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*Article*

# Black soils in the Eastern Mediterranean: Genesis and Properties

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**Abstract:** Knowledge about the genesis and evolution of black soils in the Eastern Mediterranean is vital for sustainable land management. In this study, the black soils that currently occur in the Eastern Mediterranean were analyzed in different bioclimatic zones and were found to genetically belong to three soil types: 1-Calcareous black soils (Rendzina, Para-Rendzina) (Rendzic or Somerirendzic Leptosols -Typic Rendolls or Lithic Rendolls), 2-Hydromorphic black soils (Calcic Chernozems -Haploxerolls). 3- Black soils on Basalt (Somerirendzic Leptosols) (Haploxerolls). The impact of the relief was obvious on both the thickness of the solum and the mollic horizon. Rendzina occurs on the toe and feet slope, Para-Rendzina on the shoulders, and Chernozems on a flat plain. The color of the epipedon in Rendzina reflects the origin of the prevailing parent material from which they are derived: Proper Rendzina found on limestone, chalk, sandstone, conglomerate, and claystone; Reddish Rendzina on Dolomite and hard limestone, and Grayish Rendzina on Serpentine. It was also found that the Hydromorphic black soils only occur on calcic marl and lacustrine deposits in the depressions arising from the Dead Sea faults under saturation or bad drainage conditions. This soil has a thick, dark mollic horizon and high organic matter content.

**Keywords:** semi-arid; black soils; Rendzina; Chernozems; eastern Mediterranean

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## 1. Introduction

The term 'Black Soil' refers to soft soil, with a deep humus layer and rich organic matter content on the top layer [1,2]. Its dark color is due to the abundant accumulation of soil organic carbon (SOC) [3]. The International Black Soil Network (INBS) defines black soil as soil containing (1) surface horizons with color of ≥ 3 wet, a value of ≥ 3 wet and ≥ 5 dry); (2) high organic carbon content as follows: ≥ 1.2% for cold and temperate regions and ≥ 0.6% for tropical regions and (3) thickness of very dark to black surfaces of at least 25 cm [4,5]. The WRB Classification System [6] classified black soil as Chernozems, Kastanozems, and Phaeozems, or soil with qualifies of Rendzic and Somerirendzic whereas Soil Survey Staff [7] classified black soil as being mostly Mollisols, excluding Vertisols and dark Andesols [8]. Black soils are mostly found in cold and temperate northern latitudes, such as Russian Federation, Kazakhstan; northeast China, Mongolia, Ukraine, the United States, and Canada, as well as in southern latitudes such as Argentina, Colombia and Mexico [6,9]. Black soils are relatively fertile and have a high production potential for agriculture [10], host the largest terrestrial carbon pool [11], and thus play a crucial role in the global carbon balance by regulating dynamic biochemical processes and the exchange of greenhouse gases with the atmosphere [12]. Therefore, their occurrences are crucial in climate change, food security, and land degradation. The best sustainable land management should be applied to prevent carbon loss from this soil.

In the Mediterranean region, the prevailing climatic conditions are not favorable for the deposition and accumulation of organic matter, which is the major soil-forming process of black soil [13]. In which soils are characterized by low amounts of OM often comprising less than 1 % [14-17]. Also because the region is highly vulnerable to land degradation due to the continuous erosion of soils, including the humus-bearing surface layer, caused by heavy rains after long, dry, and hot summers. Although Mediterranean landscapes typically have high elevations and slopes, the soils are fragile and soft and can be easily washed away by rain [18]. Nevertheless, black soils can be found in the Mediterranean region on a very small scale. This unique presence of these soils has led to ongoing debates regarding their origin and genesis [19]. Reifenberg [20] suggested at an early stage that the accumulation of organic matter was not essential for soil formation in the Mediterranean and attributed the immaturity of these soils to the high erodibility of the disintegration products of soft limestone. In contrast, [21] postulated that the texture of soft and hard limestone is crucial in the development of both Rendzina and Terra rossa. Geze [22] highlighted the occurrence of Rendzina soils in Lebanon, which was earlier referred to by Miklaszewski [23] as white Rendzina. These soils contain a significantly higher content of $CaCO_3$ and availability of P than any other soil [24] because they are derived from soft Miocene and Senonian limestone and can be found in the foothills of the Lebanon and Anti-Lebanon Mountains [19]. Çepel [25] argues that the genetic soil types in the karstic areas southwest of Turkey, where the Lebanon cedar occurs, are Rendzina. According to Darwish and Zurayk [26], Rendzina can be found in the coastal area, southern plateau, mountain range, and the central Bekaa Valley in Lebanon. In Syria, these soils were referred to in studies presented by Muir [27], Nahal [28,29], Van lier [30], Zain al Ab-deen, [31], Chalabi [32], as well as by Ilaiwi [33]. First mentioned of black soils in Jordan by Moormann [34], he remarked that the (A) horizon is very weak and almost absent of humus in the upper horizon (values seldom exceed 1 or 2 %) in the best soils of Jordan. The survey of the Ministry of Agriculture MoA [35,36] found that the black soils of Typic Calcixerolls, Lithic Haploxerolls, Vertic Haploxerolls, and Typic Haploxerolls could be found in minor occurrences, mainly in the higher hilly areas of Jordan such as in Um Qeis, East Nueimeh, Ajlun and Salt Subiehi. Khresat [37] pointed out that Mollisols have developed from Quaternary deposits in northern Jordan under xeric moisture and thermic temperature regimes in the 450 mm precipitation zone. Lucke et al. [38-40] found very weakly developed Rendzic Regosols on limestone regolith in the Abila ruins in northern Jordan.

Despite increasing attention to the importance of black soils as carbon sequestration pools especially in marginal and fragile environments such as the eastern Mediterranean, information regarding the properties of black soils and their use is currently limited. Hence, this study aims to shed light on the specifications and factors of deformation of these soils based on soil survey data from 15 soil profiles. Understanding the properties and genesis are essential requirements to preserve them for sustainable use.

## 2. Materials and Methods

Fifteen soil profiles with thick dark mineral surface horizons from the coastal and inland regions of the eastern Mediterranean were studied, Figure 1.

The soils were studied in four bioclimatic areas according to the pluviothermic quotient of Emberger [41], namely: 1-The upper humid stage cold, 2-lower sub-humid stage fresh 3- lower sub-humid stage temperate and 4-upper semiarid. These areas receive an annual precipitation ranging from ~500 to more than 1000 mm. The precipitation amount increases on the slopes facing south and southwest. The climax vegetation is Pinus brutia forest; the degraded areas were covered with Maquis consisting mainly of Quercus species in wet areas.

From these soil profiles, three representative profiles: Jableh (littoral plain), Al-Ghab (rift valley), and Barshin (littoral high hilly mountainous area) were selected to take soil samples for analysis.

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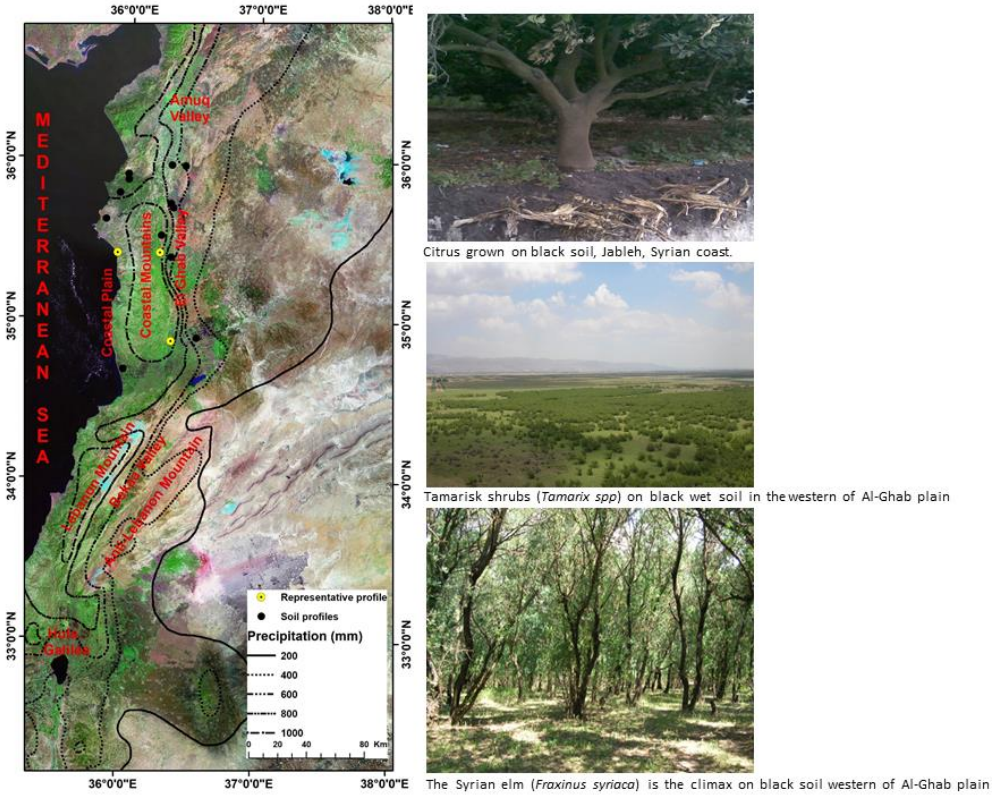


**Figure 1.** Map of the location of 15 black soil studied profiles from four bioclimatic stages of the Eastern Mediterranean.

Soil description and sampling were based on procedures of the Soil Survey Division Staff [42]. The morphological study and soil profile description were based on the Field Book for Describing and Sampling Soil [43] as well as the Keys to Soil Taxonomy [7].

All soil samples were air-dried at 95 °C for 24 h. After the removal of all stones and vegetation, they were ground, sieved, and homogenized. Organic carbon ($C_{org.}$) was determined by the Walkley-Black method [44], modified by Nelson and Sommers [45]. The particle-size analysis was performed using the hydrometer method [46]. Soil reaction (pH) was measured in a suspension of $H_2O$ (1:1), (0.01M) $CaCl_2$ (1:2) and (1M) KCl (1:2) [47]. Exchangeable cations ($Ca^{++}$, $Mg^{++}$, $K^+$, Na+) were estimated using the method ($BaCl_2$-TEA, pH=8.2) [48]. Calcium carbonates were determined by Scheibler [49]. Total Nitrogen was determined following the procedures of Kjeldahl [50] and McRae [51]. Electrical Conductivity (EC) was measured in the suspension of $H_2O$ (1:2) [47]. Available phosphorus was estimated according to Olsen et al. [52] and total potassium according to Jackson [53].

## 3. Results

The soil profiles showed that black soil occurs in some areas of the littoral plain, littoral high hilly areas, and rift depression valleys. The existence of these soils was in several bioclimatic stages, on different parent materials, and in different rain zones, Table 1.

**Table 1.** General description of soil profiles features.

| Profile Cod | Coordinates & Elevation | Rainfall mm | Bio-climate zone | Physiography & Topographic position | Drainage class | Vegetation | Parent material | Classification | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | ST | WRB |
| **Jableh** | 35°25'10.67" N 35°55'23.37" E | 863 | **Sub-humid hot** | **littoral undulating plain, very** | **moderately well drained, very slow** | **pine trees** | calcareous sandstone and conglomerates | Typic Rendolls | Rendzic Leptosols |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **28 m. a. s. l** | | | **gently slope towards east** | **surface run off** | | | |
| Al Qanjra | 35°37'43.7" N 35°49'40.13" E 10 m. a. s. l | 797 | Sub-humid hot | littoral flat plain, very gently slope towards east | moderately well drained, very slow surface run off | cultivated olive trees | Pliocene marls and limestone | Typic Calcixerolls | Somerirendzic Leptosols |
| Kassab-Zanzaf | 35°47'44.77" N 35°55'46.52" E 240 m. a. s. l | 1248 | humid temperate | littoral high hilly areas foot slopes | well drained, rapid surface run-off, moderately slow permeability | pome trees | undifferentiated complex of igneous rock predominated by serpentine of Mesozoic era | Typic Rendolls | Rendzic Leptosols |
| Kasab Nibh Almur | 35°52'41.93" N 35°59'35.60"E 380 m. a. s. l | 1248 | humid temperate | littoral high hilly areas middle slopes of mountainous area | well drained, rapid surface run-off, slow permeability | pome trees and stone fruit trees | undifferentiated complex of igneous rock predominated by serpentine of Mesozoic era | Entic Ultic Hapoloxerolls | Rendzic Leptosols |
| Kassab | 35°54'47.54" N 35°59'24.10"E 800 m. a. s. l | 1248 | humid temperate | littoral high hilly areas middle slopes of high hills | well drained, rapid surface run-off, moderately rapid permeability | pome trees | undifferentiated complex of igneous rock predominated by serpentine of Mesozoic era | Entic Ultic Hapoloxerolls | Rendzic Leptosols |
| Der Autman | 35°58'22.8" N 36°19'16.2" E 325 m. a. s. l | 679 | sub-humid temperate | Inland mountainous area – backslope of undulating hills | well drained | cultivated olive and stone fruit trees | limestone | Calcic Pachic Hapoloxerolls | Leptic Kastanozem |
| Drkosh-Al-daher | 35°58'04.8" N 36°25'37.9" E 530 m. a. s. l | 679 | sub-humid temperate | littoral high hilly areas mountainous area | well drained | shrubs and cultivated olive tress | dolostones and hard limestone | Entic Hapoloxerolls | Rendzic Humic Leptosol |
| Akkar-Zahed | 34°41'38.66" N 35°59'12.36"E 1 m. a. s. l | 1150 | sub-humid hot | littoral plain - flat plain | poorly drained, very slow surface runoff, slow permeability | irrigated vegetable and greenhouses | quaternary and recent colluvium and alluvium derived mainly from neogene basalt | Vertic Haploxerolls | Vertic Chernozems |
| Barshin | 34°52'20.60" N 36°20'37.41"E 930 m. a. s. l | 994 | humid temperate | littoral high hilly - backslopes of high hills | moderately well drained, rapid run-off, slow permeability | pome trees | Pliocene basalt | Typic Haploxerolls | Somerirendzic Leptosols |
| Houla | 34°53'42.88" N 36°32'11.59"E **375** m. a. s. l | **480** | semi-arid temperate | Historical oasis -level flood plain | somewhat poorly drained | field crops and irrigated vegetables | alluvial deposits of quaternary to more recent era, derived mainly from neogene basalt | Aquic Haploxerolls | Vertic Kastanozems |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Al-Ghab-Joureen | 35°31'58.92" N 36°15'7.67"E 183 m. a. s. l | 871 | sub-humid temperate | rift valley-level to depressional valley fills | moderately well drained, very slow surface run-off, slow permeability | elms trees | quaternary or more recent marl diatomaceous lacustrine deposits | Aquic Haploxerolls | Leptic Chernozems |
| Al-Ghab-Ennab | 35°25'25.40" N 36°14'41.89" E 182 m. a. s. l | 871 | sub-humid temperate | rift valley-level to depressional valley fills | moderately well drained, very slow surface run-off, slow permeability | elms trees | quaternary or more recent marl diatomaceous lacustrine deposits | Aquic Haploxerolls | Vermic Chernozems |
| Al-Ghab-Al Kareem | 35°23'48.30" N 36°19'49.73" E 178 m. a. s. l | 695 | sub-humid temperate | rift valley-level to depressional valley fills | moderately well drained, very slow surface run-off, slow permeability | irrigated agriculture | quaternary or more recent marl diatomaceous lacustrine deposits | Patchic Haploxerolls | Haplic Chernozems |
| Al-Ghab-Qarqor | 35°43'58.76" N 36°19'13.47"E 170 m. a. s. l | 679 | sub-humid temperate | rift valley-level to depressional valley fills | moderately well drained, very slow surface run-off, slow permeability | irrigated agriculture | quaternary or more recent marl diatomaceous lacustrine deposits | Patchic Haploxerolls | Haplic Chernozems |
| Al-Ghab-Mshik | 35°42'20" N 36°20'26.7" E 175 m. a. s. l | 693 | sub-humid temperate | rift valley-level to depressional valley fills | moderately well drained, very slow surface run-off, slow permeability | irrigated agriculture | quaternary or more recent marl diatomaceous lacustrine deposits | Patchic Haploxerolls | Haplic Chernozems |

3.1 Soil Morphology

The soil morphology of the representative profiles is listed in Table 2. The color of the topsoil ranged from black to dark brown (10YR 2/1-10YR 3/2). Distinct color differences between the horizons were only apparent in the soil profile of the Rendzina; this was related to high carbonate content in the subsurface horizon and the origin of the parent materials. A thin layer of slightly decomposed forest litter was found on top of the Rendzina (Oi) horizon. The soils were all relatively deep, except for the soil on steep slopes of intervening undulating hills and mountainous areas. Here the gully erosion posed a severe problem on deforested plots.

**Table 2.** Soil morphology of representative soil profiles.

| **Horizon** | **Depth (cm)** | **Color** | | **Structure** | **Consistence** | **Pores** | **Roots** | **Boundary** | **Special features** |
|---|---|---|---|---|---|---|---|---|---|
| | | dry | wet | | | | | | |
| | | | | | **Jableh** | | | | |
| Oi | 5-0 | very dark gray | black 10YR 2/1 | midrate medium | slightly plastic | - | abundant very | abrupt smooth | slightly decomposed plant material |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 10YR 3/1 | | fine granular | | | fine to medium | | frequent rounded stone constituting approximately 10% |
| A | 0-35 | - | very dark grayish brown 10 YR 3/2 | weak fine granular | sticky and plastic | few very fine and fine discontinuous irregular simple open | few fine and very fine | clear wavy | roots mostly inside peds |
| A2 | 35-50 | dark red 2.5Y3/6 | - | fine granular | sticky and plastic | Few fine vertical in ped simple closed | few fine | very abrupt smooth | Few small soft carbonate stones |
| C | 50+ | - | very pale brown 10YR8/2 and pink 7.5YR8/3 | - | - | - | - | - | Conglomerates calcareous sandstone |
| **Al-Ghab** | | | | | | | | | |
| A | 0-26 | dark brown 10 YR 3/3 | black 10 YR 2/1 | midrate medium granular | soft (dry) slightly firm (moist) sticky and plastic | many fine horizontal in ped simple open | plenty fine | abrupt smooth | roots between peds |
| A2 | 26-55 | - | very dark brown 10 YR 3/2 | fine granular | firm (moist) sticky and plastic | few fine vertical in ped simple closed | Plenty fine | gradual wavy boundary | Roots between peds |
| AC | 55+ | - | grayish brown 10 YR 4/1 | massive | firm (moist) sticky and plastic | few fine vertical in ped simple closed | few fine inside peds | - | few small soft carbonate accumulations on ped faces |
| **Barshin** | | | | | | | | | |
| Ap | 0-18 | dark brawn 10 YR 3/3 | very dark grayish brawn 10YR 3/2 | moderate medium subangular blocky breaking to moderate firm granular | very hard (dry) firm (moist) sticky and plastic | fine and medium dis-continuous vertical open | few fine | clear smooth | De-rocking surface |
| A2 | 18-40 | dark brawn 10 YR 3/3 | very dark grayish brawn | moderate medium subangular blocky | very hard (dry) firm (moist) | few fine dis-continuous vertical open | few fine and medium | clear smooth | few subrounded gravel 10% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 10YR 3/2 | | | | | |
| C | 40-75 | - | Very dark grayish brawn 10 YR 3/2 | weak medium subangular blocky | very hard (dry) firm (moist) | Few fine dis-continuous open | few medium and coarse | broken | Soil and partially weathered parent material |
| R | 75+ | Neogene Basalt | | | | | | |

3.2. Soil physical properties

The particle size analysis showed that the texture varies from clay to sandy clay loam to loam, Table 3. From the clay content change as a function of depth, it did not become clear that illuviation was discernible.

**Table 3.** Particle size distribution, clay/sand, and clay/silt ratios of soil profiles.

| **Soil** | **Horizon** | **Depth (cm)** | **Particle size distribution (%) Ø mm** | | | **Clay/Sand** | **Clay/Silt** | **Texture** |
|---|---|---|---|---|---|---|---|---|
| | | | Sand | Silt | Clay | | | |
| Jableh | Oi | 0-5 | 54 | 16 | 30 | 0.55 | 1.87 | sandy clay loam |
| | A | 5-35 | 60 | 14 | 26 | 0.43 | 1.85 | clay loam |
| | A2 | 35-50 | 46 | 22 | 32 | 0.69 | 1.45 | Sandy clay loam |
| | C | 50+ | 40 | 40 | 20 | 0.5 | 0.5 | sandy clay loam |
| Al-Ghab | A | 0-26 | 46 | 26 | 28 | 0.6 | 1.07 | sandy clay loam |
| | A2 | 26-55 | 48 | 34 | 18 | 0.37 | 0.69 | loam |
| | AC | 55+ | 46 | 24 | 30 | 0.65 | 1.25 | sandy clay loam |
| Barshin | Ap | 0-25 | 12 | 42 | 46 | 3.83 | 1.09 | clay |
| | A2 | 25-55 | 12 | 39 | 49 | 4.08 | 1.25 | clay |
| | AC | 55-115 | 12 | 39 | 49 | 4.08 | 1.25 | clay |
| | R | 115+ | - | - | - | - | - | - |

*3.3. Soil chemical properties*

Some soil chemical properties are presented in Table 4. The soil reaction (pH) in general ranged from slightly to moderately alkaline. These values were related to the carbonate content and base saturation. Only the soil derived from basalt was slightly to moderately acid. This was attributed to igneous non-carbonate parent materials as well as the intensive precipitation.

Apart from the Barshin soil, which seems to be carbonate-free, but only with some nodules of secondary carbonates, the calcium carbonate content was fairly high and constant in all of the soil profiles and constituted a prominent chemical feature. Moreover, the values exhibited no consistent trend, increasing to more than 77% in marl diatomaceous lacustrine deposits. Cation exchange capacities were relatively high which can be attributed to the content of organic matter.

Their trends to decrease or increase as a function of depth are not clear. The base saturation was generally high in all soil profiles; however, a few examples reached 100% base saturation. Only the soil of the Barshin soil profile exhibited a low base saturation due to low carbonate content and low soil reaction.

**Table 4.** Some soil chemical properties.

| Horizon | Depth (cm) | pH | | Carbonates as $CaCO_3$% | | EC mS.m$^{-1}$ | C org. % | Extractable bases meq.100g$^{-1}$ | | | | Ext. $P_2O_5$ mg.kg$^{-1}$ | Tot. N % | CEC meq.100g$^{-1}$ | BS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $CaCl_2$ 1:1 | $H_2O$ 1:1 | <2mm | <0.002mm | | | $Ca^{++}$ | $Mg^{++}$ | $K^+$ | $Na^+$ | | | | |
| | | | | | | | Jableh | | | | | | | | |
| Oi | 0-5 | 7.42 | 7.54 | 2.2 | ND | 0.5 | 4.42 | ND | ND | 0.4 | 0.3 | 31.3 | 0.38 | 52.5 | 100 |
| A | 5-35 | 7.64 | 7.8 | 16.4 | ND | 0.4 | 2.41 | ND | ND | 0.1 | 0.3 | 20.5 | 0.19 | 62.5 | 100 |
| A2 | 35-50 | 8.1 | 8.2 | 29.5 | ND | 0.4 | 0.9 | ND | ND | 0.2 | 0.4 | 29.0 | 0.08 | 67.9 | 100 |
| C | 50+ | 7.42 | 7.54 | 44.0 | ND | 0.5 | 0.1 | ND | ND | 0.2 | 0.3 | 19.0 | - | 70.2 | 100 |
| | | | | | | | Al-Ghab | | | | | | | | |
| A | 0-26 | | 7.23 | 41.0 | 17.0 | 1.6 | 4.2 | 28.0 | 8.0 | 0.2 | 0.9 | 11.8 | 2* | 42 | 88.2 |
| A2 | 26-55 | | 7.86 | 69.5 | 27.0 | 2.1 | 3.1 | 15.0 | 1.1 | 0.1 | 1.1 | 8.2 | 4* | 24 | 88.3 |
| AC | 55+ | | 7.64 | 77.0 | 26.0 | 2.5 | 2.2 | 11.0 | 0.6 | 0.1 | 0.6 | 3.3 | 2* | 22 | 75.7 |
| | | | | | | | Barshin | | | | | | | | |
| Ap | 0-18 | 5.6 | 5.8 | 2.0 | 3.2 | 0.3 | 1.8 | 18.7 | 8.5 | 2.02 | 0.24 | 4.1 | 1.5* | 32.8 | 67.9 |
| A2 | 18-40 | 5.5 | 5.6 | tr | 4.3 | 0.4 | 1.1 | 19.9 | 8.9 | 1.14 | 0.24 | 3.9 | 1.2* | 32.6 | 72.4 |
| C | 40-75 | 5.8 | 6.1 | 1.0 | 9.8 | 0.8 | 0.6 | 21.6 | 9.3 | 0.56 | 0.22 | 3.5 | 0.9* | 33.1 | 88.3 |
| R | 75+ | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

*Min- N mg.kg-1.

## 4. Discussion

Our study found that the black soils occur in the Eastern Mediterranean on very small-scale areas, and can be categorized into three types depending on evolution and genesis: 1-Calcareous black soils (Rendzina) on littoral plains and hilly areas, 2- Hydro-morphic black soils in depressions, and 3- Black soil on basalt. These soils can occur in a humid and sub-humid Mediterranean climate.

### Calcareous black soils

These soils can develop on limestone, sandstone, chalk, dolostones, and similar calcareous materials. The darker color of the surface horizon due to the accumulation of organic matter in (O-A) or (A) horizons. In contrast to Reifenberg [20], who postulated that these types of soils were deficient in humus, this investigation found that the soils have a high content of organic carbon. The high contents of calcium carbonate content kept soils almost completely base saturated, retarding weathering and subsequent release and redistribution of sesquioxides and silica [54]. Consequently, this soil has a weakly developed, immature profile. The more common soils are Typic Rendolls (Rendzina) that have developed from Brown Calcisols or directly from calcareous regolith by humification. The microrelief and parent materials play an important role in the development of this kind of soil. On shoulders and slopes the mollic horizon is shallow (perhaps eroded), resulting in the formation of Para-Rendzina (Somerirendzic Leptosols- Lithic Rendolls). In this case, the soil is relatively immature, not deep, and has a unique diagnostic mollic epipedon. Sometimes litter layer can be found over mollic horizon, which varies in depth from 5 to 30 cm. The general soil horizon sequence was (O-A-C or A-C), sometimes including a transitional horizon (AC), but no proper illuvial horizon could be found. The soil shows a strong reaction with dilute hydrochloric acid, indicating the high calcium carbonate content, Figure 2.

A B C D

**Figure 2.** Calcareous black soils: A. on chalk, B: on serpentine, C: on sandstone, D: calcareous materials.

**Hydromorphic black soils**

These soils are the most important in terms of extent and agricultural use. Hydromorphic black soils occur in areas with annual precipitation ranges of 500 to 1000 mm. The hydrologic conditions play a key role in the evolution and development of this kind of soil. Except for the soils found in rainy mountainous regions that developed on basalt (Barshin soil) and are relatively well drained, the prominent feature of hydromorphic black soil is that it forms in bad drainage conditions. The poor drainage is attributed to a heavy clayey texture and very slow runoff; (as is the case in the soil of the Akkar plain between Syria and Lebanon) or the location in a closed or semi-closed depression valley (Al-Ghab, Hola, El Amuq soils). This depression chronology is linked to the extension of the Dead Sea faults along the eastern coast of the Mediterranean that took place in the Tertiary and led to the emergence of many depressions (Jordan Valley, Hola Galilea, Houla Plain, El Beqaa Valley, Al-Ghab rift valley, El Amuq rift valley). Valley fills of these areas can tell a complicated story of erosion, sedimentation, and pedogenesis during periods of stability [55].

Water stagnation and poor drainage affected the accumulation of organic matter on the topsoil to the extent that these soils were considered wetlands before reclamation and drainage. The black soil of these areas developed on marl, freshwater organic, woody materials and conglomerates of lacustrine deposits (Al-Ghab, El Amuq) as well as on marl, freshwater organic material of lacustrine deposits and basalt (Houla Homs, Hola Galilea). Until recently, before undergoing reclamation and artificial drainage to dispose of excess water, ponding at least occasionally from January to February. Yet, the remains of hydrophilic vegetation such as Elms, Willow, Bulrush, Tama-risk, and acrocarpous mosses are still visible today [56], Figure 3.

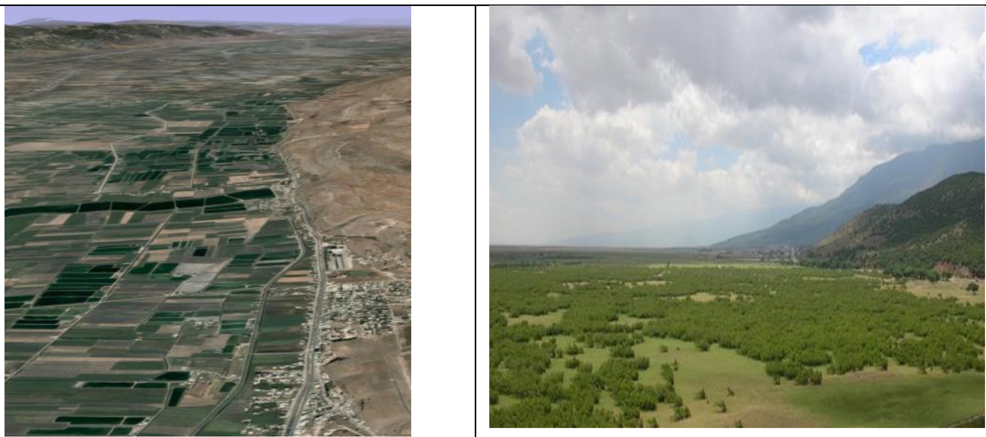

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**Figure 3.** A. The landscape and B. Natural vegetation of the Al-Ghab rift plain.

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The black soil in the Al-Ghab valley is a good example of this soil. It is located in a broken-down strip of a north-to-south fault of the Coastal Mountain Range, which is occupied by the wetland of the Al-Ghab depression. The poor drainage of the Al-Ghab is due to a lava flow, which almost completely bars the outlet of the Orontes River. At one point, only one shallow passage has been worn through this impediment. In 1956, the basalt threshold in the far north was broken to dry the area. The landscapes are highly similar since both areas are characterized by a lack of prominent topographic features, which makes soil distribution patterns difficult to grasp in a general survey [33]. The evolution of these soils seems largely connected with waterlogging conditions, which might retard or affect the decomposition of organic matter. Since the dark colors seem to persist for some time after artificial drainage of an area, it seems possible that more stable forms of humus were accumulated and are responsible for black soils. The absence of a clay migration in these soils is a result of continuous soil cultivating and extensive agriculture rotation, [57]

Mollisols with a strongly distinctive mollic epipedon cover the entire area and the isoline 200 m.a.s.l. is considered a sharp delineation between this soil and others. Three great groups represent the Mollisols in this area: Paleoxerolls, Calcixerolls, and Haploxerolls, with the latter being the predominant one due to the prevailing xeric soil moisture regime. However, data from the field and the morphological soil profiles studied show that the soil receives more moisture (ground moisture) than the prevailing moisture system suggests. The thickness of the mollic epipedon, the occurrence of carbonate within 1.5 m of the soil as well as the groundwater level (although artificial drainage is applied) are the main reasons for the soil complexity. These features facilitate the soil classification at the lower categories. However, Aquic, Cumulic, Pachic, Calcic pachic, and Typic Haploxerolls are assumed to be largely represented, Figure 4.

In Calcixerolls, the saturation of the subsoil, high groundwater level and high evaporation rates combined lead to the upward movement of carbonates, which, in turn, result in the formation of calcic horizons. This is contrary to the typical process of calcic horizon formation in Mediterranean soils, which normally includes the leaching and translocation of carbonate from the topsoil to the subsoil. Typic and Cumulic subgroups are found within the Calcixerolls. In contradiction to Ilaiwi's suggestions [33], no petrocalcic horizon was detected in any of the soil profiles, probably due to the waterlogging conditions. Further research should investigate the potential roles of vegetation types in the genesis of such humus-rich soils.

| | | | |
|---|---|---|---|
|  |  |  |  |
| Joureen<br>Aquic Haploxerolls | Ennab<br>Cumulic Haploxerolls | El Kreem<br>Pachic Haploxerolls | Nbel El Khateeb<br>Calcic Haploxerolls |

**Figure 4.** Hydromorphic black soils of the Al-Ghab rift plain.

**Black soil on basalt**

Most of these black soils have been weathered from basic olivine basalts of the Pliocene age [58]. Van Lier [30] referred to these soils as Kastanozem or dark brown soils resulting from the dissolution of basalt. The occurrence of markedly different soils in this area can be explained satisfactorily by differences in their topographic position and the progressive changes in topography.

These soils are shallow and have small and very dark grayish-brown epipedons.

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The epipedon is rich in fine roots and highly contains organic material over an intensive weathered parent materials (C) horizon. The texture is loam or clay loam with crumb to fine blocky structure and high amounts of gravel of various parent rocks through the profile. Soil colors are approximately similar, and originate from humus accumulation and dark basaltic parent material. However, the dark color in the surface horizons is mainly due to the high humus content rather than the fact that these horizons originated from basalt parent material. The appearance of some red and purple soil colors is not only related to high precipitation, as is common in the Mediterranean region but also reflects high quantities of ferric materials [59].

These soils are considered devoid of primary carbon, and this is due to the igneous parent material. However, this does not prevent the formation of nodules of secondary carbonates of sedimentation origin in Endopedons. The heavy rainfall rate (800 mm) can wash secondary carbonates from the surface horizons through cracked soil to lower horizons, but it is unable to completely remove them from the entire soil profile, Figure 5.

| | |
|---|---|
|   |  |
| A | B |

**Figure 5.** Black soils have developed on weathered olivine basalt.

## 5. Conclusions

This study found that black soils occur occasionally in the Eastern Mediterranean at small scale in different climatic zones ranging from xeric to aridic, and that they can be categorized into two types: Calcareous black soil, and Hydromorphic black soil.

The Hydromorphic black soil seems to be the most important because of its extent/distribution and intensive agricultural use. Its formation is spatially associated with the Dead Sea faults. Therefore, it is reasonable that this soil is the oldest and that the Rendzina is the most recent one. Rendzina occurs on limestone, sandstone, chalk, dolostones, and similar calcareous materials, with a dark surface horizon and high carbonate content, keeping it completely base saturated. The soil has a weakly developed, immature profile and the Rendzina is predominant in occurrence (Typic Rendolls). However, the existence of these kinds of soils under arid and semi-arid conditions raises questions on the geneses and forming processes as well as the conditions associated particularly with paleosols and paleoclimate, which require further research.

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