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Effects of Agronomic Practices on the Soil Carbon Storage Potential in Northern Tunisia

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Abstract: Sub-humid and semi-arid zones comprise a land area of about approximately 1/3 of Tunisia, good agricultural soils and major organic carbon storage are situated in this region. The objective of this study is to investigate the organic carbon distribution and stocks in soils of this region under different land uses by using different investigations: (1) The conversion from natural forest to agricultural land caused significant loss of Soil Organic Carbon (SOC) stock, it induces a decrease of SOC stock with 19.33 t C ha^{-1}, (2) however, restoring forestry after conversion from agricultural ecosystems to forest, we found an increase of SOC stock with 0.42 t C/ha/year, (3) soil carbon sinks increase most rapidly under practice of no-tillage compared with conventional tillage, no-tillage treatment was found to increase the storage of OC in the surface layer 0-20 cm compared to conventional tillage and (4) irrigation with saline water stock higher than irrigation with freshwater only at superficial layer. Although, under this depth, irrigation with freshwater and at total profile stock higher than saline water. SOC stock is 148.5 t ha^{-1} in the freshwaters irrigated soils against 139.6 t ha^{-1} in saline water irrigated soil.

Key words: Organic carbon stock, land use, salinization, sub-humid, semi-arid, Tunisia

INTRODUCTION

Soil Organic Carbon (SOC) comprises a major stock in the world, comprised between 1500 and 2000 Pg C in the upper 100 cm (Eswaran *et al.*, 1993; Batjes, 1996; IPCC, 2001) equivalent to almost three times the quantity stored in terrestrial biomass and twice the amount stored in the atmosphere, it plays an important role of the global carbon cycle and in regulating the atmospheric greenhouse gases concentration (Houghton, 2003; Smith *et al.*, 2008). Globally, SOC level is dependent on vegetation (Jenny, 1980), which is principally controlled by climate. Arid lands cover 40% of the global terrestrial surface of the earth, but stock only 16% in the upper 100 cm from the global stock. As a result, changes in soil use and management can lead to changes in OC stocks (Lal, 1997; Six *et al.*, 2002) and increases of greenhouse gas emissions in the atmosphere (Bernoux *et al.*, 2001; IPCC, 2007). A good estimation and knowledge of carbon stocks in the soils has been suggested as a means to

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help mitigate the atmospheric CO_2 increase and through which an anticipated change in climate (Kimble *et al*., 1990; Batjes and Sombroek, 1997; Batjes, 1999; Lal *et al*., 1998, 2000). Climate change has an appreciable influence on predicted global net irrigation water requirements: an increase of 409 Gm^3 by 2080 (Fischer *et al*., 2006). The impact of climate change will however differ for different parts of the world. In the Mediterranean regions, the combination of low rainfall and high temperature could lead to high evapotranspiration losses and exacerbate water stress for crops. The reduction in availability of good quality water for irrigation would increase the use of saline water, thereby accentuating salinity problems in the region (Vlek *et al*., 2008). Extensive research has been undertaken on the physicochemical properties of saline and sodic soils and their amelioration, particularly with regard to soil structure and vegetation health (Gallali, 1980; Bramely *et al*., 2003; Gardner, 2004; Valzano *et al*., 2001). However, the effects of salinity and sodicity on carbon dynamics, with respect to carbon accumulation from soils, are not as well documented or understood. Incorporation of OM notably in the form of crop residues has been shown to improve soil aggregation and increase SOC stocks (Lal *et al*., 1999). In sodic or saline soils, gypsum ($CaSO_4.2H_2O$) is the most commonly used ameliorant to maintain soil electrolyte levels for improving soil physical and hydraulic properties (Keren, 1996).

The elaboration of map of SOC density in Tunisia, by Brahim *et al.* (2009), shows that soils have different influences on the OC distribution, depending of the geographical localization and land use. 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 soils. In order to appreciate the geographical distribution of SOC densities and its pattern, we study in this paper OC sequestration by major land use in Tunisia. Changes in carbon stocks were investigated by measuring the soil carbon stocks in 4 sites with different land-use: (1) the site of Tabarka with a conversion from natural forest to agricultural ecosystems, (2) the site of Siliana a conversion from agricultural ecosystems to forest, (3) the site of Le Kef where we examine the soil organic carbon stock under conventional tillage and no-tillage practices and (4) in the site of alluvial plain of the Medjerda Valley we study the effect of salinity and saline soils.

The objective of this study is to assess and give consistent values of carbon stocks under diverse land-use and the effect of salinity in existing saline soils from carbon sequestration in Tunisia.

MATERIALS AND METHODS

Study Area and Site Descriptions

Tunisia (164.000 km^2) situated in North Africa and south of Mediterranean Sea. The study area included regions of northern Tunisia. The area is located between the latitudes of approximately 32 and 34°N and between longitudes approximately 8 and 12°E (Fig. 1). The region is bordered on the north and east by the sea, on the west by Algeria and on the south by the Dorsale Mountain. The Medjerda River represents the major water stream running through the agricultural plains of the region. The region is further characterized by a Mediterranean climate which has a rapidly increasing north to south aridity gradient and two distinct climatic zones: (1) extreme northern region is humid, the annual rainfall is usually between 1200 mm and average temperatures is 17.1°C, natural forests in this region are mainly dominated by three species *Quercus suber*, *Quercus faginea* and *Pinus pinaster*, (2) Northern region is semi-arid, the annual rainfall is usually comprised between 380 and 600 mm and average temperatures is 18.7°C natural forests in this region are largely dominated by *Olea europea* and *Pistacia lentiscus*.

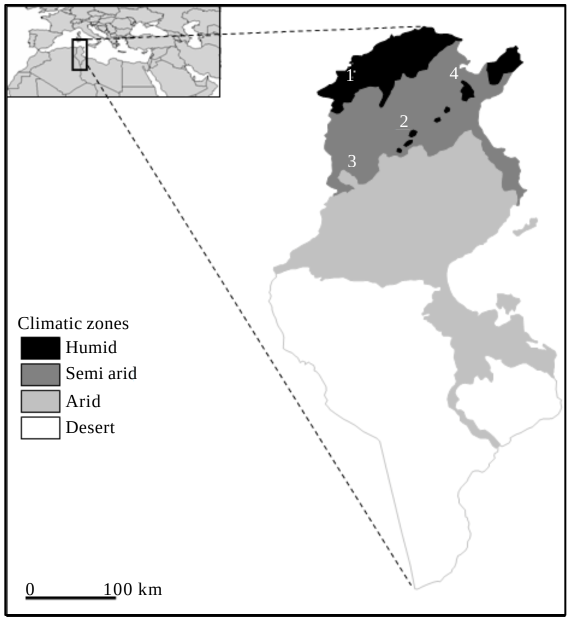

Fig. 1: Map of location of Tunisia and studies sites. 1: Tabarka, 2: Siliana, 3: Le Kef and 4: Alluvial plain of the Medjerda Valley

This Research Was Carried out in Four Experimental Sites

- The site of Tabarka is located at humid zone; first, the effect of conversion from natural forest to agricultural ecosystems from carbon stock at experimental field adjacent at forest was studied. The conversion from forest was started from 1960. The site is characterized by a humid climate with a mean annual precipitation of 1000 mm (mainly during the winter) and an average temperature of 18°C. Soil with CPCS classification is called Sol brun lessivé à mull and with FAO-UNESCO (1974) classification Podzoluvisol, with a pH = 6.8 and sandy texture (clay = 20%; silt = 20%; sand = 60%). Tabarka designed at this study T where, T1 (15 ha) is the field plot situated at the forest and T2 (15 ha) is the field plot under agricultural parcel. A toposequence method was used as described by Manlay *et al.* (2002) for all the sites included in the current study. It is worth noting that the material transfer in the toposequence semi-arid soil is insignificant (Gallali, 1980, 2004)
- The site of Siliana is located at semi-arid zone in an artificial park started from 1980. This site is characterized by a semi-arid climate with a mean annual precipitation of 650 mm (mainly during the winter) and an average temperature of 22°C. Soil with CPCS classification is called Sol brun calcaire and with FAO-UNESCO (1974) classification Cambisol, with pH = 7.6 and a loamy-sandy texture (clay = 21%; silt = 36%; sand = 43%). Siliana designed at this study S where, S1 (15 ha) is the field plot under agricultural parcel and S2 (15 ha) is the field plot situated at forest
- The field experiment from Le Kef was started from 2000. This site is characterized by a semi-arid climate with a mean annual precipitation of 500 mm (mainly during the winter) and an average temperature of 22°C. According to the CPCS classification this soil is

called Sol brun calcaire and with FAO (1974) classification is Cambisol, it is developed from alluvial sediments with a clayey-loamy texture (clay = 35.25%; silt = 32.75%; sand = 24%). Le Kef designed at this study K where, K1 (1 ha) is the field plot situated at the parcel with no-tillage (NT) practice and K2 (1 ha) is the field plot situated at parcel with conventional tillage (CT) practice

- The site from the alluvial plain of the Medjerda Valley is located at semi-arid zone. The field experiment was started from 1985 in the experimental site of the Tunisian Ministry of Agriculture in Cherfech from the Medjerda Valley (20 km northwest of Tunis City). This site is characterized by a semi-arid climate with a mean annual precipitation of 500 mm (mainly during the winter) and an average temperature of 17.3°C. The field plot covered a total surface area of 12 ha. According to the CPCS classification this soil is called Sol peu évolué d'apport alluvial peu humifère and with FAO-UNESCO (1974) classification is Gleysols, it is developed from alluvial sediments with a clayey-loamy texture (clay = 37%; silt = 34%; sand = 28%, pH = 8.5 and $CaCO_3$ = 63%). Cherfech designed at this study C where, C1 (5 ha) is the field plot irrigated with ordinary water (freshwater) (water A) and C2 (5 ha) is the field plot irrigated with saline water (water B)

Field Sampling and Laboratory Analysis

Samples were taken from 0-10, 10-20, 20-30 and 30-50 cm depths in each of the soil profiles from sites T, S and K. From site C, samples were taken from 0-20, 20-40, 40-80, 80-120 and 120-150 cm depths. The depths are different between the sites since data was collected from two different data bases (from Tunisian Ministry of Agriculture data base for C and from the data base of CORUS-2 project for T, S and K). Soils were sampled with a shovel from a soil pit at each depth interval. Soil pH was determined in water (1:1) soil-water extract. Organic Carbon (OC) of the soil fraction <2 mm by Walkley-Black method; clay content (particle 0-2 μm); silt (fine and coarse silt) content (2-50 μm); sand (fine and coarse sand) content (50-2000 μm); soil bulk density in weight per volume (Cylinder method) (Mg m^{-3}), it was determined from oven dried cores at 105°C for 24 h; Electrical Conductivity (EC) (dS m^{-1}) (Table 1); Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) are calculated with Eq. 1 and 2 below, respectively:

$$SAR = \frac{[Na^+]}{0.5[Ca^{2+} + Mg^{2+}]^{1/2}} \quad (1)$$

where, Na^+, Ca^{2+} and Mg^{2+} are in meq L^{-1}.

$$ESP = \frac{Na_{exch}{}^{+}}{[Na_{exch}{}^{2+} + Mg_{exch}{}^{2+} + K_{exch}{}^{+} + Na_{exch}{}^{+}]} \times 100 \quad (2)$$

Table 1: Laboratory analysis

Symbol	Variable information
D_b	Soil bulk density in weight per volume (Cylindre method) (Mg m^{-3})
OC	Organic carbon of the soil fraction <2 mm (Walkley-Black method) (%)
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 (pH meter) (1:1)
EC	Electrical conductivity were measured in 1:2.5 soil (Conductivity meter)

where, Na_{exch}^{+}, Ca_{exch}^{2+}, Mg_{exch}^{2+} and K_{exch}^{+} are the totals of exchangeable Na^{+}, Ca^{2+}, Mg^{2+} and K^{+} in meq/100 g soil.

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 estimate the organic carbon stock by the following Eq. 3:

$$SOC_S = \sum_{i=1}^{n} D_b i \times Ci \times D_i \quad (3)$$

where, SOCs is the soil organic carbon stocks (kg C m^{-2}), $D_b i$ is the bulk density (g cm^{-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).

RESULTS AND DISCUSSION

SOC Stock after Conversion from Natural Forest to Agricultural Ecosystems

Land transformation causes reductions in organic carbon and other nutrients and the microbial properties. Thus a decrease in microbial biomass in soil may be expected (Cleveland *et al.*, 2003). The conversion of forest into other land-uses resulted in a decrease in plant biomass (Srivastava and Singh, 1991). Conversion from forest to agricultural land strongly impacts soil nutrients and microbial biomass depending on the type of land-use change and the post conversion land management (Sharma *et al.*, 2004). Decomposition of SOM is especially increased by physical disturbance with tillage, which disrupts macroaggregates and exposes previously protected soil to microbial processes (Cambardella and Elliott, 1992). The land-use change from forest to other usage has been conspicuous over the past two decades (Rai *et al.*, 1994). The conversion of natural forest into open cropped area in north-western Tunisia has been effected since 1960. The SOC stock decline in the 0-30 cm for soil under forest to soil (T1) under agricultural systems (T2), 65.52 and 46.19 t C ha^{-1}, respectively (Fig. 2). The conversion resulted in a decrease of SOC stock with 19.33 t C ha^{-1}. This decrease is caused by annual tillage. The results suggest that conversion of forest land to agricultural systems affects soil organic matter. SOC stock may decline immediately following conversion; at this site we examine a decrease of ˜30% of stock after ≈50 years.

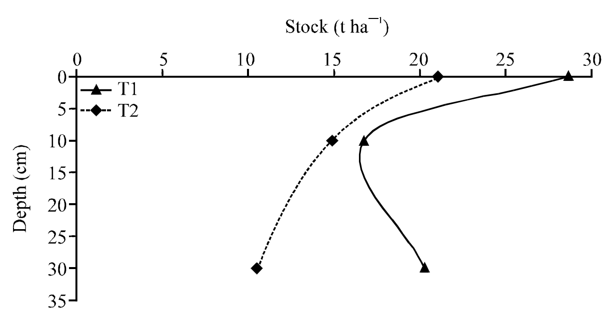

Fig. 2: Evolution of SOC stock after conversion from natural forest to agricultural ecosystems at Tabarka site (T)

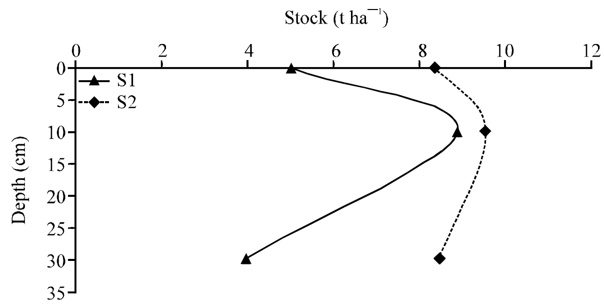

Fig. 3: Evolution of SOC stock after conversion from agricultural ecosystems to forest at Siliana site (S)

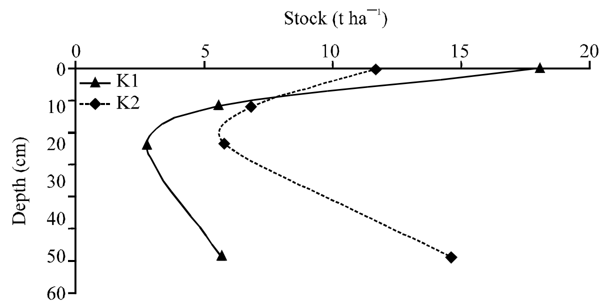

Fig. 4: Soil organic carbon stock distribution after 7 years under no-tillage (K1) and conventional tillage (K2) treatments

SOC Stock after Conversion from Agricultural Ecosystems to Forest

From Siliana site we study the effect of conversion from agricultural systems to forest of *Pinus halepensus*, the conversion has been introduced since 1985. Compared with agricultural system soil (S1: 17.85 t C ha^{-1}) at 0-30 cm depth SOC stock increases under forest soil (S2: 26.38 t C ha^{-1}) (Fig. 3). The conversion resulted an increase of SOC stock with 0.42 t C ha/year. In this site an increase of 32% of stock after 20 years was detected. SOC stocks found in the present study as those found by Arrouays and Pelissier (1994).

SOC Stock under Conventional Tillage and No-tillage Practices

At conventional tillage (CT) treatment, soil was tilled with a disk. No tillage treatment (NT), with successive cover crops (generally cereals/maize). Crop residues are modest on the soil surface, additionally to the cover crops. We compare in this study in two sites, effect of two tillage treatments: conventional tillage (CT) site K2 and no tillage (NT) K1 on adjacent plots. By comparing the distribution of rates of soil OC in both K1 and K2 practices, we see very clearly that the level of OC at the K1 plot is higher than in K2 plot at 0-10 cm and for 10-20 cm portions. However, from 20 cm depth and up to 50 cm, the rate of soil C in the plot under K2 is higher than the plot with K1 (Fig. 4). Generally, when the two tillage treatments were compared at the end of the 7 years period, the amount of SOC in the 0-10 and 10-20 cm intervals was greater in NT than in CT. Accordingly, in the portion 0-10 cm, the plot K1 stores 18.06 t C ha^{-1}, although the plot K2 stores 11.70 t C ha^{-1}. After 7 years we calculated an increase in SOC stock at K1 plot with 6.46 t C ha^{-1} compared to K2 plot, so a rise of almost 35% from conventional tillage to no-till were an average of 0.90 t C ha/year. An increase of

Table 2: Soil physicochemical properties at Cherfech site

	Superficial layer (cm)				
Physicochemical properties	0-20	20-40	40-80	80-120	120-150
*Clay (0-2 μm)	37.400	37.400	32.400	26.600	33.400
*Silt (2-20 μm)	33.800	34.800	34.600	30.700	31.600
*Fine sand (20-50 μm)	19.800	19.000	24.100	26.900	21.800
*Coarse sand (50-200 μm)	8.500	8.000	8.000	14.900	12.700
*$CaCO_3$ Total	46.000	45.000	45.000	45.000	44.000
*$CaCO_3$ actif	17.000	17.300	15.800	11.300	13.000
*Gypse $CaSO_4.2H_2O$	0.000	0.400	0.500	0.700	0.400
D_b (g cm^{-3})	1.350	1.500	1.600	1.450	1.550
CE (dS m^{-1})	1.100	1.700	4.800	9.300	9.800
†HCO_3^-	0.226	0.218	0.129	0.085	0.102
†Cl^-	0.226	0.389	1.383	2.995	3.344
†SO_4^-	0.278	0.448	1.674	2.435	3.273
†Ca^{++}	0.225	0.313	0.980	1.570	2.122
†Mg^{++}	0.064	0.094	0.420	0.980	1.395
†K^+	0.029	0.024	0.022	0.025	0.039
†Na^+	0.365	0.607	1.758	3.085	4.154
SAR	3.800	5.500	8.900	12.200	12.400

*Results in %, †Results in me/100 g of soil

OC in the topsoil (0-10 cm) appropriate to this conservative farming technique has frequently been observed elsewhere, Franzluebbers *et al.* (1994), observed a significant increase in soil organic carbon under no-tillage compared with conventional tillage, only in the surface soil layers. Generally, Organic C was higher in NT than in CT. Hunt *et al.* (1996) and conventional tillage resulted in a significant reduction in organic matter in surface layer of soils (Ding *et al.*, 2002).

SOC Stocks of Saline Soil

Soil salinity refers to a situation in which the presence of salts renders the soil sterile, whereas sodicity or alkalinity is caused by the specific effect of sodium ions adsorbed on clay particles. This leads to deflocculation of soil colloids and reduction of soil porosity (Gallali, 1980). Soil salinity results from natural and artificial causes; (1) the natural causes could be due to the influence of climate, morphology and geology, (2) whereas anthropogenic causes include saltwater intrusion, application of fertilizers and soil amendments and irrigation.

Soil Properties

Soil properties of the sample from Cherfech site are shown in Table 2. Soil has a fine texture; clayey-loamy. Soil bulk density (D_b) values under the superficial layer (20 cm) were high and did not show a clear pattern with depth. The $CaCO_3$ (total and active) was highest at the surface and showed a very little decrease at the deeper horizons. Gypsum ($CaSO_4.2H_2O$) concentrations at the superficial layer (0-20 cm) are 0%, but at deep horizons when upper limit >20 cm are comprised between 0.4 and 0.7%.

One other important measure of irrigation water quality is the sodium adsorption ratio (SAR), defined at Eq. 1. SAR is an indication of the activity of Na^+ in exchange reactions. High alkalinity of irrigation water it manifested at pH greater than 8.5 indicates the predominance of sodium in the solution and the potential for soil sodicity. The SAR of the Cherfech soil was lowest at the surface and showed a general increase with depth (Fig. 5a).

In the surface layer 0-20 and 20-40 cm electrical conductivity (EC) is significantly low than depth layer and showed a general increase with total profile (Fig. 5b). Generally,

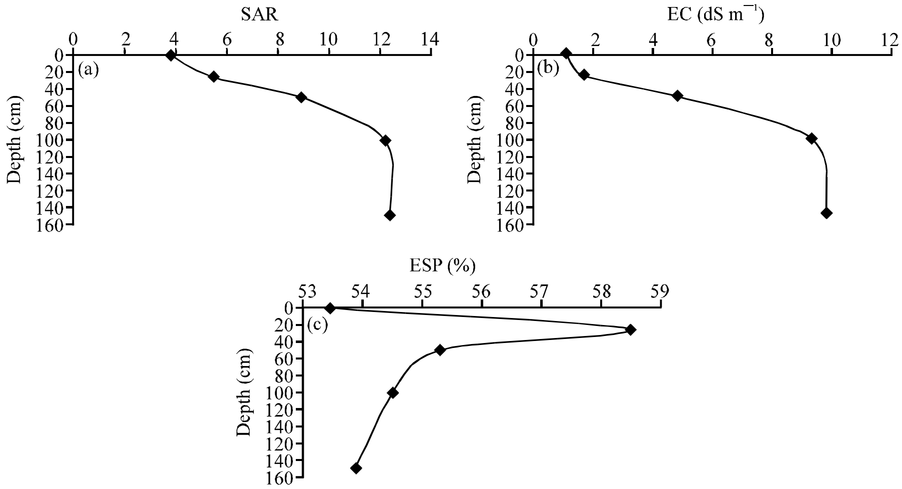

Fig. 5: SAR, EC and ESP of the Cherfech site

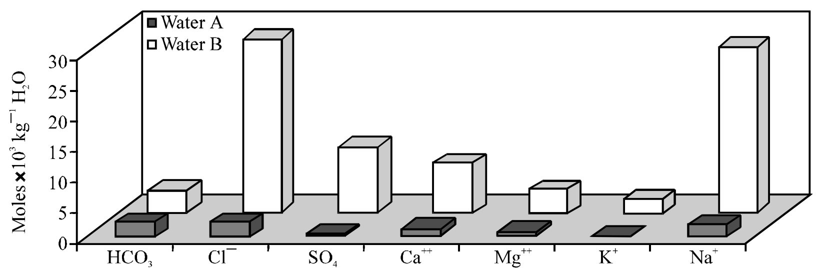

Fig. 6: Characteristics of water A and B used at Cherfech (C) experimental site

irrigation water with EC below 0.7 dS m^{-1} poses virtually no danger to crops, whereas values above 2 dS m^{-1} (Hao and Chang, 2003; Zheng *et al*., 2009) may markedly restrict crop growth.

The exchangeable sodium percentage (ESP) was lowest at 0-20 cm, it increase at 20-40 and showed a general decrease with depth (Fig. 5c).

Salt-affected soils classified as saline, sodic, or saline-sodic (Vlek *et al*., 2008). Saline when EC > 4 and ESP <15; sodic when EC < 4 and ESP > 15 and saline-sodic when EC > 4 and ESP > 15. Soil from Cherfech (C) is grouped in two types with depth; (1) from 0-40 cm the EC < 4 and ESP > 15% therefore soil is sodic; (2) from deep horizons when upper limit > 40 cm, EC > 4 et ESP > 15% thus soil is saline-sodic (Fig. 5c).

Water Characteristics

The quality of water applied during irrigation affects soil salinity and sodicity, acidity, nutrient availability, soil structure and crop yields. The salinity of irrigation water is the sum total of inorganic ions and molecules, the major components being Ca^{2+}, Mg^{2+}, Na^+, Cl^-, SO_4^{2-} and HCO_3^-. From Cherfech site, C1 is the field plot irrigated with freshwater (water A) and C2 is the field plot irrigated with saline water (water B). At Fig. 6 we reported the quality of water A and B used at experimental plots C1 and C2, respectively.

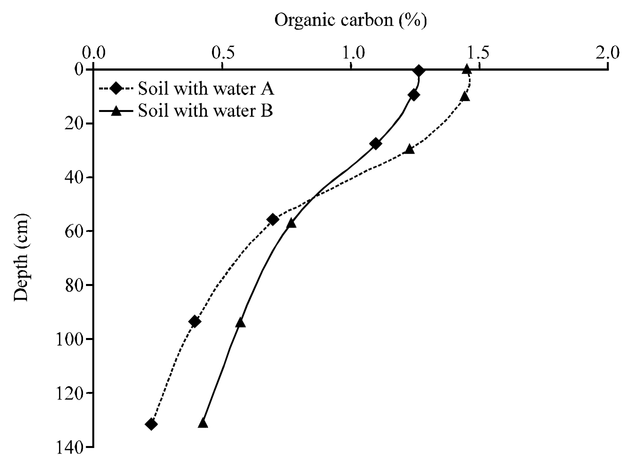

Fig. 7: Impact of irrigation with water from organic carbon content at C1 and C2

Table 3: Soil organic carbon stock under treatment with freshwater A (C1) and saline water B (C2)

	Organic carbon stocks (t ha^{-1})		
Thickness (cm)	Soil C1	Soil C2	Stock (soil C2-soil C1)
0-20	33.1	37.7	+4.6
20-40	33.2	34.4	+1.2
40-80	41.4	38.2	-3.2
80-120	26.3	22.0	-4.3
120-150	14.5	7.3	-7.2
Total	148.5	139.6	-8.9

Soil Organic Carbon

The results show that the organic carbon has different repartitions with depth under C1 and C2. This difference is caused by the irrigation water. Globally, organic carbon under two treatments have an identical allure and show a general decrease with depth (Fig. 7). At 0-50 cm the C2 field plot irrigated with saline water (B) has an organic carbon content higher than C1 irrigated with freshwater. However, after this depth (>50 cm) the organic carbon at C2 plot was lower than C1. Because soil organic carbon content is a function of the decomposition of soil organic matter and root respiration, low rates of respiration and degradation were found in the C2 soil.

Generally, results indicated an increase of organic carbon and nitrogen at surface layer from soil C2 irrigated with saline water (water B). But at the interior layer soil C1, irrigated with freshwater (water A), we find a bigger carbon content than those in C2 irrigated with water B.

Stocks

Irrigation with saline water stock higher than irrigation with freshwater only at superficial layer (20 to 40 cm). Although, under this depth, irrigation with freshwater stock higher than saline water. After twenty five years experiments, the organic matter balance carried out on 1.5 m soil depths is established as follows, organic carbon: 148.5 t ha^{-1} in the freshwaters irrigated soils against 139.6 t ha^{-1} in saline water irrigated soil (Table 3).

CONCLUSIONS

In Tunisia, globally and in the long run, SOC level is dependent on vegetation, which is largely controlled by climate. Soil carbon sequestration is a process under the control of human management. Generally, land-use change was found to have a larger net effect on SOC storage. Result of experiments showed that converting forest to agricultural systems caused significant loss of SOC stock (site T), whereas restoring forestry have an increase of SOC stock (site S). Soil carbon sinks increase most rapidly under practice of no-tillage compared with conventional tillage (site K). Experiments from site K, S and T showed that from superficial layer or total profile forest and no-tillage have an increase in SOC stocks. From site C, irrigation with saline water stock higher than irrigation with freshwater only at superficial layer. Although, under this depth, irrigation with freshwater and at total profile stock higher than saline water.

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