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Tunisian Soil Organic Carbon Stocks

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Abstract: This study has two aims, the first, to analyze the spatial distribution of Soil Organic Carbon (SOC) in Tunisia, second, to estimate carbon stocks for major soil types representative of Mediterranean drylands. Repartition of SOC stocks at the depth of 0.3 to 1 m were estimated for Tunisia, using a soil map combined with the results from a soil database. In addition, the total SOC stocks in the 0-30 cm and 0-100 cm soil depth were estimated for Tunisia using a digital soil map combined with results from a soil database. Tunisia contains nine main soil classes. The entire soil database totaled 1483 soil profiles corresponding to 5024 soil horizons. This dataset was built from previous analytical results published from Tunisian soil surveys (1960-2006). Most bulk density values were estimated using pedotransfer functions. Results showed that the upper soil layer 0-30 cm contains 405.44 TgC (1 Tg = 10^{12} g), while that in the 0-100 cm soil depth was estimated to be 1006.71 TgC. Estimates by soil types showed that the highest SOC stocks was estimated for Luvisols to 7.16 and 15.92 kgCm^{-2} for 0-30 cm and 0-100 cm, respectively. The lowest SOC stocks were estimated for the Lithosols to 1.84 kgCm^{-2} at 0-30 cm and 4.04 kgCm^{-2} for 0-100 cm. The soil types most representative in extension in Tunisia were the Lithosols, Regosols and the Cambisols and stocks were estimated to 73.22, 119.83 and 100.35 TgC, respectively. Tunisian SOC density in the surface layer 0-30 cm is 2.612 kgCm^{-2} and 6.486 kgCm^{-2} within the 0-100 cm depth.

Key words: Soil organic carbon stocks, sequestration, bulk density, Tunisia, Mediterranean soil

INTRODUCTION

The soil is a key component of the global carbon cycle. Soil Organic Carbon (SOC) stock is the biggest ecosystem carbon reservoirs in the world; it plays a critical role in mitigating the greenhouse effect. The amount of Organic Carbon (OC) contained in the world's soils is comprised between 1500 and 2000 PgC in the upper 100 cm (Eswaran *et al*., 1993; Batjes, 1996). A good estimation of carbon pools in the soil has been suggested as a mean to help mitigate atmospheric CO_2 increases and anticipated changes in climate (Batjes and Sombroek, 1997; Lal *et al*., 1998, 2000). Enhancement of Soil Organic Carbon (SOC) and its good management is very important for agriculture. It increases the fertility, as well as by carbon sequestration we attain healthy environment and generally, organic matter in soil stabilizes

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soil structure and makes it more resistant to degradation (Mbah *et al.*, 2007). Reliable inventories of SOC stocks are primordial information to help countries in fulfilling their obligations under the National United Nations Framework Convention on Climate Change (Tompkins and Amundsen, 2008). Moreover, as SOC is central for ecosystem functioning, this information is also relevant to the United Nations Conventions to Combat Desertification as areas with low SOC content are generally synonymous with land degradation, which is a major issue (Bai *et al.*, 2008). Most national evaluations of SOC stocks and their repartition were performed in temperate (Arrouays *et al.*, 2001) or tropical regions (Bernoux *et al.*, 2002; Batjes, 2005) except few notable exceptions in semi arid zones (Batjes, 2006; Al-Adamat *et al.*, 2007). Even if it is commonly admitted that SOC per unit area of drylands is low compared with other terrestrial ecosystems, the large area of drylands turns carbon sequestration potential of total drylands important. For Tunisia, it is important to assess the pools of SOC for several reasons. Organic carbon is one of the most important constituents of soils; it has a main agronomic and environmental interest. Organic carbon improves soil structure, capacity in affecting vegetation development and it mediates many chemical and physical properties. Also, organic carbon storage in Tunisian soils reflects the capacity of arid and semi-arid regions to sequester organic carbon. This study provides a first estimate of SOC stocks for the 0 to 30 cm and 0 to 100 cm depth in Tunisian soils.

MATERIALS AND METHODS

Study Site

This study was conducted in Tunisia from 2005 to 2008. Tunisia (31°38°N; 7°12°E and 164 000 km^2) is situated in North of Africa and South of Mediterranean Sea (Fig. 1) and has a wide range of natural regions. Three dominant climatic zones illustrate the country

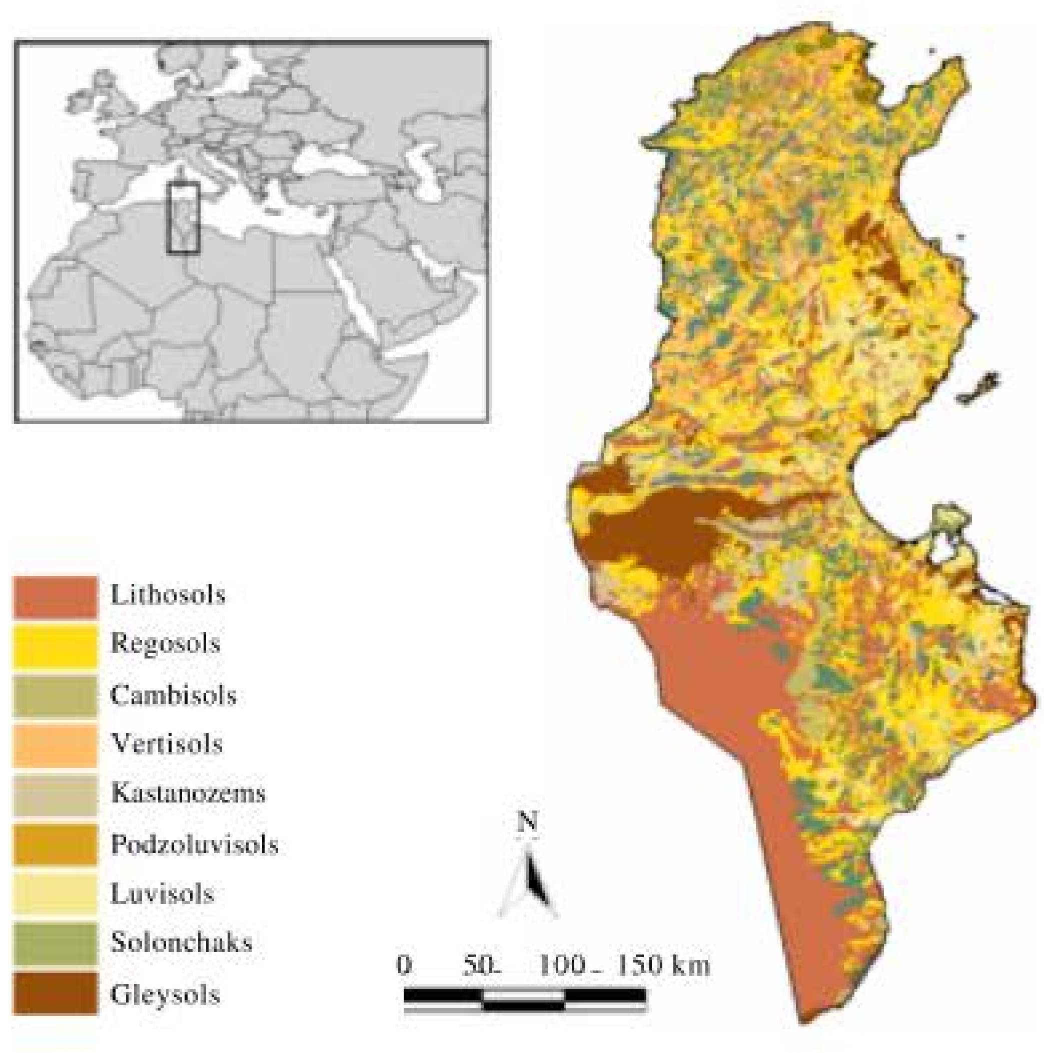

Fig. 1: Location of Tunisia in the Mediterranean basin and soil map with simplified legends

and reflect the influence by the Sea and Sahara desert: (1) the Northern region is humid (600-1200 mm year^{-1}) occupied by rainforest still; (2) the central region is semi-arid (200-600 mm year^{-1}) steppe is here dominant vegetation; (3) the Southern region is arid it's a desert (<200 mm year^{-1}). Thus, soil present an important variability (Fig. 1).

Soil Database

Tunisian soil literature from 1960 to 2006 was searched for data on soil profiles. Chosen profiles had variable depth, but they were usually more than 1 m in depth. A database was built with previous analytical results available in soil profile information reported for soils pits surveyed by teams of Tunisian and IRD (ex-ORSTOM) pedologists. The database was made of 1483 soil profiles, corresponding to 5024 soil horizons. Soils profiles were classified according to the nine main soil groups used in the soil map and their locations (Delegation and Governorate) were checked. The SOC stocks from 0.3 to 1 m were calculated, (formulae is given at section 2.5) when possible, per profile using data on soil bulk density, proportion of organic carbon and volume of fraction>2 mm. The list of soil properties available in the database and used in predictive equations are given in Table 1. Gaps in the available data, mostly for bulk density and C content for some deeper horizons were filled using specific pedotransfer functions (Bernoux *et al.*, 1998). The procedure used is fully described by Bernoux *et al*. (2002) (Table 1).

Soil Map

The 1:500,000-soil map of Tunisia (Tunisian Ministry of Agriculture, 1973) was used as spatial component. In total, the map is made of 34049 map units that were distributed into nine main soil orders plus one non-soil (water surface and urban soil) category (Table 2).

Table 1: List of soil properties available in the database and used in predictive equations

Symbol	Variable information
D_b	Soil bulk density in weight per volume (Cylinder method) (Mg m^{-3})
OM	Organic matter (%)
OC	Organic carbon of the soil fraction <2 mm (Walkley-Black method) (%)
N	Total nitrogen of the soil fraction <2 mm (Kjeldahl method) (‰)
C/N	Ratio of carbon and nitrogen
Clay	Clay content (particle 0-2 µm) (%)
F-silt	Fine silt content (2-20 µm) (%)
C-silt	Coarse silt content (20-50 µm) (%)
F-sand	Fine sand content (50-200 µm) (%)
C-sand	Coarse sand content (200-2000 µm) (%)
pH	pH measured in water (1:1)
$CaCO_3$	Calcium carbonate (Bernard calcimeter method) (%)

Table 2: Soil categories and their relation to the original soil classes of soil map

		Area	
Soil order	Soil map units	ha	%
Lithosols	4597	3979262.88	25.64
Regosols	10659	3804005.74	24.51
Cambisols	8387	2412264.85	15.54
Vertisols	922	148035.82	0.95
Kastanozems	3326	1374733.10	8.86
Podzoluvisols	753	141800.66	0.91
Luvisols	348	59213.27	0.38
Solonchaks	1514	1361507.26	8.77
Gleysols	550	70773.70	0.46
Water and urban soil	2993	2168652.50	13.97
Total	34049	15520249.80	100.00

The map for the period between 2006-2007 was digitized. The number of polygons or Soil Map Units (SMU) were 34049. Soil Map Units were classified to the FAO-UNESCO classification (FAO, 1974). The minimum surface represented is 0.34 ha, but the maximum surface represented is 9777.77 ha.

D_b Estimation

The estimation of SOC stocks for a certain area requires estimations of mean soil organic carbon concentration and bulk density (D_b). Generally, D_b is not determined in most routine analyses and for most of the Tunisian soil profiles in the database no D_b was reported. The D_b of only 707 soil horizons from the 5024 records have been measured and it is therefore, necessary to estimate D_b's for the rest of the horizons. To this end, so values have to be determined using Pedotransfer Functions (PTF) (Batjes, 1996; Bernoux *et al.*, 1998). Using all the available parameters, results showed that the OC content was always the best predictor of D_b, accounting for up to 34% of the variation, the best Multiple Linear Regression (MLR) resulted in the following equation:

$$D_b = 1.65\ (\pm 0.08)\text{-}0.117\ (\pm 0.008)\ \text{OC-}0.0042\ (\pm 0.0006)\ \text{Clay-}0.0036\ (\pm 0.0005)\ \text{C-S and}+0.031\ (\pm 0.008)\ \text{pH}\ (R^2 = 0.55,\ SE = 0.145)$$

Subdividing soils into groups by soil depth resulted in more accurate D_b predictions for soil layers. The MLR for superficial layers ($\leq$30 cm) were:

$$D_b = 0.9\ (\pm 0.1)\text{-}0.08\ (\pm 0.01)\ \text{OC}+0.007\ (\pm 0.001)\ \text{F-sand}+0.007(\pm 0.002)\ \text{F-silt}+0.05\ (\pm 0.01)\ \text{pH},\ (R^2 = 0.58,\ SE = 0.14)$$

and for deep horizons layers (>30 cm):

$$D_b = 1.90\ (\pm 0.02)\text{-}0.08\ (\pm 0.03)\ \text{OC-}0.0031\ (\pm 0.0009)\ \text{Clay-}0.0023\ (\pm 0.0007)\ CaCO_3,\ (R^2 = 0.31,\ SE = 0.14)$$

Procedure for Determining the Individual SOC Stocks

The way of calculating SOC stocks for a given depth consists of summing SOC stocks by layer determined as a product of D_b, OC concentration and layer thickness (Eswaran *et al.*, 1993; Batjes, 1996; Bernoux *et al.*, 2002). For an individual profile with n layers, we estimated the organic carbon stock by the following equation:

$$SOC = \sum_{i=1}^{n} D_b iCiDi$$

where, SOC is the soil organic carbon stocks (kgCm^{-2}), D_bi is the bulk density (Mg m^{-3}) of layer i, Ci is the proportion of organic carbon (gCg^{-1}) in layer i and Di is the thickness of this layer (cm).

Bernoux *et al.* (2002) used a similar procedure for calculating carbon stocks in soil of Brazil. In the second step of calculation, OC densities of each great group were multiplied with their respective area (Batjes, 1996) for quantification of soil organic and inorganic carbon stocks. Summation of individually of carbon of the nine great soil groups gave total carbon stock in Tunisia.

RESULTS AND DISCUSSION

Distribution of SOC Density and SOC Storage in Tunisia

Statistical results (Table 3) based on big soil orders, indicated that SOC density varied considerably across soil types. Result further showed that in 0-30 and 0-100 cm depth, Luvisols have the highest SOC densities of 7.16 and 15.92 kgCm^{-2}, respectively, but Lithosols have the lowest SOC densities, at 0-30 and 0-100 cm it have 1.84 and 4.04 kgCm^{-2}. Given a total area of 15520249.8 ha of soil in Tunisia, summation of all soil map units yielded a total SOC storage of 405.44 TgC in the 0 to 30 cm soil depth and 1006.71 TgC in the upper layer 0-100 cm and a mean SOC density of 2.612 and 6.486 kgCm^{-2} at 0-30 and 0-100 cm, respectively.

Elaboration of Maps of SOC Density

In order to appreciate the geographical distribution of SOC densities and its pattern it is useful to create a map of SOC contents. The SOC map was derived by intersection of soil map and soil database. Figure 2 showed that soil and climatic zone have different influences on the organic carbon stock distribution, depending of the geographical localization. For example, the regions with the highest organic carbon stock has a soil influence marked by the presence of forest soils. On the contrary, the Southern part of Tunisia had low carbon stock mostly because the arid climate influences the vegetation and the soil organic matter decomposition (Bernoux *et al*., 2002). The Northern region is characterized by high carbon stock and showed an important climatic influence, humid zone.

SOC is very spatially variable at the scale of the map. This could have been easily anticipated, given the large spatial heterogeneity of climate and geology, which determine the storage of organic carbon in soil (Fig. 2).

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 5.0 kgCm^{-2} for Regosols, Vertisols and Cambisols, respectively. It accounted for 0 to 100 cm depth of 9.6, 11.1 and 9.6 kgCm^{-2} for Kastanozems, Vertisols and Cambisols, respectively.

Independent of the method used, total SOC stocks for Tunisia were comparable. The calculated SOC stocks to 0-30 cm were closed to the amount (498 TgC) reported by Henry *et al.* (2009) for this country but using a world database, however the estimated stocks to 1 m were higher than the result (727 TgC).

Table 3: Soil organic carbon (SOC) density and storage by soil order in Tunisia

	0-30 cm				0-100 cm			
Soil order	n	SOC density (kgCm^{-2})	SD	SOC storage (TgC)	n	SOC density (kgCm^{-2})	SD	SOC storage (TgC)
Lithosols	88	1.84	1.48	73.22	63	4.04	2.56	160.76
Regosols	261	3.15	1.97	119.83	145	8.39	4.80	319.16
Cambisols	374	4.16	2.47	100.35	212	10.18	5.77	245.57
Vertisols	80	4.56	2.00	6.75	45	10.97	5.00	16.24
Kastanozems	204	3.74	1.94	51.42	124	9.33	4.37	128.26
Podzoluvisols	170	6.19	2.82	8.78	121	13.88	6.08	19.68
Luvisols	90	7.16	3.73	4.24	60	15.92	7.62	9.43
Solonchaks	100	2.82	1.68	38.39	61	7.50	4.85	102.11
Gleysols	116	3.48	2.20	2.46	62	7.77	4.21	5.50
Total	1483			405.44	893			1006.71

n: Number of soil profiles existing in database. SD: Standard deviation

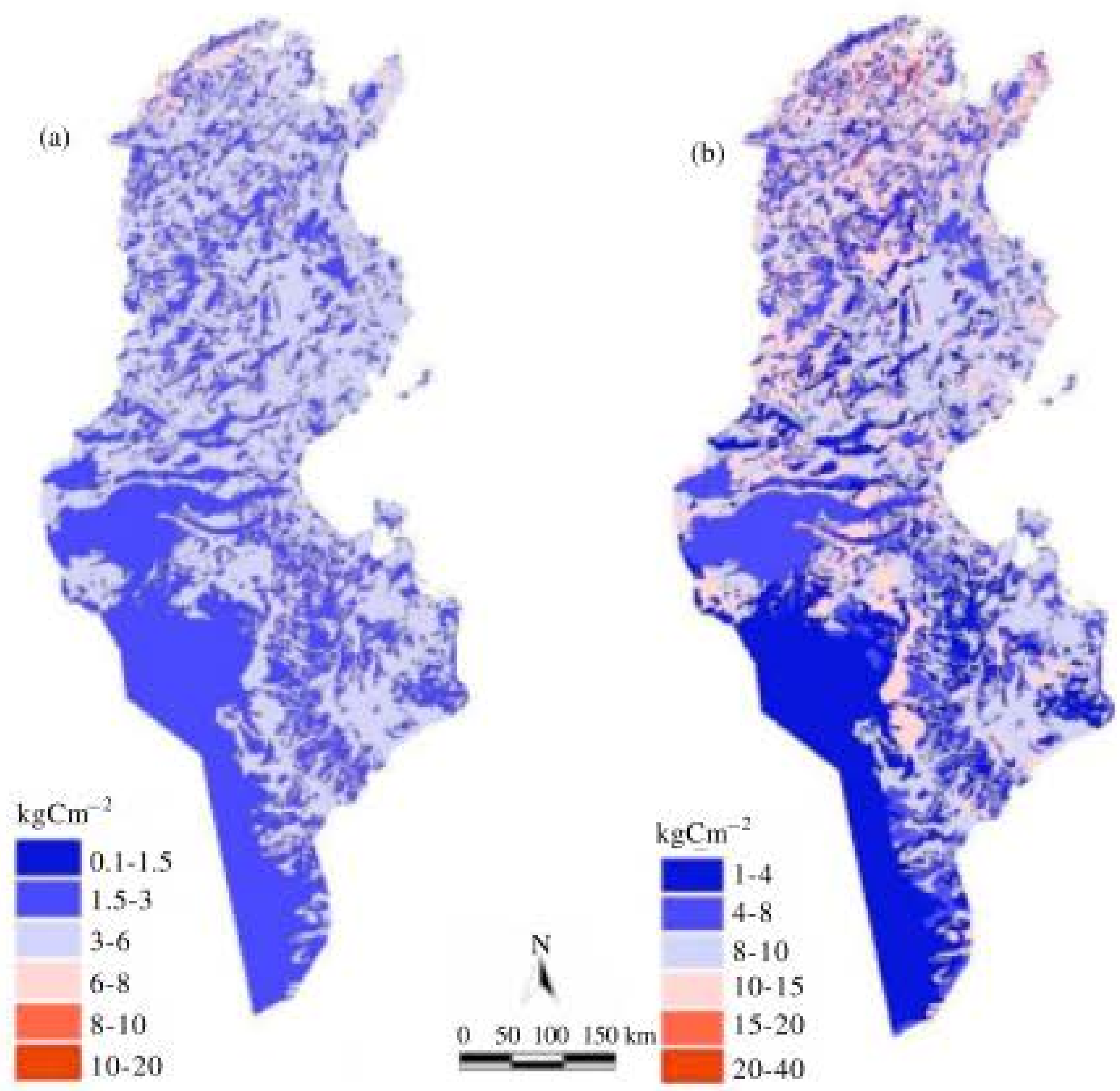

Fig. 2: Map of SOC density of Tunisia, (a) in 0-30 cm depth and (b) in 0-100 cm depth

These stocks are comparable with data for the world level derived from the FAO soils database. Henry *et al*. (2009) used 407 soil Mapping Units (MU) for Tunisia it estimate 498 and 727 TgC from 0-30 and 0-100 cm, respectively.

CONCLUSION

Soils in Tunisia stored 1006.7 TgC and a mean SOC density of 6.486 $kgCm^{-2}$ within the 100 cm soil depth and 405.44 TgC in the upper layer 0-30 cm within a mean SOC density 2.612 $kgCm^{-2}$. Soil organic carbon is very spatially variable at the scale of the maps. This could have been easily anticipated, given the large spatial heterogeneity of climate, geology and land use in Tunisia, which determines inter alia the storage of organic matter in soils. Zones with a high OC content correspond generally with areas of high rainfall; natural forests and mountain ranges in the North of Tunisia, whereas the South with low rainfall show little SOC density. Due to application of the calculated profile values method for estimating SOC density and linkage with soil map, the results of this first study for estimation Tunisian SOC stock were accurate and reliable. Thus, information obtained in this study about SOC storage and density of all soil orders, will be a first step accurately estimating and monitoring of the changes of SOC storage in Tunisia.

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