Assessment of the organic carbon stock in the green oak forest in the Morrocan Oulmes Central Plateau.

Hicham Ikraoun*
Laboratory of Environment and Valorization of Microbial and Vegetal Resources, Faculty of Sciences.
Moulay Ismail Univesity.
Meknes, Morroco.
hichamenfi40@gmail.com

Laila Nassiri
Laboratory of Environment and Valorization of Microbial and Vegetal Resources, Faculty of Sciences.
Moulay Ismail Univesity.
Meknes, Morroco.
nassiri_layla@yahoo.fr

Mohamed El Mderssa
Polydisciplinary Faculty.
Soltane Moulay Slimane University.
Beni Mellal, Morroco.
elmderssa.enfi@gmail.com

Jamal Ibijbijen
Laboratory of Environment and Valorization of Microbial and Vegetal Resources, Faculty of Sciences.
Moulay Ismail Univesity.
Meknes, Morroco.
jamal_ibijbijen@yahoo.fr

***Abstract*—the present study was conducted in the Morrocan Oulmes Central Plateau to assess the organic carbon stock (OCS) in the soil and biomass of the green oak ecosystem. Soil samples taken from green oak plots at the upper organomineral layer (<30 cm depth) were analyzed by conventional assay for the determination of carbon stock in each sample. Also, other soil physicochemical parameters namely pH, total nitrogen, total limestone, organic carbon, bulk density, texture, and stability of soil aggregates were studied. Aliquots of ten green oak trees were used to assess the carbon stock in the different compartments of the tree. The studied soil is slightly acidic to neutral with a pH ranging from 5.49 to 7.19. The texture of the studied area is loam. The soil organic carbon stock ranges from 16.03 t/ha to 97.33 t/ha with an average value of 40.07 t/ha. The total above-ground biomass of the green oak stands in the studied plots has an average value of 55.28 t/ha, and the average value of the total carbon mass is 31.06 t/ha.**

Keywords— organic carbon, carbomass, central Moroccan plateau, green oak, ecosystem.

I. INTRODUCTION

Increasing concentrations of greenhouse gases (GHGs) in the atmosphere are now recognized as the main cause of climate change [1]. In the past, the development of agriculture was the main cause of the increase in CO2 in the atmosphere, but currently, the burning of fossil carbon by industry and transport represents the main contribution [2]. 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 [3]. 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 [4]. the green oak, a multipurpose tree with significant potential for fodder and energy wood in the form of charcoal, [5], also sequesters significant amounts of carbon from the atmosphere in the form of CO2. The objectives of the present study are summarized in : (i) the physicochemical characterization of the soils at the level of the plots under green oak, (ii) the evaluation of the stock of Soil organic carbon (iii) the evaluation of the stock of organic carbon at the level of the biomass of the green oak trees in the central plateau of Oulmés.

II. MATERIALS AND METHOD

A. *Presentation of the studied area*

The study was carried out at the level of the green oak-based plots of the Zitchouéne forest as illustrated in Figure 1. The forest of Zicthouéne is located in the southeast of the territorial commune of Oulmés also called 'Haut Pays' [6]. The geological substratum at the level of the studied sites is based on schist present almost everywhere [7] and of quartzite gés at the level of the tops. according to the data of the National Office of the Agricultural Council of Oulmes, the region receives an average annual precipitation of about 550 mm to 750 mm, maximum temperatures vary from 20.5 to 38.1°C and minimum temperatures vary from -1.4 to 6.1°C. The seasonal regime is of the HPAE type, reflecting the Mediterranean character of the studied area. The number of frost days is about 15 to 20 days per year.

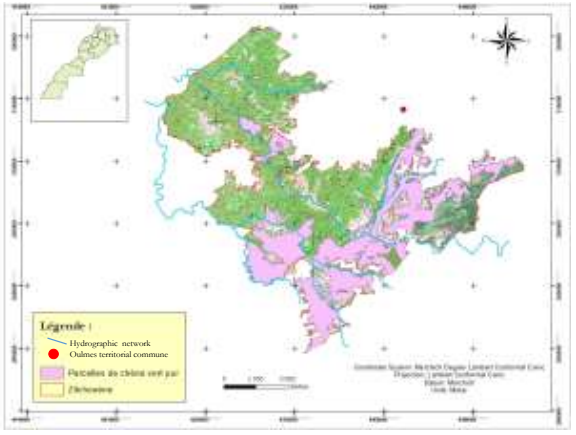

Fig. 1. Localisation of studied area

* Corresponding author: hichamenfi40@gmail.com

B. Soil physicochemical analyses

Soil samples, randomly distributed on the plots (Fig.2), taken with the help of the pedological auger, on the upper organo-mineral layer whose depth is lower than 30cm, were the object of a characterization bearing on the determination of the :

- pH of the soil solution: measured in a soil: water suspension of ratio 1/2.5 using a pH meter as stated by Zaher et al [8];
- Total nitrogen: the analysis of this parameter was carried out using the Kjeldahl/ Wilke (2005) [9,10,11] distillation method ;
- Organic carbon and organic matter: the analysis of soil organic carbon was carried out using the method of Walkley and Black (1934) [10,11,12] and the value of organic matter was deduced from the formula of Soltner (1988) [13] ;
- bulk density: consists of a calculation of the mass of the soil to its fresh volume according to the following formula :

$$DA = P/V \ (g/cm3)$$

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

- Granulometry: consists of the determination of the percentages of the constituents of the soil, namely clays, silts, and sands using Bouyoucos hydrometer method [14].

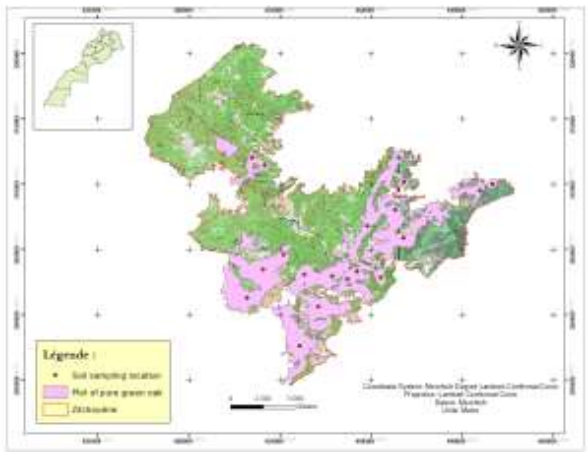

Fig. 2. Distribution of soil sampling locations.

C. Assessment of soil organic carbon stock

The soil carbon stock is calculated based on the following formula [15,16,17,18] :

$$q(ji) = 0,1 \times Ei \times da(i) \times C(ji)$$

With : q (i) : content of element (j) in soil layer (i) (t.ha-1)
- 0.1 : conversion coefficient,
- Ei : depth of the layer (i) (cm),
- da(i) : bulk density of the fine fraction, <2 mm, in layer (i) in (g.cm-3),
- C(ji) : concentration of element (j) in soil layer (i) (g.kg-1).

D. Assessment of the total carbomass of the aerial part

To assess the carbon stock at the tree level, a biomass study is necessary. It provides data on the quantity of biomass and consequently on the quantity of carbon in each compartment of the tree, i.e. the trunk, branches, twigs, and leaves. These data are then extrapolated to the scale of the parcels studied after an inventory that consists of measuring the circumferences at 1.30 m from the ground of the trees inside the circular plots of 0.5 ares distributed randomly on the said parcels.

- Study of the biomass of green oak trees

For our case study, we used the models for estimating the biomass of green oak trees developed by Belghazi et al (2001) [5] (Table I), in the central plateau of Oulmés bordering our studied area and comparable to our context.

TABLE I. BIOMASS TARIFFS DEVELOPED BY BELGHAZI ET AL. (2001)

Component	Models
Trunk	PST = 0,015 * C^(1,977)
Branches	PSB = 2,6*10^(-4)*C^(2,822)
Twigs	PSR = 2,64*10^(-3)*C^(1,943)
Leaves	PSF = 1,99*10^(-3)*C^(2,009)

PST : Dry weight of trunk in (Kg) ; **PSB**: Dry weight of branches in (kg)
PSR: Dry weight of twigs in (kg) ; **PSF**: Dry weight of leaves in (kg)

In addition, these models were validated on a sample of ten (10) felled green oak trees, on which direct measurements of the fresh mass of the different compartments were carried out [19]. Thus, for all the standing trees, we proceeded to the measurement of the circumference at 1.30 m height, and for each tree, the different compartments were separated, and the measurements concerned :

- The total weight of the trunk up to the 5 cm circumference cut ;
- The total weight of the branches ;
- The total weight of the twigs ;
- The total weight of the leaves.

The statistical parameters used for the verification of the above models are proposed by Palm (1981) [20] namely :

- the relative average of the cubing errors :

$$em = (1 / n) \sum ei /Vm$$

- the relative standard deviation of the cubing error distribution :

$$Se = (1 / n) \sum (ei - em)^2 /Vm$$

Where : ei = Vi - Ve
Vi : real volume,
Ve : volume estimated by the tariff,
Vm: actual average volume,
n: number of trees retained for checking.

These two parameters allow us to calculate the bias of the model and the degree of confidence we can place in it. The lower they are, the better is the tariffs.

In addition, wood samples were taken to measure the moisture content and the organic carbon fraction of the wood, for each tree we took :

- Three 5 cm slices of the trunk, one at the base, another halfway up, and the third at the 5 cm cut;

- One 3 cm slice from the middle branch of the tree;
- Two 3 cm slices of the middle twigs of the middle branch of the tree;
- Two handfuls of the tree's leaves after stirring the whole tree's leave ;.
- Two 3 cm slices from the root.

The moisture content of the different components of the tree was determined according to the formula illustrated below :

$$TH\ \% = \frac{PF - PS}{PS} 100$$

Where: PF: the fresh weight of the sample and PS: its dry weight.

- Determination of the carbomass of green oak trees

The knowledge of the biomass of the different compartments of green oak and their carbon fraction allows evaluating the carbomass of the whole tree. For the determination of this carbon fraction, aliquots of wood and leaves were taken from the sample trees dried to the stability of their weights. These aliquots were weighed, placed in weighed porcelain crucibles, and calcined in a muffle oven at 600°C for 12 hours. After removal from the oven, the crucibles were placed in a desiccator until they cooled, and the whole set (crucibles + mineral material) was weighed afterward. The weight loss observed during the calcination corresponds to the organic matter and the residue to the mineral matter. The organic matter is thus calculated according to the following formula:

$$OM = ME-((MM-T)-T)$$

OM: Organic Matter; MM: Mineral Matter; ME : Weight of the dried sample; T: Weight of porcelain crucible.

And the organic carbon content is deduced through the formula of Soltner (1988) [13].

III. Results and Discussion

A. *Physicochemical characterization and organic carbon stock in the soil*

The results of physicochemical analyses of soil samples collected under green oak-based plots are shown in Table II.

It emerges from this analysis that the soils in the studied area are slightly acidic, these values of pH little acid can be explained by the existence of vegetation represented by deciduous species in their natural state, namely the green oak despite the nature of the substrate based on schist. The distribution of organic carbon content, with an average value of about 1.23%, remains very heterogeneous between the replicates, with a coefficient of variation reaching 57%.

The C/N ratio considered by Lafond et al. (1992) [21] and Akselsson et al. (2005) [22] as a good indicator to evaluate carbon sequestration in soils takes a rather high value (31.85) showing a low carbon decomposition rate.

The soil texture in the studied area is loamy.

The organic carbon stock in the soil, with a mean value of 40.07 t/ha, wich is close to that found by zaher et al [30], nammely 40.83 t/ha in the natural green oak forests of the Moroccan central plateau.The variation of this value, between the different replications, is between 16.03 and 97.33 t/ha.

B. *Biomass of green oak in the studied plotss*

In addition to the fact that the assessment of the biomass of ecosystem components constitutes the basic element for the fundamental knowledge of their functions [23], the study of this parameter is necessary for the calculation of carbon stock [1].

The verification of the biomass rates developed by Belghazi et al on the 10 ten sample trees was performed based on the relative mean of the cubing errors and the relative standard deviation of the distribution of these errors. The results of the calculations are reported in Table III.

The models developed have a low relative bias of only 9.84% for the trunk biomass tariff, 9.65% for the branch biomass tariff, 8.53% for the twigs biomass tariff, and 6.37% for the phytomass tariff, and a relative standard deviation of the biomass error distribution of the order of 1.01, 2.23, 9.78 and 13.88, respectively, for the four tariffs.

The application of the biomass models retained for each tree organ and their sums allowed us to estimate the total dry biomass per hectare.

Table IV summarizes the average total biomass per hectare which amounts to 55.28 t/ha.

Compared to other green oak forests in Morocco (Table V), the biomass of the Zitchouéne forest is high, which can be explained by the high density of green oak trees in the studied area and the favorable ecological conditions.

C. *Total carbomass of green oak in the studied plots*

The results of the carbon content of the different components of the tree, calculated from the aliquots calcined in the muffle oven, are shown in Table VI.

The combination of the biomass data of all the components of the tree and their carbon content allows evaluating the carbomass of green oak, which is estimated at 31.08 t/ha in the studied plots. Compared to other studies related to the evaluation of carbon stock in the aboveground part of green oak trees in other ecological contexts (Table VII), the different values recorded for the same species between forests is explained by the different dendrometric characteristics that characterize the important potentialities of the stands composing each forest [18].

The carbon stock in the root part of green oak trees was evaluated using the ratio of below-ground biomass to above-ground biomass (R) cited in Intergovernmental Panel on Climate Change (2006) work [29]. Thus the root biomass of green oak trees is estimated at 25.42 t/ha, and the carbon stock is estimated at 14.29 t/ha.

Thus the total carbon stock in the plots based on green oak in a pure state, deduced by the addition of this stock at different levels, namely: the soil and the above-ground part and the root part amounts to 85.42 t/ha.

TABLE II. PHYSICOCHEMICAL RESULT OF SOIL SAMPLES

Sample	% N	% C	C/N	% OM	BD	pH-H2O	SOCS (t/ha)	Clay (%)	Slit (%)		Sand (%)	
									F	G	F	G
1	0,05	0,99	19,59	1,71	0,98	6,2	4,94	29,21	10,1	15,1	16,7	39,1
2	0,05	1,68	30,91	2,90	1,06	6,56	5,43	53,58	15,3	20,4	16,6	29,6
3	0,00	0,61	260,70	1,05	0,99	6,13	4,87	18,08	30,4	22,8	8,9	10,0
4	0,01	0,65	119,18	1,12	1,26	6,78	5,75	24,56	10,3	20,5	23,9	19,8
5	0,28	0,66	2,35	1,13	0,81	6,53	5,65	16,03	25,5	28,1	12,9	11,3
6	0,20	0,73	3,64	1,25	1,33	6,32	5,02	28,96	15,3	25,5	11,8	10,8
7	0,25	0,77	3,07	1,33	1,13	6,84	5,78	26,05	25,4	20,3	17,2	18,2
8	0,35	2,13	6,15	3,68	0,96	7,19	5,87	61,54	30,9	23,2	15,1	7,2
9	0,28	2,37	8,45	4,08	1,07	6,55	5,15	76,17	15,6	26,0	28,9	16,1
10	0,41	0,94	2,32	1,63	1,02	6,4	5,26	29,01	20,4	15,3	16,2	15,0
11	0,29	1,08	3,66	1,86	1,08	6,54	5,55	34,78	20,1	25,2	8,9	13,4
12	0,30	1,18	3,96	2,03	1,05	6,67	5,57	37,08	25,4	25,4	3,4	16,0
13	0,25	2,62	10,63	4,52	1,06	6,83	5,41	83,43	20,4	20,4	15,6	19,4
14	0,22	1,29	5,85	2,22	0,71	6,14	5,49	27,31	20,4	25,5	7,5	17,5
15	0,07	2,50	36,97	4,32	1,30	7,08	6,53	97,33	20,3	20,3	11,3	13,4
16	0,31	0,16	0,51	0,27	1,07	5,5	4,14	5,07	20,4	20,4	3,0	18,5
17	0,28	1,01	3,57	1,73	1,20	6,36	5,41	36,25	20,4	28,1	18,8	12,1
18	0,32	0,88	2,72	1,52	1,20	6,91	5,76	31,85	15,3	20,4	2,5	12,5
19	0,01	1,13	80,88	1,95	1,33	6,13	4,82	45,12	10,1	10,1	7,7	21,4

F: Fine G: Gross MO: Organic substance C: Carbon N: Nitrogen

TABLE III. RESULTS OF THE CHECK OF THE BIOMASS TARIFFS DEVELOPED BY BELGHAZI ET AL. (2001)

Component	Models	em	Se
Trunk	PST = 0,015 * C^(1,977)	9,84 %	1 ,01
Branches	PSB = 2,6*10^(-4)*C^(2,822)	9,65 %	2,23
Twigs	PSR = 2,64*10^(-3)*C^(1,943)	8,53 %	9,78
Leaves	PSF = 1,99*10^(-3)*C^(2,009)	6,37 %	13,88

PST : Dry weight of trunk in (Kg) ; **PSB**: Dry weight of branches in (kg)
PSR: Dry weight of twigs in (kg) ; **PSF**: Dry weight of leaves in (kg)

TABLE IV. TOTAL BIOMASS PER HECTARE AND PER TREE COMPONENT (T/HA)

Component	Biomass (t/ha)
Trunk	29,40
Branches	16,96
Twigs	4,51
Leaves	4,41
Whole tree	55,28

TABLE V. BIOMASS OF SOME GREEN OAK STUDIED IN MOROCCO

Studied area	Author	Total Biomass (t/ha)	Age
Central Middle Atlas (forest of Tafchna)	Boulmane [16]	96	30
Central Middle Atlas (forest of Regadda)	Boulmane [16]	86,4	30
Central Middle Atlas	Makhloufi [25]	20,65	41
Eastern Middle Atlas (experimental terrain of Bab Bou Ider)	Lahmini [26]	16,50	22
Central Middle Atlas (experimental terrain of Dayat Aoua)	Moussaoui [27]	24,30	28
Central plain (experimental terrain of Boukachmir)	Dahane [28]	40,24	46
Central Middle Atlas (forest of Jbel Aoua)	El Mderssa [19]	42,70	30

TABLE VI. CARBON CONTENT IN THE GREEN OAK TREE IN MOROCCO

Studied area	Author	Carbon stock (t/ha)
Central Middle Atlas (forest of Jbel Aoua Sud)	El Mderssa [18]	25,45
Central Middle Atlas (Jaâba)	El Mderssa [18]	53,48
Central Middle Atlas (Azrou)	El Mderssa [18]	15,19
Middle Atlas (Reggada)	Boulmane [16]	49,9
Middle Atlas (Dayet Hachlaf)	Boulmane [16]	55,5
Middle Atlas (Tafechna)	Boulmane [16]	56,8
Middle Atlas (Ajdir)	Boulmane [16]	88,5
Middle Atlas (Ksiba)	Boulmane [16]	91,5

TABLE VII. CARBON CONTENT IN THE COMPARTMENTS OF THE GREEN OAK TREE

Component	Trunk	Branches	Twigs	Leaves	Root
Carbon fraction (%)	56,35	56,03	56,36	55,98	56,21

TABLE VIII. CARBON STOCK OF OTHER SPECIES IN OTHER FOREST

Studied area	Author	Species	Total carbon stock (t/ha)
Central Middle Atlas (Jaâba)	El Mderssa [18]	zeen oak	214,75
CENTRAL MIDDLE ATLAS (FOREST OF JBEL AOUA)	El Mderssa [18]	atlas cedar	201,3
		maritime pine	143,9
Central Middle Atlas (Azrou)	El Mderssa [18]	atlas cedar	277,49
		zeen oak	303,25
Maâmora	Oubrahim [17]	Holm oak	121

The comparison of carbon stock values with others obtained the Central Middle Atlas region of Morocco [18], showed that the strata of green oak in a pure state of the studied area has low carbon stock potential, compared to those of the strata of the forest of Azrou and Jbel Aoua South namely, respectively, 284,48 and 207,68 t/ha. This can be explained, probably, by the nature of the soils in our studied area based on shale that stores low values of organic carbon.

Similar studies conducted on other pure species-based forest ecosystems (Table VIII) show high carbon stock values compared to our studied area.

IV. ConClusion

The study of the green oak plots shows that:

- The soils in the studied area are slightly acidic to neutral, with a loamy texture;

- The carbon stock in the soil under green oak is of an average value of 40.07 t/ha;

- The biomass of green oak in the studied plots has an average value of 55.28 t/ha, qualified to be slightly high compared to other green oak forests in the region, especially that of Boukachmir (40.24 t/ha), and this is due to the favorable ecological conditions and the high density of green oak trees;

- The carbon stock in the aerial part of green oak trees is estimated at 31.06 t/ha.

- The total carbon stock in the studied plots with pure green oak is estimated to be 85.42 t/ha.

These results confirm the important role of natural forests as a carbon storage reservoir in forest biomass and soil, and thus as a tool to fight against global warming. Nevertheless, the study of this organic carbon storage capacity under other forest compositions is worthy of interest, intending to integrate this aspect into forest management proposals.

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