below zero, and dry, hot summers [16]. In Morocco, olive tree is the primary fruit species, which accounts for 65 % of the country's olive cultivation in rain-fed conditions. It is abundant in almost the entire national territory, except for the Atlantic coastal strip [14]. The olive tree is present in ten regions with 54 % of the area concentrated in the Marrakech-Safi and Fes-Meknes regions [17]. Soils in olive-growing areas should be deep, fertile, and medium-textured. The soil organic matter content should be a minimum of around 1 % and the optimal pH is between 7 and 8 [16].

Olive trees are commonly intercropped with annual crops (cereals, legumes, forage, vegetables, aromatic and medicinal plants) in several regions of Northern Africa and Southern Europe. This traditional farming system, known as agroforestry, combines trees with the growing of crops or livestock on the same plot of land [4,18–20]. In Morocco, agroforestry is well-established practice managed by smallholder farmers in oasis and in mountainous regions with limited agricultural land area and water resources [21].

Increasing soil organic carbon storage is a win-win strategy as it improves soil quality and reduces greenhouse gas emissions. The olive production chain has significant environmental impacts that depend on the techniques and practices used [4]. Agroecological practices and agroforestry are viable options to sequester carbon in olive grove soils [22]. Agroforestry has received increased attention due to its capacity to sequester carbon dioxide from the atmosphere in both above-ground and below-ground biomass. It also

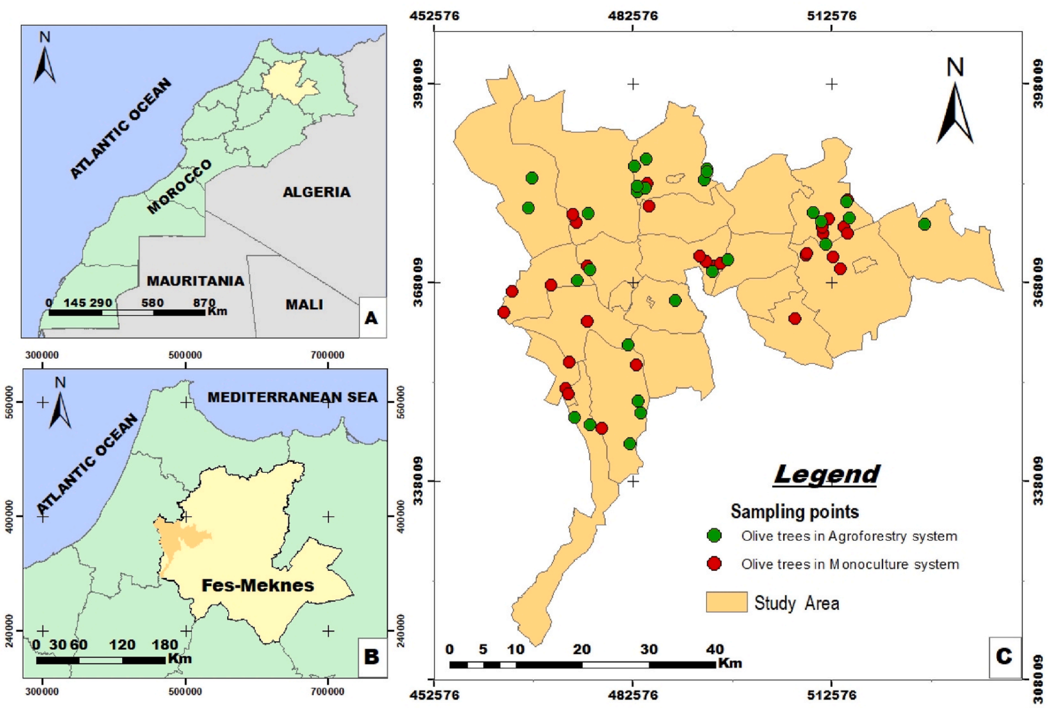

Fig. 1. Map showing the geographical location of the study area in Morocco (A), in the Fes-Meknes region (B), and the geographical location of surveyed olive orchards in the study area (C).

provides other positive environmental outcomes, such as adaptation and mitigation to climate change, with the potential for increased crop yields [23]. However, there is still little knowledge regarding the soil organic carbon storage in olive orchards and its role in climate change [4].

Considering the importance of olive production in Morocco and the Mediterranean region, as well as the scarcity of data on soil organic carbon stocks in olive groves, it is important to go further in the research concerning the role of these systems as carbon sinks to mitigate climate change. This work aimed at conducting a survey to measure soil organic carbon stock from surface (0–30 cm) and sub-surface horizons (30–60 cm) in agroforestry olive orchards comparing to olive trees in monoculture systems in the Saiss region of Morocco.

2. Material and methods

2.1. Study area and surveys

The study area covers the Saiss region, located in the Fes-Meknes region of Morocco (Fig. 1 (A, B)), which represents one of the most important agricultural areas in Morocco. The region is named after the Saiss Plain, it covers nearly 2700 km^2 and reaches an average altitude of 600 m. It is an important source of food production, known for its fertile soils and favorable climate condition. The climate of the study area is Mediterranean and it is characterized by hot and dry summers, and mild and rainy winters [24]. Long term meteorological data from the last 10 years (2012–2022) reported a mean annual air temperature of 13.3 °C and an annual precipitation of 656 mm. The warmest and driest months are June, July, and August, whereas the highest monthly precipitation was recorded in March (Fig. 2). According to the FAO classification, soil map of the study area (Fig. 3) reveals that the predominant soil types in the examined olive orchards are calcic kastanozems, Luvic kastanozems and chromic luvisols. These soils are alkaline pH, limestone, non-saline and generally contain low to moderate levels of organic matter. The chemical properties of soils in the study area is provided in Table 1. To obtain soil carbon stock data in olive groves and evaluate the contribution of agroforestry olive orchards in climate change mitigation compared to olive trees in monoculture systems, a total of 57 olive orchards with different ages (below 20 years old, between 20 and 40 years old, and above 40 years old) and different planting densities of olive trees (below 200 Tree.ha^{-1}, between 200 and 360 Tree.ha^{-1}, and above 360 Tree.ha^{-1}), including 28 agroforestry olive orchards, were randomly selected in the Saiss region (Fig. 1C). In agroforestry olive orchards, olive trees have been mixed with cereals (e.g. wheat, barley, oats), legumes (e.g. *f*aba bean, chickpea, lentil, pea, bean), forage (e.g. alfalfa) and vegetables (e.g. potatoes, onion, tomato, zucchini).

2.2. Soil sampling and analyses

A total of 114 composite soil samples were collected with a hand auger from surface (0–30 cm) and sub-surface (30–60 cm) horizons. Soil composites samples were obtained by pooling five subsamples collected using the diagonal sampling method in each studied olive orchard. The obtained soil samples were air-dried and passed through a 2 mm sieve. Then, they were analyzed for the soil organic carbon content (%) followed by assessment of the soil carbon stock (SCS).

The soil organic carbon (SOC) was performed by the Walkley and Black method: Titration method [25]. The soil organic matter concentration was calculated by multiplying the soil organic carbon value by the conventional Van Bemmelen factor of 1.724, which assumes that soil organic matter contains 58 % C [26]. Three independent experiments were performed.

The bulk density was estimated by the empirical relationship between soil organic matter content (SOM) and soil bulk density (BD)

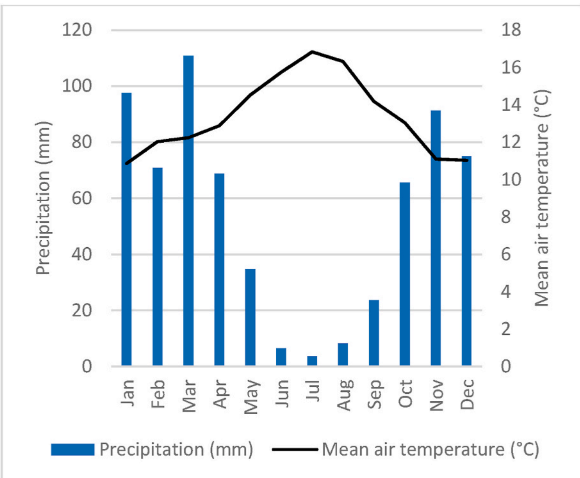

Fig. 2. Mean monthly precipitation and air temperature of the study area. Data source: NASA, https://power.larc.nasa.gov/beta/data-access-viewer/(from 2012 to 2022).

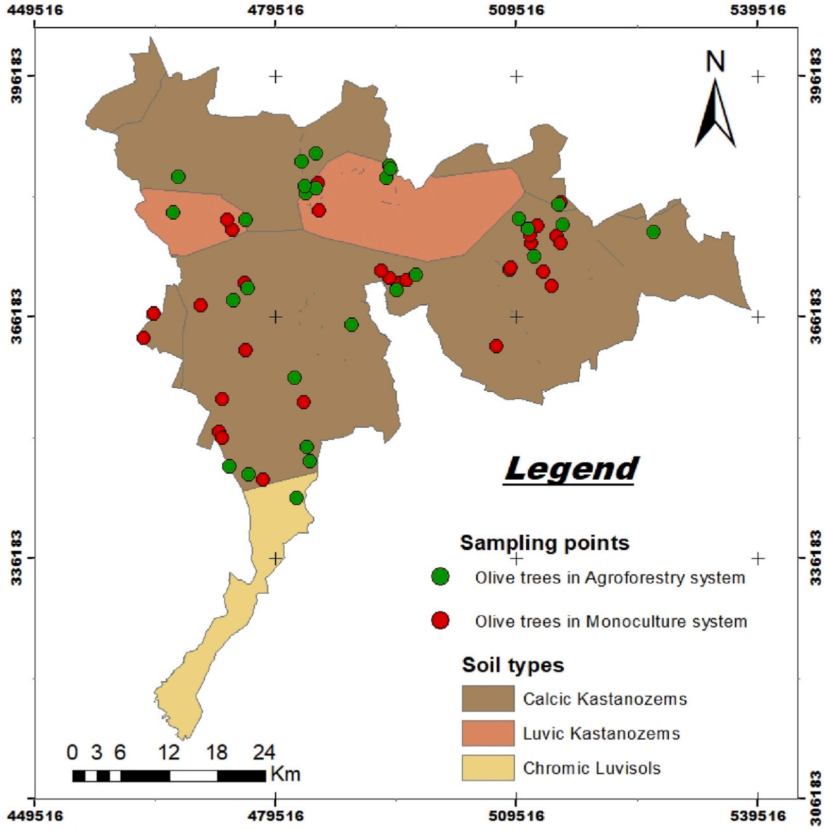

Fig. 3. Soil map of the study area. Data source: FAO, https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/446ed430-8383-11db-b9b2-000d939bc5d8.

Table 1
Chemical properties of the studied soils.

Depth (cm)		pH	EC (dS.m^{-1})	$CaCO_3$ (%)	OM (%)	BD (g.cm^{-3})	P (mg.kg^{-1})	K (mg.kg^{-1})
0–30	Min	6.3	0.1	0.0	0.1	1.3	1.3	43.8
	Max	8.8	1.5	18.0	4.5	1.6	59.3	1456.5
		8.0 ± 0.4	**0.4 ± 0.2**	**7.9 ± 5.7**	**2.1 ± 1.1**	**1.5 ± 0.1**	**17.6 ± 13.8**	**314.2 ± 217.9**
30–60	Min	6.4	0.2	0.1	0.0	1.4	1.4	34.4
	Max	8.9	1.5	19.8	2.7	1.6	41.7	997.7
		8.2 ± 0.5	**0.5 ± 0.3**	**10.9 ± 6.4**	**1.3 ± 0.6**	**1.5 ± 0.1**	**9.1 ± 7.0**	**167.5 ± 138.2**

EC: Electrical Conductivity, OM: Organic Matter, BD: Bulk Density, $CaCO_3$: Active limestone, P: Available Phosphorus, K: Exchangeable Potassium. Values are mean ± SD.

using Adams equation [27] (Eq. (1)) [28,29]:

$$\boldsymbol{BD} = \mathbf{100} / \left((\boldsymbol{SOM} / \mathbf{0.244}) + ((\mathbf{100} - \boldsymbol{SOM}) / \mathbf{1.64}) \right) \left(\text{g. cm}^{-3}\right) \quad (1)$$

The soil carbon stock (SCS) contents per hectare was calculated as follows (Eq. (2)) [9]:

$$\boldsymbol{SCS} = \boldsymbol{SOC} \times \boldsymbol{BD} \times \boldsymbol{D} \left(\text{Mg. ha}^{-1}\right) \quad (2)$$

Where **D** is the layer depth (cm).

2.3. Statistical analyses

Statistical analyses were carried out using the software package SPSS for Windows (Version 26.0, IBM). The effects of olive trees age, olive grove planting density, cropping system type and soil depth on soil organic carbon and soil organic carbon stock of all studied olive orchards were tested by factorial ANOVA. Pearson correlation was performed to identify the relationships between soil carbon stock in topsoil (0–30 cm) and soil carbon stock in subsoil (30–60 cm) of all olive orchards studied. Statistical significance was accepted at $p < 0.05$ in all cases.

3. Results

3.1. Soil organic carbon and soil organic carbon stock

The ANOVA analyses of soil organic carbon and soil organic carbon stock for olive trees ages, olive groves density, farming system type, soil depth and interactions between grouping factors are shown in Table 2. The results indicated that both soil organic carbon and soil organic carbon stocks were independently influenced by the age and planting density of olive groves. In contrast, the average amount of soil organic carbon and soil organic carbon stock exhibited significant variation depending on both the type of farming system and the depth of soil. The interactions between the influencing factors did not significantly affect the soil's organic carbon content and stock. However, they showed a significant difference among the farming system type (agroforestry and monoculture) at different olive groves planting density (Table 2).

3.2. Soil organic carbon stock in different olive groves ages

Upon sampling of 57 sites representing agroforestry olive orchards and monoculture olive orchards, soil organic carbon stocks at soil depths of 0–30 and 30–60 cm varied independently according to the age of the olive groves. The mean soil organic carbon stock in all olive orchards ranged from 44.01 $\pm$ 22.66 Mg C. ha^{-1} in mature orchards to 40.49 $\pm$ 26.06 Mg C. ha^{-1} in the young age class. The soil organic carbon stock was more dispersed in the young olive grove age class compared to the other age classes (the interquartile range was wider for the younger age class). In all three age groups, the median soil organic carbon stock values were lower than the mean values. This indicates that the data distribution was more extended towards higher soil organic carbon stock values. For each distribution of the three age classes, half of the samples had soil organic carbon stock values higher than 35.79 Mg C. ha^{-1}, 39.27 Mg C. ha^{-1}, and 39.98 Mg C. ha^{-1}, respectively, in the orchards with trees below 20 years old, between 20 and 40 years old and above 40 years old (Fig. 4).

3.3. Soil organic carbon stock in different olive groves planting density

The soil organic carbon stock varied independently with the planting density of olive groves. The largest mean soil organic carbon stock was found in intensive olive groves (45.63 $\pm$ 24.79 Mg C. ha^{-1}). The soil organic carbon stock was more dispersed in olive orchards with a planting density below 200 trees per hectare compared to other planting density classes (the interquartile range was more spread out in olive orchards with a planting density below 200). The mean was higher than the median in olive orchards with planting density below 200 and olive orchards with a planting density ranging between 200 and 360 trees per hectare, indicating that the distribution was more extended towards higher soil organic carbon stock values. For each distribution of planting density classes, half of the samples have soil organic carbon stock values higher than 40.23 Mg C. ha^{-1} and 36.16 Mg C. ha^{-1}, respectively, in olive orchards with a planting density below 200 and olive orchards with a planting density ranging between 200 and 360 tree per hectare. However, the median was higher than the mean in olive orchards with a planting density above 360 trees per hectare, indicating that the distribution was more extended towards lower values of soil organic carbon stock (Fig. 5).

Table 2
ANOVA comparison of soil organic carbon and soil organic carbon stock for olive trees ages, olive groves density, system type, soil depth and interactions between grouping factors.

	Soil Organic Carbon (%)		Soil Carbon Stock (Mg. ha^{-1})	
	F-ratio	Significance	F-ratio	Significance
Age	0.51	NS	0.57	NS
Density	0.08	NS	0.04	NS
System	4.54	*	4.54	*
Depth	10.12	**	9.76	**
Age × Density	1.24	NS	1.38	NS
Age × System	0.16	NS	0.16	NS
Age × Depth	0.61	NS	0.68	NS
Density × System	5.42	**	5.77	**
Density × Depth	0.49	NS	0.53	NS
System × Depth	0.27	NS	0.16	NS
Age × Density × System	1.27	NS	1.46	NS
Age × Density × Depth	0.13	NS	0.15	NS
Age × System × Depth	0.28	NS	0.29	NS
Density × System × Depth	1.04	NS	1.01	NS
Age × Density × System × Depth	0.36	NS	0.40	NS

Values are the F-ratio, and significance is indicated by *P $\leq$ 0.05, **P $\leq$ 0.01, ***P $\leq$ 0.001, ****P $\leq$ 0.0001 or NS, not significant.

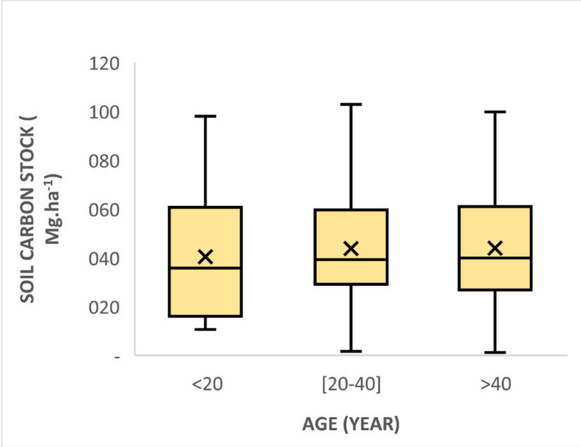

Fig. 4. Soil organic carbon stock in 0–60 cm soil depth in different olive groves age classes. The boxplots range from the first to the third quartile where the horizontal line shows the median. The vertical lines go from each quartile to the minimum or maximum, respectively.

3.4. Soil organic carbon stock in agroforestry and monoculture olive orchards

Results of soil organic carbon stock in agroforestry and monoculture olive orchards analysis showed that the soil organic carbon stock was more dispersed in agroforestry olive orchards (the interquartile range was more spread out in agroforestry olive orchards) and the distribution was symmetric. In agroforestry olive orchards, the mean of soil organic carbon stock was 47.59 ± 24.79 Mg C. ha^{-1}. However, in monoculture olive orchards, the distribution was more asymmetric; the fact that the mean was greater than the median indicates that the distribution of soil organic carbon stock values was skewed towards higher values. Half of the samples had soil organic carbon stock values higher than 36.76 Mg C. ha^{-1}. Agroforestry olive orchards have stocked approximately 1.2 times the amount of soil organic carbon as monoculture olive orchards ($F_{ANOVA} = 4.54$, $P \leq 0.05$) (Fig. 6).

3.5. Soil organic carbon stock in topsoil and subsoil

The soil organic carbon stock in topsoil and subsoil is reported in Fig. 6. Regarding the results, the soil organic carbon stock was more dispersed in topsoil (the interquartile range was more spread out in topsoil). The distribution was symmetric in both topsoil and subsoil distributions. Half of the samples had soil organic carbon stock values higher than 51.65 Mg C. ha^{-1} and 32.52 Mg C. ha^{-1}, respectively, in topsoil and subsoil. The topsoil had approximately 1.5 times the amount of soil organic carbon as subsoil ($F_{ANOVA} = 9.76$, $P \leq 0.01$) (Fig. 7). Furthermore, soil organic carbon stock in the subsoil increased linearly with increasing soil organic carbon stock in topsoil ($P \leq 0.0001$) (Fig. 8).

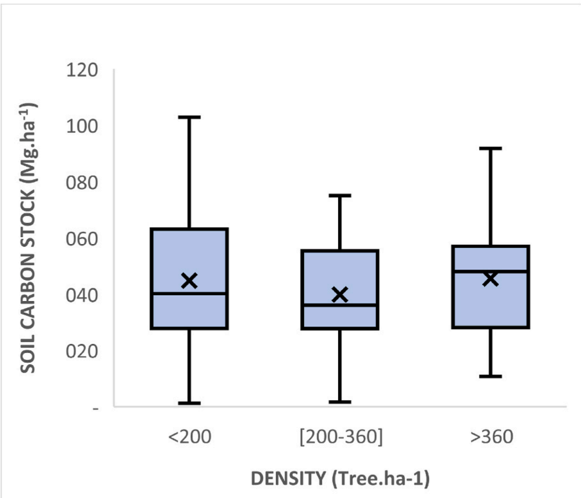

Fig. 5. Soil organic carbon stock in 0–60 cm soil depth in different olive groves planting density. The boxplots range from the first to the third quartile where the horizontal line shows the median. The vertical lines go from each quartile to the minimum or maximum, respectively.

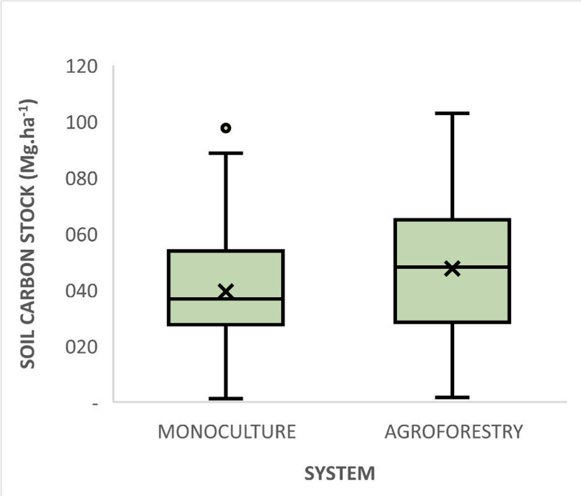

Fig. 6. Soil organic carbon stock in 0–60 cm soil depth in agroforestry and monoculture olive orchards. The boxplots range from the first to the third quartile where the horizontal line shows the median. The vertical lines go from each quartile to the minimum or maximum, respectively.

3.6. Soil organic carbon stock by the planting density in agroforestry and monoculture olive orchards

Fig. 9 displays the amount of organic carbon stored in the soil for different densities of olive groves in both agroforestry and monoculture systems. Olive groves in agroforestry systems have stocked approximately 1.4 times and 1.9 times of soil organic carbon in monoculture systems, respectively, in olive orchards with planting density below 200 and olive orchards with planting density above 360 trees per hectare. However, they have stocked 0.7 times of soil organic carbon in monoculture systems in olive orchards with planting density ranging between 200 and 360 trees per hectare.

4. Discussion

A total of 114 soil samples collected from topsoil and subsoil in 57 different olive orchards provide an excellent opportunity to investigate the role of several factors in driving soil organic carbon storage variability in agroforestry and monoculture olive groves across the Saiss region, Morocco.

In this study, agroforestry olive orchard had significantly higher soil organic carbon stocks compared to monoculture olive orchards ($F_{ANOVA} = 4.54$, $P \leq 0.05$). The results were in agreement with a previous study in Italy which concluded that agroforestry olive groves were characterized by a high level of soil carbon storage compared to those growing in other areas and in forest ecosystems [4,30]. Previous studies showed the potential of agroforestry systems to increase soil organic carbon stocks, especially, in tree row in alley cropping systems and in the top 30 cm of soil compared to durum wheat monoculture plot in the Mediterranean region [31,32]. In our results, the topsoil has stocked more than 1.5 times of soil organic carbon than subsoil ($F_{ANOVA} = 9.76$, $P \leq 0.01$). In addition, the subsoil organic carbon stock increased linearly with increasing topsoil organic carbon stock ($P \leq 0.0001$). Several authors have explained this correlation by the leaching and transfer through colloidal transport of dissolved organic matter from topsoils into subsoils and the decomposition of the fin root system [33–35].

Our results showed that the soil organic carbon stock variated independently to different planting densities. However, the soil organic carbon stock showed a significant difference ($F_{ANOVA} = 5.77$, $P \leq 0.01$) among the farming system type (agroforestry and monoculture) at different olive groves planting density. Olive groves in agroforestry systems have stocked approximately 1.4 times and 1.9 times of soil organic carbon in monoculture systems, respectively, in olive orchards with planting density below 200 and olive orchards with planting density above 360 trees per hectare. When comparing soil organic carbon stocks in two olive orchards with different planting systems, the super intensive (1850 tree.ha^{-1}) olive orchard presented a higher rate of increase in soil organic carbon stock as compared to the intensive (310 tree.ha^{-1}) olive orchard [36]. Lopez-Bellido et al. [37] found that soil organic carbon rate increased significantly between traditional, intensive and super intensive olive orchards (respectively 0.02, 0.16 and 0.31 kg. m^{-2}. year^{-1}). In addition, previous studies showed the potential of agroforestry systems to increase soil organic carbon stocks, especially, in tree row in alley cropping systems [31,32].Tree plantations are known to have a higher potential for carbon sequestration than annual crops have [37,38]. Agroforestry systems have enhanced the diversity of cultivated plants compared to monocultures, and affected associated biodiversity. Soil fauna is largely involved in litter and soil organic carbon decomposition. This soil fauna abundance and diversity are mainly positive compared to cropland in monoculture systems [39,40]. They are neutral or negative compared to forests [41,42]. In the Mediterranean region, soil carbon may decrease by up to 50 % in olive groves, compared to adjacent areas with natural vegetation [43]. A recent study by Gómez et al. [44] shows that soil organic carbon stock was on average 4.14 kg m^{-2} in olive orchard catchment under Mediterranean rainfall conditions. It was lower than soil organic carbon stock reported in olive orchards. However, it was similar to those in intensive arable crops and agroforestry fields.

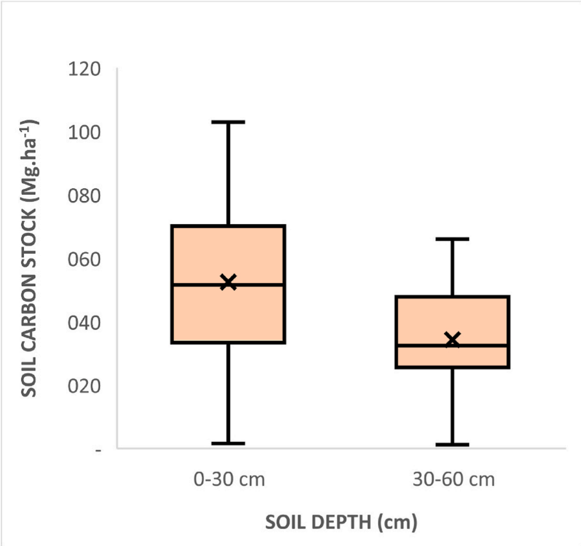

Fig. 7. Soil organic carbon stock of topsoil and subsoil. The boxplots range from the first to the third quartile where the horizontal line shows the median. The vertical lines go from each quartile to the minimum or maximum, respectively.

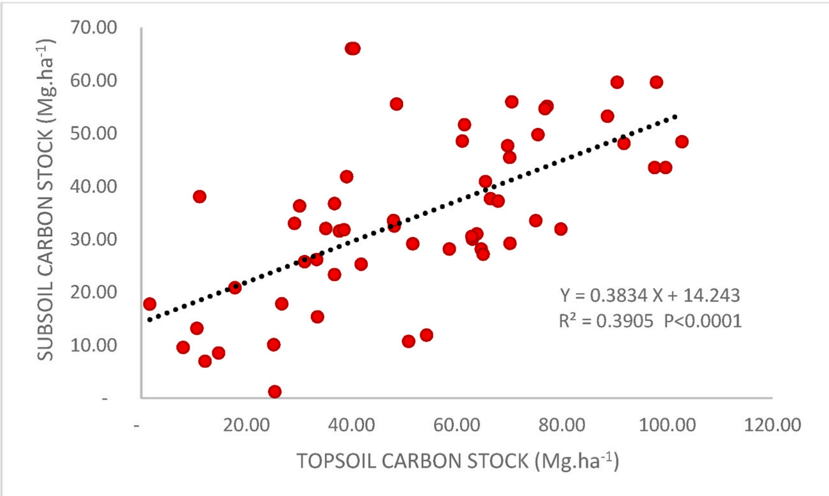

Fig. 8. Correlation between soil organic carbon stock in topsoil (0–30 cm) and soil carbon stock in subsoil (30–60 cm) of whole olive orchards studied.

The data obtained has shown that soil organic carbon storage did not differ significantly from olive groves of different ages. The plantation age could not explain the changes in soil organic carbon stock even when it interacted with other factors such as olive groves planting density, soil depth and farming system type. The results were in agreement with a previous study of Zhao et al. [34] who found that the few species records of herbaceous plants limited the accumulation of soil organic carbon stock in young age stand and the plantation age could not explain the changes in soil organic carbon content in the topsoil. In contrast, Massaccesi et al. [45] found a significantly higher value for the older orchard when investigating soil organic carbon stock in the top 90 cm of the soil in two olive orchards of different ages (7 and 30 years) in central Italy [35]. In an earlier study, Sofo et al. [46] obtained the mean values of 2.74 and 9.54 Mg ha^{-1}.year^{-1}, respectively, in young and mature olive groves when measuring the carbon sequestration in aboveground and belowground structures of olive trees in different ages and planting densities [37].

These results can provide insight into the current discussion on soil organic carbon sequestration in agroforestry systems. It provides a valuable reference for future research on the soil organic carbon storage variability in Morocco and on an international scale. Furthermore, this study can improve understanding of the effect of agroforestry on deep soil organic carbon stock in Moroccan olive orchards.

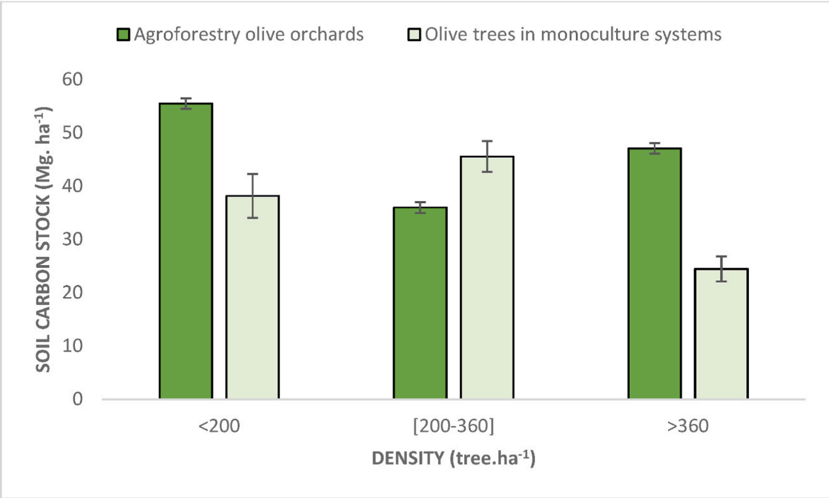

Fig. 9. Soil organic carbon stock by olive groves density in 0–60 cm soil depth in agroforestry and monoculture systems. Values are mean ± SE.

5. Conclusions

Our investigation of soil organic carbon storage in the olive orchards (Agroforestry and monoculture) showed, through a diagnosis covering 57 orchards in the Saiss region, that difference was statistically significant between the two types of plantation systems studied and between the two soil layers studied. Agroforestry olive orchard systems stored approximately 1.2 times the organic carbon in the soil compared to monoculture systems. In addition, topsoil stores 1.5 times compared to subsoil. The correlation results showed that the organic carbon stock of subsoil can increase with the increase of the organic carbon stock of topsoil. The measurement of soil bulk density based on soil organic matter using Adams equation may have weaknesses compared to using directly measured soil bulk density values. The Adams equation assumes a linear correlation between soil organic matter content and soil bulk density. However, this assumption may not always hold true, as other factors such as soil texture, compaction, and moisture content can also influence soil bulk density. Nevertheless, the Adams equation has proven to be useful as it allows for quick checks on measured bulk density values for quantitative pedological work. It is important to use the Adams equation with caution and in conjunction with other soil testing methods in order to comprehensively assess soil bulk density. The present study can provide a valuable reference for future research on the soil organic carbon storage variability in Morocco and from an international perspective. Further studies are required to gain a better assessment of the spatial distribution of soil organic carbon stock in agroforestry olive groves and the effect of distance from the tree row on this distribution.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Inass Zayani: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Mohammed Ammari:** Validation, Visualization. **Laïla Ben Allal:** Conceptualization, Investigation, Supervision, Validation. **Karima Bouhafa:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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