An Investigation of Soil Spectral Characteristics under Different Conditions in Jordan

Makhamreh, Z.,[1*] Kakish, S.[2] and Bani Khaled, H.[3]
[1]Remote Sensing and GIS, Department of Geography, The University of Jordan, Jordan
E-mail: z.makhamreh@ju.edu.jo
[2]French Department, The University of Jordan, Jordan
[3]Department of Geography, The University of Jordan, Jordan
[*]*Corresponding Author*

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Abstract
The objective of this paper is to assess soil surface properties in northern Jordan using optical remote sensing and field sampling. Soil spectral reflectance has been measured in the range of 350 and 2500 nm, and the soil chemical properties such as iron oxides, and organic and inorganic carbon were analyzed by using an infrared cell in a high-frequency induction oven. In the same manner, the traditional soil profile description, routine samples analysis, and soil classification were used to classify the same soil according to the USDA classification system. The distribution pattern of the soil reflectance behavior in relation to its soil organic carbon forms different soil groups in the feature space which are, iron affecting organic carbon affecting, and inorganic carbon affecting soil. These groups reflect the effect of different soil mineralogy, conditions, and land use. This approach facilitates the quantification of soil quality in high performance and proves that both organic and inorganic carbons are important indicators of the characteristics of soil conditions using remote sensing. Investigation of the relationship between the reflectance properties of soil groups using the USDA soil classification system and soil profile description confirms the presence of a strong relationship between the two systems. The first trend is using the soil's organic carbon content to correspond to the clay content and cation exchange capacity, and the second trend is using inorganic carbon content to correspond to the silt and carbonate content under different climatic conditions. The results show that soil spectroscopy (350-2500 nm) is a promising technique for preliminary soil description and can classify soils according to soil chemical properties especially soil organic carbon only instead of using traditional soil profile classification and analysis.

Keywords: Jordan, Soil Classification, Soil Inorganic Carbon, Soil Organic Carbon, Soil Spectra

1. Introduction

Sustainable use of land resources including soil characteristics is crucial for improved land use management and agricultural development. Northern Jordan is an important region for the natural habitat and agricultural land use production [1]. Its soils show a wide variation in their characteristics and potential agricultural utilization, therefore, there is a need for providing detailed characteristics of soils using a rapid and efficient approach. The traditional method of soil classification is based on the morphological, physical, and chemical soil characteristics, which are developed during soil formation processes [2]. However, the spectral reflectance of soils is determined by their compositions in particular texture, moisture content, humus content, iron oxides, clay mineralogy, and carbonates [3] [4] and [5].

Although the classical soil sampling and classification, schemes are very important, they have some limitations such as the requirement of frequent fieldwork and sampling rates, which are costly, and time-consuming [6]. On the other hand, remote sensing approaches are able to overcome these limitations by offering frequent information about soil surface conditions using different satellite images [7]. This is because the reflectance curve characteristics of soils are determined by the object's properties, which in return is the reason why curves can offer information on the conditions and characteristics of soil surfaces [8]. The total content of iron and organic matter are major factors that affected the shape of the spectral absorption curve of soils [9].

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In this field, many studies investigated the utility of the 400–2500 nm wavelength region in quantifying both soil organic and inorganic carbon [10] [11] and [12]. Iron absorption bands often occur near 800-900 nm wavelength [13]; their contents and forms have a significant influence on the spectral reflectance characteristics of soils. Moreover, several weaker absorption bands between 400–550 nm can be found in some spectra due to the iron ions [14]. However, only low concentrations of iron oxide are reflected on the soil reflectance curve [15]. As the iron oxide content in the soil increases, the total reflectance curve in the visible and infrared range decreases [16] and [17]. Organic matter content and composition have a significant effect on the soil reflection curve [18]. In general, as organic matter content increases, soil reflectance decreases throughout the 400–2500 nm wavelength range [19]. The role of organic matter in reducing the spectral properties of soils is obvious where the organic matter content of soils is more than 2% [20]. As the organic matter falls below 2% it becomes less, effective in hiding the effects of other soil chemical elements like iron oxides [21]. Therefore, many scientists use remote sensing, and the spectral curve of the soils was used for soil classification purposes [22].

Among the soil minerals, carbonate content plays an important role in soils having developed from limestone parent materials, especially in arid and semi-arid areas [23] and [24]. Calcium carbonate tends to increase soil brightness, [25] and exhibits diagnostic features in the infrared wavelength region, with the strongest absorption in the 2300-2350 nm [26]. Soil texture and structure affect the soil reflectance curve, in which soils with low sand content showed the lowest reflectance, while pure sand had the highest reflectance at all wavelengths. The effect of particle size distribution on the reflectance behavior in the field was demonstrated by many studies [27] and [28].

Moreover, apart from the reflectance differences, which can be accounted for differences in particle size and soil structure, the size and shape of soil aggregates, influence the soil reflectance in varying manners [29]. Remote sensing applications in soil studies are limited to the surface layer [30], while the typical soil classification approach takes into consideration both surface and sub-surface horizons [31] and [32]. As the reflectance curve characteristics in optical remote sensing are determined by the object's properties [33], such curves can offer information on the conditions and characteristics of soil surface [34] and [35]. Therefore, the main objective of this study is to investigate soils' properties using optical remote sensing and field survey and discover the relationships between soil characteristics and reflectance curve properties under different land use and climatic pattern in Northern Jordan.

2. Methodology

2.1 Study Area Description

Northern Jordan occupies the eastern part of the Mediterranean region and includes the most important agricultural production and urban centers such as Ajloun, Irbid and Mafraq cities as shown in Figure 1.

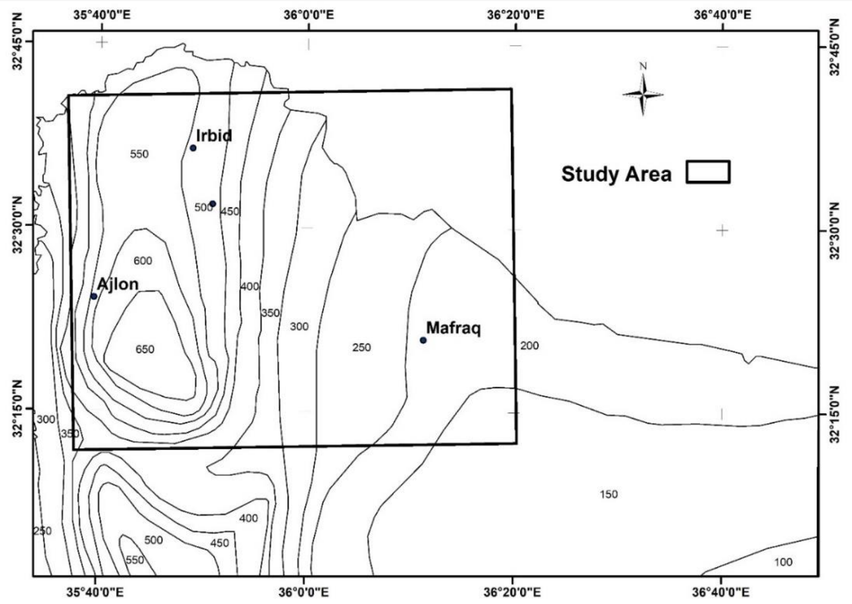

Figure 1: Study area location in Northern Jordan

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The study area is located between Latitudes 32^o 10' and 32^o 40' north and Longitudes 35^o 35' and 36^o 20' east and covers an area of (2582) km^2. The southern boundary is about 30 km from the north of Amman; while the northern boundary is a few kilometers from the south of the Syrian borders.

The prevailing climate in the study area is of arid Mediterranean type and characterized by dry hot summers and mild wet winters. Most of the precipitation occurs during the winter months from November to April. Annual and seasonal rainfall variability is very high in both space and time. The general pattern of precipitation represents different climatic gradients and this diversity ranges from semi-arid conditions where average rainfall amounts are about 200 mm, semi-humid conditions where the average rainfall is about 400 mm, to humid conditions where the average rainfall is above 600 mm. Land cover varies between natural, semi-natural, and cultivated areas. The dominant natural vegetation types are forests and shrubs; the dominant Oak Forest species is *Quercus coccifera* and exists under humid conditions [36]. The dominant shrubs are *Artemesia herba-alba* and exist under sub-humid conditions like 300-400 mm rainfall zones. Cultivated lands are characterized by rainfed agriculture, which depends on rainfall amounts and distribution. The main subdivisions of the category are fruit trees and field crops, while the dominant fruit trees are olives, and grapes followed by orchards, and the dominant field crops are wheat, and barley followed by legumes.

2.2 Soil Samples Preparations

A field survey was conducted in northern Jordan, in order to collect the soil samples for the analysis. Spatial distribution of soil samples in the study area is shown in Figure 2. The soil samples were collected for two purposes; the first one is for measuring the soil spectra characteristics (spectral analysis samples) and the second is for conducting the traditional soil classification approach (Profile description and Auger samples). The field analysis was carried out in different periods between 2017 and 2018. Soil profile descriptions were carried out according to the soil survey manual approach [37]. The sampling sites were carefully selected to represent all varieties of soil types, climate conditions, and land use types in the study area. In total, 143 samples were collected, 47 samples were selected for the soil spectra measurement, 86 samples were taken by Auger for soil properties analysis and ten representative soil profiles were described and sampled by the horizon.

2.3 Soil Chemical Analysis

For the traditional soil sampling approach, the soil samples were collected in the field, then air dried, milled, and then passed through a 2-mm sieve. Chemical and physical analyses were performed according to the standard method of analysis. The measured soil chemical properties included carbonate content, organic matter, and exchangeable cations.

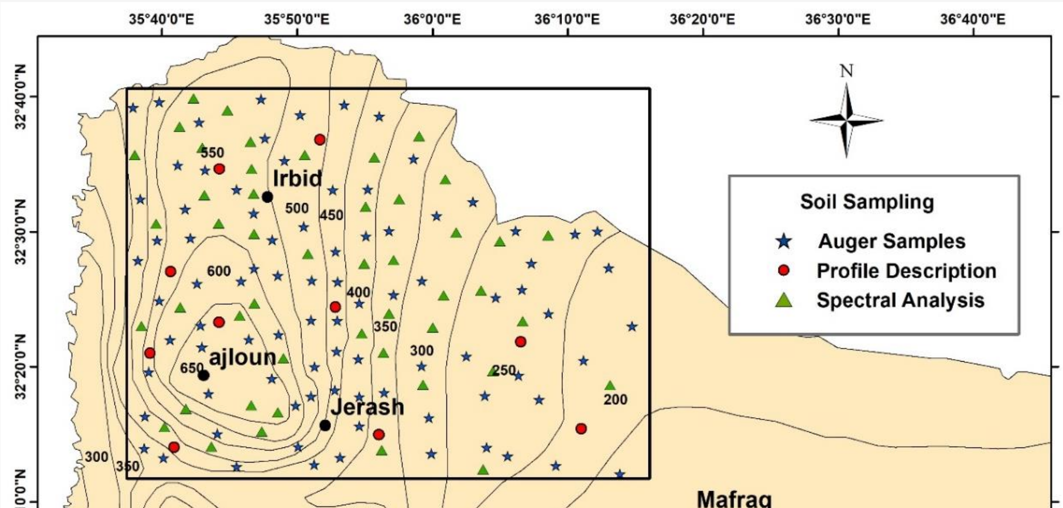

Figure 2: Spatial distribution of soil sampling in the study area

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The soil's physical properties include particle size distribution (sand, silt, and clay) which was measured using the pipette method, the sand content was separated by sieving (0.53-mm sieve) and the silt fraction was calculated by difference from the total soil mass. For the soil spectra analysis, the soil chemical analysis included the soil organic carbon (SOC) and soil inorganic carbon (SIC) content, which was analyzed by using an infrared cell in a high-frequency induction oven (LECO) [38]. The analysis involved two phases, one between 200 °C and 550 °C for (SOC) and the other between 550 °C and 1050 °C for inorganic carbon. The CO_2 flow is continuously detected by an infrared cell while the temperature is increased at a rate of 200 °C min^{-1}.

2.4 Soil Spectral Analysis

In order to measure the spectral characteristics of soils in the lab the soil samples were collected from surface layer 0-1 cm. The sampling sites were carefully selected to represent all varieties of soil types subject to the different patterns of land use. In total, 47 samples were selected for the soil spectra analysis along the west-east transects. Then each soil sample was separated into two sub-samples. One was used for spectral measurements in the lab, while the other was analyzed to study soil chemical properties particularly (SOC) and (SIC). Figure 3 show the flow chart for the soil analysis methodology for this study, and preparations of soil samples for purposes of spectral measurements were carried out according to the following procedure. The soil samples air-dried in the oven and sieved using 2 mm sieve size. Then it homogenized to a standard grain size according to Fernandez and Schulze procedure [39]. Such procedure provides precise and standardized measurements of diffuse soil reflectivity. The spectral reflectance of the soils measured in the laboratory using a spectrometer and a calibrated white standard [40], under sieved, and homogenized conditions with an ASD Field Spec II spectrometer in 10 nm intervals between 350-2500 nm. The illumination source positioned at 30 degrees zenith angle and a 1000 W quartz-halogen lamp put at a distance of approximately 30 cm. The samples laid out on a black coated board to minimize the external reflectance or backscattering.

The spectral measurements of a halon reflectance panel obtained at the beginning of each dataset measurement are to be used as a reference for the reflectance calculations. Spectral on reference panel read before the samples. Then the reflectance values are calculated by dividing each sample spectrum by the panel spectrum. In addition, a continuous spectral measurement (400 2500) nm for the soil samples was also done in order to identify the spectral characteristics and mineralogical compositions of the soils.

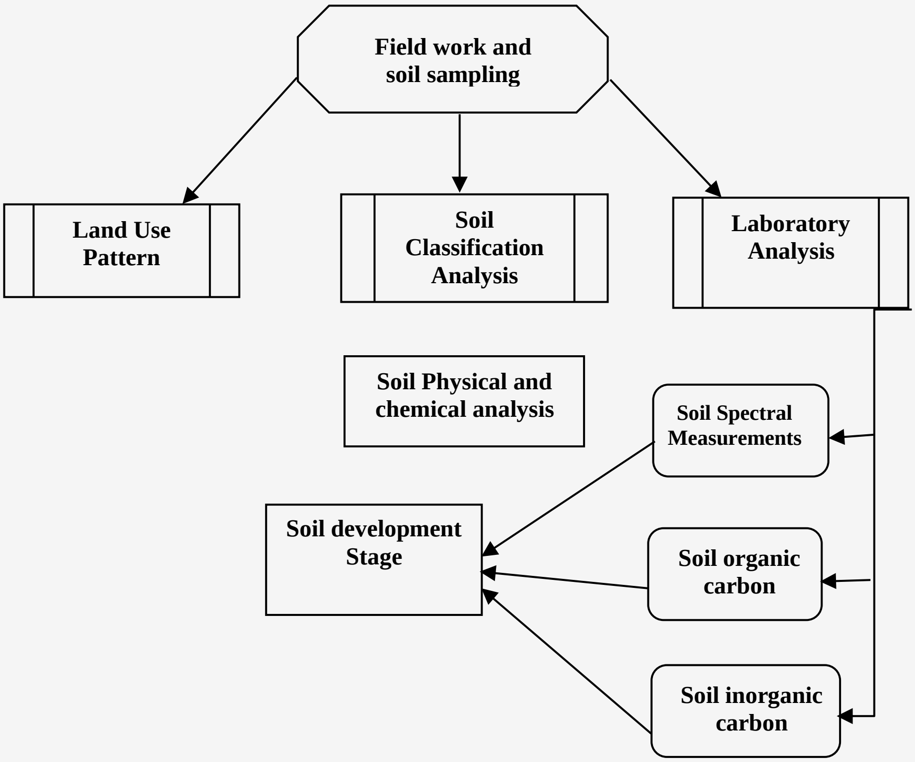

Figure 3: Flow chart explain the soil sampling analysis for this study

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3. Results

This section includes descriptive statistics, spectra analysis, and the profile description for the samples. Description of the soil spectral classification and USDA soil classification. In addition, independent soil samples in the study area were taken to study the relationship between the soil spectral properties and soil physical and chemical properties.

3.1 Soil Spectral Classification

Climatic conditions and land use patterns influence the soil's chemical and physical properties and therefore play an important role in determining soil quality and conditions. In this context, the soil's organic and inorganic carbon are considered the main factors that determine soil quality and conditions in arid-semi-arid regions. Therefore, examination of the soil reflectance behavior of the soils in relation to its chemical properties such as (SOC), (SIC), and iron content are very important factors in determining the soil types and development stages. In this study, the spectral properties of the soil samples were measured at 693 nm, this is corresponding to band 3 of Landsat TM and band 4 of Landsat 8. Figure 3 show the plotting of spectral properties which represented to band 3 of Landsat TM. Then it is plotted with the (SOC) content to study the relationship between the soil spectra and soil chemical properties. Figure 4 show the results of this relation, the distribution of the soil samples within this relation tends to form a triangle. Accordingly, it was possible to group the soil into five groups; these are three main groups G1, G3, G5, and two intermediate groups G2 and G4. Analysis of the triangle components of soil development shows a specific direction, which reflects the effect of climate, land use and mineralogical composition. The first direction **T1** representing the soil development dominated by effects of climate and characterized by the influence of soil (SOC) and (SIC). The second Direction **T2** demonstrates the effect of climate on soil development, particularly the effect of mineralogical composition and clay. The third direction **T3** displays the effect of land use on soil characteristics under similar climatic conditions and represents differences of (SOC).

Analysis of the continuous soil spectrum for the soil samples in the laboratory show the difference in soil types according to soil chemical composition and content from iron oxides, (SOC) and (SIC) in the 400-2500 nm spectral range, the soil spectra behavior of soils in the study area are shown in Figure 5. These relations are reflected on the spectral soil types (groups 1-5). In this context the group one-soil types (G1) are soils display a clear absorption feature at 900 nm and a concave curve in the 500 nm regions, in addition this group has low absorption curve in the total wavelength range; these both features are an indication of the presence of iron oxide in the soils. The group three-soil types (G3) soils demonstrate a convex absorption curve in the visible wavelength. The yellow curve indicates that carbonate is affecting soil type group five (G5) soils due to having a high absorption curve at the total wavelength and an absorption feature at 2300 nm.

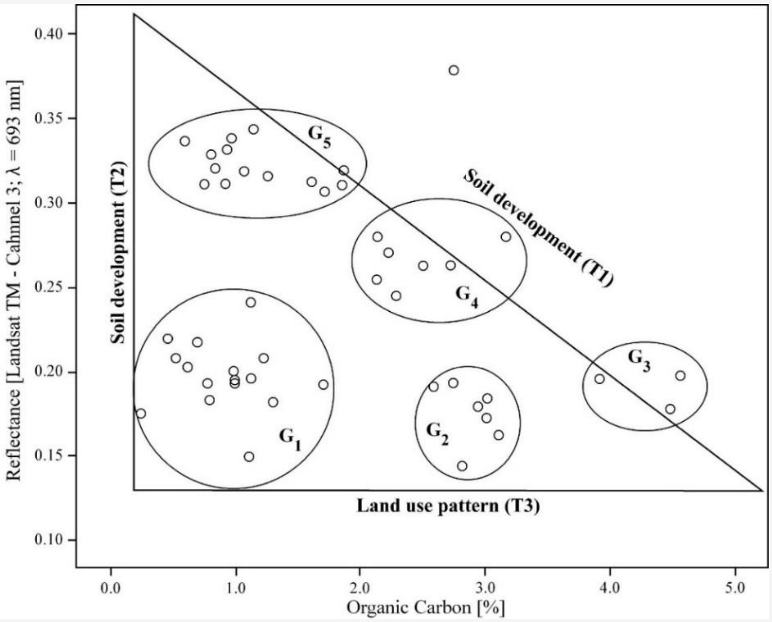

Figure 4: The main soil types in the northern Jordan as classified according to their reflectance characteristics and organic carbon content

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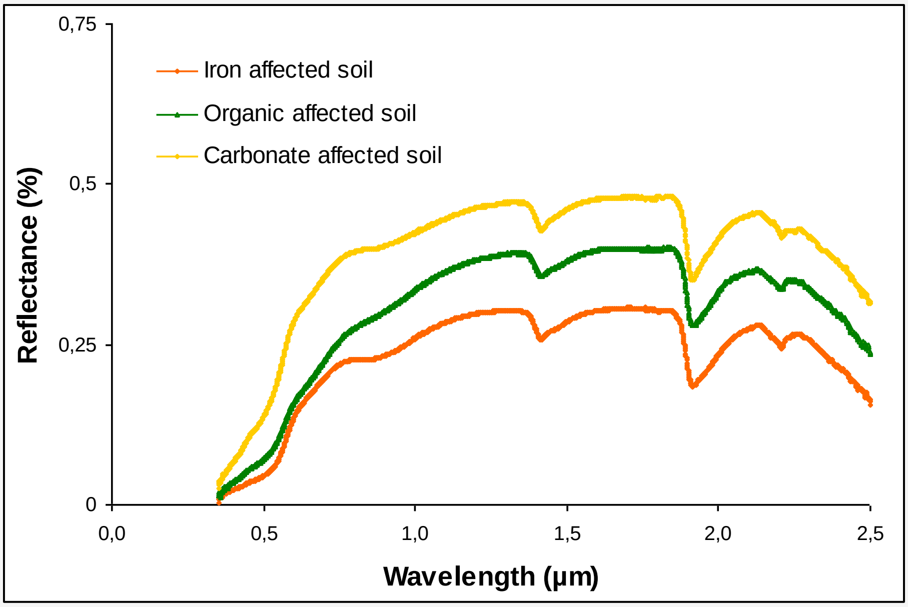

Figure 5: The spectral characteristics of soil types in the northern Jordan in the 400-2500 nm spectral range

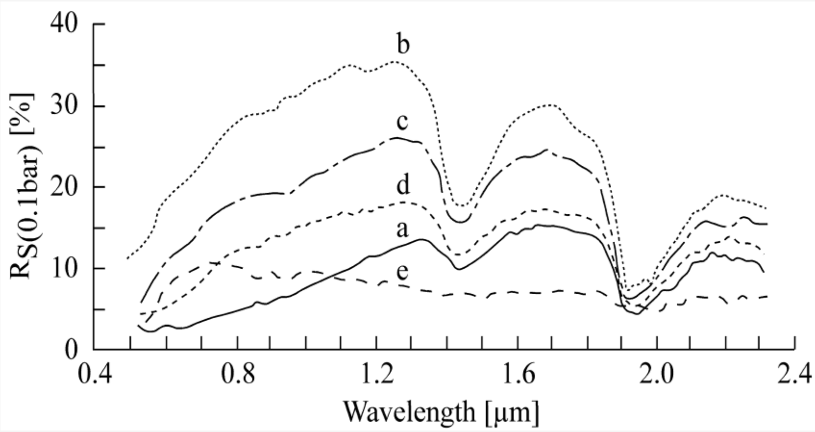

Figure 6: Characteristics of soil bidirectional reflectance after [13]

A previous investigation [13] investigated the soil spectra reflectance characteristics of major soil types, as illustrated in Figure 6. Curve (a) represents developed fine textured soils with high (>2%) organic matter content. Curve (b) represents undeveloped soils with low (<2%) organic matter and low (<1%) iron oxide content. Curve (c) represents developed soil with low (<2%) organic matter and moderate (1-4%) iron oxide content. Curve (d) represent moderately coarse textured soils with high (>2%) organic carbon content and low (<1%) iron oxide content. Curve (e) represent fine textured soils with high (>4%) iron oxide content. The soil characteristics for soil samples group (1-5) has been investigated in terms of organic and inorganic carbon under different land use and climatic conditions as shown in Table 1. The soil spectra characteristics within the study area (Figure 4) can be described in relation to Figure 5. Accordingly, it is possible to classify the soil group types in the study area into one of these spectral groups. From our analysis of the soil spectra, soil chemical properties and field investigation, it proves that G1 is an iron-affected soil, G3 is an organic affected soil, and G5 is a carbonate-affected soil. Below is details description of the soil type groups G1 to G5.

Soil type group one: developed under humid conditions with a rainfall of more than 500 mm, and the dominant land use is fruit trees and field crops. It is characterized by low (SIC) as well as (SOC). The average value for (SIC) is 0.7 % and the standard deviation is 0.6. The average value for (SOC) is 0.95 % and the standard deviation is 0.32.

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Table 1: Descriptive statistics for the chemical properties of the soil groups. (SIC) is the inorganic carbon and (SOC) is the organic carbon

Main land use	**Soil Type group one (G1) Olives, Fruit Trees and Irrigated crops**	**Soil Type group two (G2) Mixed between one and three land use**	**Soil Type group three (G3) Forest and natural vegetation**	**Soil Type group four (G4) Mixed between three and five land use**	**Soil Type group five (G5) Field crops and Rangeland**
Average Rainfall (mm)	400	500	600	300	200
Minimum (SOC) %	0.30	2.65	3.95	2.20	0.71
Maximum (SOC) %	1.8	3.30	4.60	3.2	1.93
Average (SOC) %	0.95	2.95	4.35	2.50	1.25
Standard deviation	0.32	0.20	0.30	0.41	0.41
Minimum (SIC) %	0.05	0.10	0.11	1.61	0.85
Maximum (SIC) %	1.80	3.50	0.35	5.98	7.81
Average (SIC) %	0.70	0.80	0.25	3.92	3.27
Standard deviation	0.60	1.30	0.12	1.58	0.6

Soil type group three: represents the soils, which have a relatively high content of (SOC) and low (SIC) content. The average value for (SIC) is 0.25 % and the standard deviation is 0.11. The average value for (SOC) is 4.35 % and the standard deviation is 0.30.

Soil type group five: is another significant group, which characteristically has low (SOC) and high (SIC) content. The average value of (SIC) is 3.27 % and the standard deviation is 0.6. The average value of (SOC) is 1.25 and the standard deviation is 0.41.

3.2 USDA Soil Classification

The traditional soil survey and classification is the most famous and used one [37], and many studies have been used this system for the soil classification purposes [31] and [32]. In our study, the USDA classification system was used, and the chemical and physical soil analysis as well as profile description of the major soils, types and diagnostic properties in the study area are given in Table 2. According the soil taxonomy system and criteria the main soils in the study area was classified into three types these are as follows: The soil type one has soil taxonomy of "fine montmorillonitic, a thermic family of typic chromoxerets", and a parent material of colluvium with a slope of 4%. It is located near Irbid city; land use is olives under a precipitation between 500-550 mm. The chemical and physical properties of these soil types are as given in Profile 1.

Soil type two has soil taxonomy of "clayey-skeletal mixed calcareous, a thermic family of Utic/Entic/Typic Haploxeroils", in addition to a parent material of colluvium (gravely / texture) with a slope of 10%. It is located near Ajloun city where the land use is forest under a precipitation between 550-650 mm. The chemical and physical properties of these soil types are as given in Profile 2. Soil type three has soil taxonomy of "fine mixed, calcareous, a thermic family of Xerochreptic calciorthids". The parent material is alliuvm with a flat slope of 1%. It is located near Mafraq city. The main land use is cereals and the annual precipitation is between 200-250 mm. The chemical and physical properties of these soil types are as given in Profile 3.

In order to confirm our results, in addition, to the comparison with the soil profile description and soil classification of the major soil types in the study area. The behavior of soil spectral properties and classification scheme along the different soil types and rainfall gradients is confirmed by an analysis of independent soil data of 86 samples that representing diagnostic soil surface properties of those groups at the same rainfall gradients. Figure 7 show the relation between the soil physical, chemical and spectral analysis along a climatic gradient.

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Table 2: Chemical and physical soil analysis for three diagnostic sites in Northern Jordan

Profile	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture class	CEC	CaCo3 (%)	OM (%)
(1)	AP	0-15	4.6	40.0	55.4	Clay	47.7	2.4	1.31
	BW	15-45	4.6	39.2	56.2	Clay	49.0	3.9	-
	BW2	45-75	4.1	37.5	58.4	Clay	46.4	4.9	-
	BW3	75-135	4.9	34.6	60.5	Clay	46.0	4.9	-
(2)	A	0-30	10.1	48.1	41.8	Silty Clay	41.7	8.7	8.1
	O	30-70	10.5	57.0	57.0	Clay	38.5	9.7	-
	O	70-110	8.5	41.8	41.8	Silty Clay	34.3	11.6	-
	O	110-150	11.5	45.8	45.8	Silty Clay	33.3	14.6	-
(3)	Ap	0-12	16.0	59.1	24.8	Silty Loam	20.0	18.4	1-2
	Ap	12-36	18-3	53.2	28.5	Silty Clay Loam	17.6	21.3	-
	Bw	36-85	13.6	48.4	38.4	Silty Clay Loam	16.5	32.0	-
	Bk	85-150+					6.8	63.5	-

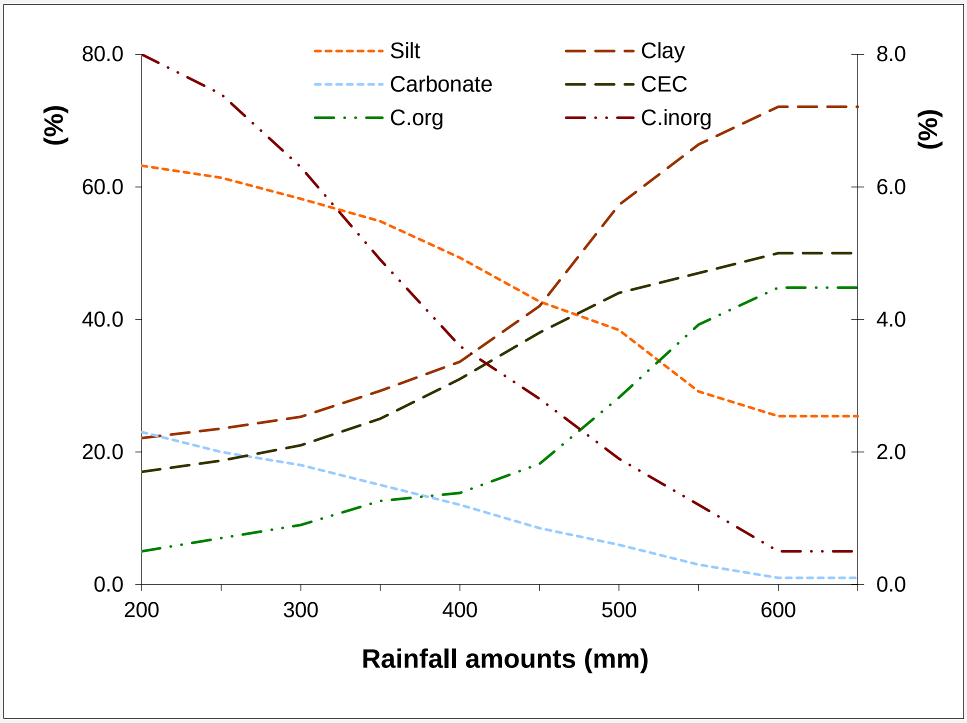

Figure 7: Physical and chemical properties of soil types in relation to the different climatic conditions in Northern Jordan. The soil properties clay, silt, CEC and carbonate are shown at Y_1-axes while the derived indicators "organic carbon and inorganic carbon" are shown at Y_2-axes

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The results show that there are two major trends that can be observed about the soil characteristics along the rainfall gradients, which can be followed either by using independent soil data (clay, silt, CEC and carbonate) as shown at the Y_1-axis or by using the derived indicators such as organic and inorganic carbon as shown at Y_2-axis.

4. Discussion

This work presents the results of the use of continuum soil spectra measurements (350-2500 nm) for soil classification. The soil samples representing different soil types and properties investigated under different climatic gradients. Investigation of the relationship between the reflectance properties of soil groups and the classification of profile description results confirm the presence of strong relationship between the two systems. This relationship is obvious when comparing the soil type's properties as shown in USDA classification system Table 2, and the soil spectra classification as illustrated in Figure 4. In this context, the soils types represented by soil profile 1 is equivalent's to soil types group one (G1), which is characterized by high clay and low carbonate content. In addition, the soil types represented by soil profile 2 is equivalent to soil type group three (G3), which is characterized by high (SOC) content and relatively low (SIC). Finally, the soil type represented by soil profile 3 is equivalent to soil types group five (G5), which is characterized by high silt and calcium carbonate content, and low organic matter. The soil spectra classification in the study area show three types of soils these are iron affected soils, organic affected soils, and carbonate affected soils. Following is detailed discussion of these groups:

Soil group type (G1) characterized by low inorganic carbon content combined with the presence of iron oxides, existing of these properties under semi-humid climatic conditions provides strong evidence that those soils are in advanced development stage and dominant of minerals soil composition [41]. Under such conditions, the effect of organic matter is not as significant on the soil spectral curve as the effect of other chemical constitutes, which was approved by many studies such as [42]. In this case, the iron content of the soils has a higher effect on the soil reflectance level than other factors as organic matter, these results have been also approved by [43] and [44]. Therefore, aaccording to the classification code used by [13] the soil samples in Group (G1) fell into group (c) classification.

Soil group type three (G3) characterized by soils developed under natural vegetation such as forest and protected vegetation conditions, where the existence of high rainfall levels and minimum human disturbance offers suitable media for the accumulation of (SOC) on the surface layer. This effect is clear by observing the (SOC) on the spectral curve along the total wavelength range. Therefore, these soils can be classified as organic affected soils, which was approved by different studies such as [45]. Therefore, according to the classification code used by [13] the soil samples fell into group code (d).

Soil group type (G5) characterized by low (SOC) and high (SIC) content under semi-arid conditions is a signal that a slow soil development stage takes place, because the climatic conditions are not favorable for effective weathering processes. Spectrally, this type of soils is characterized by having a high reflection value in the total wavelength range with an absorption band at 2300 nm and absence of iron oxide effects these results was confirmed by [18]. These soils can be classified as carbonates-affected and according to the classification, code used by [13] the soil samples fell into group code (b).

These explanations and results are supported by two trends of soil properties measurements using traditional soil survey. The first one is decreasing (SOC) content corresponds to decreasing the clay and cation exchange capacity under decreasing the rainfall amounts. The second trend is increasing (SIC) content corresponds to increasing the silt and carbonate content and decreasing the rainfall amounts. These results are comparable to the soil spectra results which forms a triangle shape that reflect the influence of climate, mineral components, and land use on the soil characteristics and classification. The above-mentioned results indicated that soil spectroscopy is a promising technique for preliminary soil description and can classify soils according to soil chemical properties especially soil organic carbon only instead of using traditional soil profile classification and analysis. In addition, these results are comparable to many other studies that used the soil spectra curve in identification of soil properties and classification of soil types under different climatic and land use conditions.

5. Conclusion

1. The soil spectra across the visible to shortwave infrared (400–2500 nm) wavelength ranges, that combined with limited soil chemical measurements demonstrate their ability to classify soils under semi-humid to arid climatic conditions in Jordan.

2. Analysis of the behavior of soil reflectance in relation to its organic carbon content are useful in classification of soils into three major soil types. It forms three trends, which reflects the effect of climate, the difference in mineralogical composition and land use on soil characteristics.
3. The USDA soil classification are comparable with the soils spectra results combined with organic and inorganic soil carbons, which confirmed also with independent soil data representing different soil surface properties at the same rainfall gradients.
4. This work recommend use of continuum soil spectra measurements (350-2500 nm) for soil classification and soil profile examination, which proved to be a promising approach for soil description and classification under different soil and climate conditions.
5. The main advantages of the method are the speed, low cost and possibility of using this approach for investigating soil properties, however, it is needing more investigation under different soil before replacing the classical methods of soil investigation and classification.

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