



Soil Organic Carbon Stocks and Their Relationships with Soil Properties Under Three Forest Covers in the Djebel Guezoul communal forest (Tiaret, Algeria)

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Received: 05/08/2026 Accepted: 07/10/2026 Published: 22/10/2026

Abstract

Forest soils store a large share of terrestrial organic carbon, but data from the semi-arid forests of the western Algerian High Plains are scarce. This study estimates the organic carbon stock of the 0-30 cm layer in the Djebel Guezoul communal forest (Tiaret, Algeria) and examines how it relates to soil properties under three covers: Prickly juniper (*Juniperus oxycedrus*.), Aleppo pine (*Pinus halepensis*) and holm oak (*Quercus ilex*). The area lies in the semi-arid, cold-winter bioclimatic stage (annual rainfall 356.7 mm; De Martonne index 13.87; Emberger quotient 27.11). Fifteen soil samples (five per cover) were analysed for particle-size distribution, bulk density, pH, electrical conductivity, total and active calcium carbonate, organic matter and organic carbon. Soils were mostly sandy loams (clay 6-18 %), non-saline and neutral to alkaline (pH 6.9-8.7), and 13 of 15 samples contained less than 1.5 % total calcium carbonate. Organic carbon ranged from 0.26 to 2.22 %, giving a stock of 7.1-77.9 Mg C per hectare (mean 34.2 ± 23.9). No property, including the stock, differed significantly among covers ($p > 0.05$), and organic carbon was not significantly correlated with clay, silt, sand, pH or bulk density. Variability among samples within each cover exceeded that among covers. These results suggest that, in this forest, tree species alone is a poor predictor of soil carbon, and that stand condition and topography, which were not measured here, should be recorded in future sampling.

Keywords: forest soils; soil organic carbon stock; physico-chemical properties; vegetation cover; Mediterranean semi-arid climate; Djebel Guezoul.

1. Introduction

Forests hold a large share of the carbon stored in terrestrial ecosystems, and their soils are one of the main reservoirs of this carbon (Lal, 2004; Pan et al., 2011; IPCC, 2019). The way forest soils gain and lose organic carbon therefore matters for the global carbon cycle and for climate policy. Beyond this climatic role, soil organic carbon (SOC) is a basic indicator of soil quality: it influences aggregate stability, water retention, cation exchange and the supply of nutrients (Duchaufour, 2001; Weil & Brady, 2017).

Most of the SOC found in a profile is concentrated in the upper layers, where inputs from litter and roots are greatest and where biological activity is most intense (Jobbágy & Jackson, 2000). These layers are also the most exposed to disturbance. In semi-arid Mediterranean regions such as the province of Tiaret (Algeria), forest soils are subjected to low and irregular rainfall, a long dry season, fires, grazing and the progressive degradation of the plant cover. These pressures can change soil properties over the long term and reduce the capacity of the soil to store carbon, so the relationships between plant cover and soil properties are central to carbon sequestration in these environments (Lal, 2004; IPCC, 2019).

Tree species can modify the soil beneath them through the quantity and chemical quality of litter, root inputs, canopy interception and microclimate (Binkley & Giardina, 1998; Augusto et al., 2002). Prickly Juniper, Aleppo pine and holm oak are among the main forest-forming trees of the Mediterranean basin and often grow side by side in mountain forests (Quézel & Médail, 2003). Whether these three covers are associated with different SOC contents and stocks in the semi-arid Atlas of western Algeria is not well documented.

The Djebel Guezoul communal forest overlooks the city of Tiaret and is representative of the forest and pre-forest formations of the western Algerian High Plains. In spite of its ecological and landscape importance, little is known about the amount of carbon stored in its soils or about the factors that control its distribution. This study addresses three questions: (i) how much

organic carbon is stored in the surface layer (0–30 cm) of the soils of this forest; (ii) whether SOC content and stock differ among Prickly juniper, Aleppo pine and holm oak covers; and (iii) which soil properties are associated with the variability of SOC.

The specific objectives are to (a) characterise the physical and chemical properties of the soils, (b) determine organic matter and organic carbon contents and estimate the SOC stock, (c) compare these variables among the three covers with formal statistical tests, and (d) examine the relationships between SOC and the other soil properties, including through a multivariate analysis. We expected SOC to differ among covers and to be related to soil texture, in particular to clay content, because fine particles are known to protect organic matter from decomposition (Six et al., 2002).

2. Materials and Methods

2.1. Study area

The Djebel Guezoul communal forest is located north of the town of Tiaret, in the western High Plains of Algeria, and belongs to the Tellian Atlas. It lies mainly in the commune of Tiaret and extends partly over the neighbouring communes of Tagdempt, Guertoufa and Mechraa Safa, between UTM coordinates $X = 343\,461 - 353\,301$ m and $Y = 3\,916\,450 - 3\,921\,100$ m (Fig. 1). The massif covers 1 304.17 ha divided into four forest cantons (Ouled Cherif Cheraga, Chaouchaoua, Aïn Kerma and Djebel Guezoul).

The mean altitude is 1000 to 1100 m, with a highest point of about 1220 m. The relief is asymmetrical: the North Slope is steeper and wetter, whereas the south slope descends gradually towards the Sersou plateau (Miara, 2011). The soils developed on Miocene sandstone–marl formations; they are generally shallow, of sandy to sandy-clay texture, low in organic matter and slightly alkaline (Bouazza et al., 2017). The vegetation is dominated by Aleppo pine (*Pinus halepensis* Mill.), accompanied locally by holm oak (*Quercus ilex* L.) and Prickly juniper (*Juniperus oxycedrus*.), in a context of pre-forest formations and plantations (Quézel & Médail, 2003; Miara et al., 2017).



Figure 1. Location of the Djebel Guezoul communal forest (Tiaret, Algeria) and of the sampling points.

2.2. Bioclimatic characterization

Monthly rainfall and mean temperatures for 2001–2025 were obtained from the Aïn Bouchekif station (35°21' N, 1°28' E, about 1000 m a.s.l.), operated by the National Meteorological Office. Aridity was assessed with the De Martonne index (De Martonne, 1926):

$$I = P / (T + 10) \quad (1)$$

where P is the mean annual rainfall (mm) and T the mean annual temperature (°C). The Emberger pluviothermic quotient was calculated as (Emberger, 1955):

$$Q_2 = 2000 P / (M^2 - m^2) \quad (2)$$

where M is the mean of the maximum temperatures of the hottest month and m the mean of the minimum temperatures of the coldest month, both expressed in kelvin. The dry season was identified with the ombrothermic criterion of Bagnouls and Gaussen ($P \leq 2T$; Bagnouls & Gaussen, 1953).

2.3. Soil sampling

Soil was sampled at stations located under the three main covers of the forest (Aleppo pine, holm oak and Prickly juniper), chosen after a field survey intended to represent the diversity of the plant formations of the massif. For each cover, five samples were taken, giving 15 samples in total (G1–G5 under Prickly juniper, C1–C5 under holm oak and P1–P5 under Aleppo pine). Sampling concerned the surface horizon (0–30 cm), which is the most directly influenced by organic inputs

and biological activity. Disturbed samples for physico-chemical analyses were taken with an Edelman auger, and undisturbed samples for bulk density with cylinders of known volume. Each point was georeferenced by GPS, labelled and packed before transfer to the laboratory.

2.4. Laboratory analyses

After air-drying, removal of coarse debris, grinding and sieving at 2 mm, the following analyses were carried out. Particle-size distribution (clay, silt and sand) was determined by the Robinson pipette method, after destruction of organic matter with hydrogen peroxide and dispersion with sodium hexametaphosphate (Baize, 2000). Bulk density (BD) was measured by the volumetric cylinder method with oven-drying at 105 °C for 24 h (Hillel, 2004). The pH was measured in a 1:2.5 soil-water suspension with a pH meter (Mathieu & Pieltain, 2003; Baize, 1988). Electrical conductivity (EC) was measured in a 1:5 aqueous extract with a conductivity meter (Richards, 1954). Total calcium carbonate (TC) was determined with the Bernard calcimeter and active calcium carbonate (AC) by the Drouineau-Galet method (Drouineau, 1942).

Organic carbon (OC) was determined by the Walkley and Black method, based on oxidation with potassium dichromate in sulphuric acid and titration of the excess dichromate with ferrous sulphate (Walkley & Black, 1934). Organic matter (OM) was estimated by multiplying OC by the Van Bemmelen factor of 1.724, which assumes that organic matter contains on average 58 % carbon (Nelson & Sommers, 1996).

2.5. Calculation of the soil organic carbon stock

The SOC stock of the 0–30 cm layer (Mg C ha^{-1}) was calculated for each sample from OC, BD and the layer thickness (Batjes, 1996):

$$\text{SOC} = \text{OC} \times \text{BD} \times \text{D} \quad (3)$$

where OC is the organic carbon content (%), BD the bulk density (g cm^{-3}) and D the thickness of the layer (30 cm). With these units, the product gives the stock directly in Mg C ha^{-1} . No correction was made for coarse fragments, because they were not quantified; the stocks may therefore be overestimated at stations where stones are present.

2.6. Data quality checks and statistical analysis

Before analysis, the data were checked for internal consistency. The three particle-size fractions summed to 100 % in all samples (maximum deviation 0.01 %), and the OM/OC ratio ranged from 1.69 to 1.72, in agreement with the factor of 1.724 used for the conversion.

Each variable, including OM, OC and the SOC stock, was compared among the three covers by one-way analysis of variance (ANOVA) followed by Tukey's HSD test at a significance level of 0.05. The normality of the data within each cover was examined with the Shapiro–Wilk test and the homogeneity of variances with the Levene test. Because several variables departed from these assumptions (in particular clay, pH and the carbonates), the nonparametric Kruskal–Wallis test was also applied, and a conclusion was considered robust only when the two tests agreed. Results are presented as mean $\pm$ standard deviation (SD). Associations between OC and the other soil properties were examined with Spearman rank correlations.

The overall structure of the data was explored by principal component analysis (PCA) on standardised variables. Clay, sand, BD, pH, EC, TC, AC and OC were included. Silt was excluded because it is fixed by clay and sand, and OM because it is proportional to OC. Statistical analyses were performed with the SciPy library in Python. With five samples per cover, only large differences among covers can be detected, and the statistical results should be interpreted with this limitation in mind.

3. Results

3.1. Bioclimatic context

Over 2001–2025, the Aïn Bouchekif station recorded a mean annual rainfall of 356.7 mm and a mean annual temperature of 15.7 °C, with a thermal minimum in January (monthly means of 5–6 °C) and a maximum in July (monthly mean around 27 °C). The De Martonne index ($I = 13.87$) places the area in the semi-arid domain, and the Emberger quotient ($Q_2 = 27.11$; $m = -4.06$ °C) places the forest in the semi-arid bioclimatic stage with cold winter (Table 1). The ombrothermic diagram shows an extended dry period from May to October.

Table 1. Main bioclimatic parameters of the study area (Aïn Bouchekif station, 2001–2025).

Parameter	Value
Mean annual rainfall, P	356.7 mm
Mean annual temperature, T	15.7 °C
De Martonne aridity index, I	13.87 (semi-arid)
Mean minimum of the coldest month, m	−4.06 °C
Mean maximum of the hottest month, M	41.04 °C
Emberger quotient, Q_2	27.11 (semi-arid, cold winter)
Dry period ($P \leq 2T$)	May to October

3.2. Texture and bulk density

The texture is dominated by the sand fraction (41.90–82.55 %; median 73.75 %) and the silt fraction (7.45–46.45 %; median 15.25 %), while clay remains low (6.15–17.55 %; median 10.00 %) (Fig. 2). According to the USDA classification, 12 samples are sandy loams, two (G4 and P4) are loamy sands and one (G1) is a loam. The most silty samples (G1 with 46.45 % and G2 with 30.95 % silt) are both found under Prickly juniper, which explains the higher mean silt content of this cover

(26.4 %) and its large dispersion (SD = 13.5 points). By contrast, the five holm oak samples are remarkably uniform (sand 75.2 ± 1.3 %). The two samples with the highest clay content (P3 and P5, about 17.5 %) are both under Aleppo pine.

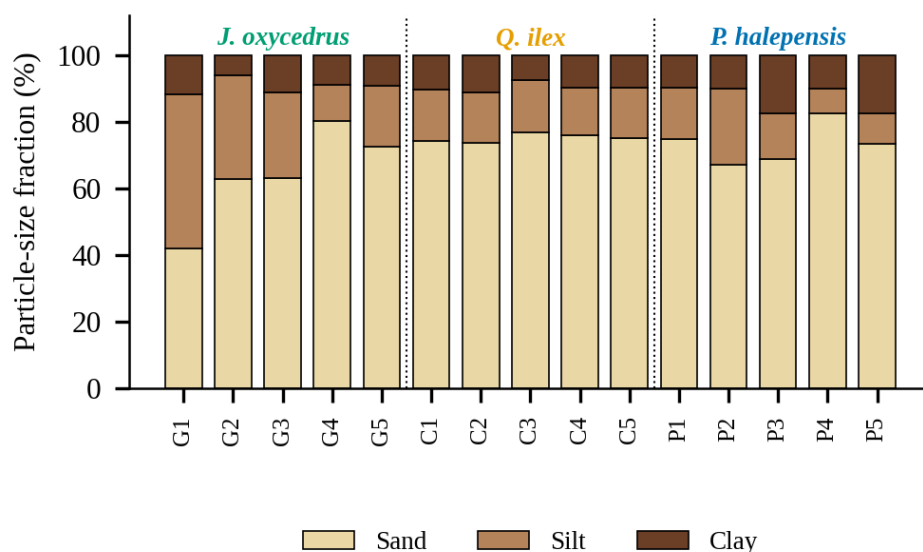


Figure 2. Particle-size composition (sand, silt, clay) of the 15 soil samples, grouped by forest cover.

None of the three fractions differed significantly among covers (Tables 2 and 3). Silt came closest to significance (ANOVA $p = 0.071$) but the variances were unequal among covers (Levene $p = 0.046$), and the Kruskal–Wallis test found no difference ($p = 0.114$). Bulk density ranged from 0.91 to 1.30 g/cm³, with means of 1.19 (Prickly juniper), 1.25 (holm oak) and 1.14 g/cm³ (Aleppo pine), and did not differ among covers ($p = 0.166$). The lowest value (0.91 g/cm³) was measured at P2. These values indicate, in general, a loose structure and a satisfactory porosity at most stations.

3.3. pH and electrical conductivity

The pH in water ranged from 6.90 (G4) to 8.70 (C2), that is from neutral to alkaline, with cover means of 7.69 (j Prickly juniper), 8.02 (holm oak) and 7.76 (Aleppo pine) and no significant difference ($p = 0.514$). The electrical conductivity was very low (0.033–0.160 mS/cm) and far below the threshold of 0.6 mS/cm usually taken as the limit of salinity; the soils are therefore non-saline. The mean EC was higher under Prickly juniper (0.092 mS/cm) than under holm oak (0.047 mS/cm) and Aleppo pine (0.069 mS/cm), but this difference was not significant ($p = 0.201$), and the Kruskal–Wallis test agreed ($p = 0.275$).

3.4. Carbonates

Most of the soils are poor in carbonates: total CaCO₃ was below 1.5 % in 13 of the 15 samples (median 0.49 %). Two samples are clear exceptions: G1 under Prickly juniper (34.94 %) and P1 under Aleppo pine (10.99 %). Active CaCO₃ was detected in only two samples (G1, 17.3 %; P4, 2.8 %). This explains the very large standard deviations of the cover means (Table 2) and the strongly skewed distributions visible in Fig. 3. The cover means did not differ significantly for TC ($p = 0.472$) or for AC ($p = 0.455$), and the removal of G1 did not change the result for TC ($p = 0.52$).

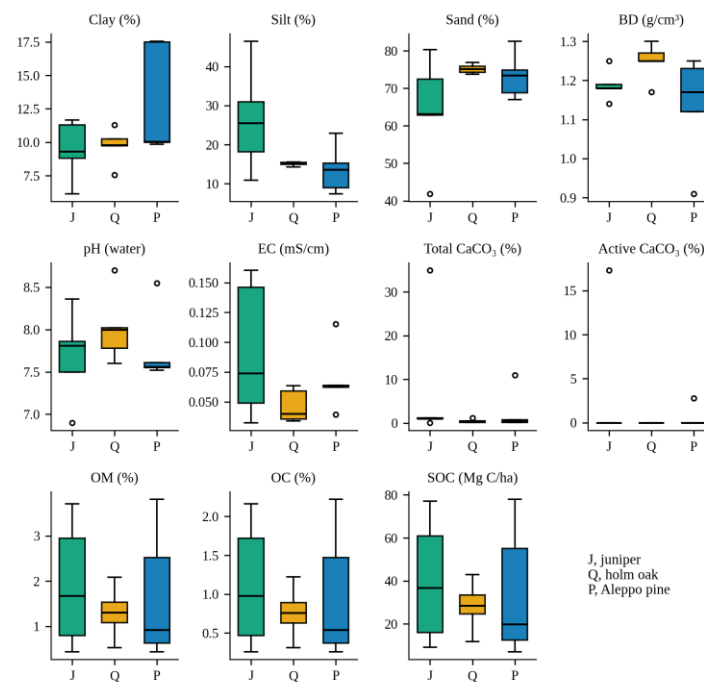


Figure 3. Box plots of the soil properties by forest cover (J, Prickly juniper; Q, holm oak; P, Aleppo pine; n = 5 per cover). Boxes show the interquartile range, the line is the median, whiskers extend to 1.5 times the interquartile range and circles are outliers.

3.5. Organic matter and organic carbon

Organic matter ranged from 0.44 to 3.81 % and organic carbon from 0.26 to 2.22 %, which corresponds to low to moderate contents. The lowest values (OM of 0.44–0.53 %) were measured at G2, P2 and C4, and the highest at P5 (OM 3.81 %, OC 2.22 %) and G3 (OM 3.71 %, OC 2.16 %). Mean OC was 1.12 ± 0.81 % under Prickly juniper, 0.76 ± 0.34 % under holm oak and 0.97 ± 0.85 % under Aleppo pine (Table 2). The differences were not significant (ANOVA $p = 0.731$; Kruskal–Wallis $p = 0.911$). The dispersion within the Prickly juniper and pine covers was large: OC varied by a factor of eight to nine within each of them (0.26–2.16 % under Prickly juniper, 0.26–2.22 % under pine), whereas holm oak was less variable (0.31–1.22 %).

Table 2. Mean $\pm$ standard deviation (n = 5 per cover) and overall range of the soil properties. BD, bulk density; EC, electrical conductivity; TC, total CaCO_3 ; AC, active CaCO_3 ; OM, organic matter; OC, organic carbon; SOC, organic carbon stock of the 0–30 cm layer.

Parameter	<i>J. oxycedrus</i>	<i>Q. ilex</i>	<i>P. halepensis</i>	Range (n = 15)
Clay (%)	9.4 ± 2.2	9.7 ± 1.4	13.0 ± 4.1	6.2–17.6
Silt (%)	26.4 ± 13.5	15.1 ± 0.5	13.7 ± 6.1	7.5–46.5
Sand (%)	64.2 ± 14.4	75.2 ± 1.3	73.4 ± 6.1	41.9–82.6
BD (g/cm^3)	1.19 ± 0.04	1.25 ± 0.05	1.14 ± 0.14	0.91–1.30
pH (H_2O)	7.69 ± 0.54	8.02 ± 0.42	7.76 ± 0.44	6.90–8.70
EC (mS/cm)	0.092 ± 0.058	0.047 ± 0.014	0.069 ± 0.028	0.033–0.160
TC (%)	7.6 ± 15.3	0.5 ± 0.4	2.5 ± 4.7	0.1–34.9
AC (%)	3.5 ± 7.7	0.0 ± 0.0	0.6 ± 1.3	0.0–17.3
OM (%)	1.92 ± 1.39	1.31 ± 0.57	1.66 ± 1.45	0.44–3.81
OC (%)	1.12 ± 0.81	0.76 ± 0.34	0.97 ± 0.85	0.26–2.22
SOC ($\text{Mg C}/\text{ha}$)	40.0 ± 28.9	28.2 ± 11.5	34.5 ± 30.7	7.1–77.9

3.6. Soil organic carbon stock

The SOC stock of the 0–30 cm layer averaged 34.2 ± 23.9 Mg C/ha over the 15 samples (median 28.5; range 7.1–77.9 Mg C/ha). Mean stocks were 40.0 ± 28.9 Mg C/ha under Prickly juniper, 28.2 ± 11.5 under holm oak and 34.5 ± 30.7 under Aleppo pine (Fig. 4). They did not differ significantly among covers (ANOVA $p = 0.766$; Kruskal–Wallis $p = 0.887$). Within covers, the stocks varied eight- to eleven-fold under Prickly juniper (9.2–77.1) and pine (7.1–77.9), but only about four-fold under holm oak (11.8–43.0).

The highest stocks were found at P5 (77.9 Mg C/ha), G3 (77.1), G5 (60.9) and P1 (55.1), and the lowest at P2 (7.1), G2 (9.2), C4 (11.8) and P3 (12.4). At P2, a very low OC (0.26 %) was combined with the lowest bulk density ($0.91 \text{ g}/\text{cm}^3$), which

produced the smallest stock. Because the stock depends on both OC and bulk density, it is a more complete indicator than OC alone, but in this data set it led to the same statistical conclusion.

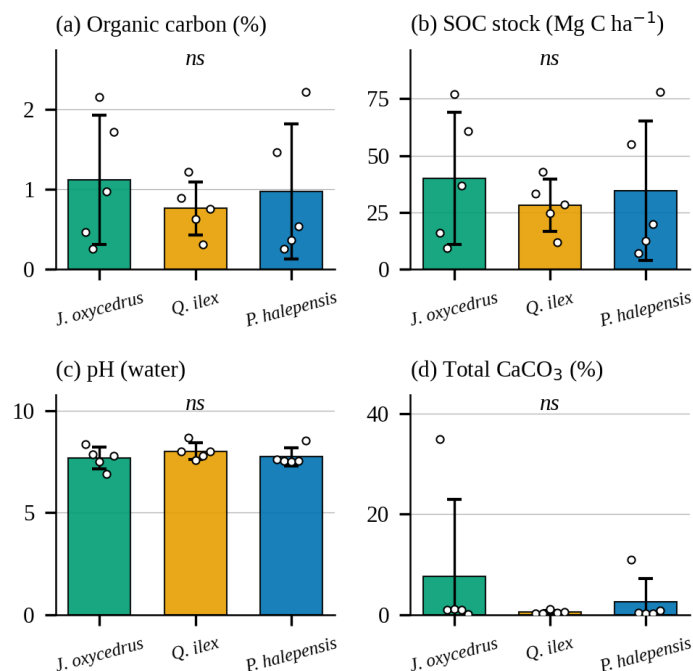


Figure 4. Organic carbon, SOC stock, pH and total CaCO₃ under the three forest covers (mean $\pm$ standard deviation; dots are individual samples, $n = 5$). ns, not significant (ANOVA, $p > 0.05$).

3.7. Comparison among covers: summary of the tests

Table 3 gives the results of the statistical tests for all variables. No variable differed significantly among the three covers, either by ANOVA or by the Kruskal–Wallis test (all $p > 0.05$). Several variables departed from normality in at least one cover (Shapiro–Wilk $p < 0.05$ for clay, pH, TC and AC), and the Levene test indicated unequal variances for silt only. The convergence of the parametric and nonparametric tests makes the absence of a detectable difference a consistent result, but it should be remembered that, with $n = 5$, the tests have little power to detect moderate differences.

Table 3. Results of the tests comparing the three covers. K–W, Kruskal–Wallis test; S–W min p, smallest Shapiro–Wilk p-value among the three covers; Levene p, test of equality of variances.

Parameter	ANOVA F	p	K–W H	p	S–W min p	Levene p
Clay (%)	2.44	0.129	2.56	0.278	0.010	0.407
Silt (%)	3.32	0.071	4.34	0.114	0.456	0.046
Sand (%)	2.14	0.161	3.66	0.160	0.637	0.111
BD (g/cm ³)	2.10	0.166	4.46	0.107	0.221	0.231
pH (H ₂ O)	0.70	0.514	2.18	0.336	0.001	0.822
EC (mS/cm)	1.84	0.201	2.58	0.275	0.131	0.099
TC (%)	0.80	0.472	1.42	0.493	<0.001	0.504
AC (%)	0.84	0.455	1.09	0.581	<0.001	0.455
OM (%)	0.32	0.733	0.19	0.911	0.226	0.376
OC (%)	0.32	0.731	0.19	0.911	0.226	0.378
SOC (Mg C/ha)	0.27	0.766	0.24	0.887	0.289	0.310

3.8. Relationships between organic carbon and soil properties

Organic carbon was not significantly correlated with any of the properties measured (Table 4). The correlation with clay was weak and positive ($\rho = 0.23$, $p = 0.41$), and that with sand, silt, bulk density, pH and total CaCO₃ was close to zero. The two samples with the highest clay content (P3 and P5) illustrate the absence of a clear relationship: P5 has the highest OC of the data set (2.22 %), whereas P3 has one of the lowest (0.37 %).

Table 4. Spearman rank correlations between organic carbon and the other soil properties (n = 15).

Property	Spearman ρ (with OC)	p
Clay	0.23	0.41
Silt	-0.20	0.48
Sand	0.12	0.68
Bulk density	0.13	0.63
pH (water)	0.14	0.63
EC	-0.30	0.27
Total CaCO ₃	0.06	0.83

3.9. Multivariate structure

The first two principal components explained 43.4 % and 19.4 % of the variance, respectively, and 62.8 % together (Table 5, Fig. 5). PC1 opposed sand (negative loading) to total and active CaCO₃ and EC (positive loadings), and PC2 was dominated by clay, pH and OC. PC1 was largely determined by a single sample, G1, whose score (6.3) lies far from all the others (below 1.5 in absolute value). PC3 (14.0 % of the variance) was mainly related to bulk density. The samples of the three covers overlapped almost completely in the plane of PC1 and PC2, with no separation by species.

The Pearson correlations of total and active CaCO₃ with silt, sand and EC (absolute r between 0.57 and 0.77) were strongly influenced by G1; they were not confirmed by Spearman correlations ($p > 0.05$) and are therefore not interpreted.

Table 5. Loadings of the variables on the first three principal components (PCA on 8 standardised variables, n = 15).

Variable	PC1	PC2	PC3
Clay	0.19	0.79	0.23
Sand	-0.91	0.01	-0.09
Bulk density	-0.36	-0.18	-0.86
pH (water)	0.45	0.56	-0.23
EC	0.79	-0.05	0.02
Total CaCO ₃	0.89	-0.14	-0.28
Active CaCO ₃	0.91	-0.16	-0.20
Organic carbon	-0.19	0.73	-0.38
Eigenvalue	3.47	1.55	1.12
Variance (%)	43.4	19.4	14.0
Cumulative (%)	43.4	62.8	76.8

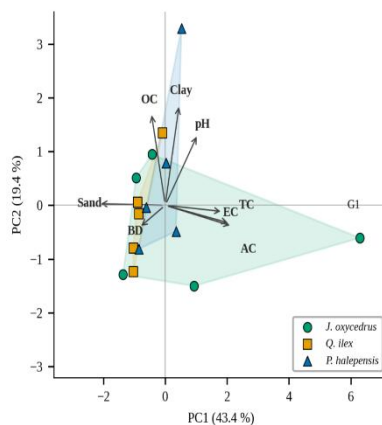


Figure 5. Principal component analysis of the 15 samples (8 standardised variables). Arrows show the variable loadings (scaled for display); shaded areas enclose the samples of each cover. BD, bulk density; EC, electrical conductivity; TC and AC, total and active CaCO₃; OC, organic carbon.

4. Discussion

4.1. Climatic and edaphic setting

The bioclimatic indices ($I = 13.87$; $Q_2 = 27.11$) place the Djebel Guezoul forest in the semi-arid stage with cold winter, a context in which a dry season of six months limits the production of biomass and favours the mechanical disintegration of parent rocks at the expense of chemical weathering, and thus limits the formation of clay (Morsli et al., 2004). This is consistent with the low clay contents recorded here (6.15–17.55 %) and with the coarse texture described for the soils of the

massif (Bouazza et al., 2017). The organic carbon contents (0.26–2.22 %) are low to moderate, in line with the generally low organic matter of the soils of the dry regions of Algeria (Halitim, 1988).

The variation in texture among stations is also compatible with a slope effect, with sandier soils on the upper positions and siltier soils further down, as is frequent on eroded Mediterranean slopes where land use strongly affects runoff and erosion (Morsli et al., 2004). This interpretation remains a hypothesis, because the slope position of the sampling points was not recorded.

4.2. Texture and the stabilisation of organic carbon

Fine-textured soils usually stabilise more carbon through organo-mineral associations (Six et al., 2002; Weil & Brady, 2017), and the low clay content of the soils studied could therefore limit the physical protection of organic carbon. Our data, however, do not support a relationship between clay and OC: the correlation was weak and not significant ($p = 0.23$, $p = 0.41$), and the two clayiest samples had very different OC contents. Several explanations are possible. The range of clay contents is narrow (6–18 %), so that it may not be wide enough to reveal an effect. With 15 samples, only strong correlations can be detected. Finally, in forest soils the amount of carbon returned to the soil, the quality of litter and the intensity of decomposition may outweigh the effect of texture. Other studies in semi-arid Mediterranean soils have used multivariate models to separate the effects of such factors on OC (Brahim et al., 2011), an approach that would require a larger data set than the present one.

4.3. Carbonates, pH and salinity

The pH values (6.90–8.70) indicate neutral to alkaline soils, which is expected on a calcareous or marly substrate, but the carbonate contents are low in most samples (13 of 15 below 1.5 %), so a uniformly carbonate-rich substrate is not supported by our data. The two carbonate-rich samples (G1 and P1) could reflect local outcrops of marl or limestone or the accumulation of carbonates at particular positions. Where carbonates are high, as at G1 (34.94 % total and 17.3 % active), they may reduce the availability of phosphorus and some micronutrients. The very low electrical conductivity excludes any salinity constraint, which is probably favoured by the good drainage of the coarse-textured soils.

The mean pH was slightly higher under holm oak (8.02) than under Prickly juniper (7.69) and pine (7.76). Because this difference was not significant ($p = 0.514$), we do not attribute it to a species effect such as the redistribution of bases by deep roots and litter (Augusto et al., 2002). The same caution applies to the higher mean EC under Prickly juniper.

4.4. Organic carbon content and stock among covers

The main result of this study is the absence of a significant difference in OC, OM and SOC stock among Prickly juniper, Aleppo pine and holm oak. The mean stock of the 0–30 cm layer (34.2 Mg C/ha) hides a wide range (7.1–77.9 Mg C/ha), and the variation among samples within a cover was larger than the variation among covers. In particular, the Prickly juniper and pine covers each included both very poor and very rich samples, while the holm oak samples were more homogeneous but not richer. The comparison with the effects of tree species reported for temperate forests (Binkley & Giardina, 1998; Augusto et al., 2002) must be made with care: those effects are usually studied in designs where species are compared on the same soil and site, which was not the case here.

Several factors that were not recorded may explain the large variation within covers. The density and structure of the stand, the thickness of the litter layer, the degree of canopy closure, the grazing pressure and the position on the slope are all expected to influence the input and the decomposition of organic matter. It is likely, for example, that dense and well-preserved stands accumulate more organic matter than open or degraded stands, and that bare soil exposed to sun is subject to faster mineralisation, but this could not be tested because these characteristics were not measured for the 15 samples. We therefore consider this as a working hypothesis for future sampling rather than as a result.

The stocks estimated here are for the 0–30 cm layer only. Since a large share of SOC lies in the upper layers but not exclusively there (Jobbágy & Jackson, 2000), the stock of the whole profile would be higher. On the other hand, no correction was made for coarse fragments, which would lower the stocks at stony stations. The values should therefore be taken as indicative.

4.5. Implications for forest management

This study cannot show that cover type controls the SOC stocks of the Djebel Guezoul forest, and it should not be used to recommend one species over another for carbon storage. What the data do show is that the soils have low to moderate carbon contents and a large spatial variability, which means that site-specific factors need to be taken into account in any carbon assessment. Since the surface horizon holds most of the carbon and is the most exposed to disturbance, practices that maintain the litter layer and limit the exposure of bare soil are consistent with the conservation of SOC (Lal, 2004). A monitoring network that records stand and site characteristics together with SOC would allow the effect of management and degradation to be quantified.

5. Conclusion and perspectives

This study characterised the physico-chemical properties of the soils of the Djebel Guezoul communal forest (Tiaret) and estimated the organic carbon stock of the 0–30 cm layer under Prickly juniper, Aleppo pine and holm oak. The area has a semi-arid cold-winter bioclimate, with 356.7 mm of rainfall per year. The soils are mostly sandy loams with low clay

contents, non-saline, neutral to alkaline and poor in carbonates in 13 of the 15 samples. Organic carbon was low to moderate (0.26–2.22 %), and the SOC stock averaged 34.2 Mg C/ha, with a range of 7.1 to 77.9 Mg C/ha.

None of the properties measured, including the SOC stock, differed significantly among the three covers, and organic carbon was not related to texture, pH, carbonates or bulk density. The variability among samples within each cover was larger than the variability among covers. At the scale and sample size of this study, the tree species alone therefore does not explain the distribution of soil carbon in this forest.

Future work should (i) record stand density, canopy cover, litter thickness, grazing pressure, slope and aspect at each station and use them to explain the variability of SOC; (ii) increase the number of stations and replicate the sampling in space and time; (iii) sample by depth increments and correct the stocks for coarse fragments; (iv) add nitrogen, phosphorus and biological indicators of soil quality; and (v) combine these data with digital soil mapping and remote sensing in order to extend the estimates to the whole massif and to follow their evolution under climate change and human pressure.

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