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Carbon stock assessment and anlysis of physiochemeical characteristics under seven woody forest formations in Oulmes Central Plateau, Morocco

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Abstract

The present work was conducted to evaluate the carbon storage potential of forest soil under different forest compositions in the Moroccan central plateau. The research was conducted in Oulmes central plateau, specifically in the forest of Zitchouene, which contains wood formations based on cork oak, holm oak, and thuja. For each forest stratum, many samples, proportional to its size, were taken, and the carbon stock was thus evaluated. Various physicochemical characteristics (structural stability, bulk density, texture, soil organic carbon, organic matter, total nitrogen, total limestone, pH, and electrical conductivity) were also determined. The results showed that the woody forest composition of the strata doesn't have a significant effect on the bulk density and stability of soil aggregates. However, it does affect the total nitrogen and organic carbon. Soil organic carbon storage (SCOS) varies significantly depending on the composition of woody species. SOCS was highest in pure thuja strata (47.91 t ha^{-1}). Soils under cork oak store more carbon (43.02 t ha^{-1}) than those under holm oak (40.07 t ha^{-1}). The high SCOS values recorded in the thuja strata more than in the cork oak and green oak strata can be explained by the floral procession that accompanies the first stratum. The mixed strata with the presence of thuja subjects have low SOCS values, storing on average 17 t ha^{-1} less than 2.5 as much as the soils under the strata with pure forest compositions. This observation inevitably led to promote reforestation of species in the pure state.

Keywords: Soil carbon organic store; central moroccan plateau; cork oak; holm oak; thuja; physicochemical characteristics

Introduction

In the past, it was considered that increase in greenhouse gases (GHG) in the atmosphere and the resulting climate change will have major effects in the 21st century (Robert, 2002), but nowadays the impacts are felt by all citizens. Indeed, CO_2 emissions have largely contributed to the changes observed in the global climate over the last decades and the link with human activities is well established (Eggleston *et al.*, 2006; Hansen and Sato, 2004). In the past, the development of agriculture was the main cause of the increase in CO_2 in the atmosphere, but currently, the burning of fossil carbon by industry and transport represents the main contribution (Robert, 2002).

The oceans are the most important sink for carbon, storing 93% of the world's carbon, or about 39,200 Gt C, with the remaining 7% distributed among epigenetic biomass, soils, and the atmosphere (Eggleston *et al.*, 2006).

The estimation of forest carbon stocks is beginning to gain importance because of the role of forests in mitigating global climate change by storing carbon in biomass and soil (Ruiz-Peinado *et al., 2012*). Organic Carbon (SOC) stocks in the soil are very large. Indeed, most of the terrestrial carbon (2000-3000 Gt C) is localized in soils, with 1500-2400 Gt C located in the first meter of soils, compared to 830 Gt C in the atmosphere and 450-650 Gt C in plant biomass (Ciais *et al*., 2013), and forest soils account for 35% of the global soil carbon stock (Robert, 2002). In this sense, and in the entire temperate and boreal forest ecosystem, SOC in the

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soil represents more than 60% of the accumulated carbon stock (Dixon, 1994).

In the Mediterranean context, the assessment of soil carbon for different forest types also highlights the relevance of the forest compartment in the region (Ruiz-Peinado, 2013), as evidenced by studies conducted by Rodeghiero *et al*. (Rodeghiero *et al.,* 2011) in the case of Mediterranean systems, Rodriguez-Murillo (2001) and Chiti *et al.* (2012) in the case of Spanish forests.

In Morocco, in addition to the crucial role that forest soils play in carbon sequestration, they also provide the basis for the survival of rural and mountain populations and all socio-economic and human development. The choice of the study area was dictated by its richness in terms of forest and its still virgin character, which will allow to make a diagnosis that will reveal the potentialities of these types of ecosystems still less studied. Our work focused on: (1) assessment of the potential of carbon stored in forest soils of the Oulmes Central Plateau under different forest formations (The case of the Zitchouine forest), (2) assessment of the physical and chemical properties of the soils, and (3) analysis of the effect of the forest composition of the studied sites on the physicochemical properties and on the soil carbon organic stock.

Materials and Methods

Presentation of the study area

The present work took place in the forest of Zitchouine, located in the southwest of Oulmes' territorial commune, in the plateau of Oulmès called by the 'High Country. It is characterized by a rugged relief that follows a main orientation to the south and southwest. The Zitchouine forest's main substrates are schists, which are found almost everywhere, and limestones, which can be found in outcrops (Aherdan, 1994).

The forest of Zitchoune is part of the future natural park of the central plateau, which contains remarkable biodiversity and offers enormous potential for rural tourism and ecotourism.

Climate is one of the main factors influencing soil and vegetation degradation (Zaher *et al.,* 2019). In terms of climate, the study area receives annual rainfall ranging from 550 to 750 mm. There are also two to three snowfalls per year that take place in December, January, and April. The region is known for the frequent phenomenon of white frosts that occurs, especially in winter. According to the Center of Works (CT) and the station of the Arbor of Oulmés, the average number of frost is 15 to 20 days per year. The climate of the region is Mediterranean with a bioclimate of the subhumid type with cool winters.

Sampling strategy and analyses

From the maps of the forest stand types, and with the use of a Geographic Information System (GIS) and field validation, we have distributed the sampling sites across the different forest strata (Table 1) in a random manner and proportional to the sizes of the strata. Thus, we took, from all forest strata, 61 soil samples from the organo-mineral layer whose depth is less than 30 cm. This layer is the one where the root concentration is stronger and where exchanges between the soil and the plant roots are important (Benjelloun *et al.,* 1997; Eggleston *et al.,* 2006). These samples were subjected to physicochemical characterization, allowing the calculation of SOC stocks under the studied stands and in particular, bulk density and soil organic carbon. Also, other parameters were determined, such as total nitrogen, soil aggregate stability, texture, pH, soil solution conductivity, and moisture content.

Table 1: Area of forest strata studied

Forest stratum	Code Stratum	Area (ha)
Cork oak	(S1)	762
Holm oak	(S2)	7662
Thuja	(S3)	139
Cork oak and holm oak	(S4)	7807
Thuja and cork oak	(S5)	314
Thuja and holm oak	(S6)	2643
Thuja, holm oak and cork oak	(S7)	1390

Soil physical analysis

Soil bulk density

The measurement of bulk density is a calculation of the soil mass with its fresh volume. The undisturbed soil samples were taken using metal boxes from the soil layer at a depth of less than 30 cm. The soil was then weighed and dried at 105°C for 24 hours. The density was calculated using the formula below :

$$DA = \frac{P}{V} \ (\frac{g}{cm^3})$$

Where : P : the dry weight of the sample.
V : the volume of the sample taken and dried.

Soil aggregate stability

Water stable aggregates (WSA) > 1mm of different soils from various study stands were estimated using the method of Pojasok and Kay (Pojasok and Kay, 1990). Five gram of wet soil samples sieved to 2 mm were placed in a 10 mL tube, 40 mL of distilled water is added, and the tube was shaken for 5 minutes at a speed of 56 oscillations/min on a horizontal shaker. After sieving, the residual material was dried at 105 °C for 24 hours and its weight was determined. These dried aggregates were dispersed in a 5% sodium hexametaphosphate dispersing solution and then passed through a 1 mm sieve and dried in the oven for 24 hours and weighed. The WSA is expressed according to the formula of Angers and Mehuys (1993):

$$WSA = \frac{\text{Mass of stable soil} > 1\text{mm} - \text{sand mass} > 1\text{ mm}}{\text{Initial soil mass} - \text{sans mass} > 1\text{ mm}}$$

Soil granulometric analysis

The soil particle size analysis consists of determining the percentage of three-dimensional classes which constitute the mineral part of the fine part of a soil, and which are: clays, silts and sands. The principle of the method is based on the sedimentation rate of a particle in a liquid (soil suspension) according to Stokes' law. The method used in our case is that of Bouyoucos hydrometer (Bouyoucos, 1962) based on the phenomenon of variation over time of the density of the "soil + water" mixture.

The particle size analysis was carried out in three stages: 1) the destruction of the total limestone with a strong acid (3N HCl) then, the destruction of the organic matter with hydrogen peroxide (H_2O_2 30%) followed by heating on a hot plate for several hours. (2) Washing with distilled water all soluble salts remaining in the soil solution and, siphoning several times. (3) Reading through the Bouyoucos hydrometer after adding a dispersing solution (sodium pyrophosphate $Na_4P_2O_7$) and stirring for one hour. Two readings were taken, one at 6 min (clay + fine silt) and one reading after 6 hours (clay). Fine and coarse sands are determined by sieving using an Afnor sieve. As for the coarse silt, it is calculated by subtraction following the equation:

100% = % A + % LF + % LG + % SG + % SF
Where:
% A: Percentage of clay present in the soil samples
% LF: Percentage of fine silt present in the soil samples
% LG: Percentage of coarse silt present in the soil samples
% SG: Percentage of coarse sand present in the soil samples
% SF: Percentage of fine sand present in the soil samples

Soil chemical analysis

Soil pH

A pH meter was used to measure the pH of a soil/water suspension at a ratio of 1/2.5 and a 1N KCl solution at the same ratio.

Electrical conductivity

It was measured by a salinometer also called conductivity meter at µS cm^{-1} in a soil/water suspension. These measurements were performed using a HACH laboratory conductivity meter, model sensION™+ EC 71.

Total nitrogen, organic carbon, and soil organic matter

Total nitrogen was determined using the Kjeldahl procedure (Wilke, 2005). Soil organic carbon was determined using the Walkley and Black (1934) wet oxidation method. The organic matter was obtained by applying the formula of Soltner (1988) while multiplying the organic carbon rate by the coefficient of 1.724.

Statistical analysis

All statistical analyses were performed with SPSS V26 software. Comparisons of land use means for the different variables studied were provided by one-way analysis of variance (ANOVA 1). Also, to test whether the soil carbon stock is significantly different from one stratum to another. When ANOVA indicates that there is a significant difference between the different land uses for a given parameter, the post hoc test (significance level at probability $p \leq 5\%$) was run to differentiate between sites (Watson, 1982). The conditions for the application of ANOVA are, especially, the normality of the distribution and the homogeneity of the variance.

Results and Discussions

The main physicochemical characteristics of the soils in the study area namely : structural stability, bulk density, texture, soil organic carbon, organic matter, total nitrogen, total limestone and pH, under different forest plant formations, are presented in Tables 2, 3, and 4.

Effect of land use on some soil physical properties

The determination of bulk density is essential. It allows the calculation of porosity and indirectly appreciates the permeability, the resistance to root penetration (Watson, 1964), the cohesion of horizons (Yoro, 1983; Yoro and Assa, 1986), and the water reserve of the soil (Henin *et al.,* 1969). Also, this parameter contributes to the estimation of soil carbon stock (Henin *et al., 1969*; Baize, 1988; Solomon *et al.,* 2002; Mendham *et al.,* 2003*;* Zaher *et al., 2020*). Indeed, this stock is calculated on the basis of three parameters, namely the concentration of organic carbon, the thickness of the layer studied and the apparent density. Investigation of the variation of bulk density with the composition of the forest strata studied (Table 2) showed that there is no significant difference in the mean density of the sites at the 5% significance level (p=0.099 > 0.05). This result is similar to the study conducted in the Middle Atlas by El Mderssa (2019), where it was found that there is not a significant difference in the average density of the sites studied under forest formations based on holm oak, Zeen oak, cedar of the Atlas and maritime pine. We also note, in our study, that values of coefficients of variation oscillated between 6.6 to 16%, testifying to a great homogeneity within the strata studied.

The estimation of water-stable aggregate (WSA > 1 mm) in the upper soil layer (0-30 cm) shows that this parameter characterizing soil structural stability is not influenced by the forest composition of the stratum (p=0.186 > 0.05). Nevertheless, we notice that this parameter is influenced mainly by land use and land-use change, such that the proportion of stable macroaggregates in water decreases in the following order: Forest > pasture > arable land (Ashagrie *et al.,* 2007, Zaher *et al.,* 2019).

The texture of the soil determines the other physical properties of the soil. It plays an important role in porosity, drainage, and carbon storage in the soil (Lagacé Banville , 2009; EL Mderssa , 2019). The results of the granulometric analysis of the studied soils are grouped into Table 3. The texture of the soil was identified using a textural diagram. The most represented texture classes of the studied sites are by order of importance of loam type (Stratum S1, S2, S4, and S6), clayey loam (S5 and S7), and sandy loam (S3). The one-way ANOVA results show that the fraction of clay differs significantly between strata (p = 0.000) at the 95% significance level.

Table 2: Bulk density and water-stable aggregate with land use in 30 cm of soil depth

Forest stratum code	Bulk density (g cm^{-3})	WSA > 1mm (g 100 g^{-1})
(S1)	0.96	2.65
(S2)	1.08	3.02
(S3)	1.03	1.23
(S4)	2.32	2.59
(S5)	0.88	5.95
(S6)	1.82	3.31
(S7)	1.74	9.71

Each value represents the average of the analyses on the samples taken by stratum

Table 3: Variation of different particles by granulometric analysis with land use in 30 cm of soil depth

Forest stratum code	Clay (%)	Limon fin (%)	Coarse loam (%)	Fine sand (%)	Coarse sand (%)	Texture
(S1)	24,1 abc	26,0	13,2	17,4	19,3	Loam
(S2)	19,6 abc	21,7	13,0	16,9	28,8	Loam
(S3)	9,6 a	18,4	18,1	20,3	33,6	Sandy loam
(S4)	21,6 abc	22,9	15,6	20,1	19,8	Loam
(S5)	30,3 b	16,3	18,4	12,2	22,8	Clay loam
(S6)	22,3 abc	28,4	16,5	15,7	16,9	Loam
(S7)	32,7 bc	23,0	5,5	10,2	28,7	Clay loam

Each value represents the average of the analyses on the samples taken by stratum. Treatments followed by different letters indicate significant statistical differences at p≤0.05.

Table 4: Chemical analyses of soil samples

Forest stratum code	% N	% C	C/N	OM	% Lim	pH-H_2O	pH-KCL
(S1)	0.03bc	1.48ac	61.38	2.56	0	6.20	5.16
(S2)	0.21ac	1.23ac	31.85	2.12	0	6.47	5.42
(S3)	0.05bc	1.62abc	32.52	2.80	0	6.45	5.64
(S4)	0.03b	1.35c	49.38	2.32	0	6.33	5.14
(S5)	0.05bc	0.55ba	28.32	0.95	0	6.40	5.29
(S6)	0.02b	0.21b	13.69	0.36	0.2	6.70	5.90
(S7)	0.04bc	1.01ab	25.99	1.74	0	6.40	5.47

Each value represents the average of the analyses on the samples taken by stratum. N : total nitrogen, C : Carbon, OM : Organic matter, Lim : total limestone. Treatments followed by different letters indicate significant statistical differences at p≤0.05.

Effect of land use on some soil chemical properties

Soil chemistry was measured for pH-H_2O, pH-KCL, nitrogen, organic carbon, and organic matter. Table 4 presents a summary of the chemical analyses by forest stratum.

The values of total nitrogen as illustrated in Table 4 vary from 0.03%, at the level of the cork oak and holm oak strata, to 0.21%, the highest value recorded at the level of the holm oak stratum. In this study, by statistically analyzing our data on total soil nitrogen in the layer (0-30 cm), we found that the total nitrogen content varies very

Table 5: Variation of store organic carbon with land use in 30 cm of soil depth

Forest stratum code	SOCS (t ha^{-1})
(S1)	43.02ab
(S2)	40.07a
(S3)	47.91a
(S4)	42.70a
(S5)	17.10ab
(S6)	6.71b
(S7)	26.37ab

Each value represents the average of the analyses on the samples taken by stratum. Treatments followed by different letters indicate significant statistical differences at $p \leq 0.05$.

Table 6: Soil Organic Carbon Stock (SCOS) in different areas in Morocco

Study area	Author	Species	Parent rock	Depth (cm)	SOCS (t ha^{-1})
Ait Ichou East forest (Oulmes area)	Zaher *et al.,* 2019	G.O	---	30	40,83
Harcha Forest (Oulmes area)	Zaher *et al.,* 2019	H.O	---	30	109,14
Azrou forest (Middle Atlas)	Zaher *et al.,* 2020	C.A	---	30	183,33
Dayet Hachlaf (Middle Atlas)	Boulmane *et al., 2014*	C.A+G.O+ Ox + Le	---	100	124,6
Ajdir (Middle Atlas)	Boulmane *et al., 2014*	G.O+C.A+J.O+Q.C	---	100	141,4
Ksiba (Middle Atlas)	Boulmane *et al., 2014*	G.O	---	100	65,5
Tafechna Ajdir (Middle Atlas)	Boulmane *et al., 2014*	G.O + J.O	---	100	71,9
Reggada (Middle Atlas)	Boulmane *et al., 2014*	G.O	---	100	52,5
Jaaba Forest (Central Middle Atlas)	El Mderssa *et al.,* 2019	G.O+Q.C	Basalt	30	109,02
Forest of Jaaba (Central Middle Atlas)	El Mderssa *et al.,* 2019	Q.C	Basalt	30	144,22
Forest of Jbel Aoua South (Middle Atlas Central)	El Mderssa *et al.,* 2019	G.O	Sandy dolomite	30	174,50
Forest of Jbel Aoua South (Middle Atlas Central)	El Mderssa *et al.,* 2019	C.A	Sandy dolomite	30	160,86
Forest of Jbel Aoua South (Middle Atlas Central)	El Mderssa *et al.,* 2019	M.P	Sandy dolomite	30	134,06
Forest of Jbel Aoua South (Middle Atlas Central)	El Mderssa *et al.,* 2019	C.A + G.O	Sandy dolomite	30	119,13
Forest of Azrou (Middle Atlas Central)	El Mderssa *et al.,* 2019	C.A	Basalt	30	178,07
Forest of Azrou (Middle Atlas Central)	El Mderssa *et al.,* 2019	Q.C	Basalt	30	251,54
Forest of Azrou (Middle Atlas Central)	El Mderssa *et al.,* 2019	G.O	Basalt	30	264,73

G.O : Green oak, H.O : Holm oak, Ced : Cedrus atlantica, Ox : Juniperus oxycedrus, Q.C : Quercus canariensis, Le : Leaf, M.P : Maritime pine.

significantly with the type of land use (p=0.000). Indeed, combining the total nitrogen data with the pH_H_2O values, we can deduce that the fertility of the observed strata is low according to the general fertility scale of Dabin (1970).

For organic carbon content, statistical analysis of the data by an ANOVA test shows that there is a highly significant difference between the forest strata studied (p=0.000). Therefore, there is an effect of the stratum in our case on the sequestration of organic carbon in the soil and consequently on the organic matter reserve of the soil since OM = Organic Carbon x 1.724 (Soltner, 1988). The distribution of organic carbon remains very heterogeneous between the repetitions of the same stratum, varying between 30 and 77%. The highest values are recorded in the thuja and cork oak strata, respectively, at 1.62% and 1.48%, while the lowest values are noted in the mixed stratum between holm oak and thuja (0.21%) and the mixed stratum of thuja and cork oak (0.55%).

The C/N ratio allows the evaluation of the quality of organic matter as well as the estimation of the importance of humification and mineralization processes acting in soils (Lagacé Banville , 2009; EL Mderssa, 2019). Lafond *et al*, (1992) and Akselsson *et al,* (2005) mentioned the C/N ratio as a good indicator to evaluate carbon sequestration in soils. Except for the thuja and holm oak stratum S6 where the C/N ratio recorded a low average value of 13.69, indicating a high concentration of nitrogen and a high degree of decomposition, and the cork oak stratum where the highest value was recorded at 61.38, indicating a low rate of carbon decomposition since decomposer organisms use nitrogen, which quickly becomes limiting, the other strata record values ranging from 25.99 in the stratum where the three forest species are represented to 49.38 for the cork oak and holm oak based stratum.

Soil pH is an important parameter of soil dynamics. It has a direct effect on the bioavailability of nutrients, through solubilization and insolubilization phenomena, specific to each element (Oubrahim, 2015). The results of the pH-H_2O parameter show that the pH values of the studied soils vary from 6.20 to 6.70 (Slightly acidic to near neutral), indicating that the soils are well balanced, allowing for a good mineral supply. The pH-KCL is always lower than the pH-H_2O. The pH-KCL values vary between 5.14 and 5.40. The statistical analysis of ANOVA with only one criterion shows that there isn't a significant difference between the means (p= 0,830 for pH-H_2O), so there is no effect of the composition of the strata on the acidity of the soil. There is also a high homogeneity within strata between replicates illustrated by the coefficient of variation values from 2 to 15.21%.

Soil organic carbon storage at different sites

The soil organic carbon store (SOCS) of the different strata is recorded in Table 5. The ANOVA results indicate a significant difference between sites (p=0.01) in SOCS, indicating an effect of forest type on soil organic carbon stock variation. SOCS (Table 5) was highest in the Thuja-based stratum (47.91 t ha^{-1}), followed by the soil under cork oak (43.02 t ha^{-1}) and the mixed cork and holm oak (42.70 t ha^{-1}), and lowest in the mixed Thuja and holm oak stratum (6.71 t ha^{-1}). The high values of the SOCS recorded at the level of the strata under the resinous species, i.e., the thuya, can be explained by the accompanying floral procession which is based on deciduous species of arbutus unedo and *Pistachio lentiscus* in abundance in these strata. The presence of thuya subjects in mixed strata results in low SOCS values, which can be explained by the variability brought within these strata in terms of soil chemistry, rooting depth of tree species, and litter quality (EL Mderssa, 2019). Carbon storage values within the same stratum are very heterogeneous and vary from 35 to 84%.

In our case, the geological substratum is based on shale, which is present almost everywhere, and quartzite sandstone, which constitutes the summit caps, compared to other studies on soil carbon stock in Morocco as illustrated in Table 6, soil organic carbon stock varies from one woody cover to another but obviously from one parent rock to another, indeed there is an effect of site and forest type on the variation of SOCS (El Mderssa *et al.,* 2019), which doesn't arise in our case of study as we have the same geological substratum.

Conclusions

The investigation of certain physicochemical characteristics of soils at the Oulmes central plateau level, in the case of the Zitchouine forest, revealed that the effect of forest composition, particularly the composition of woody forest species, on the same mother rock, namely the schist in our case, has no effect on the physical properties of the soil, known as bulk density. Also, the effect of woody species composition is essentially manifested in the chemical properties of the soil (organic carbon, total nitrogen, organic matter).

The effect of forest stratum composition is significant on total nitrogen. Soil fertility in terms of nitrogen in the study area is considered low.

The carbon storage in the study area ranges from 7 t ha^{-1} to 48 t ha^{-1}. The highest values are recorded for the strata based on pure species (thuja, cork oak, and holm oak). Nevertheless, the variability within strata between repetitions remains high, which indicates the heterogeneity of this parameter.

These results should guide future forest management to focus on species selection in reforestation to maximize the carbon sequestration potential of the forest ecosystem, especially for Morocco, located in the southern Mediterranean, which is known to be a very vulnerable region to climate change. For our study area, reforestation based on pure species (thuja, cork oak, and holm oak) will promote SOCS. Also, the thuja species will be an excellent choice among these species.

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