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Impacts of land use and topography on soil organic carbon in a Mediterranean landscape (north-western Tunisia)

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Abstract:

This study evaluated the impact of land use and landscape forms on SOC within the Wadi Beja watershed in north-western Tunisia. A soil spectral library was set to assess the variation of the SOC of 1440 soil samples from four land use types (field crops, permanent crops, forest, and grazing land), three slope categories (flat, moderate, and steep) and two aspects (north- and south-facing). For field crops, only one factor – slope – significantly affected SOC, which SOC levels in north-facing areas appear higher in flat areas (0.75%) than in hilly areas (0.51%). However, in south-facing areas, SOC levels were also higher in flat areas (0.74%) than in hilly areas (0.50%). For permanent crops, which was interplanted with field crops, the slope significantly affected SOC levels where SOC levels have been improved to 0.97% in flat north facing and 0.96% in flat south-facing areas, which are higher than hilly south - and north-facing areas (0.79%). In the grazing land use system, both investigated factors – aspect and slope – significantly affected the SOC levels which, SOC levels were significantly higher in flat areas (north-facing: 0.84%, south-facing: 0.77%), compared to hilly areas (north-facing: 0.61%, south-facing: 0.56%). For the forest, none of the factors had a significant effect on the SOC, which they are higher in flat areas (north-facing: 1.15%, south-facing: 1.14%), compared to 1.09% in north and 1.07% in south-facing in steep areas. This study highlights the importance of the land use and landscape forms in determining the variation in SOC levels.

Keywords: soil organic carbon – landscape - land use – spectroscopy – topography - northwestern Tunisia

1. Introduction:

Land degradation, and especially soil degradation, is a major challenge for Mediterranean arid and semi-arid ecosystems (Hill et al., 2008). In Tunisia, people are responsible of land degradation through deforestation, overgrazing, removal of natural vegetation, and agricultural practices that erode soils. Long-term anthropogenic pressure from agricultural use (Kosmas et al., 2015) in addition to abiotic factors such as climatic variability and topographical variability (Scarascia-Mugnozza et al., 2000), create diverse situations for which it is difficult to draw generally valid assumptions concerning soil organic carbon (SOC) distribution and its determinant factors (Jobbagy and Jackson, 2000).
Soil degradation is a key component of land degradation in the Mediterranean region (Hartemink 2003), and the soil quality deterioration drives to deteriorate other components of land resources (e.g. water and vegetation) (Karamesouti et al., 2015).

When using the term "soil quality", it must be linked to a specific function. In this study, soil quality was seen in relation to soil conservation in agricultural systems, which aims at sustaining the productive capacity of soils and at enhancing ecological services at the same time (Doran and Zeiss, 2000). The soil quality concept has been proposed for application in studies on sustainable land management (Doran, 2002). To measure soil quality, minimum data sets have been proposed that allow detailed description by including soil chemical and physical indicators (Lal 1998). However, integrative indicators are more appropriate for preliminary studies, as they efficiently provide insight into general soil quality.

Soil degradation processes include biological degradation (e.g. a soil fertility and soil fauna decline), physical degradation (e.g. compaction, soil erosion, and waterlogging), and chemical degradation (e.g. acidification nutrient and depletion (Diodato and Ceccarelli, 2004 and Post and Kwon, 2000).
OM is one such integrative measure of soil quality, influencing soil stability, soil fertility, and hydrological soil properties. OM plays a crucial role in soil erosion: When the erosion removes surface soil, OM and clay are vanished, resulting in fertility decline, biological activity, and aggregation (Wolfgramm et al., 2007). In soils with high calcareous silty amounts and in the absence of clay, OM is particularly important with regard to the soil physical properties (e.g. soil structure, porosity, and bulk density), which again determine erodibility (Hill and Schütt, 2000).

Some soil biological degradation types were caused by agricultural practices. Mediterranean soils are characterized by low amounts of OM, which results in a soil fertility decline and structure loss. Further, SOC is variable across land use (Brahim et al., 2010), and most agricultural soils are poor in OM, often comprising less than 1% of OM (Achiba et al., 2009, Parras-Alcántara et al., 2016 and Muñoz-Rojas et al., 2012). In Mediterranean soils, loss of OM leads to root penetration reduction, soil moisture, and soil permeability, which in turn reduces vegetation cover and biological activity, and increases the runoff and risk of erosion (Stanners and Bourdeau, 1995).

Tunisia has one the highest SOC depletion rates found in Mediterranean countries. Its low soil fertility is considered an sign of the predominant inappropriate land management systems (Hassine et al., 2008 and Achiba et al., 2009). The soils from the study region of north-western Tunisia are mostly derived from an alteration of carbonate sedimentary soils (marl, limestone, clay), cultivated under rainfed conditions to produce cereal crops (wheat and barley). This form of cultivation decelerates the mineralization of OM through a series of unsustainable practices ranging from deep ploughing in spring and summer, stubble ploughing in autumn to protect wheat against Fusarium, and various tillage operations preceding sowing. This relatively intensive soil cultivation, accompanied by the practice of an annual application of phosphate and nitrogen fertilizers, is at the origin of the decrease in the OM contents following a stimulation of the microbial activity (Álvaro-Fuentes et al., 2008).

Understanding the dynamics and SOC distribution as influenced by land use systems and landscape features is critical for assessing land use management planning (Kosmas et al., 2000). SOC distribution is influenced by topographic factors and climate variation, specifically temperature and water.

SOIL Discuss., https://doi.org/10.5194/soil-2019-15
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In this study, we explore SOC distribution according to land use systems and changes across landforms (slopes and aspects). The aim of this study is to quantify SOC content and evaluate the factors that affect the variation of these amounts, specifically, the mechanisms affecting differences in SOC distribution patterns along different land use systems and landscape forms in a Mediterranean ecosystem dominated by agricultural activities. We are not aware of any study evaluating the impacts of environmental factors (slope and aspect) and existing land use systems on SOC dynamics in Mediterranean agricultural soils, specifically in Tunisia, based on an accurate and consistent database such as a soil spectral library.

The first research objective was to build a soil spectral library in order to apply it in the Wadi Beja watershed, as there was no accurate or valid soil database in the studied region or even in the whole country. The second objective was to examine the distribution of SOC under the different slopes, aspects, and land use systems. The third objective was to investigate, specifically, three research questions: (1) How does SOC vary under cereal monoculture and then after interplantation of permanent crops? (2) How and why are ecosystems more sensitive to soil degradation (SOC loss) on steep and south-facing slopes than on gentle and north-facing slopes? (3) How can land management practices under different abiotic factors (e.g. topography) influence the soil organic carbon (SOC) variation and what practices are recommended in this case study?

2. Materials and Methods:

2.1. Study area

The study area, Wadi Beja watershed, lies between 36°37'60" N and 9°13'60" E, in north-western Tunisia. Upstream of Wadi Beja is the Amdoun region and downstream the junction with Wadi Medjerdah in the Mastutah region. Wadi Beja is a tributary of the Wadi Majerdah, the most important river in Tunisia (figure 1).

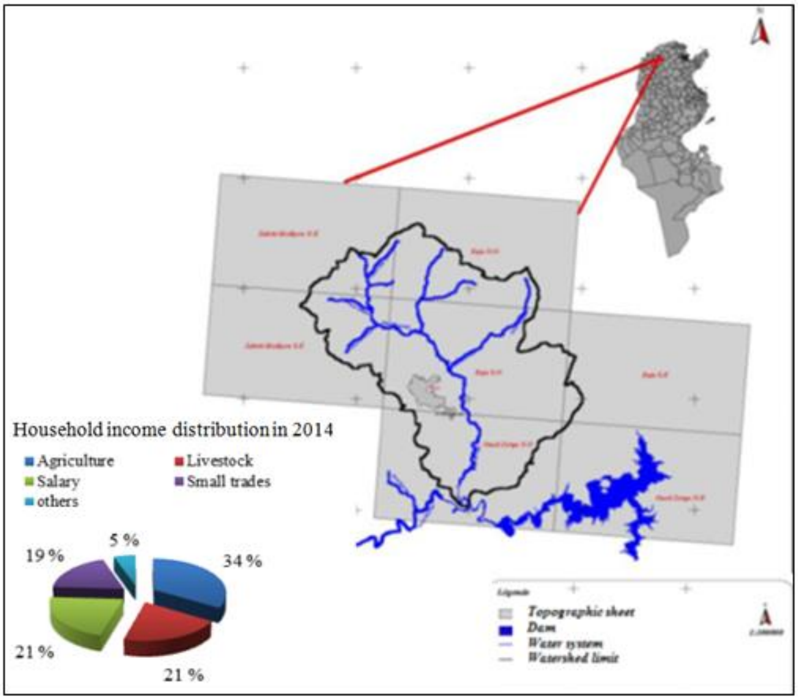

Figure 1. Location and characterization of household income of the study area, Wadi Beja watershed, north-western Tunisia. Source: Jendoubi et al. 2019

The watershed (about 338 km2) covers diverse topographic environments with an elevation ranging from 110 m to nearly 750 m; 64% of the surface has a high to steep slope and 36% has a moderate slope. Annual rainfall is irregular and varies from 200 mm to 800 mm. Early October to the end of April (late autumn to early spring) are considered the rainy seasons (AVFA, 2016). During the summer it is very dry and hot. The maximum temperatures are recorded at the end of July, when they range from 38°C to 44°C. Minimum temperatures are recorded at the end of December, when they are between 6°C and 8°C (AVFA, 2016). Most soils are exposed to water erosion, which is provoked by poor cover cultivation practices and the hilly topography. In Beja region, the population is mainly rural (56%), with 48.5% active in the agricultural sector. Agriculture remains the main source of household income (55%, including livestock) (figure 1). Nearly 78% of rural households live entirely from their farms (AVFA, 2016). There are three types of farming systems: extensive (83%), intensive (6%), and mixed (11%). Five different land use systems (LUS) were defined: field crops (71%), grazing lands (10%), forest (9%), permanent crops (7%), and built-up areas (3%). Wadi Beja watershed was selected because it comprises a variety of conserved and degraded areas. It is the most productive and extended cereal area in Tunisia, and faces serious risks associated with monoculture production of field crops under inappropriate land management practices. Some new practices, such as agroforestry, were introduced into the region in the 1980s, along with permanent crops such as olive and almond trees.

SOIL Discuss., https://doi.org/10.5194/soil-2019-15
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2.2. Methods

2.2. 1. Land use change history

This study investigated four land use system types – field crops, permanent crops, forest plantation, and grazing land – in order to assess their effects on the variation of SOC (table 1). Built-up areas and roads were excluded. We used atmospherically corrected Landsat images (4–5, 7 and 8) from 1985, 2002, and 2016 to derive the land use maps, in order to evaluate the changes between those years (Jendoubi et al., 2019).

Table 1. The five major land use and management classes studied in the Wadi Beja watershed, Tunisia

Aggregated land use classes	1985		2002		2016	
	%	km^2	%	km^2	%	km^2
Field crops	**82.1**	272.7	**76.4**	254.0	**71.0**	236.2
Grazing lands	9.3	30.9	10.2	33.7	9.7	32.2
Forests	**3.9**	13.1	**7.7**	25.6	**8.9**	29.6
Permanent crops	**3.4**	11.2	**4.2**	14.1	**7.3**	24.4
Built-up areas	**1.3**	4.5	**1.5**	4.9	**3.1**	10.0
Total	**100**	332.4	**100**	332.4	**100**	332.4

Source: Jendoubi et al. 2019

Table 1 illustrates a substantial land use and land cover change (LULC) in the Wadi Beja watershed after 1980. Field crops constituted the predominant land use type, accounting for approximately 82% in 1985 and 71% in 2016. Plantation forest also increased from 3.9% in 1985 to 9% of the watershed in 2016. In 1980, to remedy the degrading effects of monoculture of annual cropping, deforestation, and overgrazing on the pastures and the forests, a programme developed by ODESYPANO (Office Development Sylvo-Pastoral Nord Ouest) and financed by the World Bank implemented some conservation activities including development of permanent vegetative cover by olive trees and sylvo-pastoral management. An agroforestry (agrosylvopastoral) system was introduced in 1982 as an alternative programme of development and conservation in the region. This system included converting annual cropping into a combination of annual crops but interplanted with olive trees (in this study classified as "permanent crops"). This area increased from 3.4% in 1985 when it was introduced for the first time in the region and extended to 7.3% in 2016. The local farmers took this alternative when they believed that their soils had become poor and no longer gainful for annual crop production. Grazing land remained almost unchanged in terms of area, as it is spread over badlands, barren lands, and riverbanks with a high concentration of eroded and poor soils.

2.2.2. Soil sampling

We selected four land use classes (excluding built-up areas), three slope classes, and two aspect classes to study the relations between them and their effects on SOC. The LUS were forests, field crops, permanent crops, and grazing land (table1). Aspect and slope units were derived from Lidar DTM, aligned and resampled to 30m. Slope categorization was based on the FAO soil description guidelines (Barham et al., 1997). The slope categories were grouped into three. Aspect was categorized into two classes: north and south. Details about slope and aspect categories are presented in table 2.

Table 2. Slope and aspect categories

Slope categories (in %)	Aspect categories (azimuth degrees)
0 to 8 (Flat)	0 to 90, 270 to 360 (North)
8 to 16 (Moderate)	90 to 270 (South)
> 16 (Steep)	

From all slope, aspect classes, and different land use systems (LUS), soil samples were collected randomly from the topsoil (0-20 cm). In a factorial randomized design considering the four land use types, the three slopes, and two aspects, a total of 24 different sampling units (n= 4×3×2) were considered. In total, 1440 soil samples were collected from all the sampling units in the topsoil layer (0–20 cm) using a soil auger (10 cm diameter) with an average of 60 samples per sampling unit.

2.2.3. Soil analysis and spectral library

Information on soil quality is crucial to improve decision-making for efficient support of sustainable land management. Thus, methods are needed to allow fast and inexpensive prediction of important soil quality indicators such as SOC. The potential of diffuse reflectance spectroscopy in the visible and near infrared (VNIR) range for fast prediction of soil properties in a non-destructive and efficient way has been demonstrated in a number of studies (Amare et al., 2013, Shiferaw and Hergarten, 2014, Shepherd and Walsh, 2002).

All samples were taken for spectroscopy analysis in the laboratory. Soil samples were air dried (to 30 °C) and sieved to pass through a 2 mm mesh. The soil spectral library was set according to protocols cited by (Shepherd and Walsh 2002), and includes the following steps: (1) Representative sampling of soil variability in the study area; (2) Establishing the soil reflectance spectral dataset using VNIR spectrometry; (3) Selecting a reference dataset to be analysed with traditional soil chemical methods required as reference values (450 samples, or 30% of the total, were selected according to their spectral variability); (4) Determination of soil properties by means of soil chemical analysis (CN elemental analysis); (5) Calibrating soil property data to soil reflectance spectra by applying multivariate calibration models; and finally, (6) Prediction of new samples using the spectral library.

The performance evaluation of the prediction model was created on the following statistical criteria: the coefficient of determination (R^2), which measures how well a regression line estimates real data points; the Residual Prediction Deviation (RPD), which evaluates the quality of a validation; and the Root Mean Square Error of the prediction (RMSEP), which assesses the accuracy of the model. These parameters evaluate the performance quality of the soil spectroscopy model (Vicsarra et al., 2006).

2.2.4. Statistical analysis

Regarding soil spectral library analysis, the partial least squares regression (PLS regression) was used in RStudio to validate the spectral prediction model while assessing the coefficient of determination (R2), residual prediction deviation (RPD), and root mean square error of the prediction (RMSEP).

Variables for each sample were computed using analysis of variance (ANOVA) in order to determine which factors significantly affect (sig. <0.05) the SOC variation. The statistical investigation was performed using SPSS software. Results were presented in histograms using excel. We then assessed the variation of SOC under the different selected factors.

3. Results

3.1. Soil spectral library as an integrative indicator of soil quality

For a sample set of the case study, SOC analysis was carried out at the laboratory of the Institute of Geography at University of Bern. SOC value measured in chemical analysis (CN elemental analysis) was used to validate SOC model prediction. These SOC contents were plotted against the SOC content predictions as displayed in figure 2.

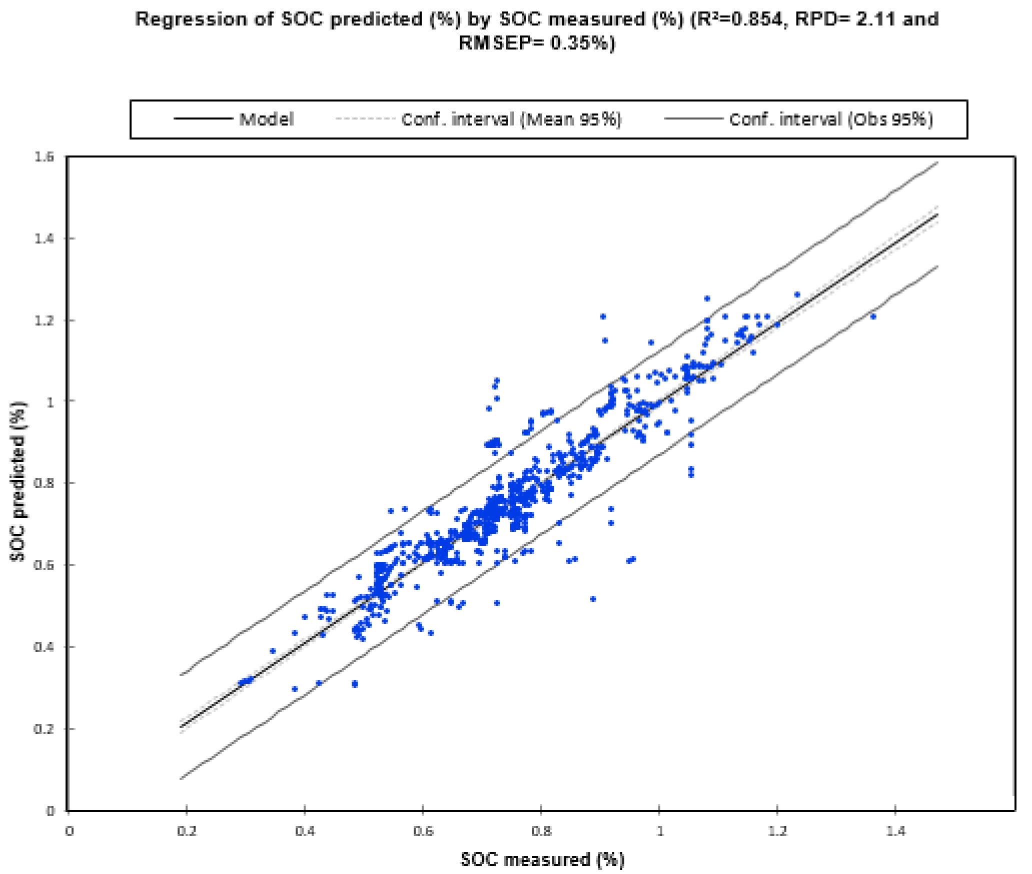

Figure 2: SOC values from chemical analysis plotted against SOC predicted.

The obtained spectral prediction model has R2= 0.85, RPD= 2.11, and RMSEP= 0.35%, which was rated excellent for prediction because the RPD>2 (Rossel et al. 2006). This means that the model is able to accurately determine the SOC content of 85% of the samples. The RPD (2.11>2) shows also that the model developed is of good quality and can be used to predict the remaining spectra and for further development of the spectral library.

3.2. Significance effects of all the variables

A univariate ANOVA revealed which variable had statistically significant differences in SOC related to land use systems, slopes, and aspects. Table 3 reveals the results of the significance analysis for each of the three variables. The highest significance was reported for land use, followed by slope and aspect.

Table 3. ANOVA results showing the significance of the impact of land use, slope, and aspect for soil organic carbon (SOC) (n= 1440)

	F	Sig.
LUS	395.263	**0.000**
slope	76.505	**0.000**
aspect	11.093	**0.001**

Sig. < 0.05 (statistically significant difference), in bold.
Sig. > 0.05 (no statistically significant difference)

The analysis of the significance of the different variables for each land use type is presented in table 4. In the forest land use, all variables were not significant, indicating that the variation of the SOC with high amounts in these components was not related to slope, and aspect. The explanation for this is that the forest has a dense cover that protects the soil from being exposed to any other factors such as erosion and the SOC cannot be affected. It can be assumed that the soil under forest has no degradation caused by soil erosion by water as observed in some surrounding fields.

Table 4. ANOVA results regarding significance of all the variables under different LUS.

LUS	Variables	F	Sig.
Forests	slope	1.806	0.176
	aspect	2.931	0.094
Field crops	slope	51.429	**0.000**
	aspect	1.028	0.312
Permanent crops	slope	36.474	**0.000**
	aspect	0.068	0.795
Grazing lands	slope	8.242	**0.001**
	aspect	5.971	**0.017**

Sig. < 0.05 (statistically significant difference), in bold.
Sig. > 0.05 (no statistically significant difference)

For field crops, only slope has a significant effect on SOC. Of the whole ANOVA analysis, this has the highest significance after the importance of land use. (Kravchenko et al., 2002 and Jiang and Thelen, 2004) found that within variability in topography, slope plays a great role on crop yield; they considered it a main yield-limiting factor. (Herrick and Wander, 1997) showed that after introducing permanent crops, the slope significantly affects

SOC levels. Regarding grazing lands, all the variables revealed significant effects on the SOC levels as shown in the study of (cf. Bird et al., 2001) as well. In the following, we separately discuss the impact of land use, slope, and aspect on SOC stocks.

3.3. SOC according to land use systems

SOC contents for different land use systems are shown in figure 3. Forests showed significantly (sig. < 0.05) the highest SOC content of 1.09%. Permanent crops have the second highest values with 0.87% of SOC. The lowest SOC contents were found for field crops (0.70%) and grazing soils (0.74%).

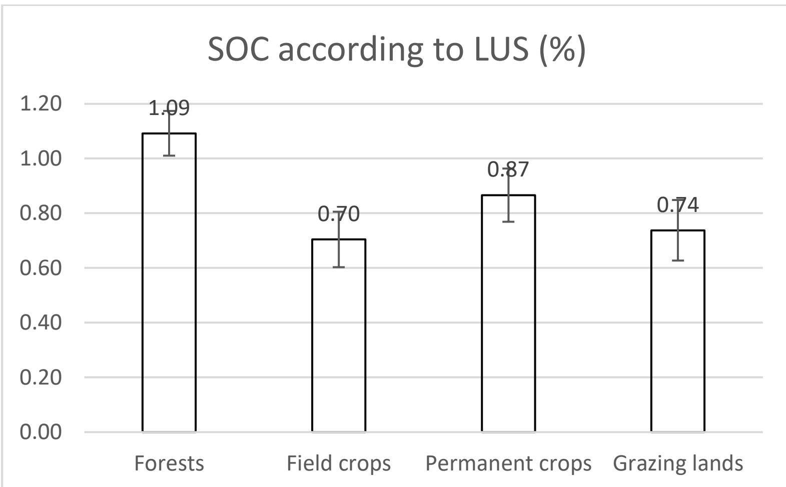

Figure 3. SOC rates according to land use systems in the Wadi Beja watershed Tunisia.

According to the ANOVA results, land use systems significantly affect SOC content. In the study area, the lowest SOC was found in field cropping soils (0.70%) compared to the highest SOC contents in the forests (1.09%).

3.4. Impact of slope and aspect on SOC

SOIL Discuss., https://doi.org/10.5194/soil-2019-15
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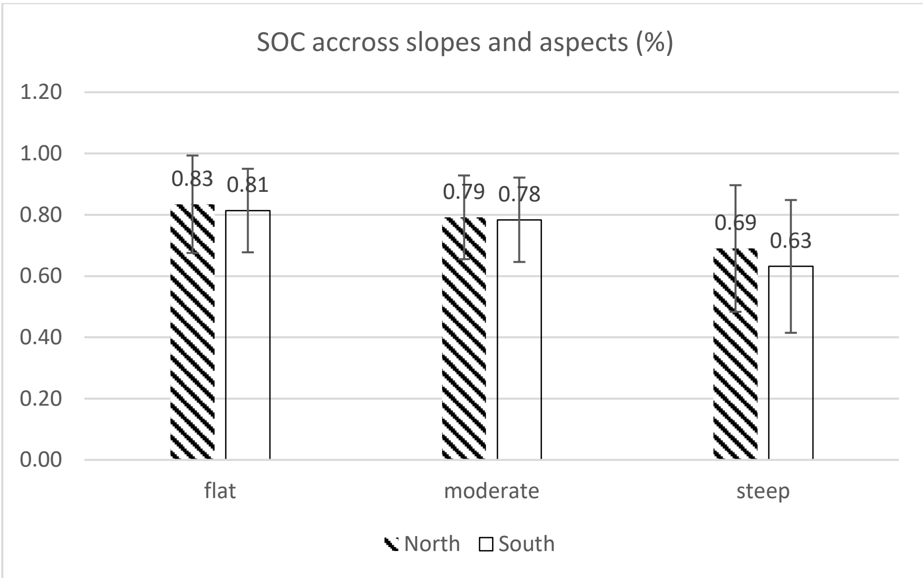

Figure 4. SOC rates according to slope and aspect in the Wadi Beja watershed Tunisia.

Figure 4 shows highest SOC content (0.81%-0.83%) on the flat slope and slightly reduced SOC on moderate slope (0.98%-0.79%). Both flat and moderate slopes show no significant difference between northern and southern slopes (difference <0.02%). The lowest SOC was revealed on the steep slopes and southern aspects with 0.63%, followed by steep northern slopes with 0.69% SOC.

3.5. Impact of land use and slope on SOC

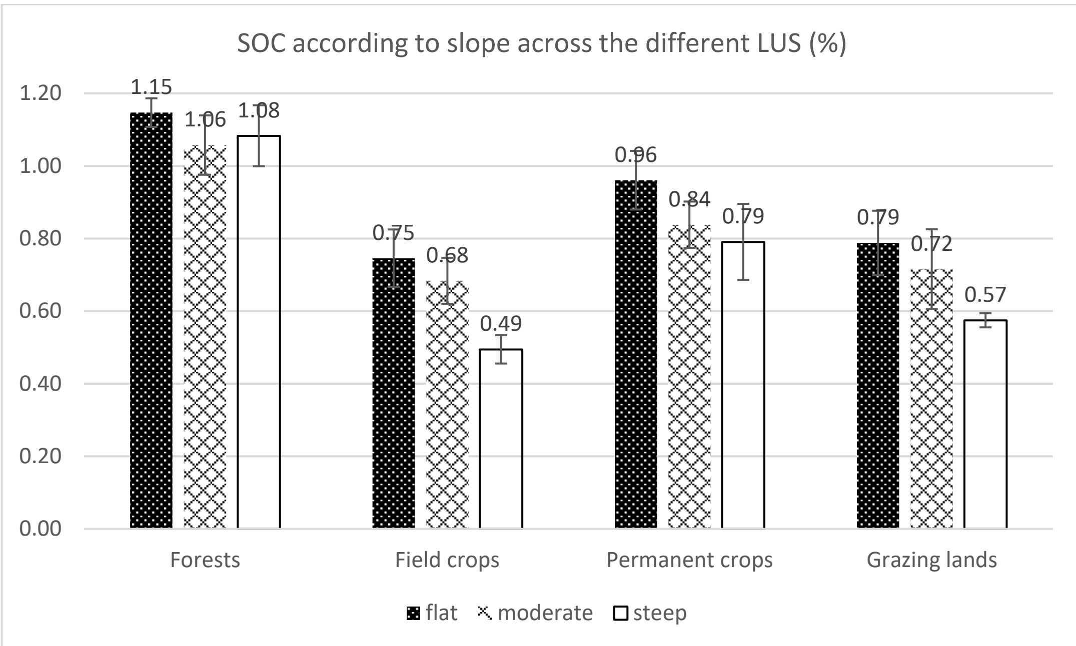

Figure 5. SOC rates according to slope for the different land use systems in the Wadi Beja watershed, Tunisia.

In order to evaluate the impact of slopes on the SOC variations under the different LUS, results presented in figure 5 revealed that in forest plantations, the highest SOC amounts were observed in flat areas (1.15%), with 1.06% found on moderate slopes and 1.08% found on steep slopes. As previously shown, statistically, the slope has no significant effect on the SOC variation. For field crops, the highest SOC content was found in the flat area (0.75%), followed by 0.68% on the moderate slope and the very low figure of 0.43% on the steep slope. Figure 5 clearly shows the marked decline of SOC with increasing slopes under field crops. For permanent crops, the decline with increasing slopes is less that on the field crops and the SOC for all slopes are increased. The highest SOC content was found in flat areas (0.86%), followed by 0.84% in moderate and 0.79% in steep areas. Finally, on grazing lands the different slopes show marked differences with 0.79% of SOC in flat areas, 0.72% in moderate, and 0.57% in steep sloping areas.

3.6. Impact of land use, slope, and aspect on SOC

The ANOVA test shows that aspect has no significant effect on SOC variation in forests, field crops, and permanent crops. Only for grazing land does aspect have a significant effect on SOC variation, with north-facing soils having a greater SOC level than south-facing areas. See figure 6 and table 4.

SOIL Discuss., https://doi.org/10.5194/soil-2019-15
Manuscript under review for journal SOIL
Discussion started: 8 April 2019

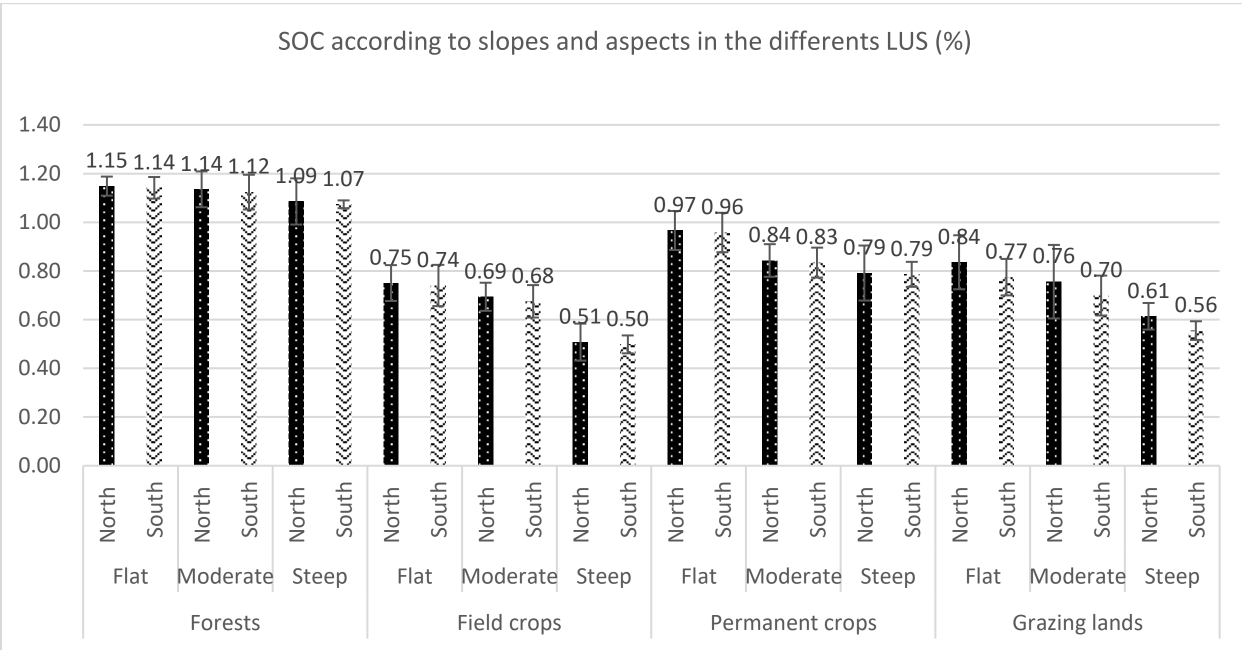

Figure 6. SOC rates according to slope and aspect for the different land use systems.

The highest SOC values were observed in forests, then permanent crops then fields crops and grazing lands. The lowest values were found under field crops, especially in the steep south-facing areas (0.5%). The most likely clarification for this is that in this land use system, soils are affected by soil degradation initiated by inappropriate land management and consequently, a weak vegetation cover. This condition makes these soils more sensitive to the south-facing exposition characterized by higher solar radiation and evaporation, and thus decreases soil moisture and biological activity and SOC loss.

4. Discussion

Regarding the soil spectral library, comparing the results from the study carried out by (Hassine et al., 2008), which concluded that SOC levels do not exceed 2% in north-western Tunisia, our prediction model falls within this amount with a maximum organic carbon percentage of 1.2%. This state of low OM in soils used for agriculture, compared to forests with little indication of soil degradation, is confirmed by various authors (Arrouays et al., 1994, Cerri, 1988 and Robert, 2002). These low levels have negative impacts on the soil structure, which would be built mainly by means of mineral colloids and whose stability is affected, leading to numerous deficiencies in production and susceptibility to degradation factors. Cereal soils may have acquired a balance between SOC inputs and losses, but at a very low equilibrium level, if we compare with forests that still have less decline of SOC and have been protected against erosion, which is the main type of land degradation in the study area (Hassine et al., 2008).

Previous studies show that SOC can play an significant role in monitoring soil quality related to land use and reduction of soil degradation (Shukla et al., 2006 and Hassine et al., 2008). We thus focussed on the SOC content, which we calibrated to soil reflectance spectra. Chemical analysis of SOC made it possible to calibrate and validate a model using soil spectra to predict a wider range of soil samples. We established a soil spectral library for 1440 soil samples to investigate SOC under the various combinations of land use, soils, slopes, and aspects in the study area.

Land management in the study area is similar in relation to land preparation, organic amendments, crop rotation, and mulching (stubble, roots). Mineral fertilizers have been applied for several decades and cropland – the major land use – has been used as monoculture of cereal crops such as wheat and barley. This management has its impact on the organic stocks of these soils.

Results on the impacts of land use on SOC indicate that the decline in OM on cropland could be the result of land degradation due to inappropriate agricultural management such as intensive tillage, the removal of crop residues, reduced vegetation cover, deteriorated soil aggregation and erosion, and continuous monoculture system. This finding is coherent with the results of several researchers (Lemenih and Itanna, 2004, Lal, 2005, Muñoz-Rojas et al., 2015, and Hamza and Anderson, 2005) who reveal a significant decline in OM content in cropland compared to natural forest. (Herrick and Wander 1997) found that in annual cropping systems, the distribution of SOC is highly influenced by land management practices such as reduced tillage, rotation, fertilization, and shifting cultivation. Consistent with a study by (Hassine et al., 2008) in north-western Tunisia, the reduced OM decomposition rates as a result of intensive agricultural practices (monoculture, tillage on steep slopes, tillage in wet seasons) in addition to other topographic factors may lead to the decrease in the SOC.

Changing annual field crops by interplanting them with permanent tree crops has lifted SOC of soils under previous annual field crops almost halfway to the level of forests (0.87%). Intercropping previously monocropped fields with tree crops (olive, almond, and pomegranate trees) between 1982 and 1985 significantly improved the SOC within 30-35 years. Creating agroforestry systems in this way is considered a good land management intervention in north-western Tunisia, as it reduced the area covered only by very old cereal monocultures and it also reduced soil degradation. However, some farmers made no changes to their land management, as they did not perceive the advantages of the agroforestry system (Jendoubi and Khemiri, 2018). Yet, agroforestry systems are globally recognized to have a high potential to sequester C, since they are more accomplished of capturing and utilizing resources compared to grassland systems or single-species cropping (Nair et al., 2011).

Grazing lands, even though they are not tilled, have a low level of SOC (0.74%), only slightly higher than annual crops (Figure 3). Continued overgrazing and reduction of vegetation cover seem to degrade the soils and their SOC. A low SOC content can be clarified by a lack of appropriate grassland management. The open pasture without canopies and the weak grass-vegetation cover increase the vulnerability of this land use system to soil degradation and to SOC decline.

Various studies show that the way grazing land is managed affects SOC (Wu et al., 2003 and Soussana et al., 2004): overused grazing lands with less vegetation cover were more affected by soil erosion and soil exposure to wind and rain, leading to greater SOC loss. However, there were no systematic investigations or sufficient measurements to support their statements. Notably, grassland management strongly affects SOC stocks, which are decreased as grazing intensities increase (Neff et al., 2005).

The highest SOC amounts was found in the forests, This finding was confirmed by many authors who showed that in Mediterranean areas, many forest soils are rich in OM; as a consequence, these soils supply a large quantity of carbon, which means that these soils are distinguished by high SOC (Lal, 2005 and FAO, 2010), which is highly related to the lower disturbance in the forests.

While assessing the results of the impact of slope and aspects on SOC variation, the south-facing terrain has the lowest SOC contents compared to the north-facing terrain, which is explained by its exposition to the highest solar radiation and especially the highest temperature during the vegetation period and the long hot summers. This implies high evaporation and a high burndown of OM due to high temperature, less moisture in the soils, and consequently a slow-down of the decomposition of OM.

In addition, regarding our findings, the impact of slope and aspect on SOC content was very distinct, as indicated statistically by a significant effect on SOC content in the ANOVA. The issue is that steep and south-facing slopes are more sensitive to degradation than other areas, explained by the fact that steepness increases runoff and soil erosion, and southern exposure increases evapotranspiration and temperatures, thus decreasing the availability of nutrients, water and SOC to plants. Apart from differences in land use management, SOC variation is mainly affected by environmental factors on soil along landscape forms.

The literature links temperature and moisture to OM decomposition in soils (García Ruiz et al., 2012 and Griffiths et al., 2009).

As shown by (Garcia-Pausas, 2007), In the Mediterranean area, the shaded areas such as northern faced or the colder southern areas, sustain regularly high moisture levels longer and consequently become more fertile and productive, in contrary to the southern faced areas that are exposed to high radiation and thus occasional water deficits.

With regard to steepness and aspect, the higher the slope and the more exposed to the south, the more affected by erosion and different climatic conditions, the lower the SOC content (Yimer et al., 2007 and Yimer et al., 2006). Different topographic positions are considered to have different microclimatic and vegetation community types and thus significant variations in SOC. Topography (slope and aspect) thus plays a crucial role in relation to temperature and moisture regimes.

The temperature is highly influenced by the solar radiation, which has a role on soil chemical and biological processes and vegetation distribution (Bale et al., 1998). Hence, the temperature of the soil plays a key role in monitoring the biomass decomposition rate, and thus affect the SOC distribution, either delaying or accelerating its decomposition (Scowcroft et al., 2008).

From the results assessing the impact of slope combined with land use, we can see that the highest SOC contents were observed in the flat area under all the land use systems and then tend to decrease on the steep positions. This can be explicated by the fact that soils on the flat slope tend to be thicker as a result of deposition. Erosion causes stripping of the soil in the hillslope areas. As shown by (Yoo et al., 2006), the prevalent portion of SOC is deposited in depositional areas with hillslopes being more susceptible to sporadic mass wasting events, continuous

soil erosion and production, and consequently, less SOC storage. Together with this, the highest erodibility was related to the hilly areas where soils have a tendency to be shallow, coarse in texture and low in OM, while lower erodibility was observed at the flat areas with organic-rich, deep, and leached soils (Lawrence, 1992).
From the clear difference between the variation of SOC under forest and field crop land use systems, we interpret that the land use factor dominates the SOC distribution compared to the slope factor.
In general, steep slopes had a lower SOC content than flat land, as they are more vulnerable to erosion, especially when associated with inappropriate management and overuse (Reza et al., 2016 and Bouraima et al., 2016). Cropland in sloping areas are highly vulnerable to water erosion, which leads to extensive soil disturbance, while land use patterns affect vegetation cover, soil physical properties such as SOC and surface litter. Therefore, this provokes the runoff and soil erosion processes accompanying nutrition loss (Dagnew et al., 2017 and Montenegro et al., 2013). Therefore, the extent of nutrition loss differs according to land use systems, as it is the case with cereal monoculture in the study site.
Land management is revealed as a key indicator affecting SOC distribution, influencing topsoil in particular (Ferreira et al., 2012). Especially in Mediterranean areas, land management is a significant factor given the limitations to SOC accumulation under various climatic and topographic conditions. Moreover, high SOC reflect undisturbed soil and high soil quality as it is the case in the forest land use (Corral-Fernández et al., 2013).
However, Mediterranean region is generally characterized by poor soils with low OM content (around 1%) due to their nature and the fact of being over used by agriculture, which means that these soils have low C inputs from plant residues, low canopied density, and are subjected to inappropriate management practices (Verheye and De la Rosa, 2005 and Cerdà et al., 2015).
(Wakene and Heluf 2004) have also indicated that intensive cultivation aggravates OM oxidation and hence reduces OC content. Therefore, under different land use systems, the difference in SOC contents is related to the effect of variation in the land use systems intensity along the toposequences. As shown by our results, higher SOC contents were recorded in the forest where there is less disturbance and use and statistically the slope has no significant effect on the SOC variation. In the field cropping area, where soils are overused and are subject to continuous intensive cultivation without appropriate soil management practices, this condition has contributed to the degradation of the important soil quality indicators such as SOC. Hence, in order to improve and maintain the soil quality parameters for sustainable productivity, it is crucial to reduce intensive cultivation, and integrate the use of inorganic and organic fertilizers. Correspondingly, after plantation of permanent crops in combination with field crops, SOC contents were enhanced, in keeping with the tendency of the highest SOC contents in flat areas and the lowest in steep areas.
Regarding the effect of slope under the different land use systems, we can observe the same tendency of SOC variation, going from higher SOC content in flatter positions to the lowest in steep positions.
According to (Irvin, 1996), specified that generally, with increasing slope, the OM lixiviation is reduced, mineral weathered, clay are translocated, and horizon are differentiated.
Moreover, Landscape position has a significant impacts on soil temperature, soil erosion, runoff, drainage, and soil depth – and hence soil formation. Different soil properties encountered along landscapes will affect the litter production and decomposition, which will definitely have effects on SOC content. The accumulation of SOC variation on hillslopes is explained by the decomposition rates of OM and litter input differences (Yimer et al., 2006).
Regarding grazing lands, SOC contents are generally low with better SOC content in the flat areas. This is explained by the issue of overgrazing and pressure in the different topographic positions as they are all easily accessible by livestock. Even on steep slopes there is pressure and overgrazing, in addition to the exposure of these areas to erosion by wind and rain. This condition may reveal the vulnerability of this land use system to erosion and deterioration of soil quality.

Therefore, some options for sustainable land management practices can be recommended such as establishement of enclosures (Mekuria and Aynekulu, 2013), which could be effecient in recovering degraded grazing land areas of the watershed. In addition to the protection of trees against damage caused by uncontrolled grazing animals by installing fences and trunk protection, mixing of animal species (mostly sheep and goats, but also cows and horses), as well as setting additional fodder provision features during summer season.
According to the obtained results on the impacts of all the factors on SOC variation, our finding lends strong support to implicate the interaction effects of slope and aspect on OM decomposition (Griffiths et al., 2009), as the difference between the north- and south-facing areas is the solar radiation, wind, and rainfall.

According to (McCune and Keon, 2002), the reason for these results is that slope aspect plays a significant role in solar radiation redistribution, hence the solar radiation heterogeneity on hillslopes led to differences in soil moisture and temperature. (Huang et al., 2015) cited that the SOC concentration on shaded aspects areas was significantly higher compared to the sunny aspects areas. Therefore, as discussed previously, increasing in SOC and OM accumulation are generated by means of increased moisture and reduced temperatures. Decreased soil temperature usually results in decreased OM decomposition rates and litter decay rates (Blankinship et al., 2011).

Why are grazing land use systems the most sensitive to all the tested variables? This can be explained by the fact that in the case study, grazing land was generally open grassland and it is evident that soils are more sensitive in open grassland than under tree canopies, as SOC stocks under tree canopies is in general higher compared to open grassland (e.g. Seddaiu et al., 2013). In addition to what (Moreno et al., 2007) cited: “The amount of SOC in the topsoil beneath the tree canopies projection was around twice as high as beyond the tree canopy”.

In addition, this can be related to overgrazing, as shown in a literature review of the effects of overgrazing in the Mediterranean basin (Sanjari et al., 2008 and Costa et al., 2012). Further, the semi-arid climate and inclined topography prevailing in the Mediterranean grazing lands render ecosystems vulnerable to SOC losses. As shown by (Ryan et al., 2008), the higher the level of grazing, or the greater the residue removal, the greater the decline in mean OM level. The reason behind the decrease in carbon and nutrient cycling is mainly that OM in grassland is accumulated in roots, which leads to its lost on every removal of aboveground biomass.

5. Conclusions

The study showed that different land uses vary considerably in their storage of SOC and that SOC variability is most strongly related to land use systems.
The effect of the land use system on reducing OM content was confirmed as a major factor influencing SOC variation, followed by slope and aspect. SOC is reduced on steeper slopes, with the greatest decreases of SOC on field crops and on south-facing grazing land. Thus, introducing perennial vegetation (i.e. trees) among field crops in cultivated land increases SOC, with higher SOC in flat areas than in moderate and steeper areas.
The decline in SOC on steep slopes and south-facing lands may result in adverse effects on soil structure and increase vulnerability of the soil to erosion and runoff. Therefore, it is recommended to convert degraded lands to restorative land uses, to diminish further depletion of soil carbon in the steep south-facing part. SOC loss on agricultural soil in sloping areas poses a serious problem for the environment as well as for soil quality and

productivity. Topography plays a major role in these processes and thereby influences the development and characteristics of the soils along the toposequences. Most of the important soil quality indicators such as SOC are influenced by the different landscape positions, particularly at the surface horizon. In areas with exceedingly erodible soils, such as those in steep slopes and south-facing zones shown in this study, application of soil and water conservation measures is crucial to sustain agricultural fields and to prevent or reduce soil degradation.

Improved management of grazing land must be considered to decrease overgrazing, which can lead to soil degradation and SOC loss. In agricultural areas, continuous intensive cultivation without appropriate soil management practices has contributed to loss of SOC. Therefore, in order to maintain an improved soil quality and sustainable productivity, there is a need to reduce the intensive cultivation and integrate use of inorganic and organic fertilizers.

There are strong indications that agroforestry has been successful in retaining and even improving SOC and soil fertility: results showed that introducing an agroforestry system – e.g. combining an olive plantation with annual field crops – increased SOC content in the most vulnerable areas. Thus, such types of sustainable land use need the attention of land managers. The steep slopes and south-facing areas of the watershed have different degrees of soil degradation. Accordingly, a distinction should be set based on landscape and landform units during the selection of appropriate land use systems and land management practices. Greater efforts are required on steep slopes and south-facing land to reduce the SOC decline than in flat areas and north-facing land. However, further study of the areas is recommended, especially in combination with other topographic factors such as altitude and curvature.

Finally, this paper contributes towards filling a gap in analyses on the impacts of various land uses on SOC in Tunisia. The results presented in this paper are valid for SOC in the study area. While the methodology can be replicated and applied to other areas, further studies on the variation of SOC depending on land use type and land form are needed to inform sustainable land management in Tunisia.

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7. Conflict of Interest Statement

The authors affirm that there are no conflicts of interest regarding the publication of this paper.

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