Soil organic carbon density and storage in Tunisia

Tahar Gallali[A], Nadhem Brahim[B] and Martial Bernoux[C]

[A]UR Pédologie 04/UR/10-02. Département de Géologie, Faculté des Sciences de Tunis, Campus Universitaire el Manar, Tunis 2092, Tunisie, Email gallali.tahar@planet.tn
[B]UR Pédologie 04/UR/10-02. Département de Géologie, Faculté des Sciences de Tunis, Campus Universitaire el Manar, Tunis 2092, Tunisie, Email brahimnadhem@yahoo.fr
[C]UMR 210 Eco&Sols, IRD, 2 place Viala, Bâtiment 12, 34060 Montpellier cedex 1, France, Email martial.bernoux@ird.fr

Abstract
The stock of soil organic carbon (SOC) in Tunisia was calculated using soil profile descriptions available in the Tunisian soil literature defined by FAO/UNESCO classification, and the digital soil map 1:500 000. A soil database has been compiled, containing data from 5024 horizons and 1483 profiles. SOC stocks have been calculated for each profile by a classical method for a given depth, it consists of summing SOC stocks by layer determined as a product of bulk density (D_b), organic carbon (OC) content, and layer thickness. D_b values were calculated from pedotransfer functions when we have missing values. SOC stocks by profiles were calculated and linked by soil type to polygons of a digital soil map of Tunisia. In total, Tunisian SOC stocks are 1.006 Pg C in the 0 to 100cm soil depth, and 0.405 Pg C in the upper layer 0-30 cm. The surface horizon (0-30 cm) stored 40% of the soil organic carbon stock. OC stocks were higher in Luvisols 71.6 and 159.2 t/ha in 0-30 and 0-100cm soil depth, respectively. In Podzoluvisols there are 6.19 and 138.8 t/ha, but amounts are lower in Lithosols at 18.4 and 40.4 t/ha.

Key Words
Geographic dataset, sequestration, carbon pools, arid and semi-arid regions.

Introduction
Global climate change threats and the contribution of soil organic carbon (SOC) stock to its mitigation have demanded national estimates of soil carbon stocks (Eswaran *et al.* 1993). SOC stock is the biggest ecosystem carbon reservoir in the world; 1500 - 2000Pg C at 0-100cm (Batjes 1996; IPCC 2001). A good estimation from carbon pools in the soils has been suggested as a means to help mitigate atmospheric CO_2 increases and anticipated changes in climate (Batjes and Sombroek 1997; Lal *et al*. 1998). Regional and global estimates of soil C 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 (Batjes 1996; Bernoux *et al.* 2002). Regarding 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), and the high spatial variability of soil OC even within one soil map unit. Thus, regional studies are necessary to refine global estimates, mainly at country scale. SOC density according to soil type was estimated by calculating the mean SOC density of its sub-type soils weighted by their area; then SOC storage of the soil type was calculated by multiplying its SOC density by its area obtained from a digital soil map (Yu *et al.* 2007)**.** For Tunisia, it is important to assess the pools of SOC for several reasons. OC is one of the most important constituents of soils; it has a main interest agronomic and environmental. Also, OC storage in Tunisian soils reflects the capacity of arid and semi-arid regions to sequester OC. The objective of this study is to assess and give consistent values and distribution maps, for the 0 to 30cm and 0 to 1m depth of the organic carbon stocks in the soils of Tunisia.

Materials and methods
Study site
Tunisia (32°38°N; 7°12°E and 164.000 km^2) situated in north of Africa and south of Mediterranean Sea (Figure1), has a wide range of natural regions. In fact, the geographical position and the general orientation of the main relieves are influenced at the North by the Mediterranean Sea and at the South by the Sahara.

Soil database
Tunisian soil literature from about 1960 to 2006 was searched for data on soil profiles. Chosen profiles have variable depth, but they are usually more than 1 m in depth. A database was built from previous analytical results from soil profile information for soils pits surveyed by Tunisian research groups by the IRD project and the Ministry of Agriculture of Tunisia. The data contained information for OC, pH, bulk density (D_b),

clay (%), silt (%), sand (%) and $CaCO_3$ (%).The entire soil database comprised 1483 soil profiles corresponding to 5024 soil horizons.

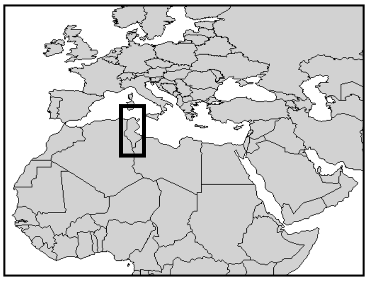

Figure 1. Location of Tunisia in the Mediterranean basin and semi-arid zone

Descriptive statistics of the entire database:
The number of observations varied between 707 and 4716 due to some missing data. The mean D_b value was 1.60 varying between 0.68 and 2 Mg/m^3 (Table 1). All chemical properties, except pH measurements, had a coefficient of variation (CV) > 87%. The OC contents ranged from 0 to 8.99%, and had a CV of 104%. This huge variation in the OC content is due to the great differentiation between the bioclimatic zones in Tunisia (Bernoux *et al.* 1998).

Table 1. Descriptive statistics for the entire database

	Valid cases	Minimum	Maximum	Mean	SD*	CV¤ (%)
Clay (%)	4595	0	88,85	23,76	16,79	71
Fine silt (%)	4433	0	62	13,96	10,73	77
Coarse silt (%)	4429	0	56	10,24	6,43	63
Fine sand (%)	4388	0	89	29,73	18,86	63
Coarse sand (%)	4618	0	96	21,03	19,78	94
pH	3642	4,45	9,95	7,81	0,95	12
OC (%)	4716	0	8,99	0,71	0,74	104
D_b (g/cc)	707	0,68	2	1,6	0,21	13
$CaCO_3$ (%)	3600	0	160	17,18	15,01	87

* Standard deviation
¤ Coefficient of variation

Soil map
The soil map was constructed by the Tunisian Ministry of Agriculture (1973) at the scale (1:500.000). Nine big orders of soils have inventoried; Lithosols, Regosols, Cambisols, Vertisols, Kastanozems, Podzoluvisools, Luvisols, Solonchaks and Gleysols. We digitized this map in the period 2006-2007. The total number of soil map units was 34049.

D_b and stoniness estimation
In Tunisia, Bulk density (D_b) is not determined in most routine analyses, and for most of 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*. 2002). Using all the available parameters, results showed that:
for superficial layers (≤ 30cm) were: D_b = 0.9 (±0.1) – 0.08 (±0.01) OC + 0.007 (±0.001) F-Sand + 0.007(±0.002) F-Silt + 0.05 (±0.01) pH. *(R^2=0.58, SE=0.14).*
and for deep horizons layers (>30cm): D_b = 1.90 (±0.02) – 0.08 (±0.03) OC – 0.0031 (±0.0009) Clay – 0.0023 (±0.0007) $CaCO_3$. *(R^2=0.3, SE=0.14).*

Procedure for determining the individual SOC stocks
To estimate SOC stocks, requires knowledge of the vertical distribution of OC in profiles. 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. For an individual profile with *n* layers, we estimated the organic carbon stock by the following equation:

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

where SOCs is the soil organic carbon stock (kg C/m^2), $D_b i$ is the bulk density (Mg/m^3) of layer i, Ci is the proportion of organic carbon (g C/g) in layer i, Di is the thickness of this layer (cm). Next step of calculation, SOC density of each great order was multiplied by its respective area to estimate SOC storage for each soil map units. Summation of individually of carbon of the 9 great soil orders gave total carbon stock in Tunisia

Results and discussion

Distribution of SOC density and SOC storage in Tunisia

Statistical results, exposed in Table 2, based on big soil orders, indicated that SOC density varied considerably. Table 2 showed that in 0-30 and 0-100cm depth, Luvisols have the highest SOC densities 71.6 and 159.2 t/ha, respectively. But Lithosols have the lowest SOC densities, at 0-30 and 0-100cm it have 18.4 and 40.4 t/ha, correspondingly. Given a total area of 15520249.8 ha of soil in Tunisia, summation of all soil map units yielded a total SOC storage of 1.006 Pg C in the 0 to 100cm soil depth, and 0.405 Pg C in the upper layer 0-30 cm, and a mean SOC density of 64.86 and 26.12 t/ha at 0-100 and 0-30cm, respectively. Changes in the relative distribution of soil organic carbon stocks with depth have been showed in table 2, the ratio of the total SOC storage of 0-30cm (405.43 Mt) divided by that in the 0-100cm zone (1006.71 Mt). More than 40% of the total SOCS in the upper 100cm of mineral soil is held in the first 30cm.

Table 2. Soil organic carbon (SOC) density and storage by soil order in Tunisia.

	0-30 cm				0-100 cm			
Soil order	n*	SOC density t/ha	SD¤	SOC storage Mt	n*	SOC density t/ha	SD¤	SOC storage Mt
Lithosols	88	18.4	1.48	73.22	63	40.4	2.56	160.76
Regosols	261	31.5	1.97	119.83	145	83.9	4.8	319.16
Cambisols	374	41.6	2.47	100.35	212	101.8	5.77	245.57
Vertisols	80	45.6	2.00	6.75	45	109.7	5.00	16.24
Kastanozems	204	37.4	1.94	51.42	124	93.3	4.37	128.26
Podzoluvisols	170	61.9	2.82	8.78	121	138.8	6.08	19.68
Luvisols	90	71.6	3.73	4.24	60	159.2	7.62	9.43
Solonchaks	100	28.2	1.68	38.39	61	75	4.85	102.11
Gleysols	116	34.8	2.20	2.46	62	77.7	4.21	5.50
Total	1483			405.43	893			1006.71

* Number of soil profiles existing in database.
¤ Standard deviation.

Comparison between Tunisian SOC densities of nine big orders with similar soil orders in the world

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 30cm layer of 31, 45 and 50 t/ha for Regosols, Vertisols and Cambisols, respectively. It accounted for 0 to 100cm depth of 96, 111 and 96 t/ha for Kastanozems, Vertisols and Cambisols, respectively. But Batjes (1996) calculated for the soils of arid zone slightly higher values for Lithosols (36 t/ha) and for Gleysols (77 and 131 t/ha, respectively for 0-30 and 0-100cm) and lower values for Solonchaks, Luvisols and Podzoluvisols (18, 31 and 56 t/ha, 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 international database includes several Gleysols from other regions that contain more carbon than the Tunisian soils.

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 concentrations. Using as for this the digitized map of soil and the SOC density of the 1483 soil profiles, a SOC density map was constructed. Figure 2 shows that soils have different influences on the OC distribution, depending of the geographical localization, heterogeneity of climate, and geology, which determine the storage of organic carbon in soils.

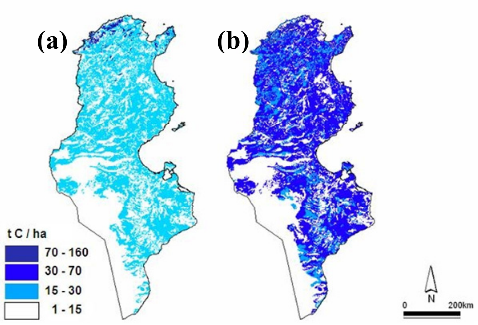

Figure 2. Map of SOC density of Tunisia, (a) in 0-30cm depth (b) in 0-100cm depth

Conclusion

Soils in Tunisia stored 1.006 Pg C and a mean SOC density of 64.86 t/ha within the 100 cm soil depth, and 0.405 Pg C in the upper layer 0-30 cm within a mean SOC density 26.12 t/ha. 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.

References

Batjes NH (1996) Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science* **47**, 151-163.

Batjes NH, Sombroek WG (1997) Possibilities for carbon sequestration in tropical and subtropical soils. *Global Change Biology* **3**, 161-173.

Bernoux M, Arrouays D, Cerri CC, Bourennane H (1998) Modeling vertical distribution of carbon in Oxisols of the western Brazilian Amazon. *Soil Science* **163**, 941-951.

Bernoux M, Carvalho MDS, Volkoff B, Cerri CC (2002) Brazil's soil carbon stocks. *Soil Science Society of America Journal* **66**, 888-896.

Eswaran H, Van Den Berg E, Reich P (1993) Organic carbon in soils of the world. *Soil Science Society of America Journal* **57**, 192-194.

IPCC (2001) 'Good practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES) for the IPCC'. (Hayama JP).

Lal R, Kimble JM, Follett RF, Cole CV (1998) 'The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect'. (Ann Arbor Press, Chelsea MI).

Sombroek WG, Nachtergaele FO, Hebel A (1993) Amounts, dynamics and sequestration carbon in tropical and subtropical soils. *Ambio* **22**,417-426.

Tunisian Ministry of Agriculture (1973) 'Carte Pédologique 1 :500 000 de la Tunisie'. (TMA Publishing).

Yu DS, Shi XZ, Wang HJ, Sun WX, Warner ED, Liu QH (2007). National scale analysis of soil organic carbon storage in China based on Chinese Soil Taxonomy. *Pedosphere* **17**, 11-18.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.