Comparison of organic carbon stock of Regosols under two different climates and land use in Tunisia

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Abstract
Drylands are affected by desertification and by a serious process of degradation. Studying the properties of their soils and their carbon sequestration characteristics is a key step as a major contribution for their conservation to cope with global warming issue. Considering the geographical position of Tunisia, most of its territory is in dryland zone with a deficit water balance, and half of its area is only occupied by Lithosols and Regosols. The laters and despite their existence in dry climates are either pastureland or agricultural land, they play a considerable role for the peasants, however, their organic carbon stocks remain little studied and not well known.
The present work focuses on the state of the carbon stock in the Regosols of Tunisia. Two study sites were studied; the first a Regosol in Gafsa under arid climate, the second, another Regosol in Kairouan under semi-arid climate. In these two sites, we also have two different modes of land use. In fact, in each site we have a plot in an olive grove adjacent to another in a pastoral mode.
Results showed that soils particle size, pH, bulk density were very close. The difference was observed in the content of organic carbon and therefore in organic carbon stock. In olive groves, the organic carbon stocks of the soil, in one meter deep, were 8.22 (±0.72) Kg C m^{-2} in Gafsa and 12 (±0.46) Kg C m^{-2} in Kairouan. This increase mainly concerned the surface layers (0-20 cm) and the deepest layers (80-100 cm). By comparing the carbon stocks of soils under olive groves with those under pasture, the gain in 15 years varied between 1.48 and 2.46 Kg C m^{-2}.

These results prove the low organic matter content of Regosols from North Africa, but on the other hand, their great capacity to sequester organic carbon. These same soils, if organically amended, could be fertile and productive soils, but also, could act as a carbon sink to cope with global warming.

Keywords: Dryland, Regosol, Soil organic carbon, Land-use change, Carbon pools, Tunisia.

1. Introduction

The fertility and sustainability of many soil systems on our planet is under treat from a diverse range of stresses put upon them, from actors like global environmental change and pollution, loss of organic matter, erosion, salinization, reduction of available water quantity and quality. Only few places in the world experience more of these simultaneous stresses upon their natural soil ecosystems environment like semi-arid and arid regions. The Aridity Index (AI) is a numerical indicator of aridity based on climatic water deficits and is calculated as the ratio of annual precipitation and potential evapotranspiration totals (P/PET). Referring to the United Nations Environmental Programme (UNEP), this index defines drylands as being areas with AI between 0.05 and 0.65 (UNEP, 1992). These regions cover 41% of total global land area and host 37% of world population (Bernoux et Chevallier, 2013). These soils in semi-arid and arid region are characterized by low organic matter contents, yet, because of their large extend they represent a significant potential to global organic carbon store.

Based on the AI and on the soil map of Tunisia, two major soils are distinguished and characterize the country. The most of these soils are classified as "little developed soils" or commonly known as Aridisols, their distribution in the country is as follows "Lithosols" 25.64% and "Regosols" 24.51% (Brahim et al. 2014). For Lithosols, they occupy the desert areas of the South of the country, and for Regosols they are in the mountainous areas around the desert and in the center of the country. According to WRB (2015) classification, Regosols are very weakly developed mineral soils in unconsolidated materials. They are extensive in eroding lands and accumulation zones, particularly in arid and semiarid areas and in mountainous terrain.

These soils arose in extreme climatic conditions, characterized by a high temperature in summer, a disturbance in the low winter precipitation, and very high risk of erosion. These soils are known for their low organic matter content (Gallali 2004 ; Zhu et al. 2012 ; Hua et al. 2015). Several studies have been devoted to Regosols in China (Wang et al. 2012 ; Hua et al. 2015 ; Ji et al. 2019; Gu et al. 2020) also in Brazil (Do Sacramento et al. 2018; Melo et al. 2019), in Indonesia (Gusnidar et al. 2019) and in Japan (Lukito et al. 1998). However, studies of these soils in the Mediterranean basin are very rare or even non-existent. Studies of Regosols are relatively rare. Internationally, the cultivated Regosols of Zhifanggou watershed at China studied by Li et al. (2020) showed that their abundance over long periods considerably increased the stock of organic carbon. For Mediterranean countries, the Spanish Regosols are the most studied (Fernández-Romero et al. 2014, 2016; Parras-Alcántara 2015, 2016) where authors are interested in the disturbances by human activity of these soils located in the south eastern Spain and Andalusia.

Despite these poverty in fine matter like the clay and especially in organic matter, these soils are sometimes exploited on small agricultural exploitation when irrigation is possible or when crop is adapted to drought. Otherwise, they constitute large areas of grazing lands. Compared to many soils in the northern part of Tunisia, soils in the center and south of the country are often severely limited for agricultural production by the lack of nutrients, the accumulation of salt and poor water retention (Brahim and Ibrahim 2018). In addition, the arid to desert climate could further limit the carbon sequestration potential of these Aridisols. However, the change in land management within existing crop and livestock systems, could maintain or increase the organic carbon in agricultural soils in southern Tunisia. This is possible when trying to limit erosion of vulnerable sandy soils by creating olive grove. According to the Tunisian Ministry of Agriculture (2019), olive cultivation is the main crop in the country, covering more than 30% of its cultivable land. This production structure culture, mostly private, small and family type, represents in most arid and semi-arid regions the main component of successful cropping systems. In the harshest weather conditions and on soils poor in organic matter, the cultivation of olives is an adequate solution to make the best use of Regosols and preserve them against desertification. As these soils are poor in organic matter, so they have the capacity to better sequester organic carbon, which is a solution for the reduction of atmospheric greenhouse gases, thus reduction of global warming, but also the improvement of agriculture in these areas. Tunisian Regosols are mainly located on mountains slopes. Generally used as a pasture for goats and camels. For more than 20 years, local farmers began to use them as support for olive cultivation. The study was carried out on the same type of soil "Regosol" on two different study sites. The first site in Gafsa in arid climate, the second site in Kairouan, in semi-arid climate. We also studied the two soils under two different occupations, olive grove and grazing land. The objective of this study is to compare the response of Regosol to the storage of organic carbon under two different bioclimates and following the land use change.

2. Materials and Methods

2.1. Study area

Two locations within two different Tunisian governorates, one in El Guettar-Gafsa (34° 19’ 8’’ N and 8° 59’ 53’’ E) located south-west of Tunisia, between the high steppes and the Sahara, and the other in Chebika-Kairouan (35° 38’ 22’’ N and 9° 55’ 09’’ E) located in the central region of the country, it enjoys a privileged geographical position between the rainy north and the arid south of the country (Figure 1). The two sites have an elevation of approximately 250 m and 150 m respectively for Gafsa and Kairouan, and a distance as the Crow Flies of about 170 km apart. These two locations were chosen because of their common calcareous soil parent materials, their location in watersheds in mountains, their common occupations by vegetation, and their common class of Regosols, but in two different climates. We expected to affect soil organic carbon differently respond to management activities and climate.

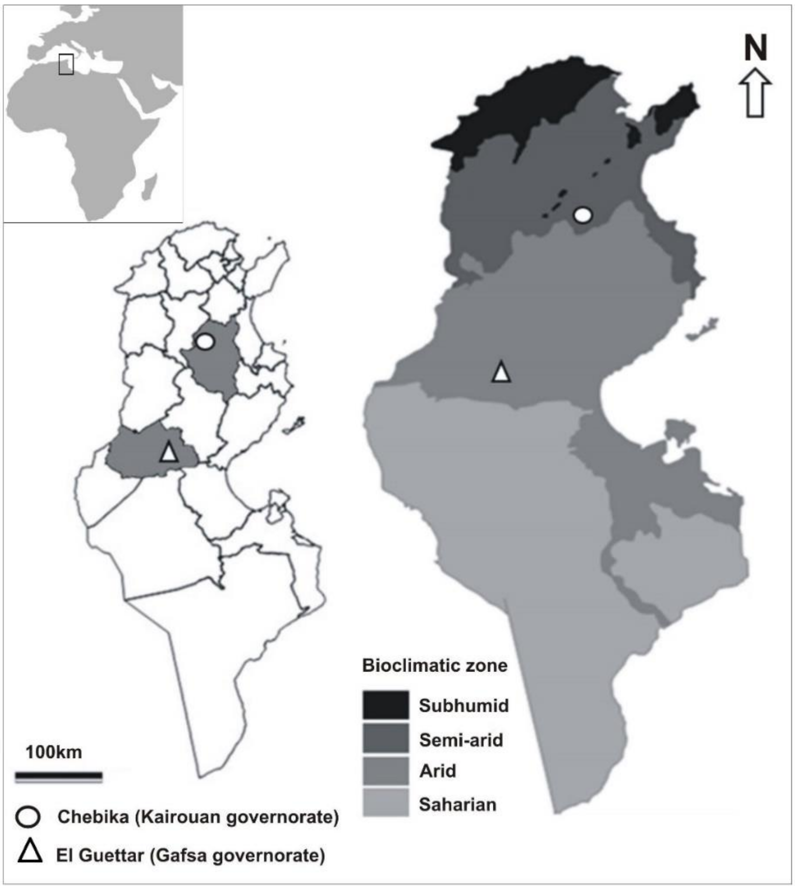


Fig. 1. Location of the two study sites on the bioclimatic map of Tunisia

Regarding the two sites climate, the one of Gafsa is characterized by the following climatic data calculated over more than 30 years in the period (1985-2019); average precipitation (P) 173.3 mm/year, average annual temperature (T) 19.1 °C, minimum temperature “Tm” 3.9 °C, maximum temperature “TM” 37.1 °C, and the potential evapotranspiration totals (PET) 2449.1 mm/year. The aridity index (AI = P/PET) is equal to 0.070 which gives an arid climate.

For the second site of Kairouan, climatic measurements measured for the same period (1985-2019) are the following; P: 355 mm/year, T: 18.1 °C, Tm 5 °C, TM: 37.1 °C, and PET 1878.2 mm/year. AI is equal to 0.189 which gives a lower semi-arid climate.

Based on the Emberger’s climagram that consider on the x- and y-axes, the temperatures of the coldest month “Tm” and the “Emberger pluviometric quotient Q_2” values respectively (Emberger 1955) the Mediterranean area is classified in several sub-bioclimates. it classifies the Mediterranean area in several sub-bioclimates. The Q_2 quotient is calculated as follows ($Q_2 = 2000 \times P/(TM^2 - Tm^2)$) with TM and Tm in Kelvin degree. Therefore, our two study sites were classified as arid bioclimates with temperate winter for Gafsa and semi-arid bioclimates with temperate winter for Kairouan (Figure 2).

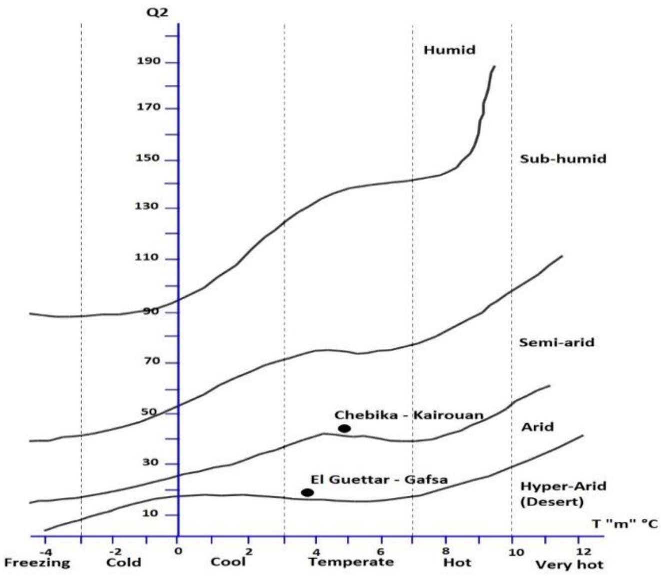


Fig. 2. Study sites climate according to Emberger’s climagram compared to different Mediterranean bioclimatic zones

2.2. Geological setting

According to the geological map of Tunisia, sheet n ° 63 of Kairouan, the geological age of the rock of the soil of the Chebika-Kairouan plot is Pontian and Pliocene, where we find series of sandstone conglomerates, red sands and red clays at Hélix (Castany 1950).

According to the geological map of Tunisia, sheet n ° 67 of El Ayacha, the geological age of the soil rock of the plot of El Guettar-Gafsa is the Mio-Pliocene with red or ocher silts with lenticular intercalations of conglomerates and gypsum, and also from Middle Miocene with Beglia sands (Zouari et al. 1991)

The similarity of the geological ages of the two study sites and their similar reliefs on hills, explain the same type of Regosols obtained, despite the difference in climate which is essentially reflected in the variability of the organic matter content.

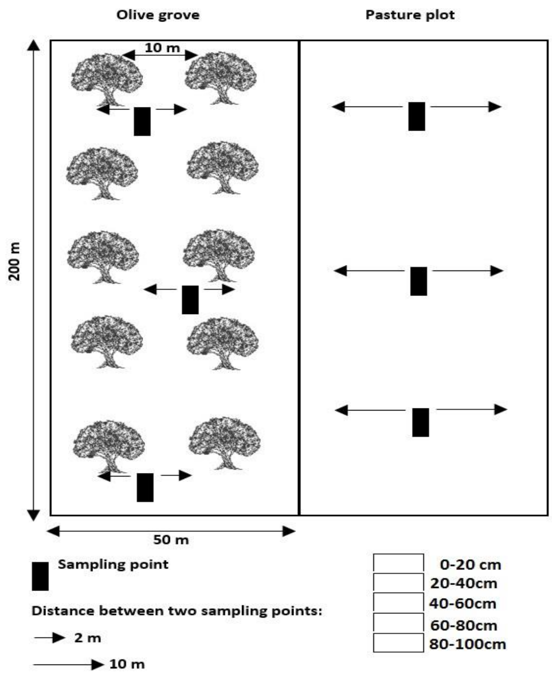


Fig. 3. Sampling scheme at the two study sites

2.3. Soil sampling

At each location, two management regimes were studied; one is a pasture plot, the other is adjacent, a 15-year-old olive grove. Making a total of four plots of one hectare almost the area of each, two occupied by olive trees and two by pasture. Despite the distance between the two sites, the soil class is the same; Regosols. Soil samples were collected in April - May 2018. Within each plot, soil samples (0-20; 20-40, 40-60; 60-80 and 80-100 cm depth) were collected from three points with a soil auger (7 cm diameter), giving three replicate samples per plot at each location. The sampling points of the soils under olive groves were one meter apart from the olive trees. At the level of the olive plot, the other two replication points are 2m apart so that we are close to the olive tree, as for the pasture plot the two replication points are 10m apart (Figure 3).

2.4. Soil analysis

The bulk density (D_b) was determined by the cylindrical core method, then samples are dried in an oven for 24 hours at 105 °C (D_b = dry soil weight/cylinder volume in g cm^{-3}). All soil samples were air-dried and passed through a 2 mm sieve, for removal of roots and rock fragments. The sieved part of the soil (< 2mm) were used for the other physico-chemical analyzes of the soils. SOC content was measured by oxidation method of Walkey and Black by the mixture of $K_2Cr_2O_7$-H_2SO_4 (Nelson 1996). The particle size distribution (i.e. coarse sand, fine sand, coarse silt, fine silt and clay) reflected that of the whole soil (AFNOR 2003). The soil pH was determined in (1:2.5) in water suspension. Carbonates were analyzed according to Sherrod method (Sherrod et al. 2002).

2.5. Soil organic carbon stock

To estimate soil organic carbon stocks (SOC stock) in the 0-100 cm, we summed SOC stocks of the individual layer. The SOC stocks were calculated using the following equations (Brahim et al. 2014; Yigini and Panagos 2016):

$$SOC\ stock = OC\ \times Db\ \times D \qquad (1)$$

where SOC_{stock} (t ha^{-1}) then converted in (kg C m^{-2}), D is the depth or thickness of the considered soil layer (cm), D_b is the bulk density (g cm^{-3}), and OC is the organic carbon content (%).

2.6. Statistical analysis

Data were analyzed using IBM SPSS Statistics Version 20. Analysis of variance was conducted to test the significance of treatments, soil depth, particle size and their interaction regarding SOC stocks.

3. Results and discussion

3.1. Particle size and bulk density

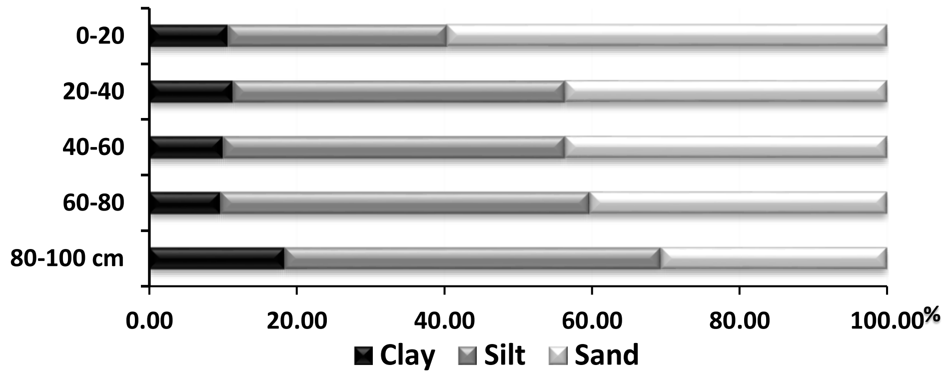
Results of the physical properties of the soils at the five depths 0-20, 20-40, 40-60, 60-80 and 80-100 cm for the two study sites and under the two land uses are reported in Table 1. Particle size analysis reveal significant percentages of sands and silts compared with clays (Table 1 and

Figure 3). The soils have a sandy loam texture on the surface (0-20 cm) and in depth (> 20 cm) a silt loam texture at Gafsa and loam texture at Kairouan site. The exception is in the soil of the plot of the olive grove in Kairouan where the texture is loam over the entire profile. In the both soils type the pedogenesis is the same, the geographical distribution does not have much significance if the topography is similar even if the climatic variable changes. Indeed, the results clearly show that the mineralogical constituents or the mineral fraction of a soil remain almost invariable. The only variation is the abundance of annual organic restitution that returns to the soil and is related to the vegetation cover which is in turn related to the climate. All these results of particle size analysis for the two Regosols corroborate with what it is found in other investigations such as in the Regosols of China (Hua et al. 2015; Ji et al. 2019) under arid and semi-arid climate.

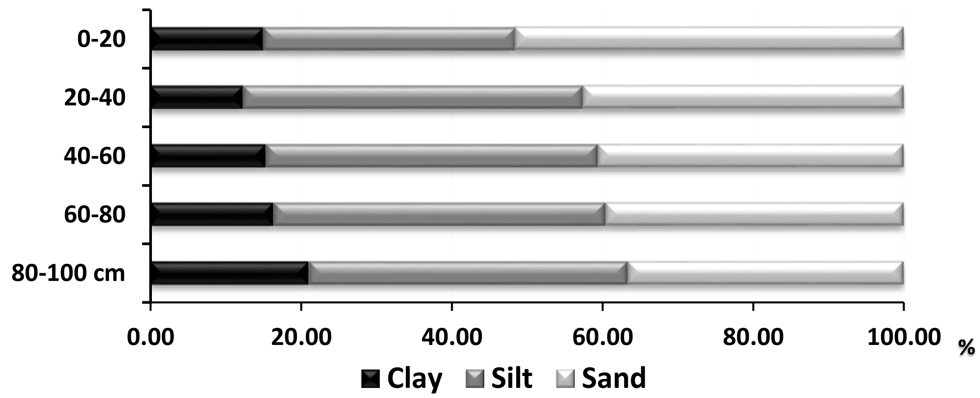
Table 1. Physical properties of the study area.

Location	Land use	Depth (cm)	D_b (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	Textural class (IUSS 2015)
Gafsa	Olive grove	0-20	1.54 ± 0.023	59.67 ± 0.33	29.67 ± 0.33	10.67 ± 0.33	Sandy loam
		20-40	1.58 ± 0.023	43.67 ± 0.33	45.00 ± 0.58	11.33 ± 0.33	Loam
		40-60	1.61 ± 0.018	43.67 ± 0.33	46.33 ± 0.33	10.00 ± 0.00	Loam
		60-80	1.66 ± 0.023	40.33 ± 0.33	50.00 ± 0.58	9.67 ± 0.33	Silt loam
		80-100	1.72 ± 0.012	30.67 ± 0.67	51.00 ± 0.58	18.33 ± 0.33	Silt loam
	Pasture	0-20	1.53 ± 0.010	55.00 ± 1.15	33.67 ± 0.67	11.33 ± 1.33	Sandy loam
		20-40	1.59 ± 0.047	42.67 ± 0.33	46.67 ± 0.33	10.67 ± 0.33	Loam
		40-60	1.65 ± 0.017	43.33 ± 0.33	47.00 ± 0.58	10.33 ± 0.33	Loam
		60-80	1.70 ± 0.026	37.67 ± 0.88	51.33 ± 0.88	11.00 ± 0.00	Silt loam
		80-100	1.72 ± 0.020	30.00 ± 0.58	52.00 ± 0.58	18.00 ± 0.00	Silt loam
Kairouan	Olive grove	0-20	1.47 ± 0.024	51.67 ± 0.88	33.33 ± 0.33	15.00 ± 1.15	Loam
		20-40	1.48 ± 0.012	42.67 ± 0.88	45.00 ± 0.58	12.33 ± 1.45	Loam
		40-60	1.58 ± 0.020	40.67 ± 0.33	44.00 ± 1.15	15.33 ± 0.88	Loam
		60-80	1.63 ± 0.018	39.67 ± 0.88	44.00 ± 0.58	16.33 ± 0.88	Loam
		80-100	1.68 ± 0.020	36.67 ± 1.76	42.33 ± 1.45	21.00 ± 0.58	Loam
	Pasture	0-20	1.48 ± 0.015	54.67 ± 0.88	35.00 ± 0.58	10.33 ± 1.45	Sandy loam
		20-40	1.49 ± 0.015	45.67 ± 0.67	43.67 ± 1.86	10.33 ± 0.88	Loam
		40-60	1.61 ± 0.032	39.67 ± 0.88	45.67 ± 0.33	14.67 ± 0.88	Loam
		60-80	1.66 ± 0.009	39.00 ± 0.58	46.33 ± 1.86	14.67 ± 1.45	Loam
		80-100	1.70 ± 0.015	35.33 ± 1.20	44.00 ± 0.58	20.67 ± 0.67	Loam

Soil bulk density (D_b) ranged from 1.47 g cm^{-3} to 1.72 g cm^{-3}. In both site, soil D_b showed regular trend whatever land use types; an increasing trend with depth (olive grove and pastureland). The least D_b value (1.47 g cm^{-3}) was recorded at 0-20 cm depth of Kairouan olive grove, while the highest value of 1.72 g cm^{-3} was obtained in Gafsa at 80-100 cm depth whatever the nature of vegetation. But generally, by comparing the average of the D_b of the two sites, we notice a slight decrease throughout the profile of the Kairouan D_b's in comparison with the Gafsa D_b's (Figure 4). Soil bulk is the main physical indicator reflecting soil structure, fluid permeability, organic matter abundance, and water retention capacity. With the increase in soil depth, soil D_b of each land use mode showed an increasing trend. That is, the average soil bulk density of the four plots, all climates and land of use combined, in the 0-20, 20-40, 40-60, 60-80, and 80-100 cm soil layers was 1.50 (±0.01), 1.53 (±0.02), 1.61 (±0.02), 1.66 (±0.02) and 1.70 (±0.01) g cm^{-3}, respectively.



(a)



(b)

Fig. 3. Particle size (%) of the two soils: (a) Gafsa soil and (b) Kairouan soil.

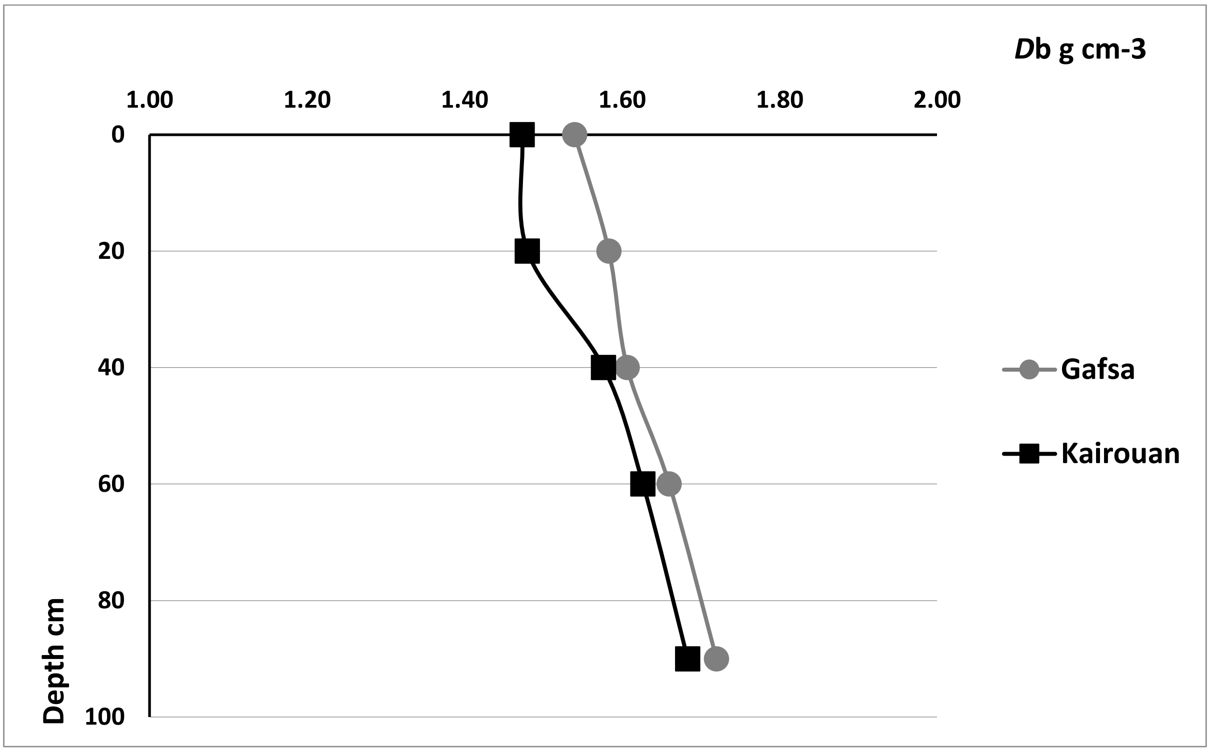


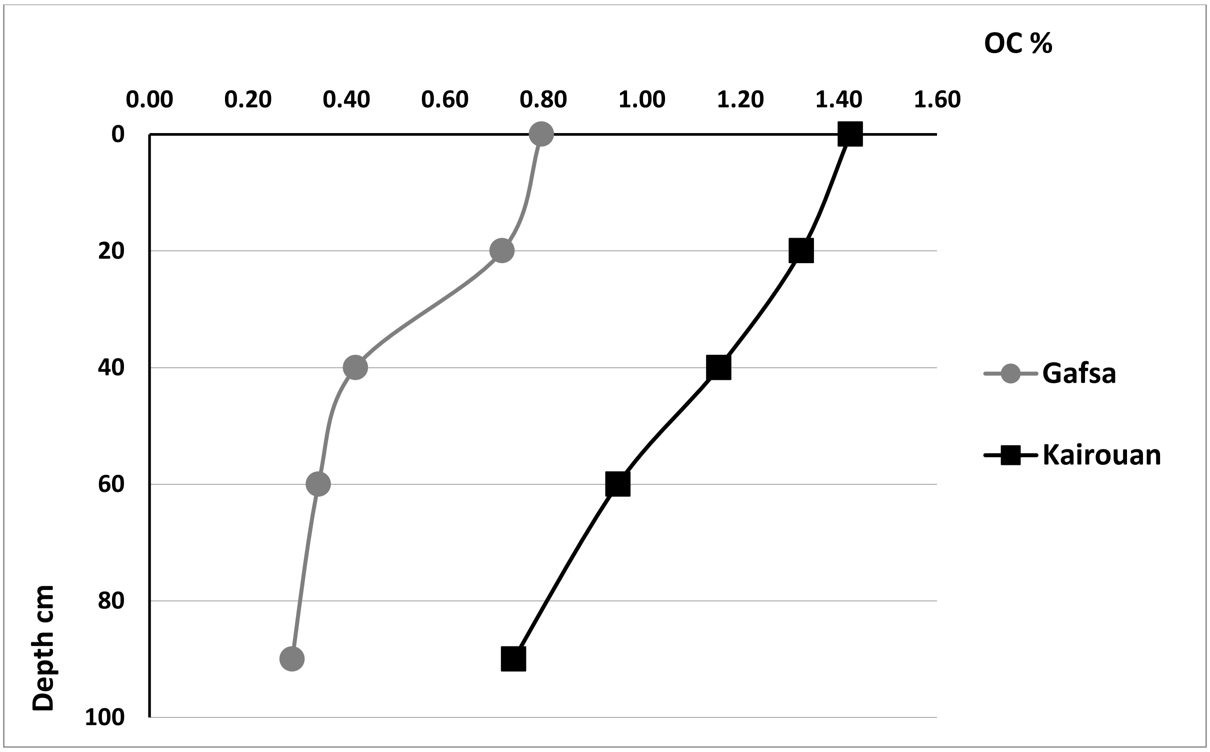
Fig. 4. Variation in the D_b of the two soils throughout the profile under olive grove.

3.2. Organic carbon content and pH values

The organic carbon (OC) concentrations in soil layers ranged between 1.17 (±0.02) % and 0.48 (±0.01) % in the surface layer and between 0.30 (±0.01) % and 0.19 (±0.02) % at a depth of one meter. Organic carbon concentration decreased in all soil plots with increasing soil depth. The OC content also shows a clear difference between the plots under olive groves and those under pasture. In fact, at the Gafsa site, the average content of the 0-20 cm surface layer between the olive grove and pasture mode was 0.80 (±0.10) % and 0.48 (±0.01) %, respectively. This notable increase is explained by the manure supply by the farmers. This observation is also observed in the Kairouan site with averages: 1.17 (±0.02) % and 1.07 (±0.05) %, respectively. These same observations remain true throughout the profile at the two sites.

By comparing the contents according to the mode of use in the two sites, the site of Kairouan showed a clear difference compared to that of Gafsa with averages: 1.17 to 0.8% in the 0-20 cm layer. Figure 5 shows the difference in organic carbon levels throughout the profile in the two olive grove plots.

Average OC concentration in Regosol surface layer was twice as high in Gafsa olive grove soil compared to pasture soil. This shows the capacity of these soils to sequester organic carbon if there are possible organic amendments. However, in the deep layers (60-80 and 80-100cm), a slight difference is observed whatever the area studied, or the use of the soil compared to the surface layers.



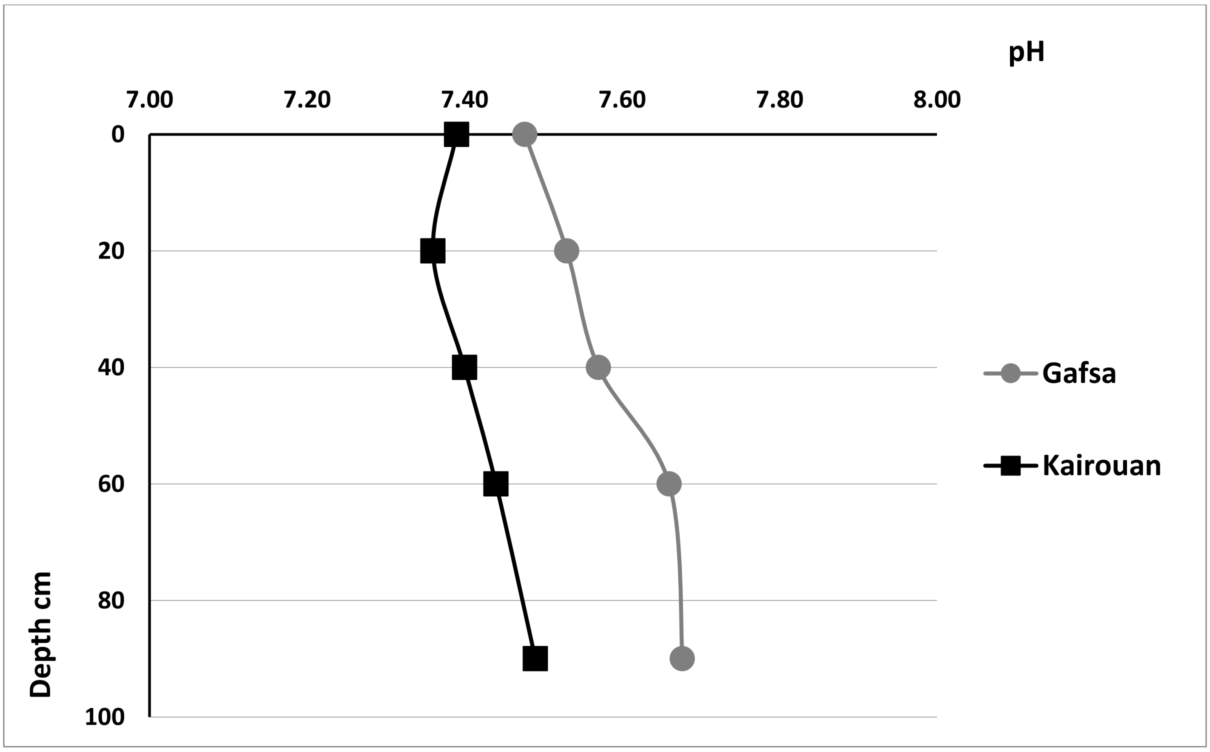


Fig. 5. Organic carbon content % and pH for Gafsa soil and Kairouan soil under olive grove.

Apart from the small difference in OC content, both soils have very similar values. The organic matter content of Kairouan soil under semi-arid climate showed a slight increase throughout the profile to a depth of one meter, it is explained by the abundance of plant cover under the olive trees in spring, but this improvement also is under the effect of the temperature a little lower compared to that which reigns in the severe climate of the Gafsa.

This interpretation requires further investigations and study of the residence of organic carbon in these soils (Balesdent and Recous 1997) to know, whether there is an annual renewal, or it is a carbon sequestered years past.

The pH of the four plots are very close. They all show the same evolution, a slight increase depending on the depth of the soil. The pH of our Regosols are neutral to slightly basic.

In Gafsa, in an arid climate, the pH values rise between 7.45 (±0.02) and 7.48 (±0.02) in the first 20 cm of the surface layer and between 7.69 (±0.02) and 7.68 (±0.01) at a depth of one meter, for the grazing soils and the soil of the olive grove, respectively.

In Kairouan, in a semi-arid climate, the pH values of the 0-20 cm surface layer are between 7.49 (±0.02) and 7.69 (±0.02), and in depth of one meter between 7.39 (±0.06) and 7.45 (±0.02) for the grazing soils and the soil of the olive grove, respectively.

Overall, in a semi-arid climate, the pH values of our Regosols are slightly lower than that of the pH of soils in an arid climate. Figure 5 illustrates the example of the pH difference in our Regosols under olive groves in the two study sites.

3.3. Organic carbon stocks

Table 2 shows the dynamic changes of SOC storage in 0-100 cm soil layers in different plots, with different climate and land use. Globally, the studied Regosols, SOC storage decreased with the increase of soil thickness. After 15 years of olive growing, the organic carbon storage increased slightly. Indeed, the SOC storage under different olive grove was higher than that under pasture.

In the four plots, the highest stocks are those of the surface layers.

In the 0-20 cm soil layer, the organic carbon stocks difference with other layers was significant in all plots. The experimental data showed that under olive grove mode, the average organic carbon storage in the 0-20 cm soil layer was significantly different from pasture mode.

At the first site of Gafsa, the conversion of pasture into an olive grove changes the carbon stock in 0-20 cm, it changes from 1.48 (±0.03) to 2.46 (±0.33) Kg C m^{-2}; and in 20-40 cm, it changes from 1.44 (±0.07) to 2.27 (±0.04) Kg C m^{-2}, respectively. In the second site, at Kairouan, stock goes from 3.16 (±0.18) to 3.46 (±0.09) Kg C m^{-2}, respectively (Table 2).

At the first site of Gafsa, the conversion of pasture into an olive grove changes the carbon stock in 80-100 cm, it changes from 0.65 (±0.05) to 1.00 (±0.20) Kg C m^{-2}; respectively. In the second site, at Kairouan, stock ranged from 0.89 (±0.09) to 1.01 (±0.06) Kg C m^{-2}, respectively.

These results clearly showed the increase in carbon stock in each layer after changing land use, ranging from pasture to olive grove. These agriculture practices changes increased the carbon stock mainly in the first and last layers. (i) The 0-20 cm surface layer of Gafsa soil recorded an increase of 66.21%, while at the deepest layer 80-100 cm it increased 53.84%. (ii) The 0-20 cm surface layer of Kairouan soil recorded an increase in its stock of 9.49%, and in the deepest layer 80-100 cm an increase of 13.48%.

The change in stocks is not very significant in comparison with Gafsa soil site. This is mainly due to the addition of organic amendments made by farmers, mainly in the form of manure in arid areas, a tradition stemming from the work of oasis desert soils. However, this practice is not well implemented among farmers in areas in semi-arid and sub-humid bioclimates.

The study of the average organic carbon stock in the total profile (0-100 cm) in the 4 plots, showed that the highest stock is that of the Kairouan soil under olive grove with 12.00 (±0.46) Kg C m^{-2}. While the lowest stock is the Gafsa soil under pasture with 5.76 (±0.35) Kg C m^{-2} (Table 2).

Table 2. Distribution of organic carbon stock in the 4 plots

Depth (cm)	OC (%)	D_b (g cm^{-3})	Stock (Kg C m^{-2})	OC (%)	D_b (g cm^{-3})	Stock (Kg C m^{-2})
Gafsa		*Olive grove*			*Pasture*	
0-20	0.80 ± 0.10	1.54 ± 0.02	2.46 ± 0.33	0.48 ± 0.01	1.53 ± 0.01	1.48 ± 0.03
20-40	0.72 ± 0.02	1.58 ± 0.02	2.27 ± 0.04	0.45 ± 0.03	1.59 ± 0.05	1.44 ± 0.07
40-60	0.42 ± 0.03	1.61 ± 0.02	1.35 ± 0.10	0.35 ± 0.01	1.65 ± 0.02	1.14 ± 0.03
60-80	0.34 ± 0.01	1.66 ± 0.02	1.14 ± 0.05	0.31 ± 0.04	1.70 ± 0.03	1.05 ± 0.17
80-100	0.29 ± 0.06	1.72 ± 0.01	1.00 ± 0.20	0.19 ± 0.02	1.72 ± 0.02	0.65 ± 0.05
			8.22 ± 0.72			*5.76 ± 0.35*
Kairouan		*Olive grove*			*Pasture*	
0-20	1.17 ± 0.02	1.47 ± 0.02	3.46 ± 0.09	1.07 ± 0.05	1.48 ± 0.01	3.16 ± 0.18
20-40	1.14 ± 0.01	1.48 ± 0.01	3.38 ± 0.05	1.08 ± 0.05	1.49 ± 0.02	3.21 ± 0.17
40-60	0.90 ± 0.03	1.58 ± 0.02	2.83 ± 0.12	0.71 ± 0.03	1.61 ± 0.03	2.30 ± 0.11
60-80	0.40 ± 0.04	1.63 ± 0.02	1.32 ± 0.14	0.29 ± 0.03	1.66 ± 0.01	0.96 ± 0.10
80-100	0.30 ± 0.02	1.68 ± 0.02	1.01 ± 0.06	0.26 ± 0.03	1.70 ± 0.01	0.89 ± 0.09
			12.00 ± 0.46			*10.52 ± 0.65*

At the beginning, the two plots of Gafsa and those of Kairouan were at the origin steppe pastureland. Fifteen years ago, half of each was converted into an olive grove. We can draw the following observations: (i) at Gafsa, the total soil organic carbon stock in the profile (1m deep) increased from 5.76 to 8.22 Kg C m^{-2}, an increase of 2.46 Kg C m^{-2}. This gain, established after 15 years of the transition to the new use of the land, gives an increase of 0.164 Kg C m^{-2} $year^{-1}$; (ii) in Kairouan, the same experiment was repeated, an increase in the stock of 1.48 Kg C m^{-2} in 15 years, going from 10.52 to 12 Kg C m^{-2}, i.e. an increase of 0.098 Kg C m^{-2} $year^{-1}$ (Table 2).

Soil carbon sequestration is mainly achieved by reducing the soil carbon pool decomposition and increasing soil carbon pool input. The soil under olive grove is better protected against wind erosion by installing barriers and seats, generally made of Cactus, but also by an external supply of manure by farmers, maintain the soil organic carbon storage, which is consistent with the results of Mlih et al. (2019) in Tunisian oasis ecosystems, similar to what we find on these olive grow Regosols.

The results of this study showed that on a regional scale, and despite the severe climatic conditions and the scarcity of plant cover, Regosols could have a good stock of organic carbon. Brahim and Ibrahim (2018) have shown that several conditions such as drainage, slope position, texture and organic matter abundance influence soil OC stocks. For Gafsa soil organic carbon stock under olive grow, the stock values at a depth of one meter (8.22 Kg C m^{-2}) are very close to that found in the Regosols of Tunisia by Brahim et al. (2014) and which are of the order of 8.39 Kg C m^{-2}. Results for Gafsa pasture's carbon stocks (5.76 Kg C m^{-2}) coincide perfectly in comparison with the other Regosols carbon stock of the world which are 5 Kg C m^{-2} according to Batjes (1996). However, for Kairouan soil organic carbon stocks over a depth of one meter, they are quite high in comparison with the other Regosols in the world. However, their stocks are comparable to the fertile soils of Tunisia such as Cambisols (10.18 Kg C m^{-2}) or Vertisols (10.97 Kg C m^{-2}) (Brahim et al. 2014). Overall, the range of SOC content assessed in this study complies perfectly with other reported studies in the literature, particularly for southern Tunisia region (Brahim et al. 2014; Kouki and Bouhaouach 2009).

Differences of OC stocks among the Regosols of Gafsa and Kairouan, were significant because of the high variability of organic carbon content of individual soil layers and plots themselves. Differences of OC stocks in our study can partly be explained by soil texture which is a result of different parent materials on which the soils developed. Our Regosols occurred at sites that were characterized by loess deposits leading to silty loam as dominant texture, and which added to weathering products of limestone.

The present results on Regosols corroborate with those of Sanderman et al. (2010) on Tenosols from Australia which showed that it is possible to preserve or increase organic carbon stocks in the soils of arid climate zones. and semi-arid in Australia. The integration of the cultivation of olive trees, perennial trees, in a pastural environment in semi-arid and arid zones has sequestered 1.48 Kg C m^{-2} and 2.46 Kg C m^{-2}, respectively, over a period of 15 years. Without counting the carbon stock in the plant biomass, seems very motivating. Given the loss of carbon from land degradation by wind and water erosion of sandy soils in these drylands farming systems, incorporating this perennial species into these farming systems could restore lost carbon and provide benefits additional environmental and socio-economic. There is very little data in the literature in these areas of the southern shore of the Mediterranean on the carbon stock. The results of the carbon stock obtained for olive groves in Spain (Fernandez-Romero et al. 2014; Fernandez-Romero et al. 2016; Parras-Alcántara et al. 2016), do not reflect the nature of soils in climates " lower semi-arid "and arid. During the sampling, the soils taken from the two olive groves were close to one meter from an olive tree, we noted an improvement in the carbon stock in the 80-100cm layer. These results support the hypothesis that the larger root systems of perennials can help increase SOC deeper in the soil profile (Fernandez-Romero et al. 2016; Parras-Alcántara et al. 2016). But these results could also be due to the leaching and cheluviation of organic matter from the surface layers of our porous Regosols.

The organic carbon stocks in the soils of the two olive groves at Gafsa and Kairouan and for the first layer 0-20 cm showed very significant correlations ($P < 0.01$) with the clay content, the organic carbon content and the apparent density. However, the correlation of these parameters between them is not always identical, in the two study sites. Indeed, under Gafsa olive grove, we have a positive correlation between pH and Sand, which is the same case in Kairouan olive grove, but correlated elements in a soil can be observed and show no correlation or else a negative correlation in the other (Table 3).

This correlation clearly showed that the carbon stock in Regosols in both arid and semi-arid climates is only linked to organic intake and the presence of clay, these are the two key elements of carbon sequestration in these areas. However, if the contribution of organic matter seems feasible for increasing the carbon stock, the low clay contents in these Regosols constitute a real handicap to the good improvement of the sequestration. This problem is reminiscent of that encountered in Tunisian oasis Lithosols of the Leptosols and Arenosols type (Brahim and Ibrahim 2018; Mlih et al. 2016; Mlih et al. 2019).

Table 3. Pearson correlation matrix of total SOC stocks and different parameters of soils under olive grove (0-20cm).

	Sand	Silt	Clay	OC	pH	D_b
Gafsa olive grove						
Sand	-					
Silt	-0.500	-				
Clay	-0.500	-0.500	-			
OC	0.245	-0.962	**0.717**	-		
pH	**0.904**	-0.822	-0.082	**0.636**	-	
D_b	0.000	-0.866	**0.866**	**0.970**	0.427	-
SOC_{stock}	0.231	-0.958	**0.727**	**1.000**	**0.624**	**0.973**
Kairouan olive grove						
Sand	-					
Silt	**0.866**	-				
Clay	-1.000	-0.866	-			
OC	-0.500	-0.866	**0,500**	-		
pH	**0.500**	**0.866**	-0.500	-1.000	-	
D_b	-0.500	0.000	**0.500**	-0,500	**0.500**	-
SOC_{stock}	-1.000	-0.866	**1.000**	**0.500**	-0.500	**0.500**

Bold values indicated significant positive correlations (Level of significance : $p < 0.01$)

Interestingly, this study showed notable increases in SOC storage following the establishment of olive grove. The data prospected from these two sites must be repeated and validated in a large scale. The results presented here underline the need to investigate more thoroughly the carbon coming from the foliar system of the olive tree, coming from the root system, the rate of erosion, labile carbon especially since these soils have good porosity. In addition, when assessing the organic carbon stock of the soil, it is important to consider the organic carbon fractions, as they indicate the sensitivity of carbon stocks to changes in management or land use (Baldock et al. 2012).

Li et al. (2020) conducted a study on Regosols from China to examine changes in SOC and total nitrogen stocks in a chronosequence of abandoned cropland on the Zhifanggou watershed highlands (1010-1400m altitude and rainfall of 503 mm/year), these results suggest that restoration of grasslands from 18 years of abondon and up to 30 years could be an effective strategy to restore C and N sequestration in soils. These results highlight that the age of restoration and the type of species selected must be considered when evaluating regional carbon stocks and C budgets in the future management of land under different future climate scenarios. This finding shows that the olive tree in our Tunisian Regosols seems an effective choice.

In the same context and this time in the Mediterranean basin in Southeast Spain, in a mountainous area ranging from 540 to 1250 m altitude and under a slope of up to 45%, Parras-Alcantara et al. (2015) quantified organic carbon stocks in Regosols in Despenaperros Natural Park, a natural area free from human disturbance. The result is that the topsoil, if it is undisturbed, can store much more CO, moreover the slicing by horizon, better explains the nature of the carbon sequestration according to the pedogenic characteristics. According to this study, carrying out a pedogenetic division by horizon helps to better understand the behavior of each layer in sequestration, better than systematic division, such as that carried out in the present study. However, the IPCC (2001) in its methodology for estimating SOC stocks, requires systematic division like ours so that we can comply with international standards.

Conclusion

The Regosols studied are generally poor in organic carbon. The change in the land use of our two plots, from grazing mainly to olive groves, was followed by a marked improvement in the carbon stock over the entire profile up to a meter deep. This improvement is clearly observed in the 0-20 cm surface layers, but also it reached the deepest layers up to 100 cm deep.

After 15 years in olive groves, the organic carbon stock over a meter deep in the Gafsa site is 8.22 Kg C m^{-2} and in the Kairouan site is 12 Kg C m^{-2}. By comparing with the Regosols stocks of adjacent pastures, the soils under olive groves showed a benefit of 2.46 and 1.48 Kg C m^{-2}, respectively.

Having organic carbon stocks in these soils and an annual production of olives, it seems very interesting to focus more researches on these soils in order to improve their fertility and help to mitigate the increase in greenhouse gases. Facing the current threat of global warming, these Regosols are threatened by degradation. Confronted with the advancing desert, the slightest agricultural activity, especially the forest type, draws attention to its great capacity to sequester carbon if the soils are well maintained, even to produce specific crops like the olive and fix a population in exodus.

Acknowledgements

This work is part of the Exploratory Grant project Tunisian-German n° STC TUNGER-006/INTOASES. The authors thank the two CRDAs of Kairouan and Gafsa for their technical support for sampling in the both study sites.

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