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SPATIAL DISTRIBUTION OF SOIL ORGANIC CARBON STOCK 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 cm 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 totalised 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, 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 summing available values down to 1 meter. In total, Tunisian SOC stock was 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.

KEYWORDS

Soil organic carbon stock, stock by administrative division, spatial distribution, map unit, maps of SOC density, Tunisia.

1. INTRODUCTION

Increases in decomposition of soil organic matter resulting from global warming or from land use change could significantly increase the atmospheric burden of CO2, 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 its article 3.4, 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 stapes is to knowledge and calculate this SOC stocks. A good estimation of carbon pools in the soils has been suggested as a means to help mitigate atmospheric CO2 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 (1 Pg = 1015 g, or 1 Pg = 1 billion tonnes) in the upper 100 cm (Batjes, 1996,). 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) (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 (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 (Parton et al. 1987). Thus, regional studies are necessary to refine global estimates, mainly at country scale (Bernoux et al. 2002).

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. In their Articles 3.3 and 3.4, 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 30cm and 0 to 100cm 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.

2. MATERIALS AND METHODS

2.1. Study site

Tunisia (32°38°N; 7°12°E and 164.000 km2) 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.

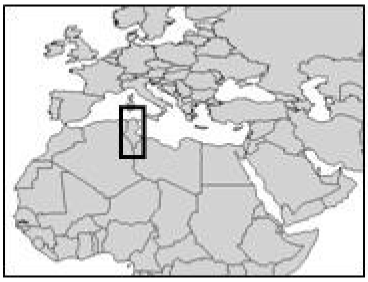

Figure 1: Location of Tunisia in the Mediterranean basin and semi-arid zone

2.2. 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 (Db), clay (%), silt (%), sand (%) and CaCO3 (%).The entire soil database totalised 1483 soil profiles corresponding to 5024 soil horizons.

2.3. Descriptive statistics of the entire database

The number of observations varied between 707 and 4716 due to some missing data. The mean Db 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).

2.4. 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 (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 with the country it covers alone 0.38% from total area, although, lithosols and regosols are the biggest soil orders covering 25.63% and 24.50% from total area, respectively. (Figure 2.a)

Departmental maps: In this paper, we mean by departmental maps, the map of governorates and those of delegations. (i) Governorate map was built from 27 MU; (ii) Delegation map was built up from 264 MU. (Figure 2.b)

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. Each MU of the output map was characterized by combining the information derived from the soil (9 categories) and governorate (24 governorates) maps. The MU 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". (Figure 2.c)

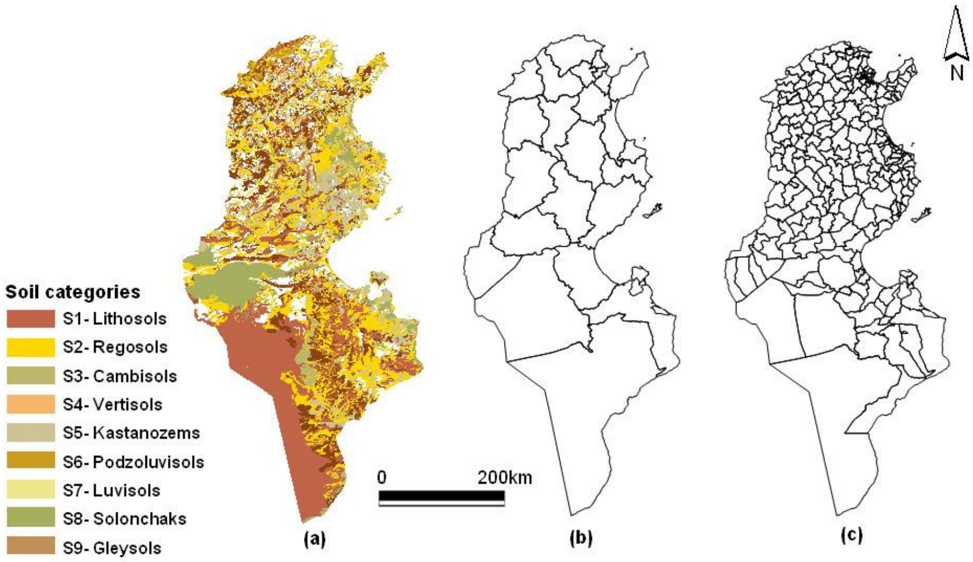

Figure 2: Soil, governorate and delegation maps, with designation (a), (b) and (c) respectively, used in elaboration of soil-department association maps

2.5. 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. The map totalized 23160 MU. The largest SGA category (18551 km2) corresponded to the "S1 G24" association, but the smallest (<1km2), we make zero (0) value, when SGA category it inferior at 1km2, for example; S4 G2, S6 G2, S9 G19, in totality we have 10 cases SGA <1km2. More than 84% of the SGA categories (223 of the total) had an area smaller than 1000 km2 and covered 41 171 km2 (26.5% from Tunisian area), but 16% of the SGA categories (41 of the total) had an area> 1000 km2 covering 114 131 km2 (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.

2.6. Db and stoniness estimation

In Tunisia, Bulk density (Db) is not determined in most routine analyses, and for most of soil profiles in the database no Db was reported. The Db of only 707 soil horizons from the 5024 records have been measured, and it is therefore necessary to estimate Db'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 ($\leq$ 30cm) were: Db = 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): Db = 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).

2.7. 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 Db, 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), Dbi 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). 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

3. RESULTS

3.1. 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. Figures 3 and 4 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.

3.2. Organic carbon stock by soils

The potential total organic carbon stocks of Tunisian soils in different soil groups for the 0 to 30cm and 0 to 1m 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 (0-30cm) (figure 3-a) and 1.131 Pg C in 1m depth (figure 4-a). 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.

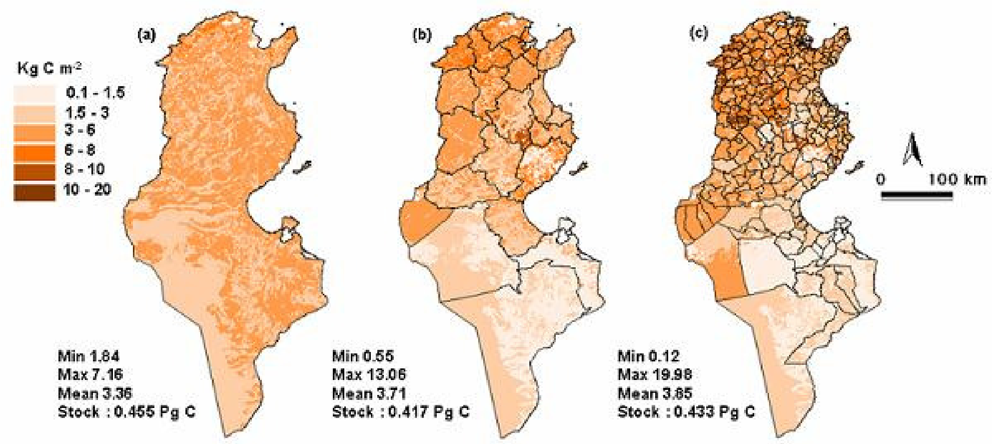

Figure 3: Organic carbon stocks in 0-30cm depth by soils (a), soils-governorates (b), and soils-delegations (c).

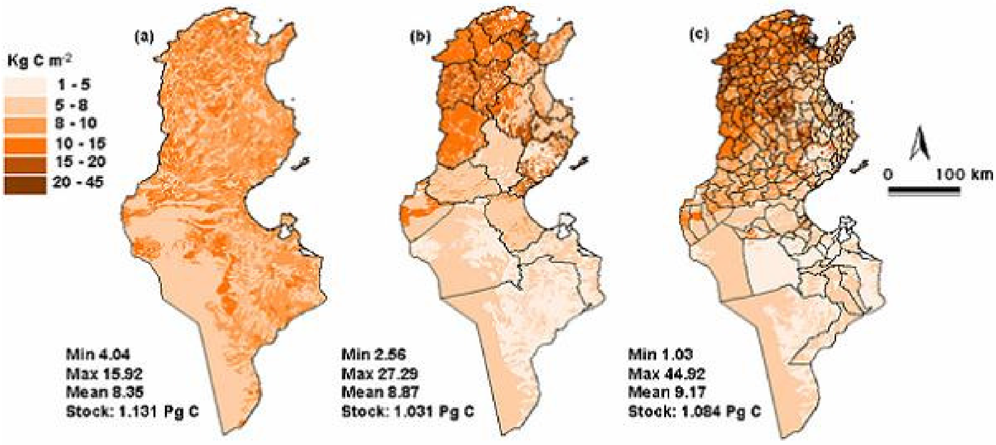

Figure 4: Organic carbon stocks in 0-100cm depth by soils (a), soils-governorates (b), and soils-delegations (c)

3.3. Organic carbon stock by soils and governorates

The potential total organic carbon stocks of Tunisian soils by governorates for the 0 to 30cm layer (figure 3-b) 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 100cm we obtained 1.031 Pg C (figure 4-b). By this way, we remarked a decrease in organic carbon stock minimum value from the country level (0.55 kg C m-2 in 0-30cm, and 2.56 kg C m-2 in 0-100cm) and increase from maximum value (13.06 kg C m-2 in 0-30cm and 27.29 kg C m-2 in 0-100cm).

3.4. Organic carbon stock by soils and delegations

We calculate Tunisian SOC stocks using SDA map following combining the soils map with delegations map. We calculated that a total of 0.433 Pg C was stored in 0-30 cm layer (figure 3-c) and 1.084 Pg C was stored in 0 to 1m depth (figure 4-c). 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 0-30cm layer and between 8.35 and 9.17 kg C m-2 in 0-100cm 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. Figures 3 and 4 showed that an area dominated by forests and mountainous zone contains significant amounts of organic carbon in north and Tunisian centre.

4. 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 3 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 figure 3-b and figure 3-c shows that soils and governorates or delegations have different influences on the SOC distribution. For instance, in sud west of Tunisia in Tozeur governorate (figure 3-b) 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 0-30cm 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 figure 3-c and figure 4-c 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.

Figures 3-a and 4-a show 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 witch 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 (0-30cm) the same as between 1 and 8 kg C m-2 at 1m depth.

5. CONCLUSION

The total mass of organic carbon stored in the first 30cm 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 100cm. 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.

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