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Research article

Soils with more clay and dense vegetation were rich in soil carbon along Wadi Al-Sharaea, Makkah, Saudi Arabia

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ABSTRACT

In arid ecosystems, lack of vegetation and nutrients can negatively impact soil carbon (C) content. In the current study, our goals were to assess soil C stocks to a depth of 50 cm in an arid ecosystem (Wadi Al-Sharaea, Saudi Arabia) and determine their relation to different vegetation cover. To address our research objective, a total of 102 quadrate (randomly selected) were established along the desert wadi. Soil samples were collected to a depth of 50 cm with 5 cm interval, then Soil Bulk Density (SBD, g/cm^3), Soil Organic C Content (SOC, g C/kg), and stocks (kg C/m^2) were estimated. Both soil mechanical and chemical analyses were conducted for a composite soil sample. Study sites were categorized based on their visual vegetation cover (VC) percentage (%) into three major groups: 1) scarce vegetation cover (VC less than 25%); 2) medium vegetation cover (VC is higher than 25% and less than 75%); and lastly 3) dense vegetation cover (VC is higher than 75%). Soils were characterized by higher sand content (48.2%, both fine and coarse compiled) than silt (36.7 ± 1.64%) or clay (10.1 ± 1.28%). There were significant differences among soil Calcium (Ca) and Potassium (K) content ($p < 0.05$), while those plant communities with medium vegetation cover showed the highest soil content of Ca and K (1.7 ± 0.24 and 0.2 ± 0.03 meq/l, respectively). Plant communities with dense vegetation cover had the lowest SBD (1.96 ± 0.03 g/cm^3) and the highest SOC stocks (14.9 ± 2.1 kg C/m^2). Moreover, our data analyses indicated that SBD and SOC content had strong and negative correlation, where soils with dense vegetation cover had the most significant correlation ($R^2 = 0.95$). Our results recommend that soil carbon stocks to a depth of 50 cm based on different vegetation cover of arid ecosystems should be implemented on global soil carbon budget to better elucidate factors controlling SOC content at the regional and global scales.

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1. Introduction

Desertification and deforestation are among major causes for increasing atmospheric greenhouse gases (GHGs), and that had increased public concerns in the last few decades. Three distinct pools among which global Carbon (C) circulates: atmosphere, oceans, and land biosphere [1]. The concept of "4 per 1000" to increase global soil C stocks by 0.4% to offset the exploiting increase of atmospheric carbon dioxide (CO_2) emissions had been acknowledged [2,3]. However, emissions of atmospheric CO_2 reached a record of 417.1 ppm in 2020, equivalent to 147% of the preindustrial levels in 1750 [4,5]. Depending on C inputs-outputs, soils can act as an efficient C sink. Soil organic matter (SOM) is a major consistent of soil C pools and has a major implication on soil physical and chemical properties [6].

Soils are the main sink of terrestrial C as they store more C (2344 Gt C up to 3 m depth) than terrestrial biomass (560 Gt C) and atmospheric pools (750 Gt C) [7-9]. In addition to low water holding capacity of arid soils, arid ecosystems are characterized by low soil C content and low plant available nutrients [10]. Lack of vegetation cover can lead into desertification in arid ecosystems and that can be accelerated by many factors including social, political, and cultural activities. Moreover, less biodiversity and soil C content are direct consequences of desertification in arid soils [11]. On the other hand, however, arid ecosystems provide many ecosystem services including recreation activities and ecotourism. Therefore, conserving arid ecosystems from habitat loss, similar to other coastal ecosystems [12], should be a top priority at all government levels. Factors impacting and controlling spatial variability of Soil Carbon Content (SOC) are many and the interaction between them is complex. These factors include soil type, moisture content, plant species diversity, C inputs, biomass allocation, soil depth, and soil aggregation [13-21].

Among arid climate countries is Saudi Arabia with a dry desert covering the majority of the Arabian Peninsula. Common habitats includes wadis, sandy and rocky deserts, mountains, and meadows [22,23]. Evaluation of C stocks in arid ecosystems requires soil C data that are based on field studies that would establish baseline for C stocks evaluation in desert wadis which would contribute to climate change mitigation. Many research studies had been conducted about wadis in Saudi Arabia [22,24–30], but little is known about soil C content and stocks in such arid regions.

Many processes impact soil C stocks including vegetation cover [31] and soil texture [15]. The current study would provide soil C data that are essential for establishing management plans for wadis plants conservation and climate change mitigation. The main objective of the current study were to: 1) assess soil C stocks up to a depth of 50 cm, and 2) investigate the relationship between soil C content and vegetation covers of plant species along Wadi Al-Sharaea, Saudi Arabia. We hypothesized that soils with medium or dense vegetation cover would retain more soil C content than lands with vegetation cover less than 25%. Moreover, higher soil C content would be associated with soils with higher clay and silt content compared with sandy soils.

2. Materials and methods

2.1. Study area

The kingdom Saudi Arabia is a country on the Arabian Peninsula in Western Asia and follows the pattern of desert climate with the exception of the southwest region which is characterized by semiarid climate. The current study was focused on Wadi Al-Sharaea located southeast of Makkah city (Fig. S1). It has an area of 638.98 km^2 and receives water mainly from the discharge ground water [32]. Monthly average for ambient air temperature was 24.5–36.7 in January and June, respectively, during the period of 2003–2019, while rain ranged from 0.2 to 27.6 mm/month during July and October, respectively, (Meteorological Station at Makkah Al-Mukaramah, Presidency Meteorology and Environment). A total of 17 study sites (Table S1, Fig. S1) were established and distributed randomly along the wadi for both soil and vegetation sampling. Six quadrates were randomly chosen within each site (17 site * 6 quadrats = 102 quadrats, (20 × 20 m each)). Distance between the quadrates was chosen randomly, depending on the presence of stands that can be sampled and away from the people's property. Since the plant communities were representing wild plant species, age was difficult to determine. Site selection was conducted to represent the vegetation physiognomy along the wadi (Table S1 and Fig. S1). Plant species diversity in the study area, similar to other desert wadis in Saudi Arabia, has been impacted by several anthropogenic activities including climate change, agriculture development, and urban expansion [33,34] – resulting in less plant diversity and species extinction.

2.2. Soil sampling and analyses

Using a soil corer (stainless steel, 100 cm long and 70 mm inner diameter), soil samples (as a profile of 50 cm depth) were collected (three soil cores were collected at each quadrate as replicates). Soil sampling was conducted during April to May 2018. Soil cores were sectioned, in the field, into 5-cm intervals (0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40, 40–45, and 45–50 cm) and packed in plastic bags. Soil sample were stored on ice box and brought to the laboratory where kept at 4 °C to minimize microbial activity [35] until analyses. Soil samples were ground and sieved in 2 mm to remove debris. Soil Bulk Density (SBD, g/cm^3) was estimated on dry basis [36], while Soil Organic Matter (SOM, %) was estimated by Loss-On-Ignition method for 2 h at 550 °C [37]. SOC density (kg C/m^3), SOC mass per unit surface area (kg C/m^2), and total SOC stock (kg C/m^2) were estimated and described in details by Eid et al. [38], and others [37,39–42].

At each quadrate, a composite (0–50 cm depth) soil sample was collected for both mechanical and chemical analyses. Particle size analyses were conducted according to the sieve method [43], and then soil texture was determined. Amount (%) of gravel, coarse sand, fine sand, silt, and clay were calculated following the sieving process. Soil-water extract (1:5, w/v) was prepared, then pH, Electrical

Conductivity (EC, dS/m) to express salinity, and Total Dissolved Solids (TDS, mg/l) were determined [44,45]. Sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) were determined using a flame photometer after soil digestion [45]. Total chloride (Cl), sulfate (SO_4), bicarbonate (HCO_3), and carbonate (CO_3) were determined in the soil solution [44,45].

2.3. *Vegetation groups*

List of plant species recorded at each site (Table S3, S4, and S5) and their plant species abundance, relative density, frequency, importance value, and relative cover were available from Elaidarous et al. [32]. Since one of our goals was to assess soil C stocks among different vegetation covers, we grouped plant species data in three different vegetation groups (Table S2). Group 1 represents scarce vegetation (plant cover less than 25%); group 2 (medium vegetation cover) represents those plant communities with medium vegetation cover that is higher than 25% and less than 75%; and lastly group 3 (dense vegetation cover) which represent those plant communities with plant cover that is higher than 75%. *Rhazya stricta* was the most common plant species among all vegetation groups, while *Citrullus colocynthis*, *Polycarpaea repens*, and *Aristida funiculata* were codominant plant species (Tables S3, S4, and S5). During our data analyses, we grouped sampling sites in their correspondent vegetation groups (Table S2), and hereafter named them as scarce, medium, and dense vegetation cover, respectively.

2.4. *Data analyses*

Analysis of variance (ANOVA, one-way) was used to test the main effects of vegetation cover groups: 0–<25%, 25–<75%, and >75 on chemical and mechanical soil properties, then mean separation were conducted using Tukey's Honestly Significant Difference (HSD) test. Repeated measure two-way ANOVA was used to identify statistically significant differences in SBD (Fig. 1), SOC content (Fig. 2), and SOC density (Fig. 3) among the vegetation cover groups and soil depth (0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40, 40–45, and 45–50 cm), then mean separation using Tukey's Honestly Significant Difference (HSD) test. Data were tested and found to be normally distributed; accordingly, no data transformation was needed. Data presented here are means and standard errors (mean ± SE), unless otherwise noted. Regression analyses (both linear and non-linear) were conducted between SOC content (g C/kg) in relation to SBD (g/cm^3), SOC density (kg C/m^3), and SOC stocks (kg C/m^2). Pearson simple linear correlation coefficient (r) was calculated for assessing the relationship between vegetation cover and soil clay, silt, and sand content. All statistical analyses were performed using SPSS 23.0 software [46].

3. Results

3.1. *Soil analyses*

Soil gravel, sand, silt, and clay content were significantly ($p < 0.05$, Table 1) different among the three vegetation groups (scarce, medium, and dense vegetation). Sites that were dominant with medium vegetation cover had the highest gravel content (7.2 ± 0.87%), while both dense and scarce vegetation cover sites had less gravel content (2.4 ± 0.53 and 5.1 ± 0.90%, respectively, Table 1). Soil

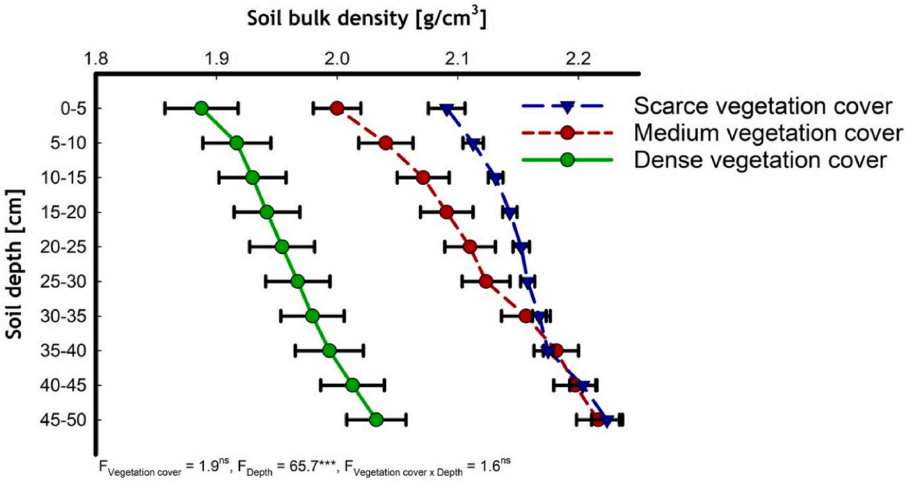

Fig. 1. Soil bulk density (g/cm^3) in relation to soil depth (cm) for different vegetation groups along the Wadi Al-Sharaea, Makkah Province, Saudi Arabia. Horizontal bars indicate the standard errors of the means. *F*-values represent repeated measures two-way ANOVA. Vegetation cover: Scarce = 0–<25%, Medium = 25–<75%, and Dense = >75; Depth: 0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40, 40–45, and 45–50 cm; *: $p < 0.05$; ***: $p < 0.001$; *ns*: not significant (i.e., $p > 0.05$); $n = 9$ for Scarce vegetation cover, $n = 11$ for Medium vegetation cover, and $n = 10$ for Dense vegetation cover.

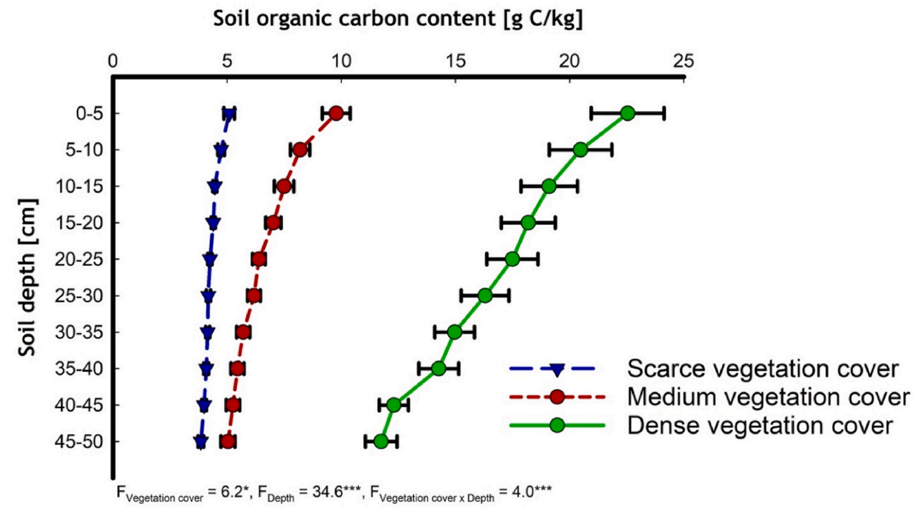

Fig. 2. Soil organic carbon content (g C/kg) in relation to soil depth (cm) under different vegetation group along the Wadi Al-Sharaea, Makkah Province, Saudi Arabia. Horizontal bars indicate the standard errors of the means *F*-values represent repeated measures two-way ANOVA. Vegetation cover: Scarce = 0–<25%, Medium = 25–<75%, and Dense = >75; Depth: 0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40, 40–45, and 45–50 cm; *: $p < 0.05$; ***: $p < 0.001$; *ns*: not significant (i.e., $p > 0.05$); $n = 9$ for Scarce vegetation cover, $n = 11$ for Medium vegetation cover, and $n = 10$ for Dense vegetation cover.

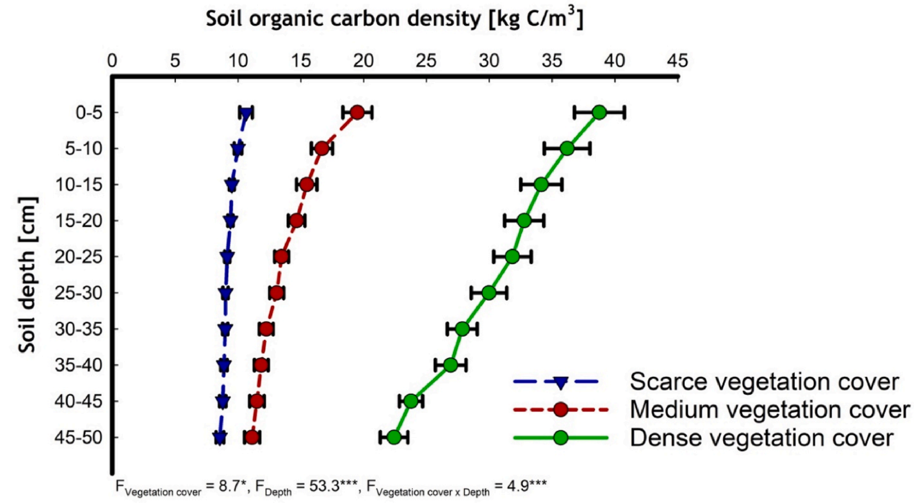

Fig. 3. Soil organic carbon density (kg C/m^3) in relation to soil depth (cm) under different vegetation group along the Wadi Al-Sharaea, Makkah Province, Saudi Arabia. Horizontal bars indicate the standard errors of the means. *F*-values represent repeated measures two-way ANOVA. Vegetation cover: Scarce = 0–<25%, Medium = 25–<75%, and Dense = >75; Depth: 0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40, 40–45, and 45–50 cm; *: $p < 0.05$; ***: $p < 0.001$; *ns*: not significant (i.e., $p > 0.05$); $n = 9$ for Scarce vegetation cover, $n = 11$ for Medium vegetation cover, and $n = 10$ for Dense vegetation cover.

sites with dense vegetation cover had the highest clay and silt content (14.7 ± 2.13 and 44.4 ± 2.03%, respectively, Table 1). Scarce vegetation communities had the highest fine sand content (53.8 ± 3.32%) and significantly different from both medium and dense vegetation plant communities. Plant communities with scarce and medium vegetation cover had soils with sandy loam texture, while dense vegetation cover had silty loam soil texture. Soils at Wadi Al-Sharaea, as an overall, were characterized by higher sand content (48.2%, both fine and coarse compiled) than silt (36.7 ± 1.64%) or clay (10.1 ± 1.28%).

Soil pH, EC, TDS, and Cl showed slightly significant differences between different vegetation cover groups ($p < 0.03$), while both soil Mg and HCO_3 showed no difference ($p > 0.05$, Table 1). Soils, on average, of Wadi Al-Sharaea were non saline (0.2 ± 0.02 ds/m) and slightly alkaline (8.2 ± 0.07, Table 1) with TDS of 98.8 ± 11.88 mg/l. Both soil Ca and K content were significantly different among vegetation cover groups ($p < 0.05$), while the soil of plant communities with dense vegetation cover had the highest content of Ca and K (1.7 ± 0.24 and 0.2 ± 0.03 meq/l, respectively, Table 1).

Table 1
Soil (mean ± SE) chemical and mechanical characteristics along Wadi Al-Sharaea, Makkah Province, Saudi Arabia. p values here represent one-way ANOVA of vegetation groups, while means with different superscripted capital letters in the same row are significantly different at $p \leq 0.05$ according to Tukey's HSD (Honest Significant Difference) test.

	Vegetation groups				p-value
	1 ($n = 6$) Scarce vegetation cover	2 ($n = 48$) Medium vegetation cover	2 ($n = 48$) Dense vegetation cover	Total average ($n = 102$)	
Soil chemical characteristics					
pH	$8.0^{A} \pm 0.05$	$8.3^{A} \pm 0.12$	$8.0^{A} \pm 0.07$	8.2 ± 0.07	0.0363
EC ds/m	$0.1^{A} \pm 0.01$	$0.1^{A} \pm 0.01$	$0.2^{A} \pm 0.04$	0.2 ± 0.02	0.0167
TDS mg/l	$81.3^{A} \pm 4.15$	$64.2^{A} \pm 3.32$	$135.5^{A} \pm 24.05$	98.8 ± 11.88	0.0122
Ca meq/l	$1.0^{BA}\pm0.07$	$0.8^{B} \pm 0.04$	$1.7^{A} \pm 0.24$	1.2 ± 0.12	0.001
Mg meq/l	$0.3^{A} \pm 0.02$	$0.4^{A} \pm 0.02$	$0.5^{A} \pm 0.08$	0.5 ± 0.04	0.1985
Na meq/l	$0.1^{A} \pm 0.01$	$0.1^{A} \pm 0.01$	0.3A ± 0.09	0.2 ± 0.05	0.0468
K meq/l	$0.1^{B} \pm 0.00$	$0.1^{B} \pm 0.01$	$0.2^{A} \pm 0.03$	0.1 ± 0.02	0.0058
HCO_3 meq/l	$1.0^{A} \pm 0.07$	$0.6^{B} \pm 0.05$	$0.7^{B} \pm 0.07$	0.7 ± 0.04	0.139
SO_4 meq/l	$0.3^{B} \pm 0.03$	$0.2^{B} \pm 0.02$	$0.7^{A} \pm 0.17$	0.5 ± 0.08	0.0077
Cl meq/l	$0.3^{B} \pm 0.00$	$0.8^{BA}\pm0.10$	$1.3^{A} \pm 0.23$	1.0 ± 0.12	0.0165
Soil mechanical characteristics (%)					
Gravel	$5.1^{BA}\pm0.90$	$7.2^{A} \pm 0.87$	$2.4^{B} \pm 0.53$	4.9 ± 0.53	<.0001
Coarse sand	$16.2^{A} \pm 1.36$	$12.3^{A} \pm 1.30$	$5.0^{B} \pm 0.86$	9.1 ± 0.83	<.0001
Fine sand	$53.8^{A} \pm 3.32$	$43.1^{B} \pm 1.78$	$33.3^{C} \pm 2.67$	39.1 ± 1.63	0.0007
Silt	$21.3^{C} \pm 2.62$	$30.9^{B} \pm 2.32$	$44.4^{A} \pm 2.03$	36.7 ± 1.64	<.0001
clay	$3.2^{B} \pm 1.12$	$6.3^{B} \pm 1.42$	$14.7^{A} \pm 2.13$	10.1 ± 1.28	0.0019
Soil texture	Sandy loam	Sandy loam	Silt loam	–	–

3.2. *Soil carbon stocks*

Soils with different vegetation covers (scarce, medium, and dense) showed significant ($p < 0.05$, Table 2) differences in SBD, SOC content, SOC density, and SOC stocks. Soils with dense vegetation cover had the lowest SBD (1.96 ± 0.03 g/cm^3) and the highest SOC stocks (14.9 ± 2.1 kg C/m^2), while soils of scarce vegetation cover had the lowest (4.5 ± 0.2 kg C/m^2). For the three different vegetation cover groups (scarce, medium, and dense) and over the soil profile (0–50 cm soil depth), SBD increased from top to bottom (Fig. 1) where soils near the soil surface were less dense than those soils at a deeper soil depth (50 cm soil depth). On the other hand, however, both SOC concertation and density showed the exact opposite (Figs. 2 and 3), where soils near the soil surface had higher SOC content and density. SBD for plant communities with dense vegetation cover increased from 1.88 ± 0.03 g/cm^3 at 0–5 cm to 2.03 ± 0.02 g/cm^3 at 45–50 cm (Fig. 1) – same pattern was noticed for scarce and dense vegetation cover groups. Dense vegetation cover plant communities had the highest SOC content (22.54 ± 1.59 g C/kg) at 0–5 cm and then continued to decrease until it reached the lowest SOC content (11.74 ± 0.69 g C/kg) at 45–50 cm soil depth (Fig. 2). Our regression data analyses showed that there is a strong and negative correlation between SBD and SOC content, while soils with dense vegetation cover had the most significant correlation ($R^2 = 0.95$, Fig. 4A). Moreover, plant communities with dense vegetation cover had strong and positive correlation between SOC content with SOC density and stocks ($R^2 = 0.996$ and 0.994, Fig. 4B and C, respectively).

4. Discussion

Along Wadi Al-Sharaea, soil C stocks were significantly different between the three different vegetation cover groups, with dense vegetation cover sites had the highest soil C stocks (14.9 ± 2.1 kg C/m^2). Variations between these vegetation cover groups in soil texture, plant productivity, and vegetation composition might explain their differences in C pools. Soils with medium vegetation cover had the highest gravel content (7.2 ± 0.87%), while those sites with dense vegetation cover had the highest clay and silt content (14.7 ± 2.13 and 44.4 ± 2.03%, respectively). Moreover, those plant communities with dense vegetation cover had a silt loam texture with the highest clay and silt content (14.7 ± 2.13 and 44.4 ± 2.03%, respectively). Comparing the particles size of sand grains with silt or clay, sand grains have larger particle size than those of silt and clay particles – implying that clay particles have larger surface area

Table 2
Soil bulk density (SBD; g/cm^3), soil organic carbon (SOC) content (g C/kg), SOC density (kg C/m^3) and SOC stock (kg C/m^2) under different vegetation group along the Wadi Al-Sharaea, Makkah Province, Saudi Arabia. Data are mean ± SE.

Vegetation group	SBD	SOC content	SOC density	SOC stock
Scarce vegetation cover	$2.15^{A} \pm 0.01$ [$n = 86$]	$4.3^{C} \pm 0.1$ [$n = 86$]	$9.3^{C} \pm 0.1$ [$n = 86$]	$4.5^{B} \pm 0.2$ [$n = 9$]
Medium vegetation cover	$2.12^{A} \pm 0.01$ [$n = 108$]	$6.7^{B} \pm 0.2$ [$n = 108$]	$14.0^{B} \pm 0.3$ [$n = 108$]	$6.9^{B} \pm 0.3$ [$n = 11$]
Dense vegetation cover	$1.96^{B} \pm 0.03$ [$n = 97$]	$16.9^{A} \pm 1.1$ [$n = 97$]	$30.7^{A} \pm 1.4$ [$n = 97$]	$14.9^{A} \pm 2.1$ [$n = 10$]
F-value	41.3***	110.7***	167.1***	19.1***

F-values represent 1-way ANOVA, degrees of freedom (*df*) = 2. Means in the same column followed by different superscripted capital letters are significantly different at $p < 0.05$ according to Tukey's HSD (Honest Significant Difference) test. ***: $p < 0.001$.

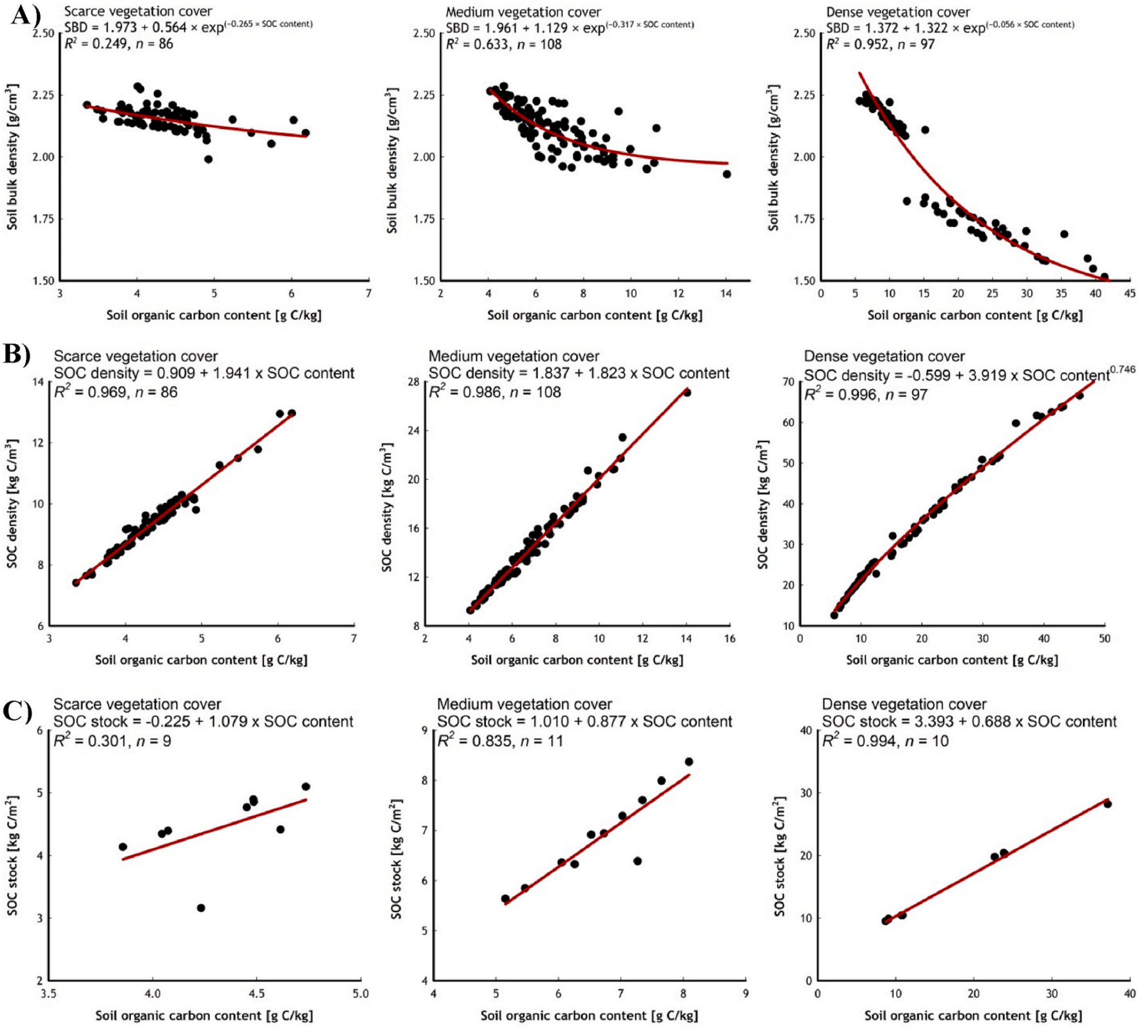

Fig. 4. Linear and non linear regression analyses for soil organic carbon content (g C/kg) in relation to (A) soil bulk density (g/cm^3), (B) SOC density (kg C/m^3), and (C) SOC stocks (kg C/m^2) of soil samples under different vegetation group along the Wadi Al-Sharaea, Makkah Province, Saudi Arabia.

compared to sand [47,48]. Moreover, clay particles can accommodate more C to be stored since their particles has larger surface area and high electrostatic force [49]. We hypothesized that soils with higher clay content would retain more soil C. Having higher silt and clay content with lower SBD at those sites of dense vegetation cover might explain higher SOC stocks at their soils compared with those of scarce vegetation cover – supporting our hypothesis.

Soil bulk density has a major role in soil C content build up [50,51], where less dense soils would have higher soil C content especially with more fresh and less decomposed plant materials. Our results indicated that SBD was strongly and negatively correlated with SOC content ($R^2 = 0.95$ for soils with dense vegetation cover, $p < 0.05$), and many research studies reported similar findings [38,41,52–57]. Sites with no or scarce vegetation cover had the highest SBD, while soil sites with dense vegetation cover had the lowest (less dense) – and that our findings were similar to others [54,55]. Growth of plant roots along with litter inputs of growing plant species at the sites with medium or dense vegetation cover might explain the lower bulk density with higher SOC content and stocks. Our results indicated that soils had less density near the soil surface compared with deeper soil. There are some physical and chemical factors that impact SBD and that include SOM content, plant roots, porosity, and soil texture [40,58,59]. More fresh plant litter near the soil surface would lead into less SBD compared with deeper soil that has less root productivity and higher mineral constituent.

Soil is a complex system and factors affecting spatial variability of SOC content are, to a great extent, unknown [14]. Land use, soil texture, bedrock material, electrical conductivity, plant species diversity, shoot/root biomass allocation, hydrology, and various microbial activities govern the SOC content spatial variability [13–17,60,61]. Moreover, soil aggregation and C storage capacity would impact the SOC content buildup and SOM persistence [18,19]. Complex interactions of these factors govern the SOC content spatial variability [14] at different vegetation and sites scales (reginal and global). Along soil depth, variation in soil bulk density, soil type, and geology would affect the SOC content spatial variability [62]. Our results indicated that SOC content was higher near the soil surface where higher litter inputs from plants and then decrease with soil depth – agreeing with other studies with arid climate [54,56]. However, SOC showed higher variability with soil depth. SOC content higher variability could be attributed to the complex interaction between many variables including SOM decomposition rates, nutrient leaching, mineral deposition, and microbial processes [63,64]. Comparing our soil C stocks (ranged from 4.5 to 14.9 kg C/m^2, to a 50 cm soil depth) in an arid climatic conditions to other similar studies, we found out that our soil C stocks were in a similar range. Eid et al. [54] reported 6.7–12.8 kg C/m^2 (up to a 50 cm soil depth) in coastal ecosystems along the Mediterranean coast of Egypt that has arid climatic conditions. However, El-Sheikh et al. [56], reported lower SOC stocks in Wadi Al-Thulaima, Saudi Arabia, with an average of 2.0 kg C/m^2 (up to a 18 cm soil depth) in the vegetated areas compared to 0.5 kg C/m^2 in bare lands. Our results highlights the relationship between soil characteristics and how they influence SOC content in desert wadi – which is novel and unique since there were limited studies about SOC content in arid ecosystems. Plant biomass and their inputs to the soil are among factors governing the SOM persistence to decomposition and SOC stocks accumulation. Soil C studies on desert wadis are limited, and accordingly our finding of soil C content in relation to plant vegetation covers is pioneer to provide data for researchers to better evaluate and elucidate processes underlying C budget at the regional and global scales to better cope with ongoing climate change.

The notion of higher precipitation and more plant species diversity enhance soil C content are well established [65–67]. More plant species diversity promotes higher productivity and more belowground biomass, and that would increase soil C content in vegetated areas compared with soils with no or scarce vegetation. Li et al. [66] indicated revegetation had significantly enhanced SOC storage and reduced soil erosion in natural ecosystems. We hypothesized that sites with higher plant species cover would have higher soil C content. In our study, soils with dense vegetation cover had significantly ($p < 0.05$) higher soil C stocks (14.9 ± 2.1 kg C/m^2) than those of scarce vegetation (4.5 ± 0.2 kg C/m^2) – in support of our hypothesis. Enhancing soil C content as a result of higher productivity might explain higher soil C stocks at those sites with dense vegetation cover compared with scarce or no vegetation sites. One limitation to the current study is that the research was conducted during one season and accordingly the data presented here reflect soil C content among different groups of plant vegetation cover during that season. However, studying the relationship between soil C content and the plant species vegetation cover would be more comprehensive to draw conclusion based on analyzing the context of soil C content under various seasons with different plant species and various vegetation covers.

5. Conclusions

Based on our study findings, we concluded that those sites with dense vegetation cover communities had soils with higher clay content and C stocks compared with those sites of scarce vegetation plant communities. Moreover, medium vegetation cover sites had the highest gravel content, while sites with dense vegetation cover had the highest clay and silt content. SBD was lowest at those sites of dense vegetation cover, but they had the highest SOC stocks. Moreover, there was a strong and negative correlation between SBD and SOC content, where soils of the dense vegetation cover had the most significant correlation ($R^2 = 0.95$). Since precise estimation for global C budget is challenging, inclusions of soil C stocks of different vegetation strata among arid regions is highly recommended.

Author contribution statement

Hanan E. Osman; Abeer A. Elaidarous; Mohamed H. El-Morsy: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ebrahem M. Eid and; Amr E. Keshta: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no competing interests

Appendix B. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.heliyon.2023.e12988.

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