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Carbon Stock by Soils and Departments in Tunisia

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Abstract: This study aims to understand the spatial distribution of organic carbon and its sequestration potential in Tunisian soils. Soil Organic Carbon (SOC) stock was estimated in the 0-30 and to 0-100 cm soil depth for Tunisia using maps of soils and of the departments, combined with results from a soil database. The original soil classification was simplified to nine soils. Tunisia contains 24 governorates and 262 delegations. The entire soil database is 1576 soil profiles corresponding to 5024 soil horizons, the soil-governorate map association comprised 23160 Map Units (MU) and the soil-delegation map association included 41759 MU. The method used for estimation of SOC stocks is based on soils and departments maps combined with the results from soil database. The way of calculating SOC stocks for a given depth consisted in summing SOC stocks by layer determined as a product of bulk density, organic carbon concentration and layer thickness. We estimated the organic carbon stock profile by profile. Therefore, we used three methods for evaluating SOC stocks; by soil orders, by governorate and by delegation. Bulk density values were calculated from pedotransfer functions when we had missing values. We calculated SOC stocks by classical methods by adding available values down to 1 m. In total, Tunisian SOC stocks ranged between 1.031 and 1.131 Pg C in the 0 to 100 cm soil depth. However, in the upper layer (30 cm), soil carbon ranged between 0.417 and 0.455 Pg C.

Key words: Carbon sequestration, spatial distribution, map unit, stock by department, Tunisia

INTRODUCTION

Increases in decomposition of soil organic matter resulting from global warming or from land use change could significantly increase the atmospheric burden of CO_2, which would further enhance the greenhouse effect. Inventories of Soil Organic Carbon (SOC) stocks at national scale are needed in the context of the Framework Convention on Climate Change (UNFCCC) (Smith, 2004; Smith *et al*., 2008). In this study, the Kyoto Protocol allows carbon dioxide emissions to be offset by demonstrable removal of carbon from the atmosphere, by improved management of agricultural soils. In order to use this possibility, the first step is the knowledge of the SOC and how to calculate this SOC stocks. A good estimation of carbon pools in the soils has been suggested as a means to help mitigate atmospheric CO_2 increases and anticipated changes in climate (Batjes, 1999; Lal *et al*., 1998, 2000; Bernoux *et al*., 2002).

The soil is a key component of the global carbon cycle. In the world, soils compartment represent a large reservoir of carbon, with estimates ranging from 1500 to 2000 Pg C in the upper 100 cm (Post *et al*., 1982; Eswaran *et al*., 1993; Batjes, 1996; IPCC, 2001). SOC stocks may be very sensitive to climate change, having a negative feedback which could enhance global warming. The soils of the world are thought to store three times more organic carbon than is held in the plant biomass of terrestrial ecosystems (650 Pg) and about twice as much than is current in the atmosphere (750 Pg) (Eswaran *et al*., 1993; Kimble *et al*., 1990; Post *et al*., 1982; Batjes and Sombroek, 1997). Regional and global estimates of soil carbon stocks had to be made by extrapolating means of soil carbon content for broad categories of types of soils or vegetation across the areas occupied by those categories (Kimble *et al*., 1990; Batjes, 1996; Bernoux *et al*., 2002). The soil compartment, global carbon pools are difficult to estimate because of still limited knowledge about specific properties of soil types (Sombroek *et al*., 1993; Batjes, 1996), the high spatial variability of soil carbon even within one soil map unit (Cerri *et al*., 2000) and the different effects of the factors controlling the soil organic carbon cycle (Pastor and Post, 1986; Parton *et al*., 1987). Thus, regional studies are necessary to refine global estimates, mainly at country scale (Bernoux *et al*., 2002).

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Organic carbon storage in Tunisian soils reflects capacity that arid and semi-arid regions to sequester carbon (Brahim *et al.*, 2010). The importance of an understanding of the national organic carbon pool levels is reinforced by the statements of the United Nations Framework Convention on Climate Change (UNFCCC) signed at Rio de Janeiro in 1992. In fact, the UNFCCC aims to stabilize greenhouse gas concentrations in the atmosphere at a level that limits adverse impacts on the global warming. Potential mechanisms cover emission reductions and activities that increase carbon sinks, including terrestrial sinks (Smith, 2004).

The objective of this study is to assess and given consistent values and a distribution maps, for the 0 to 30 cm and 0 to 100 cm depth of the organic carbon stocks in the soils of Tunisia, by governorate and by delegation. The aim of this study is to provide a valuable baseline data for evaluating the effect of soil occupation and climatic region for Tunisian SOC stocks.

MATERIALS AND METHODS

Study area: This study was conducted for all Tunisian soils during the period 2007 to 2009. Tunisia (31°38°N; 7°12°E), situated in north of Africa and south of Mediterranean Sea (Fig. 1) and it covered an area of 164,000 km^2, a wide range of natural regions. Three dominant climatic zones illustrate the country and reflect influence by Sea and Sahara desert: (1) Northern region is humid (600-1200 mm year^{-1}) occupied by rainforest still; (2) Central region is semi-arid (200-600 mm year^{-1}) steppe is here dominant vegetation; (3) Southern region is arid it's a Desert (<200 mm year^{-1}). From north to south Tunisian's region, soils vary widely, due to variability in climate, vegetation, parent material, texture, structure and anthropic effect (Brahim *et al.*, 2010). Nine big orders of soils have been inventoried (Table 1).

Database: A database was built from previous analytical results from soil profile information for soils pits surveyed by Tunisian research groups and the IRD (ex-ORSTOM) project, the Ministry of Agriculture of Tunisia and Tunisian thesis reports. The data contained information on organic carbon in soil (fraction <2 mm; walkley-black method), pH (measured in water 1:1), bulk density (D_b) (Cylindre method; Mg m^{-3}), granulometric fraction (after dispersion with sodium hexametaphosphate of soils), Clay (particle 0-2 μm), Silt (fine and coarse 2-50 μm), Sand (fine and coarse; 50-2000 μm) and $CaCO_3$ (Carbonate of calcium measured with Bernard calcimeter method).

Fig. 1: Location of Tunisia in the Mediterranean Sea and semi-arid zone

Table 1: Soil categories and their relation to the original soil classes of soil map

Soil groups	Code Soil	Map units	Area (km^2)
Lithosols	S1	4597	39793
Regosols	S2	10659	38040
Cambisols	S3	8387	24123
Vertisols	S4	922	1480
Kastanozems	S5	3326	13747
Podzoluvisols	S6	753	1418
Luvisols	S7	348	592
Solonchaks	S8	1514	13615
Gleysols	S9	550	708
Water and urban soil	S10	2993	20035

Elaboration of soil-department association map: The soil-department association maps are obtained by association soil map and the map of departmental divisions in the country. In this study, the mean departmental maps, the map of governorates and the map of delegations. Therefore, you find soil-governorate association (SGA) map and soil-delegation association (SDA) map.

Soil map: The original soil map 1/500 000 in Fig. 2a (Belkhodja *et al.*, 1973) was built up from 35007 map units. We used it in this study the term map unit: MU definition given by Bernoux *et al.* (2002), that is a single-part polygon of a digital map. These MU were split into nine soil groups. We made S10 code when the MU is water and urban soil. The Tunisian soil map showed that Luvisols is the lowest soil order area within the country it covers alone 0.38% of the total area, although, Lithosols and Regosols are the biggest soil orders covering 25.63 and 24.50% from total area, respectively. The list of available soil groups and here codes used for analysis are described in Table 1.

Departmental maps: This is the map of governorates and the map of delegations which was built from. (1)

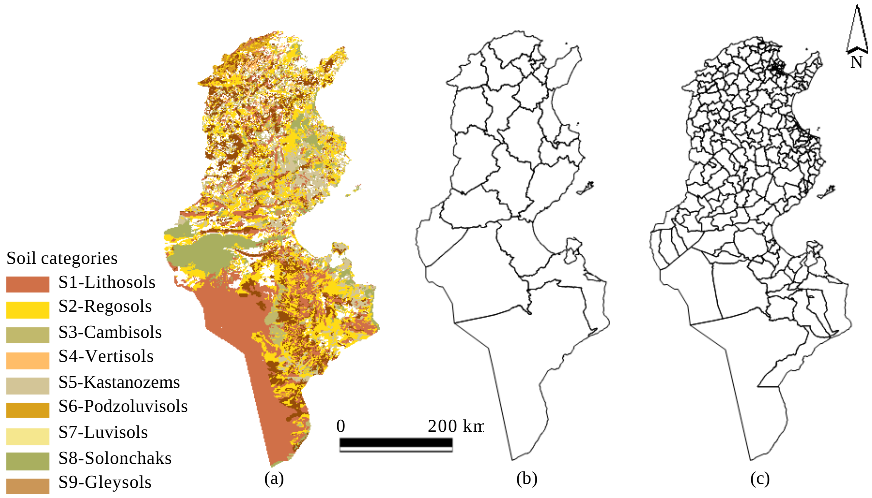

Fig. 2: Soil, governorate and delegation maps, with designation (a), (b) and (c), respectively, used in elaboration of soil-department association maps

Table 2: Tunisian governorates and their codes

Governorate	Code governorate	Area (km^2)
Tunis	G1	285.73
Ariana	G2	451.50
Ben arous	G3	685.60
Manouba	G4	1133.59
Nabeul	G5	2837.50
Zaghouan	G6	2844.53
Bizerte	G7	3746.56
Beja	G8	3680.10
Jendouba	G9	3082.74
Kef	G10	5107.46
Siliana	G11	4609.42
Kairouan	G12	6576.16
Kasserine	G13	8190.92
Sidi bouzid	G14	7416.10
Sousse	G15	2617.43
Monastir	G16	1028.06
Mahdia	G17	2924.34
Sfax	G18	6998.22
Gafsa	G19	7579.83
Tozeur	G20	5892.09
Kebili	G21	22492.77
Gabes	G22	7418.07
Mednine	G23	9365.70
Tataouine	G24	38237.98
Total		155203.00

Governorate map with 27 MU's and (2) Delegation map which was built from 264 MU's. The soil governorate and delegation maps are illustrated in Fig. 2a-c.

Soil-Governorate Association map (SGA): The SGA map was derived by intersection of the soil and governorate maps. In Tunisia, a governorate is an administrative division. It is the equivalent of a state or province in other parts of the World. Each MU of the output map was characterized by combining the information derived from the soil (9 categories in Table 1) and governorate (24 governorates in Table 2) maps. The MU's of the SGA map that corresponded to a MU characterized as lagoon or sebkha or urban zone in the soil map, were classified as water and urban soil (S10).

Soil-Delegation Association map (SDA): The SDA map was derived by intersection of the soil and delegation maps. The Delegations of Tunisia are the second level administrative division. The delegation is the equivalent of sector, it is the smallest division. The 24 Tunisian governorates were divided into 264 delegations. Every MU's of the output map was characterized by combining the information derived from the soil (9 categories in Table 1) and delegation maps (262 delegations, Fig. 3). The MU's of the SDA map that corresponded to a MU characterization as a lagoon or urban zone in the soil map were classified as water and urban soil.

Bulk density: Bulk density is not determined in most routine analyses, so values have to be determined using Pedotransfer Functions (PTF) (Batjes, 1996; Bernoux *et al*., 2002; Brahim *et al*., 2010).

Calculation of the individual organic carbon stocks

Classical way: profile by profile: In most studies (Eswaran *et al*., 1993; Batjes, 1996) SOC stocks has been calculated to a depth of 30 and 100 cm. To estimate SOC stocks, requires knowledge of the vertical distribution of organic carbon in profiles (Bernoux *et al*., 1998). Calculation of SOC stocks traditionally report results to 1 m depth (Eswaran *et al*., 1993; Batjes, 1996; Brahim *et al*., 2010) or the surface layer (0-30 cm)

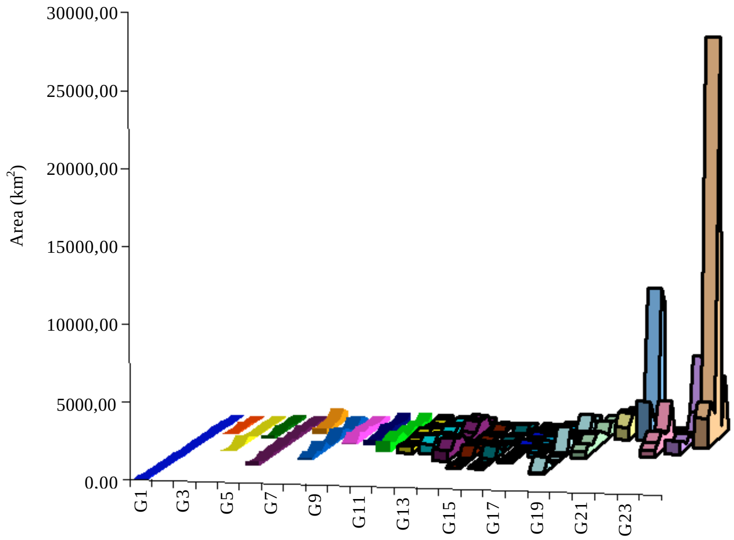

Fig. 3: Tunisian governorates and their delegations area

(Bernoux *et al*., 2002; Brahim *et al*., 2010) level in direct contact (exchange) with atmospheric gas. Calculations of the SOC 0-30 cm in the classical way for a given depth consists of addition of SOC Stocks by horizon and multiplied by D_b and the organic carbon concentration and horizon thickness. For an individual profile with n layers, we estimated the organic carbon stock by the following equation:

$$SOC = \sum_{i=1}^{n} D_b i \; Ci \; Di$$

where, SOC is the organic carbon stock (kg C m^{-2}), D_bi is the bulk density (Mg m^{-3}) of layer i, Ci is the proportion of organic carbon (g C g^{-1}) in layer i, Di is the thickness of this layer (cm).

Predicted organic carbon: However, when using large database at continental scales, problems of interpolation appear, if not all horizons are sampled or analyzed and the sampling depth crosses a horizon (Bernoux *et al*., 1998). In present study, distribution from vertical organic carbon profile was calculated using Arrouays and Pelissier (1994) model. With this model, we have obtained several missing values from organic carbon in profiles. Usually, organic carbon content in soils decline progressively with depth over the entire profile and was fit by an exponential equation:

$$(C(X)-C2)/(C1-C2) = (e^{-bx} - e^{-bx2})/(e^{-bx1} - e^{-bx2})$$

where, X and C(X) are the depth and the C the carbon content, X1 and C1 the depth and the carbon content of a fixed upper position and X2 and C2 depth and carbon content for a fixed deeper position.

The carbon content used in these equations can be expressed in different ways: weight percentage of the <2 mm fraction, or weight per volume. However, this way of expressing results requires knowledge of the bulk density (D_b) and the D_b of most soil samples is usually not determined.

RESULTS

Large amounts of organic carbon, which are not yet considered in most global carbon budget (Eswaran *et al*., 1993; Batjes, 1996), are stored between depth of 100 and 200 cm. Much of this deeper carbon occurs in fairly stable forms and therefore will not contribute much to current gaseous emissions. In most studies, a SOC stock has been calculated to a depth of 100 cm. The 30 cm depth that is most directly involved in interaction with the atmosphere and that is most sensitive to land use and environmental changes. A metre depth was the lower limit of biological activity in arid and semi-arid regions (Singh *et al*., 2007).

SGA and SDA maps organization: SGA map: We elaborate SGA map after intersection of the soil and governorate maps. Theoretically the new SGA map contains 264 possible cases from MU's. In the map there is the total of 23160 MU's. The surface covered by each SGA category is given in Table 3. The largest SGA category (18551 km^2) corresponded to the S1 G24 association, but the smallest (<1 km^2), we make zero (0)

Table 3: Number (N) of map units and corresponding area (km^2) of the SGA categories

Results	Governorate	Soil categories*								
		S1	S2	S3	S4	S5	S6	S7	S8	S9
N	G1	15	29	86	7	a	a	a	15	a
Area		4	18	86	5	a	a	a	6	a
N	G2	11	45	30	2	a	1	8	33	a
Area		17	165	38	0	a	0	25	122	a
N	G3	48	156	167	48	18	a	9	19	a
Area		24	207	137	45	9	a	11	16	a
N	G4	58	164	251	19	7	a	37	14	a
Area		73	371	389	15	19	a	97	18	a
N	G5	89	545	491	33	54	112	122	91	111
Area		55	801	595	70	33	146	163	55	82
N	G6	135	507	803	103	106	a	26	20	20
Area		87	730	888	111	86	a	19	54	40
N	G7	339	441	394	127	12	403	54	75	183
Area		505	724	856	241	8	431	132	99	116
N	G8	531	686	886	283	164	201	70	2	91
Area		451	625	975	351	159	174	61	4	36
N	G9	130	376	103	26	13	193	12	1	3
Area		209	1002	319	64	12	664	10	0	1
N	G10	278	627	879	154	147	1	a	15	1
Area		366	1304	1543	186	269	0	a	23	0
N	G11	389	544	1105	204	103	1	83	30	1
Area		628	871	1399	298	130	0	73	27	0
N	G12	166	622	522	3	134	a	a	82	6
Area		758	1862	1612	2	1103	a	a	651	6
N	G13	234	971	936	25	264	a	a	74	34
Area		743	1614	2677	38	506	a	a	121	24
N	G14	468	877	359	10	523	a	a	78	3
Area		1174	2563	903	14	1483	a	a	314	149
N	G15	289	1053	665	33	355	a	a	299	15
Area		147	655	420	38	442	a	a	839	13
N	G16	136	586	92	2	312	a	a	69	a
Area		54	384	82	0	294	a	a	128	a
N	G17	430	1307	483	a	588	a	a	203	5
Area		288	1026	388	a	782	a	a	350	1
N	G18	295	664	619	a	540	2	a	201	10
Area		504	1646	1211	a	2465	0	a	470	19
N	G19	183	541	302	a	130	a	a	53	1
Area		1650	2635	1427	a	786	a	a	216	0
N	G20	38	173	82	a	13	a	a	81	52
Area		350	989	783	a	233	a	a	3340	16
N	G21	235	376	223	a	4	a	a	147	55
Area		9708	3358	3189	a	18	a	a	4539	83
N	G22	336	475	238	a	163	a	a	82	7
Area		1295	2139	1198	a	943	a	a	579	43
N	G23	178	327	35	a	143	a	a	119	17
Area		2152	2988	391	a	2147	a	a	1234	34
N	G24	405	581	103	a	142	a	a	26	9
Area		18551	9363	2616	a	1820	a	a	410	45

*Categories not represented in the digital SGA map are indicated with a

value, when SGA category it inferior at 1 km^2, for example; S4 G2, S6 G2, S9 G19, in totality we have 10 cases SGA <1 km^2. More than 84% of the SGA categories (223 of the total) had an area smaller than 1000 km^2 and covered 41 171 km^2 (26.5% from Tunisian area), but 16% of the SGA categories (41 of the total) had an area >1000 km^2 covering 114 131 km^2 (73.5% from Tunisian area).

SDA map: We find this new map with intersection of soil by delegation maps. It totalled 41759 MU. The MU was spread into 2882 theoretically possible cases, 11 soil categories or groups crossed with 262 delegations.

Soil profile database representatives: Only 1572 soil horizons of the total (5024 soil horizons) were sufficiently documented to permit the organic carbon stocks calculations to 0-30 cm and 0-100 cm. First, the representativeness of the information contained in the soil profile database was analyzed. For that, the number of individual organic carbon stocks calculated by soil groups (Table 4), SGA and SDA categories was examined.

Table 4 showed that in 0-30 cm depth, Luvisols (S7) have the biggest organic carbon stocks 7.16 kg C m^{-2} and Lithosols (S1) has the lowest organic carbon stocks 1.84 kg C m^{-2}. Mean SOC content in the upper 100 cm of

Table 4: Organic carbon stock by soil

		0-30 cm			0-100 cm		
Soil	N	Average*	SD	N	Average	SD	Average (0-30 cm)/average (0-100 cm) (%)
S1	88	1.84	1.48	63	4.04	2.56	45.54
S2	261	3.15	1.97	145	8.39	4.80	37.54
S3	374	4.16	2.47	212	10.18	5.77	40.86
S4	80	4.56	2.00	45	10.97	5.00	41.56
S5	204	3.74	1.94	124	9.33	4.37	40.08
S6	170	6.19	2.82	121	13.88	6.08	44.59
S7	90	7.16	3.73	60	15.92	7.62	44.97
S8	100	2.82	1.68	61	7.50	4.85	37.60
S9	116	3.48	2.20	62	7.77	4.21	44.78

*Average values are expressed in kg C m^{-2}

the various Tunisian soils ranged from 4.04 kg C m^{-2} for Lithosols to 15.92 kg C m^{-2} for Luvisols.

The large values for the latter are due to the abundance of organic matter in north-western Tunisian zone. Similarly large amounts 13.88 kg C m^{-2} is encountered in Podzoluvisols, because they are situated under forest with an environment rich of organic matter. Small amounts of organic carbon are encountered in Lithosols and Solonchaks from the semi-arid and arid regions where vegetation is limited.

Changes in the relative distribution of soil organic carbon stocks with depth have been observed in Table 4, the ratio of SOC of 0-30 cm divided by that in the 0-100 cm zone. On average, 37.54 to 45.54% of the total SOC in the upper 100 cm of mineral soil is held in the first 30 cm. these figures illustrate the potentially large amounts of CO_2 that can be released when soils are deforested or with changes in land use.

When, SGA/SDA categories exist in the SGA/SDA maps and is not a Water and urban soil category, it was decided to use the mean of organic carbon stocks with SGA/SDA categories adjacent. In case those SGA/SDA categories don't exist we make the value of the means by soil groups (Table 4).

Soil organic carbon stocks values: It could be noted that for some SGA/SDA categories, which are many associations are not represented in the digital SGA/SDA maps. From SGA categories, we have 216 possible association cases (24 governorates multiply with 9 soil groups), however from the SGA map we have only 96 association cases. As well as SGA, we have 2358 possible association cases from SDA categories (262 delegations multiply with 9 soil groups), but from the SDA map we have only 213 association cases. Generally, at routine study fewer samples were taken from the deeper layers (0-100 cm) than from the superficial layers (0-30 cm). This difference in the number of samples at the various depths must be kept in mind, as it implies that the results are less reliable for the deeper layers. Additionally, sampling soil profiles is technically difficult and sample preparation for analysis is time consuming. Thus most studies on soil carbon were restricted to the upper 30 to 50 cm of the soil and only few include deeper sections of the soil cover.

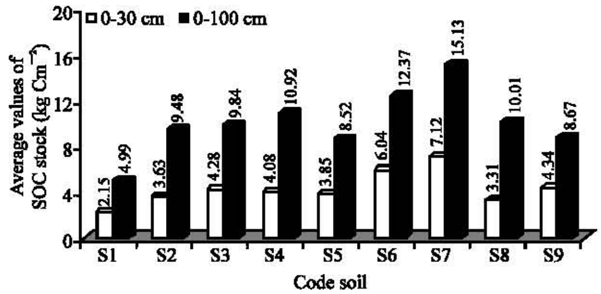

Fig. 4: The average stock for each soil categories according to its distribution by governorates

In the level 0-30 cm, the organic carbon stocks ranged from 0.77 kg C m^{-2} (S2, Regosols-G21, Kebili governorate) to 13.61 kg C m^{-2} (S7, Luvisols-G5, Nabeul governorate). More than 34% of all SGA categories was associated with organic carbon stocks from 0.77 to 2.99 kg C m^{-2}, 46% was associated with 3.05 to 5.75 kg C m^{-2} and 19% of the extent covered by SGA showed organic carbon stocks ranging from 6.02 to 13.61 kg C m^{-2}. In 0-100 cm, the biggest organic carbon stocks in SGA categories it 27.29 kg C m^{-2} and corresponded to the S7, Luvisols-G5, Nabeul governorate, but the smallest it 2.56 kg C m^{-2} and corresponded to the SGA categories S5, Kastanozems-G18, Sfax governorate association. In Fig. 4, we note the average stock for each soil categories according to its distribution by governorates.

These stocks are consistent with data for the world level (Batjes, 1996) derived from the WISE (World Inventory of Soil Emission Potentials) soil database. Batjes (1996) reported worldwide mean carbon stock values for the 0 to 30 cm layer of 3.1, 4.5 and 5 kg C m^{-2} for Regosols, Vertisols and Cambisols, respectively. It accounted for 0 to 100 cm depth of 9.6, 11.1 and 9.6 kg C m^{-2} for Kastanozems, Vertisols and Cambisols, respectively. But Batjes (1996) calculated for the soils of arid zone slightly higher values for Lithosols and

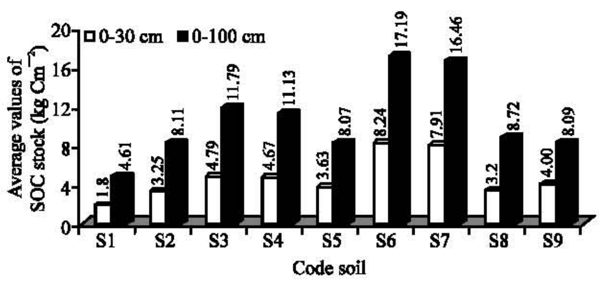

Fig. 5: The average stock for each soil categories according to its distribution by delegations

Gleysols, (3.6 and 7.7 kg C m^{-2}, respectively for 0-30 cm and 13.1 kg C m^{-2} for 0 to 100 cm for Gleysols) and lower values for Solonchaks, Luvisols and Podzoluvisols (1.8, 3.1 and 5.6 kg C m^{-2}, respectively).

When the international database of Batjes (1996) derived from the WISE data is used for Gleysols, the estimated total carbon for this group is high, presumably because the SCD international database includes several Gleysols form other regions that contain more carbon than the Tunisian soils.

The regions with the highest organic carbon stocks are located in northern part of Tunisia. On the other hand, Southern part of the country has governorates incorporated the lowest organic carbon stocks. This geographic organic carbon stocks repartition is influenced by regional climatic conditions, when north of Tunisia is rainfall but south is deserted. This consequence is detailed with delegations.

At the superficial layer (0-30 cm), the organic carbon stocks ranged from 0.12 kg C m^{-2} (S1, Lithosols-1G20, Degueche delegation) to 19.98 kg C m^{-2} (S7, Luvisols-13G5, Menzel Temime delegation). More than 69% of all SDA categories were associated with organic carbon stocks from 0.12 to 4.99 kg C m^{-2} and 30% of the extent covered by SDA showed organic carbon stocks varying from 5 to 19.98 kg C m^{-2}.

In 0-100 cm, the biggest value of organic carbon stocks in SDA categories is 35.54 kg C m^{-2} and corresponded to the S7, Luvisols-13G5, Menzel Temime delegation, but the smallest it 1.03 kg C m^{-2} and corresponded to the SDA categories S3, Cambisols-1G21, Douz delegation. In Fig. 5 we note the average stock for each soil categories according to its distribution by delegations.

Total organic carbon stored at the country level (0-30 and 0-100 cm): In the following text, three estimates are given for the soil carbon pool of Tunisia, for 0 to 30 cm and 0 to 1 m depth. The first value is based on the soils map and database, the second is founded of soils-governorates maps and database and the third is for soils-delegations maps and database.

Organic carbon stock by soils: The potential total organic carbon stocks of Tunisian soils in different soil groups for the 0 to 30 cm and 0 to 1 m layer was obtained by combining the table of the representative organic carbon stocks in the database with soils map. Using this way, we calculated that the soils of Tunisia store 0.455 Pg C in the superficial layer (0-30 cm) (Fig. 6a) and 1.131 Pg C in 1 m depth (Fig. 7a). Maps of organic carbon stocks by soils showed that Tunisian north have a highest stock, it's influenced by vegetation and geographical relief. Organic carbon stocks by soils have an average value 3.36 kg C m^{-2}, but the minimum and the maximum values are 1.84 and 7.16 kg C m^{-2}, respectively.

Organic carbon stock by soils and governorates: The potential total organic carbon stocks of Tunisian soils by governorates for the 0 to 30 cm layer (Fig. 6b) was obtained by SGA map, after combining the soils map with governorates map. We calculated that a total of 0.417 Pg C (417 Tg C). From 0 to 100 cm we obtained 1.031 Pg C (Fig. 7b). By this way, we remarked a decrease in organic carbon stock minimum value from the country level (0.55 kg C m^{-2} in 0-30 cm and 2.56 kg C m^{-2} in 0-100 cm) and increase from maximum value (13.06 kg C m^{-2} in 0-30 cm and 27.29 kg C m^{-2} in 0-100 cm).

Organic carbon stock by soils and delegations: We calculated Tunisian SOC stocks using SDA map following combining the soils map with delegations map. It was observed that a total of 0.433 Pg C was stored in 0-30 cm layer (Fig. 6c) and 1.084 Pg C was stored in 0 to 100 cm depth (Fig. 7c). By this method, minimum and maximum of organic carbon stock decrease, but value of means by the three ways have in global a few variation between 3.36 and 3.85 kg C m^{-2} in 0-30 cm layer and between 8.35 and 9.17 kg C m^{-2} in 0-100 cm layer.

This analysis gives as a clear picture about the characteristic of regions where climate is arid and similar soils are common, which includes much of Maghreb countries in North Africa and South Mediterranean sea. Total soil organic carbon stocks of these regions may have been underestimated because of insufficient studies and sampling of soils at many depths, by previous approaches based on soils types and by providing data on spatially referenced estimates of inclusions within map units. Figure 6 and 7 showed that an area dominated by forests and mountainous zone contains significant amounts of organic carbon in North and Tunisian centre.

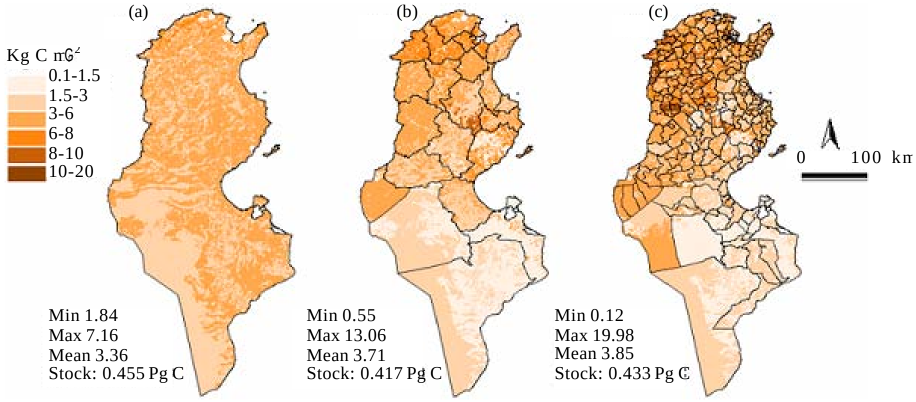

Fig. 6: Organic carbon stocks in 0-30 cm depth by (a) soils, (b) soils-governorates and (c) soils-delegations

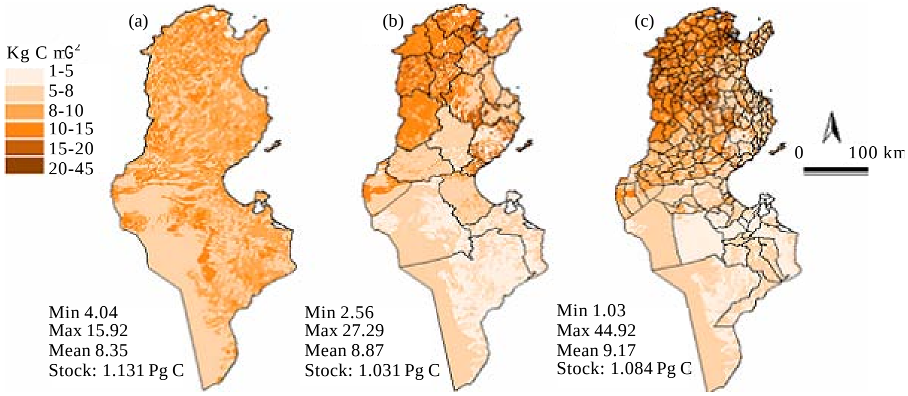

Fig. 7: Organic carbon stocks in 0-100 cm depth by (a) soils, (b) soils-governorates and (c) soils-delegations

DISCUSSION

SOC stocks at the clay rich Tunisian soils (Vertisols) were almost twice as high as at the sandy soils (Lithosols). This is most likely due to effective stabilisation mechanisms of clay (Bernoux *et al*., 2002). Inaccessibility of organic carbon in aggregates and micropores and adsorption on clay surfaces are acknowledged as major stabilisation mechanisms (Six *et al*., 2002).

Figure 6 shows SOC stocks by three methods. In most studies in database, soils where sampled in extreme southern Tunisia only in Oasis soils. Irrigation and fertilization used in oasis have an effect on SOC stocks repartition on SGA and SDA maps. Both Fig. 6b and 6c showed that soils and governorates or delegations have different influences on the SOC distribution. For instance, in sud west of Tunisia in Tozeur governorate (Fig. 6b) we estimate 3 to 6 kg C m^{-2}, but in this region SOC stock has a values varying between 0.1 and 3 kg C m^{-2} in 0-30 cm layer. We explain this result that sampled soils have collected with Oasis and all values from our database have the same origin and influenced SOC stocks in their soils at this governorate. Equal observations of estimation of soils and delegations illustrated in Fig. 6c and 7c at the same sector Tunisian sud west, precisely in Douz and El-Faouar delegations in Kebili governorate. This result is not surprising in view of the processes of database elaboration in which punctual sites of sampling has an immense influence. The result is significant; however, it illustrates the danger of extrapolating understanding of process from one region.

Figure 6a and 7a showed that soils have different influences on the organic carbon stocks distribution, depending of the geographical localization. For example, the regions with the highest organic carbon stocks has a soil influence marked by the presence of mountainous zones. On the other hand, North-western Tunisian region had high organic carbon stock mostly because of the colder climatic influence, which influences soils directly by forest and those organic matters.

Generally, South country regions are characterized by low SOC stocks and sandy soils which showed an important climatic influence. This sector surround semiarid and arid zones and SOC values have ranged between 0.1 and 3 kg C m^{-2} in superficial layer (0-30 cm) the same as between 1 and 8 kg C m^{-2} at 1 m depth. Clay with high surface area protects organic carbon from decomposition on developing stable clay-organic carbon complexes (Singh *et al*., 2007). Organic carbon associated with sand particles was readily decomposable as compared to that in silt and clay. Singh *et al*. (2007) confirmed that intensive agriculture without proper management in the semi-arid region was the cause of rapid SOC depletion in cropland as compared untilled soils under scrub vegetation.

In similar conditions in Jordan if climate change and/or human land uses alter these lands, then soil carbon storage could decline (Batjes, 2006). Changes in soil carbon storage, either positive or negative, are unlikely to be uniform throughout the globe, because the distribution of soil carbon stocks, the factors that stabilize soil carbon and the forces that contribute to change vary widely among regions. Moreover, mean annual rainfall, tillage, period of canopy cover, clay content, land use history and productivity have pronounced effects on SOC stocks (Bouajila and Gallali, 2008; Brahim *et al*. 2009). Bernoux *et al*. (2002) showed several sources of uncertainties with national SOC stocks estimation, because the information from soil database stem different sources and the methodology used for the analyses of organic carbon content and D_b may be varied among different laboratories.

Present results are in support of previous work and provide more details for aridisols. Indeed, related to previous findings from Tunisian soil carbon stocks, the calculated SOC stocks to 0-30 cm using the FAO world soils database were closed to the amount 0.498 PgC reported by Henry *et al*. (2009), however the estimated stocks to 1 m were lesser than the result (0.727 Pg C). These stocks are comparable from stock by soils with estimation established by Brahim *et al*. (2010) using 1483 soil profiles for Tunisia it estimate 0.405 and 1.006 Pg C from 0-30 and 0-100 cm, respectively. In this study, we used a larger database (1576 soil profiles) and estimates stocks by soil type and the administrative division, it provides more precision.

CONCLUSION

The total mass of organic carbon stored in the first 30 cm of the Tunisian soils is comprised between 0.417 and 0.455 Pg C. The estimates of SOC stocks for the entire country are comprised between 1.031 and 1.131 Pg C for the upper 100 cm. The spatial distribution of SOC stocks was mainly determined by the distribution of the organic carbon concentration. Variability of SOC stocks is caused by different factors, like clay contents and climatic zones. Generally, organic carbon stocks by Tunisian soils has a smallest values, low and erratic rainfall inputs of organic carbon into the system while warm conditions facilitate the decomposition of organic matter during the short growing season.

This study provides useful baseline data for future studies dealing with land use changes, the impact on carbon dynamics at regional scale and the first step for calculated CO_2 fluxes from soils in Tunisia.

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