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SOIL CHEMISTRY

Lateral and Vertical Variations of Soil Organic and Inorganic Carbon Content in Aridisols and Entisols of a Rangeland

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Abstract—The influence of biological and physicochemical soil properties on the variations in soil organic and inorganic carbon (OC and IC) contents at the soil surface was studied. Three-dimensional plots of variations in OC, IC and the correlated properties were obtained. Soils of the study area were classified as Aridisols and Entisols used as a rangeland. Soil samples were collected from 38 representative points with a wide range of physicochemical soil properties; in addition, three important microbiological indicators—dehydrogenase enzyme activity (DHA), soil basal respiration, and bacterial population—were analyzed. Variation partitioning analysis was carried out to assess the determining factors influencing soil OC and IC variations in the vertical soil profiles. Additionally, the principal component analysis (PCA) was applied to explore the patterns of determinant soil variables. Variation partitioning demonstrated that the physicochemical soil properties were the determining variables in explaining the variations of both OC and IC. A remarkable portion of the variations remained unexplained by any of the two explanatory sets according to this analysis. Soil OC was not significantly related to the biological soil properties. Soil OC was inversely related to IC, clay, and sodium contents in the soil profiles. Soil type-specific vertical trends were observed for soil OC and IC. Soil conditions and pedogenic processes were deduced to have a major role in OC and IC spatial variations according to the results of soil type-specific trends of variation. The results of this study can be useful for better soil management and OC and IC prediction, or spatial distribution patterns modeling.

Keywords: variation partitioning, dehydrogenase enzyme, vertical soil variation, spline function

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INTRODUCTION

Soil carbon is one of the key properties, which affects soil quality to a large extent and has a significant influence on atmospheric CO_2 concentration, as soil is the largest terrestrial carbon pool [1, 2]. Soil carbon plays a major role in soil fertility and prevention of land degradation and provides many ecosystem services and climate regulation. For example, due to the major contribution of soil C in global C dynamics, even small changes in soil carbon stock leads to significant atmospheric CO_2 concentration change [3, 4].

Generally, soil carbon has been investigated with regard to climate [5, 6], topography [7, 8], land use [9] and soil type [10, 11]. In the latter ones, the effect of biome and deforestation has been influencing factors as well. However, the challenge in soil carbon is also the soil conditions that affect it [12, 13]. The conditions under a relatively uniform land cover and climate could be soil type-specific or soil physico-chemical properties. In addition, from the soil security point of view, this is particularly important to study the conditions to obtain more thorough understanding of soil carbon drivers for more precise soil management and land use planning. Therefore, exploring soil-specific factors affecting carbon will help better designs for local soil-type specific land management and have a better understanding of soil OC and IC for predictive models in such areas, where soil factors are the main drivers of OC and IC variations.

Studies on quantifying the relationships between soil C and other soil properties have been mainly limited to physical and chemical characteristics with relatively narrow range of variables without taking into account the role of microbiological properties (e.g. [14, 15]).The role of soil important microbiological characteristics cannot be ignored in assessing soil spatial variation, as they vary within space and the main causes of organic carbon decay are microbiological activities. Soil IC has been neglected in most carbon studies. Inorganic carbon plays an important role in the carbon cycle [16, 17] and can be dynamic in soils [18]. In particular, soils of arid and semi-arid regions, covering a vast area of the earth surface, contain signifi-

Table 1. Soil types and number of observations

Soil type	Number of observations
Argigypsids	4
Calcigypsids	11
Haplogypsids	3
Haplocalcids	7
Haplocambids	2
Xerofluventic Haplocambids	2
Natrigypsids	6
Sodic Haplogypsids	3
Torrifluvents	1

cantly higher inorganic C in comparison with other regions. Therefore, taking inorganic C into account for soil C variations studies is vital in such regions. Furthermore, studying soil-specific properties and soil types effects that might be potential drivers of soil carbon variations is necessary to decrease our uncertainty and unknowns about soil carbon [19].

In this research, for achieving a deeper understanding of the major factors influencing soil organic and inorganic carbon variations, a wide range of soil physical, chemical, and biological characteristics were analyzed. The microbiological characteristics include dehydrogenase enzyme activity, soil basal respiration and bacteria count, which are the most common indicators of soil biological activities [20]. This research aims to: (a) investigate the relative contribution of sets of soil physiochemical and biological properties on organic and inorganic C contents variation using variation partitioning technique; (b)investigate soil OC and IC in the 6 standard soil depth intervals with relation to other soil physicochemical properties by harmonizing soil legacy profiles; and (c) explore the vertical trends of variation in OC and IC with regard to different soil types.

MATERIALS AND METHODS

Study area Description

The study area was in Parsabad-e-Moghan in Ardebil province located on North West of Iran. Mean annual precipitation is 271 mm and mean annual average of daily temperature is 15°C with mean altitude of 255 m above sea level. Most of the precipitation occurs from March to May and September to December. The warmest month is July with mean temperature of 27°C and the lowest mean temperature is 3.7°C in January. According to the De Martonne climate classification, the climate of the study area is semi-arid and it is temperate arid according to the Emberger method. Soils of the region include Aridisols and to a lesser extent Entisols, according to the USDA soil taxonomy [21]. The lands cover is mostly rangeland with mainly grass, *Astragalus* and *Artemisia* plants. The whole area covers around 12000 ha. Dominant physiographic unit of the study area is plateau with hills and piedmont plains in smaller extents.

Soil Sampling and Analyses

In an area of about 12000 ha, 452 soil profiles were dug. After morphological description of the soil genetic horizons, 38 representative soil families were selected according to the USDA soil taxonomy [21]. Samples were collected from genetic horizons of these representative soil profiles up to a depth of 1.5 m. The soil families were reclassified to 8 great groups to study soil type effect on vertical variations of soil OC, IC (Table 1). For soil profiles with more than one observation, average of different horizons values of the considered properties were calculated and the vertical graphs were obtained using the mean of multiple observations for a given soil type. In addition, Soil samples were collected from 0–15 cm of top soil separately to analyze microbiological properties. The location of sampling sites is shown in Fig 1. Soil surface was analyzed to find out the effect of two groups of soil physicochemical and microbiological properties on both OC and IC. Then, sub-surface was analyzed to explore the effect of physicochemical properties on OC and IC variations. Physical and chemical characteristics include soil texture by hydrometer method, bulk density by the core method, particle density by the pycnometer method, available water by subtracting the permanent wilting point (*w*/*w*%) from the field capacity (*w*/*w*%) that were measured by the pressure plate method [22]. The total porosity was calculated from:

$$\text{Porosity} = 1 - [\rho_b/\rho_p],$$

where ρ_b is bulk density and ρ_p is particle density of soil samples.

EC was measured using electrical conductivity meter using soil saturation extract and acidity by pH meter using saturated paste. Cation exchange capacity (CEC) and was measured by Bower method [23] and exchangeable sodium percentage (ESP) was determined by ammonium acetate and the use of flame photometer [23]. Ca^{2+} and Mg^{2+} were determined using titration method and Na^+ and K^+ were determined using flame photometer. Plant available phosphorus was determined by Olsen method [24] and total nitrogen was measured by Kjeldahl method [25]. Soil organic carbon and total carbonates equivalent were measured by Walkley-Black and calcimetry methods, respectively [26, 27]. Gypsum, soluble carbonate and bicarbonate were determined by methods described in [27] and Cl^- was measured by the method described in [28]. Soluble sulfate was determined by barium precipitation and spectroscopy method [28]. Saturation percentage (disturbed) was determined by dividing soil water weight (after saturation of soil and weighing and oven drying) by soil dry weight multi-

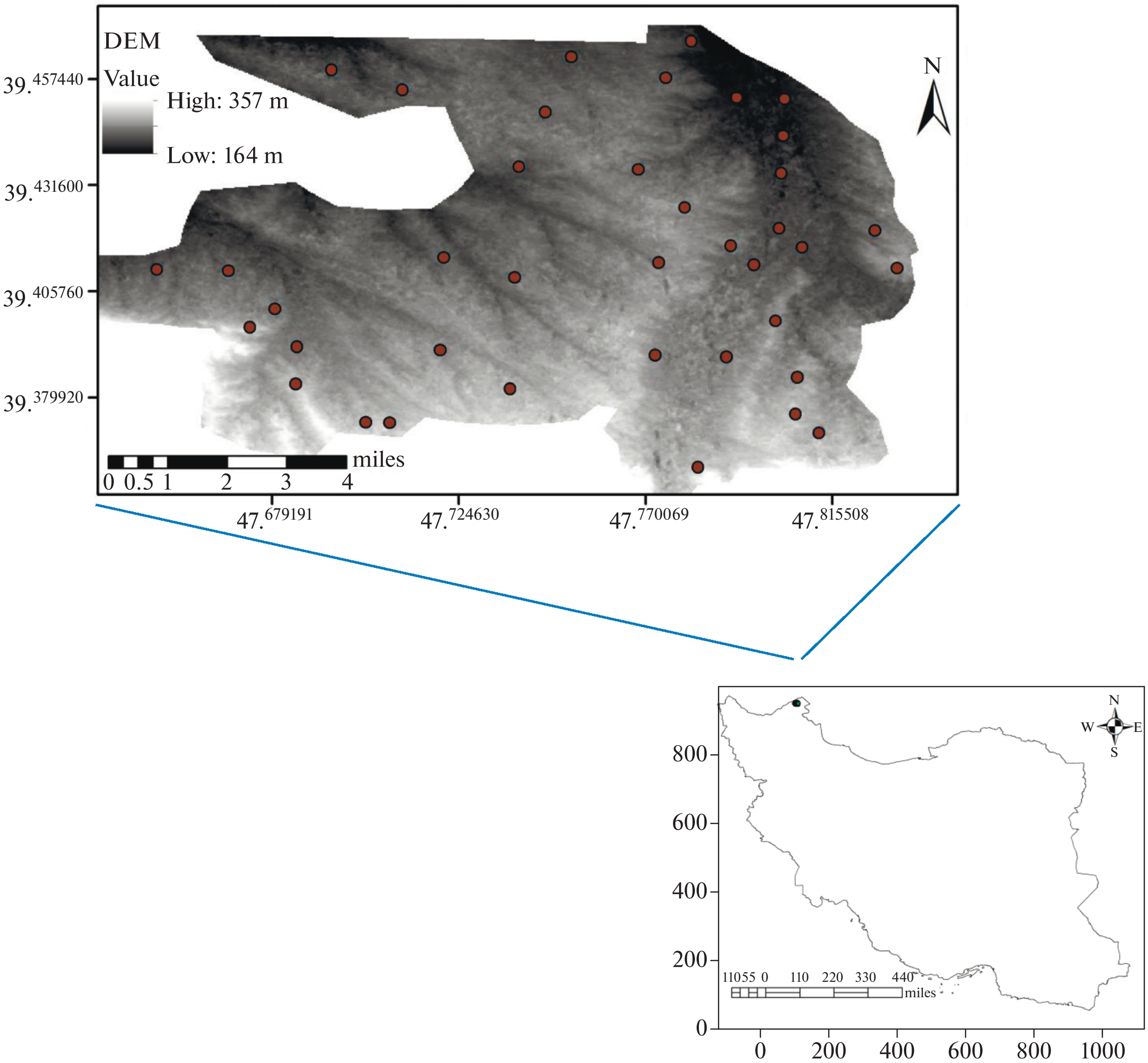

Fig. 1. Study area and sampling locations.

plied by 100. Total carbonates equivalent percentage (total neutralizing value) (TNV) is considered as inorganic carbon in this study.

Separate samples were collected from the sampling points with extra care by having disinfected the sampling tools and using sterile materials for each sample and transferring the samples to the laboratory as soon as possible for the biological properties measurements. Three samples within 5-m distance were collected at each site for replication. The samples were maintained at 4°C temperature, and the analyses were performed immediately within around one month to decrease the biological changes during the analysis. Dehydrogenase enzyme activity was measured by triphenyltetrazolium chloride (TTC) substrate by determining the produced triphenylformazan(TPF)using spectrophotometer at 546 nm wavelength [29]. Soil basal respiration was measured using titration method by determining the reaction of CO_2 with NaOH per week (calculated for 24 hours) [29]. Soil bacteria population number was measured by most probable number method with 8 dilutions and5 replicates using nutrient broth substrate [30].

Soil Profiles Harmonization

Since the soil profiles had been sampled with regard to genetic horizons and these horizons do not have equal depth intervals in all of the profiles due to natural variations and soil types, they need to be har-

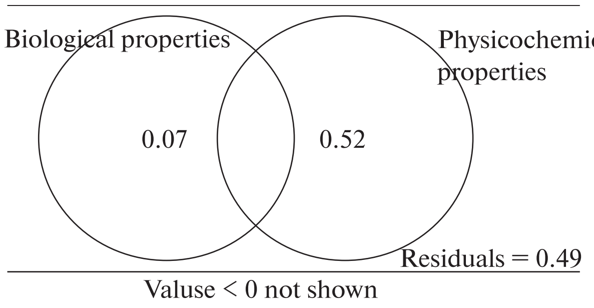

Fig. 2. Venn diagram showing the partitioning of variation of soil OC between the two sets of explanatory variables of biological and physicochemical properties. Here, the shared section has a negative value. HCO_3^- and TNV were excluded from the predicting properties.

monized for comparison. Equal-area quadratic spline function [31, 32]was fitted for all of the profiles to generate 6 depth intervals. The harmonized depths comprise 0–5, 5–15, 15–30, 30–60, 60–100 cm and 100–200 cm intervals, which are according to standard depths for soil studies in Global Soil Map project specifications [33]. Then, we will be able to explore lateral and vertical variations and correlations of soil desired properties in different profiles. Intuitively speaking, we investigated 6 soil layers covering the study area as a whole from surface to the depth of 2 meters to study correlations of soil OC and IC with other variables. This analysis was performed using *ea_spline* function in R software within the *ithir* package [34].

Statistical Analyses

Variation partitioning [35] was used to quantify the relative importance of soil physicochemical properties and considered biological characteristics in explaining the variations of soil organic and inorganic carbon. Adjusted R^2 value was calculated to gain unbiased estimates [36] using *varpart* function in the *vegan* package [37]in the *R* software. In this analysis, the common and unique contribution of sets of explanatory variables (two sets including soil physicochemical and microbiological indicators) in soil organic and inorganic carbon variations is determined. Additionally, a fraction of response variables variations that could not be explained by any of the considered explanatory sets of variables is determined as residuals.

The principal component analysis (PCA) was carried out in the SPSS® software (version 16.0) to investigate the patterns of soil determining properties variations and find out the most important variable(s) with the highest variance in soil surface. Where necessary, the data were transformed using logarithm and 1/x formulae to correct the skewness and kurtosis, for normalization. Spearman correlation analysis was performed by SPSS® software (version 16.0).

RESULTS

Three Dimensional. Soil Properties Variations

For the topmost soil horizon (0–5 cm), the soluble carbonate, exchangeable sodium, and sulfate were highly variable with a coefficient of variation (CV) of 236.4, 120.1 and 116.7%, respectively, however, pH (3.5%) and bulk density (4.7%) were the least varying properties. In general, soil OC content is low and ranges from 0.32 to 1.98% but IC was fairly high and showed more variability across the study area (1.90 to 20.90%) (Table 2).

In the layer of 5–15 cm, EC was the most varying soil property with CV of 121%, a plausible driver could be an equally high variability in sulfate (116%), Ca^{2+}(79%) and Cl^-(71%). In the 15–30 cm depth, Cl^- and gypsum were the most variable properties. Chloride, gypsum and soluble sodium were also highly variable in the fourth layer (30–60 cm). In the 60–100 cm depth, OC with the CV of 155% was the most varying property followed by chloride with the CV of 120%. In the 100–200 cm depth interval, OC and gypsum were found as the most varying properties with CVs of 118% and 93%, respectively.

The Relative Importance of Soil Physicochemical and Microbiological Properties Groups on OC Variation in Soil Surface

Variation partitioning analysis showed the relative influence of each group of explanatory variables on OC variability alone and commonly (Fig. 2 and Table 3). As can be seen from the Table 3 and Fig. 2, most of the soil OC variations were explained uniquely by soil physicochemical properties rather than biological properties. The shared influence of these two groups was –0.081, which indicates that the two explanatory groups are uncorrelated. The total sum of the unique effect of biological properties, "**a**", unique effect of physicochemical properties, "**c**", shared influence of these two sets, "**b**" and the portion of variation that cannot be explained by any of the two sets "**d**", equal to 1. A proportion of 49% of the total variation in soil OC could not be explained neither by soil physicochemical nor microbiological variables. Inclusion or exclusion of some properties during the analysis changed the results. Most importantly, bicarbonate, which had a significant positive correlation with OC, induces a positive common effect on the two sets of explanatory variables in explaining the variation of OC. It also led to an increase in the contribution ration of physicochemical set (Fig. 3 and Table 4).

The Relative Importance of Soil Physicochemical and Microbiological Properties Groups on IC Variation in Soil Surface

Variation partitioning results for quantifying the unique and shared effects of soil physicochemical and

Table 2. Descriptive statistics of the measured soil properties

Soil property	Minimum	Maximum	Mean	Variance	CV
Resp[1]	0.01	1.92	1.28	0.28	40.7
DHA[2]	11.05	106.12	49.48	540.91	46.4
Bacteria[3]	0.17	92.00	20.27	833.81	140.6
Clay[4]	18	50	36.11	56.75	20.6
Silt	22	57	43.74	76.85	19.8
Sand	7	60	19.92	151.75	61.0
SP	33.00	62.00	52.47	29.82	10.3
EC_e[5]	0.58	2.67	1.12	0.26	44.5
pH	7.09	8.27	7.73	0.08	3.5
OC (%)	0.32	1.98	1.14	.15	33.9
N[6]	0.04	0.18	0.12	0.01	25.1
P[7]	2	16	5	11	66.0
K[8]	155	606	314	8696	29.3
TNV[9]	1.9	20.9	8.3	20.6	54.0
Gypsum (%)	0.9	5.1	2.1	1.0	47.4
CEC[10]	14.0	40.0	31.7	25.4	15.7
ESP	0.5	14.0	2.1	6.4	116.9
SAR	0.3	8.1	1.7	3.0	102.3
*Ca^{2+}	1.6	33.6	8.6	48.2	79.9
$ExNa^+$	0.1	4.5	0.7	0.7	120.1
Mg^{2+}	0.0	10.0	2.4	3.1	72.1
Na^+	1.0	11.0	3.1	5.7	75.7
CO_3^{2-}	0.0	3.2	0.32	0.6	236.4
HCO_3^-	1.6	8.0	4.8	2.4	32.3
Cl^-	0.4	5.6	1.6	1.4	72.3
SO_4^{2-}	0.0	36.2	7.9	87.1	116.7
BD	1.29	1.55	1.42	0.01	4.7
PD	2.20	2.70	2.52	0.02	5.7
** AW	5.0	12.0	9.3	2.5	16.5
Porosity (%)	0.30	0.51	0.43	0.01	11.7

[1] Basal respiration, mg CO_2/g soil 24 h^{-1}; [2] dehydrogenase activity, µg TPF/g soil 16 h^{-1}; [3] bacterial population, million cells; [4] clay, silt, and sand, g 100 g^{-1}; [5] electrical conductivity, dS/m; [6] total nitrogen, %; [7] available phosphorus, mg L^{-1}; [8] available potassium, mg L^{-1}; [9] total neutralizing value, %; [10] cation exchange capacity, $cmol_c$ kg^{-1}.
* All soluble cations and anions, $mmol_c$ L^{-1}.
** Available water, vol %.

Table 3. Variation partitioning of soil OC as a function of soil physicochemical and biological variables in the study area.

Fractions	DF[1]	R. squared	Adj. R. squared[2]
[a + b] = X1	3	0.07	–0.01
[b + c] = X2	23	0.79	0.44
[a + b + c] = X1 + X2	26	0.85	0.51
[a] = X1|X2	3		0.07
[b]	0		–0.08
[c] = X2|X1	23		0.52
[d] = Residuals			0.49
Total variation (SS): 5.65			
Variance: 0.15 No. of observations: 38			

X1 is the set of soil biological properties (mentioned earlier), X2 is the set of soil physicochemical properties, and b is the shared effect of X1 and X2. [1] Degrees of freedom of the numerator in the *F*-statistic. [2] Adjusted R squared is used as an unbiased estimate for comparing different soil sets of properties effects. For detailed explanation on the statistics please see Legendre (2008).

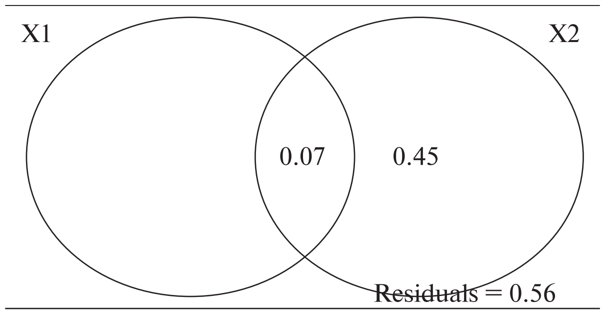

Fig. 3. Variation partitioning in soil OC by the two mentioned sets with inclusion of HCO_3^-. X1 is the set of biological properties and X2 is the set of physicochemical properties.

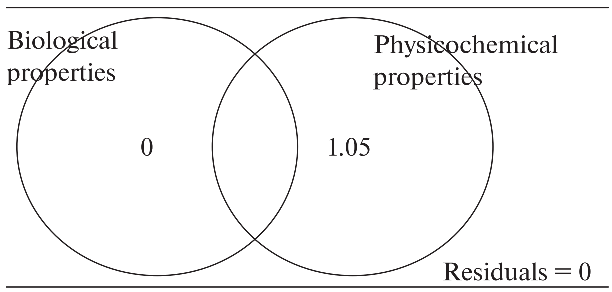

Fig. 4. Venn diagram representing unique and common influences of soil properties groups on the soil IC variation in the study area.

microbiological properties on IC variations revealed that soil physicochemical properties explain nearly 100% of IC variation in the study area (Fig. 4 and Table 5). The intersection (shared effect) in Fig. 4 and fraction [b] in Table 3 show that there is no correlation between the two explanatory sets of variables in explaining the IC variations. When OC, which had a negative (R = –0.26) correlation with IC, was included in the predicting properties (physicochemical set), no unique positive influence was observed for any of the explanatory sets, but a common positive effect of 22% was found in explaining the variation of IC (Fig. 5 and Table 6).

Significantly Related Variables with OC in Different Soil Depths

Macronutrients, total nitrogen, available phosphorus and total potassium were measured for the first 4 depths. In all of the depth intervals, nitrogen showed a significant positive correlation with OC at $^{**}P < 0.01$. Phosphorus was significantly related to OC only in the 15-30 cm depth, which showed a negative correlation. Potassium was not significantly related to OC in any of the depths. With regard to other soil properties, in the 0–5 cm depth, HCO_3^- showed a significant positive correlation with OC, while clay, ESP and gypsum showed significant negative relationships with OC. For the 5–15 cm depth, results were similar, except that clay did not show a significant correlation, but soluble Na^+ showed a significant negative correlation with OC. In the 15–30 cm depth, OC had a significant positive correlation with HCO_3^-. For the deeper intervals, results were different; the significant positive correlation with OC was for CEC, and gypsum showed a significant negative correlation (both at $^{*}P < 0.05$). In the 60–100 cm depth, the only significantly correlated property with OC was IC, which showed a negative relation. In the layer of 100–200 cm, OC displayed a significant positive correlation with chloride.

Significantly Related Variables with Inorganic Carbon in Different Soil Depths

With regard to the macronutrients, total nitrogen and potassium showed a significant negative correla-

Table 4. Variation partitioning of soil OC as a function of soil physicochemical and biological variables with HCO_3^- included in the explanatory variables

Fractions	DF[1]	R. squared	Adj. R. squared[2]
[a + b] = X1	3	0.07	–0.01
[b + c] = X2	25	0.84	0.52
[a + b + c] = X1 + X2	28	0.86	0.44
[a] = X1|X2	3		–0.08
[b]	0		0.07
[c] = X2|X1	25		0.45
[d] = Residuals			0.56
Total variation (SS): 5.65			
Variance: 0.15 No. of observations: 38			

Explanation of the table items is provided in the footnote of Table 2.

Table 5. Variation partitioning analysis of soil IC as a function of soil physicochemical and biological properties

Fractions	DF[1]	R. squared	Adj. R. squared[2]
[a + b] = X1	3	0.03	–0.05
[b + c] = X2	25	1.00	1.00
[a + b + c] = X1 + X2	28	1.00	1.00
[a] = X1|X2	3		0.00
[b]	0		–0.05
[c] = X2|X1	25		1.05
[d] = Residuals			0.00
Total variation (SS): 762.64			
Variance: 20.61 No. of observations: 38			

Note: X1 is the set of soil biological properties, X2 is the set of soil physicochemical properties, and b is the shared effect of X1 and X2.

Table 6. Variation partitioning analysis of soil IC as a function of soil physicochemical and biological properties, with OC included in the explanatory variables

Fractions	DF[1]	R. squared	Adj. R. squared[2]
[a + b] = X1	3	0.03	–0.05
[b + c] = X2	24	0.54	–0.30
[a + b + c] = X1+X2	27	0.58	–0.57
[a] = X1|X2	3		–0.27
[b]	0		0.22
[c] = X2|X1	24		–0.52
[d] = Residuals			1.57
Total variation (SS): 762.64			
Variance: 20.61 No. of observations: 38			

Explanation of the table items is provided in the footnote of Table 2.

tion with IC in 0–5, 5–15 and 15–30 cm depth intervals (at $*P < 0.05$). Phosphorus showed a significant negative correlation with IC only in the 15–30 cm depth. There was no significant correlation between macronutrients and soil IC in the 30–60 depth interval. In the 0–5 cm and 5–15 cm depths, CEC, clay percentage and pH showed a significant positive correlation with IC (at $*P < 0.05$). In the 30–60 cm depth, soluble calcium and gypsum contents showed a significant negative correlation with IC (at $*P < 0.05$). In the 60–100 cm depth, IC had a significant positive relation with soluble sulfate (at $*P < 0.05$) and a significant negative correlation with OC (at $**P < 0.01$). In the 100–200 cm depth, correlations were not significant, but the highest ones were chloride, which was positively correlated and sulfate, which was negatively correlated with IC.

Principal Component Analysis Results in the Soil Surface

As the physicochemical set of properties was found to be more determining in explaining the variations of soil OC and IC, PCA was performed to investigate the variables with more and less importance given the explained variances. With regard to the eigenvalues of more than 1.0, we maintained 6 components. The first and the second components accounted for most of the variance in the data with 34.4% and 16.6% of the total amount respectively (Table 7). The first component

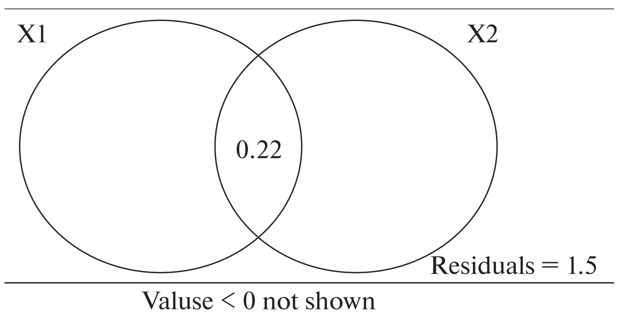

Fig. 5. Venn diagram of the variation partitioning in soil IC with OC included in the explanatory set X2. X1 is the set of biological properties and X2 is the set of physicochemical properties.

Table 7. Results of components' factorization in PCA

Total Variance Explained						
Component	initial Eigenvalues			rotation Sums of Squared Loadings		
	total	% of Variance	cumulative %	total	% of Variance	cumulative %
1	9.80	36.31	36.31	9.30	34.44	34.44
2	5.17	19.14	55.45	4.49	16.62	51.07
3	2.95	10.94	66.39	2.61	9.68	60.74
4	2.28	8.44	74.83	2.51	9.31	70.05
5	1.61	5.95	80.78	2.45	9.06	79.12
6	1.16	4.29	85.07	1.61	5.96	85.07

Extraction Method: Principal Component Analysis.

(axis) in PCA showed that most of the variance is explainable by saturation percentage, pH, CEC, K, AW, HCO_3^-, porosity, and OC, which are negatively related to N, P, BD and EC. Variables with loading values more than 0.5 are expressed here as the most important ones. In the sixth component, TNV and gypsum percentage were the most important variables.

Vertical Trend Of Variations; Is There a Soil-Type-Related Trend for OC, IC in Depth?

Organic carbon showed a decreasing trend with depth in all of the soil types, except for the Xerofluventic Halocambids, which showed an increasing trend from 15 cm to 100 cm depth and then decreased downward the profile (Fig. 6). It is obvious that this situation could have happened because of some surface process of translocation of deposits, as the soil type name indicates. Inorganic carbon content showed a subsurface increasing trend from 15 cm to 60 cm depth for Torriorthents, Halpocalcids, Calcigypsids, Natrigypsids and Sodic Haplogypsids, but a decreasing trend for this depth was observed for Xerofluventic Haplocambids and Argigypsids. It can be observed that there is an inverse trend downward the soils between OC and IC. However, for Argigypsids, this relationship was not inverse.

DISCUSSION

Generally, it has been reported that soil macronutrients (N, K, and P) and OC are related with dehydrogenase activity. For example, some researchers found positive correlations between DHA, OC, and macro-nutrients, however, for N they were only correlated with NH^+ nitrogen form [38]. In contrast to this, some researchers reported low or no correlation between soil DHA and OC [39, 40].

In the literature, typically, it has been stated that soil clay percentage is positively related to soil organic matter content, but in some cases, an inverse correlation has been reported too. A very low correlation ($R = 0.07$) between soil clay content and OC percentage has been also observed [41]. Regarding the Na^+-related characteristics correlation with OC, it has been reported that soil Na^+ could affect OC negatively by decreasing aggregation, which increases mineralization. Also, soil organic matter and Na^+ form complexes, which are highly soluble and hence prone to losses through drainage or runoff [42].This argument seems applicable to our research, as there was a significant [$^{**}P < 0.01$] negative correlation between soil OC and Na^+ related characteristics of SAR, ESP, and exchangeable Na^+. On the other hand, soil clay percentage was positively correlated with sodicity indicators including soluble Na^+, ESP, and SAR. These could be reasons why there has been a negative relationship between soil clay and OC content.

The lower effect of biological properties on OC might be due to the type or quality of the organic matter in soils of the study area [43]. Some other determinant variables may have affected the study area, as nearly 50% of the variation could not be explained by any of the two groups of soil properties, according to the variation partitioning analyses.

For example, livestock grazing intensity and the animal waste can affect soil organic carbon significantly [44] and this factor may have influenced the distribution and spatial variation of OC. Our findings are close to those of Lucas-Borja et al. [45], who observed a low negative correlation between soil OC and DHA. They also found a positive relationship between soil P and DHA. It seems that the quality of organic matter in soil has a higher impact than its quantity, as it can provide a desirable substrate for microorganism activities. This is particularly true in DHA relationship with OC [46, 47]. This could be a reason for the low association between soil DHA and OC in our study. In addition, there could be autotrophic organisms prevailing in the soils of the study area, which do not rely on OC for their living activities. There was a non-significant and low correlation ($R = 0.11$) between soil OC and soil CEC in soil surface. This may signify

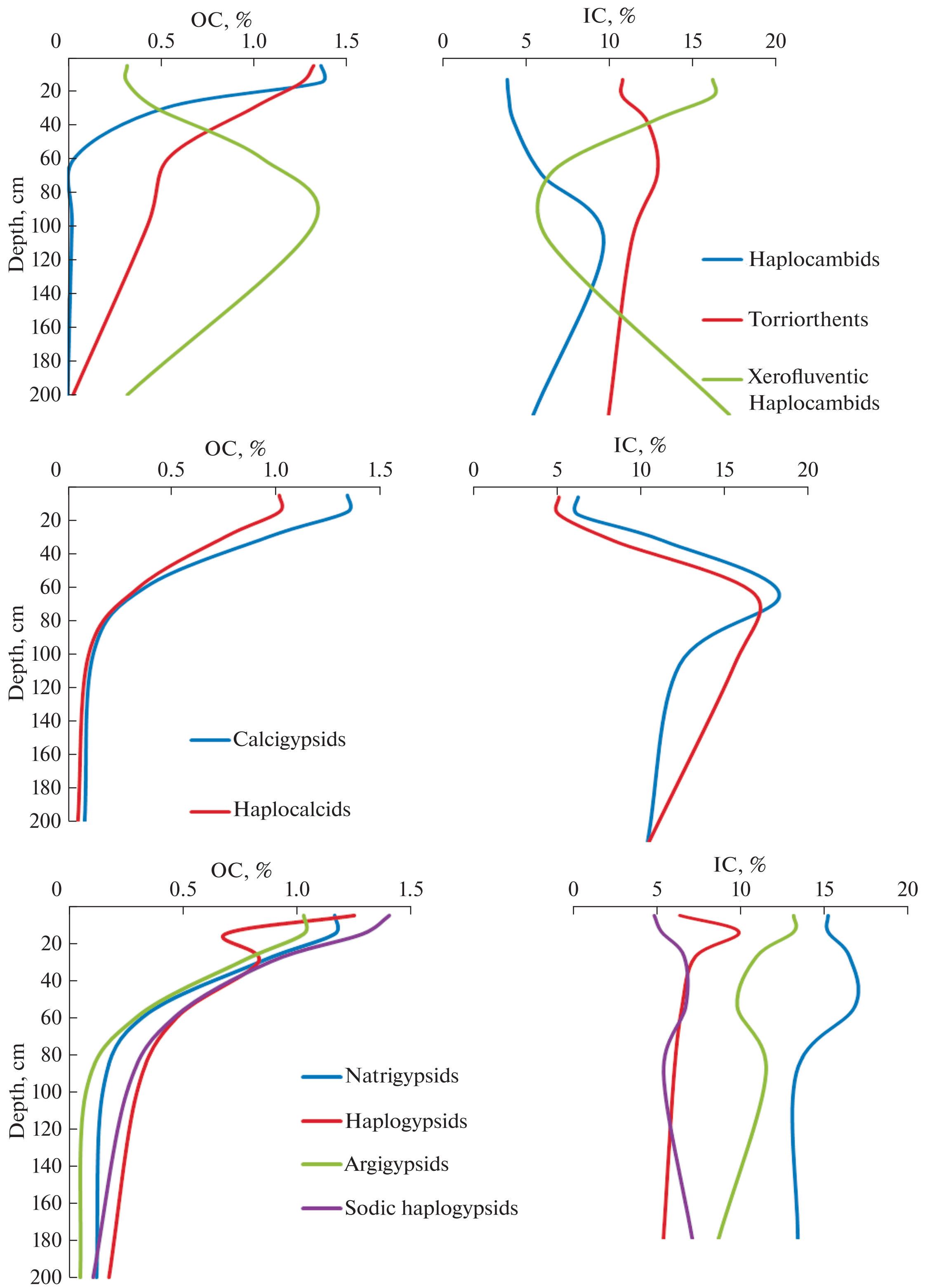

Fig. 6. Vertical variations of soil organic and inorganic carbon in different soil types.

the importance of the quality of organic matter again, as OC did not account for the CEC as much as it was expected in the soils of the study area. Some researchers have emphasized the significant influence of clay mineralogy on soil OC stabilization [48, 49]. In contrast, it has been reported that soil OC is driven by microbial communities more than clay mineralogy [50]. By and large, it could be deduced that although soil OC decomposition is due to microbiological activities, its spatial distribution and maintenance in soils is not necessarily thoroughly accounted for by mere microbiological activities. Soil OC maintenance and variations could be due to different physicochemical properties and pedological processes like chemical and physical stabilization [51]. It has also been reported that soil organic matter maintenance is highly influenced by its stabilization through interactions with minerals and chemical soil properties [52]. In a research [53], it was stated that in semi-arid areas, abiotic factors (physicochemical soil properties) might overshadow the biotic factors in controlling soil C, due to the climatic conditions, which limits the situation for biological activities.

Some studies [54, 55] have reported that a remarkable portion of CO_2 emission from soil is attributable to carbonates, particularly in calcareous soils. While, others [56, 57] reported that air CO_2 could be trapped in soil and transformed to carbonate and calcium carbonate. It can be presumed that some part of the CO_2 in the experiment containers could have been absorbed into the soil samples during the experiment. This may explain why there was a negative correlation between basal respiration and TNV in our study, but this hypothesis needs further investigation. In a similar research in an arid area, researchers found different spatial distribution patterns for soil DHA, organic matter, and $CaCO_3$ content. They also observed low correlation among these three properties and ascribed it to the disparity of distribution of vegetation cover [58].

CONCLUSIONS

Results of this study showed that organic and inorganic carbon variations are mainly controlled by soil physicochemical properties in the soil surface in the study area. This study brought insight into the different controlling factors in soil carbon variations in an arid region, which can be useful for future research and better soil management and carbon modeling. Soil inorganic carbon was not significantly affected by microbiological activities in the study area. There could be some other factors affecting soil C, as the variation partitioning results show a fairly high portion of variations unexplainable by any of the considered groups of soil properties in the soil surface. Soil types and different pedogenic or geologic processes, such as deposition or burying seem to have affected the spatial variation of soil properties.

Variation partitioning analysis stands as a sound methodology to investigate the relative importance of different groups of explanatory variables on a dependent variable or a set of variables. Deriving different portions of variation sources including unique, common, and unexplainable parts gives us an understanding to plan future research better. Particularly, the part that cannot be ascribed to any of the considered explanatory sets of variables can make us think of restructuring future studies by considering other sources of variations or influencing factors.

According to the results, it can be concluded that soil properties and conditions as well as pedogenic factors could affect soil organic and inorganic carbon variability, as environmental factors are fairly uniform across the study area. This is deducible from the observed variations of soil OC and IC in different soil types, which have been exposed to different pedogenic factors.

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