International Journal of Research in Applied Sciences, 02 (2014) 5-8



Research article

# Soil organic carbon stocks and its variation according by different land uses in Tunisia

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Article history:
Received 5 February 2013; Received in revised form 12 April 2013.
Accepted 12 April 2013.

**Abstract**

Soils are the third biggest sink of carbon on the world after the oceans and fossil fuels. For this reason, suitable land uses for a climatic condition are expected to sequester optimum atmospheric carbon in soils. However, information on how climatic conditions and land uses influence carbon storage in the soils on the semi-arid Mediterranean area are not well known. This study reports the impact of climatic conditions and land uses on the concentrations and stocks of soil organic carbon in upper (0-30 cm) and deeper (30-100 cm) soil depths in Tunisia. The stock of soil carbon was calculated using soil database containing data from 5024 horizons and the digital soil map 1:500 000. Tunisian carbon stocks are 1.006 Gt C in the 0 to 100 cm soil depth, and 0.405 Gt C in the upper layer 0-30 cm. Depending the user use: (i) deforestation relayed by conventional agriculture results in a net decrease in stock could be up to 1/3 the soil profile (0-50 cm); (ii) switching from agriculture to forestry mode, resulting in a significant increase in carbon stock could be up to 40% from the initial stock, (iii) and no-tillage is controlled by the aridity index (I). For the sub-humid bioclimatic zone ($I > 0.4$), no-tillage produces a net improvement in the stock of carbon on the surface and a decrease in bulk density. The aridity index $I < 0.23$ constituting a critical limit where this mode of use does not present significant difference compared to no-tillage.

***Keywords:*** Carbon sequestration, climate change, land use, aridity index, Tunisia, Mediterranean zone.



## 1. Introduction

Stabilization of increasing $CO_2$ concentration in the atmosphere is the major ecological concern in our day the world over (Mishra et al., 2010). Globally the soil organic carbon (SOC) stock is the largest terrestrial carbon pool 1550 Pg (1 Pg=$10^{15}$ g) to 1m depth; it is as much as two times higher than the atmospheric carbon pool and three times higher than in the vegetation (Batjes, 1996; Eswaran et al., 2000; Watson et al., 2000; Lal, 2008). Soils are still the largest organic carbon sink on the Earth. Therefore sequestration of the atmospheric carbon to soils is a possible option for mitigating the global warming.

In soils carbon stock is influenced by vegetation, soil types, climatic conditions, and topography (Bedison and Johnson, 2009; Chaplot et al., 2009). The vegetation is the major source of soil organic matter. For this reason, land uses are known to play a major role in SOC stock build up through organic matter input (Pandey et al., 2010) in different depths (Batjes, 1996, Bernoux et al., 2002; Brahim et al., 2010), and bioclimatic zones into soils through the processes of soil aggregation (Brahim et al., 2011; Bouajila and Gallali, 2008).

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 (i) to assess and given consistent values 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, and (ii) the effect of land use on the carbon stock.

## 2. Materials and Methods

### *2.1. Study site*

Tunisia (32°38°N; 7°12°E and 164.000 $km^2$) situated in north of Africa and south of Mediterranean Sea, 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.

For the effect of land use on the carbon stock, we studied the three possible (Fig. 1) cases which are:

- Deforestation; transition from forest to agriculture (the site of Tabarka);
- The reverse process; agriculture to forest (the site of Lakhmess);
- No-tillage (sites of Mateur, Sidi Ahmed Saleh and Le Krib).

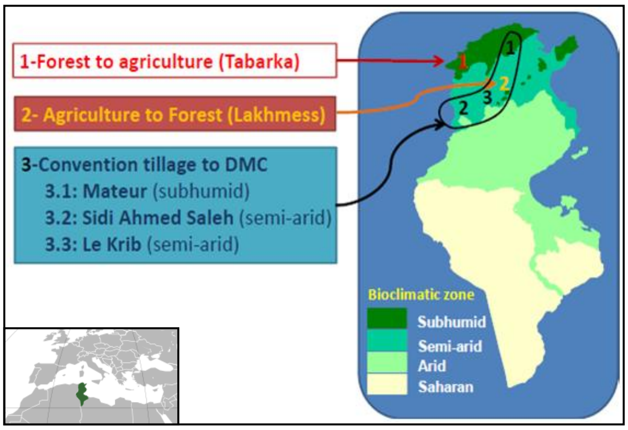



**Fig. 1** Location of Tunisia in the Mediterranean basin and location of the various study sites

### *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 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 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 $D_b$ value was 1.60 varying between 0.68 and 2 Mg $m^{-3}$. 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.

### *2.5. Effect of mode of use*

We selected study sites as follows:

- Deforestation (effect 50 years after of conversion from natural forest to conventional agriculture);
- The reverse process (effect of the transition from agriculture to forest, 20 years after).
- No-tillage: was conducted under three field situations: i) No-tillage under sub-humid bioclimate (Mateur, P: 643mm/year, ETP: 1453 mm/year, aridity index I = 0.44); ii) No-tillage under semi-arid bioclimate: (i) Sidi Ahmed Saleh P: 468mm/year, ETP: 1841 mm/year, I = 0.25) and (ii) Le Krib P: 428mm/year, ETP: 1855 mm/year, I = 0.23.

## 3. Results

### *3.1. 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 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. 2). 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 0-100cm) 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).

### *3.2. 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 and 1.084 Pg C was stored in 0 to 1m depth (figure 2-a). 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. Fig. 2a and fig. 2b showed that an area dominated by forests and mountainous zone contains significant amounts of organic carbon in north and Tunisian centre.

## 4. Discussion

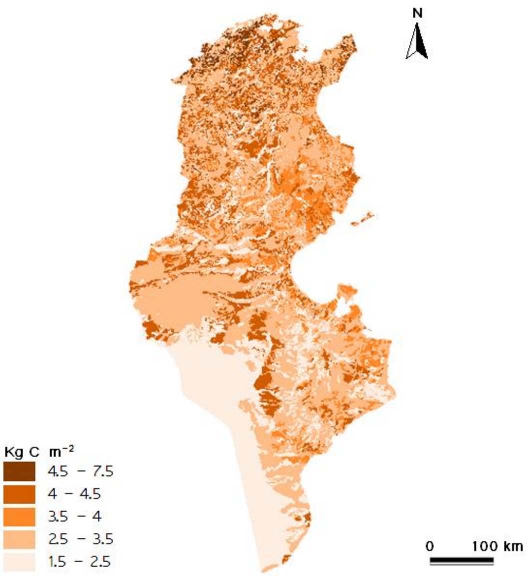
### *4.1. Spatialization of carbon stock at the country*

Depending on soil type (legend FAO/UNESCO), three levels of stock can be considered (Fig. 2a):
- Relatively high level: Luvisols (72 t/ha at 0-30 cm and 159 t/ha at 0-100 cm) and podzoluvisols (62 t/ha at 0-30 cm and 139 t/ha at 0-100 cm).
- Middling level: soil as vertisols (46 t/ha to 0-30 cm and 110 t/ha at 0-100 cm), Cambisols (42 t/ha to 0-30 cm and 102 t/ha at 0-100 cm) or Kastanozems (37 t/ha at 0-30 cm and 93 t/ha at 0-100 cm).
- Low level: Regosols (32 t/ha at 0-30 cm and 84 t/ha at 0-100 cm) lithosols (18 t/ha at 0-30 cm and 40t/ha to 0-100 cm), solonchaks (28 t/ha 0-30 cm and 75 t/ha at 0-100 cm). This is indeed raw mineral soils where organic matter is at most a trace, or soils that are stockpiled in the form of rapidly dissolving fulvates and sodium humate.

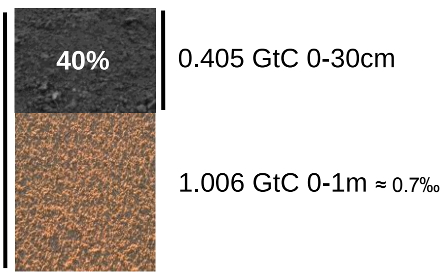
Beyond the soil type, texture appears to play a role in stabilizing the organic stock. In clay soils, chemical and physical properties (bulk density) play an important role in controlling the organic carbon content. In sandy soils, chemical and biological properties (pH and organic matter) explain better the organic carbon storage than the physical properties.

### *4.2. Variation of the stock depending on the mode of use*

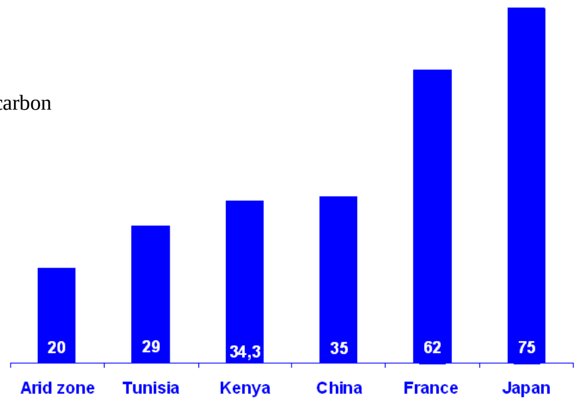
Concerning the variation of the stock depending on the mode of use, we opted to the synchronic approach which consists to compare the carbon stock of a plot led by sequestering practice for a time "t" to that of a second plot managed conventionally, and assumed to be the time "t0" of the plot in sequestering system. The main results can be summarized as follows:
- Deforestation relayed by conventional cultivation results in a net decrease in stock. This decrease, up to 1/3 of the soil profile (0-50 cm);
- The reverse process, namely switching from agriculture forestry mode results in a significant increase in carbon stock, the increase up to 40% from the initial stock (fig. 2b);
- Sequestration depending on the mode of use conventional agriculture/conservation agriculture is heavily influenced by bioclimatic data.
- On comparing our stock with other countries, we see that Tunisia stores more than arid zones, but less than other rainy country like France or Japan (Fig. 2c).




a) Map of organic carbon stock t/ha (0-30 cm) (Brahim et al., 2011)




b) Total organic carbon stock




c) The organic carbon stock t/ha (0-30 cm) compared to other countries

**Fig. 2** Tunisian organic carbon stock t/ha (0-30 cm)

Under sub-humid bioclimate (aridity index I > 0.4), conservation agriculture leads to substantial gains in carbon stocks on the layer exploited by the roots of annual plants (0-30 cm). Under semi-arid bioclimate (I < 0.25) improved carbon stock is limited to the first centimeters of the soil surface (0-10 cm).

## 5. Conclusion

In conclusion, the present study has shown that:

- At the spatial level of distribution of the stock of carbon, the established maps, which constitute a precursor step to the possible "carbon funds", can be presented: by soil type, by-level layer surface or deep - by administrative division: Governorate and/or delegation. In terms of changes in carbon stocks, it's a multivariable function. The first explanatory variable is the type of soil itself, and then comes the user use.
- For the sub-sub-humid bioclimate (aridity index I > 0.4), no-tillage produces a net improvement in the stock of carbon on the surface and a decrease in bulk density, reflecting an improvement in the pore system.

Under semi-arid bioclimate (I < 0.25) improvement in the stock of carbon is less noticeable, the aridity index I<0.23 constituting a critical limit where this mode of use does not present significant difference compared to conventional agriculture. However, conservation agriculture retains a distinct advantage in that it comes in all bioclimatic, environmental benefits related.

With this limit, no-tillage does not present significant difference compared to conventional agriculture. However, no-tillage retains a distinct advantage in that it comes in all bioclimatic, environmental benefits related (Fig. 3).

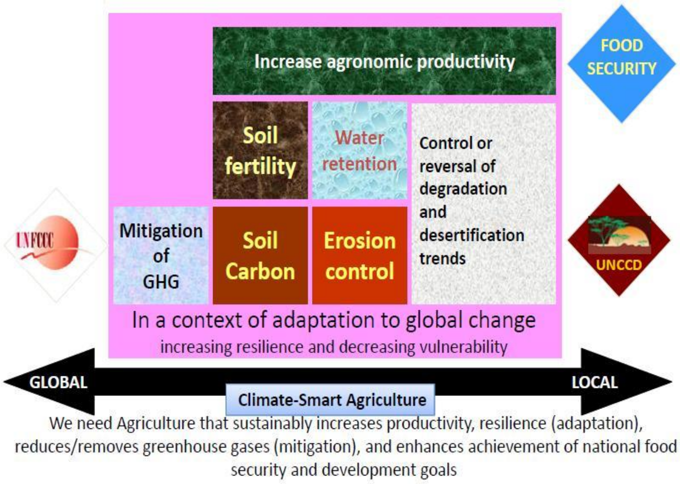



**Fig. 3** “Soil carbon sequestration” is not just a matter of “Mitigation” and “Climate Change”

Compared to geological sequestration and/or ocean sequestration has the advantage of generating environmental benefits virtuous. Consolidating wells greenhouse gas emissions, it contributes at the same time to conserve soil and improve its functional properties; these beneficial effects becoming critical in arid areas like Tunisia where soils are naturally vulnerable and easily erodible (Fig. 3).

## Acknowledgements

This research was supported by AFD (Agence Française pour le Développement), the French Ministry of Foreign Affairs (MAEE), the Fond Français pour l’Environnement Mondial (FFEM), the IRD (Institut de Recherche pour le Développement) through the CORUS-2 project number 6112 and Rime-Pampa project n° CZZ 3076.

## References

Batjes, N.H., (1996). Total carbon and nitrogen in soils of world. Eur. J. Soil Sci. 47, 151-163.

Bedison, J.E.; Johnson, A.H., (2009). Controls on the spatial patterns of carbon and nitrogen in Adirondack forest soils along a gradient of nitrogen deposition. Soil Sci. Soc. Am. J. 73 (6), 2105-2117.

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

Bernoux, M.; Carvalho, M.D.S.; Volkoff, B.; Cerri, C.C., (2002). Brazils soil carbon stocks. Soil Sci. Soc. Am. J., 66: 888-896.

Bouajila, A. ; Gallali, T., (2008). Soil organic carbon fractions and aggregate stability in carbonated and no carbonated soils in Tunisia. J. Agron., 7: 127-137.

Brahim, N.; Bernoux, M.; Blavet, D.; Gallali, T., (2010). Tunisian soil organic carbon stocks. Int. J. Soil Sci., 5: 34-40.

Brahim, N.; Gallali, T.; Bernoux, M., (2011). Carbon Stock by Soils and Departments in Tunisia. Journal of Applied Sciences, 11: 46-55.

Chaplot, V.; Podwojewski, P.; Phachomphon, K.; Valentin, C., (2009). Soil erosion impact on soil organic carbon spatial variability on steep tropical slopes. Soil Sci. Soc. Am. J. 73 (3), 769-779.

Eswaran, H.; Reich, P.F.; Kimble, J.M.; Beinroth, F.H.; Padmanabhan, E.; Moncharoen, P., (2000). Global carbon stocks. In: Lal, R.; Kimble, J.M.; Eswaran, H.; Stewart, B.A. (Eds.), Global Change and Pedogenic Carbonate. CRC Press, Boca Raton, FL, pp. 15-25.

Lal, R., 2008. Carbon sequestration. Philos. Trans. R. Soc. London B 63, 815-830.

Mishra, U.; Lal, R.; Liu, D.; VanMeirvenne, M., (2010). Predicting the spatial variation of the soil organic carbon pool at regional scale. Soil Sci. Soc. Am. J. 74 (3), 906-914.

Pandey, C.B.; Begum, M., (2010). The effect of a perennial cover crop on net soil N mineralization and microbial biomass carbon in coconut plantations in the humid tropics. Soil Use Manage. 26, 158-166.

Smith, P., (2004). Monitoring and verification of soil carbon changes under Article 3.4 of the Kyoto Protocol. Soil Use Manage. 20, 264-270.

Watson, R.T.; Noble, I.R.; Bolin, B.; Ravindranmath, N.H.; Verardo, D.J.; Dokken, D.J. (2000). Land Use Change, and Forestry. Cambridge Univ. Press, Cambridge, UK.