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Article

Black Soils in the Eastern Mediterranean: Genesis and Properties

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Abstract: This study investigates the distribution, morphology, and properties of these soils, focusing on areas such as littoral plains, high hilly areas, and rift depression valleys. Black soils occur in the eastern Mediterranean with a limited distribution, and some of them meet the requirements for black soils according to the INBS (International Network of Black Soils), while others do not. Black soils can be categorized into three types based on their genesis and evolution: calcareous black soils (mainly raw rocky rendzina), hydromorphic black soils, and black soil on basalt. While black soils were found in various bioclimatic stages and parent materials, their presence was notably limited in certain areas, contrary to prior indications. A soil morphology analysis revealed distinct color variations and depths, influenced by the accumulation of organic matter for hydromorphic and calcareous black soils and basaltic parent material for black soils on basalt. A particle size analysis indicated texture variations from clay to loam, with no clear indication of illuviation. A chemical analysis showed alkaline pH levels, except in basalt-derived soils, which exhibited a slight acidity. Hydromorphic black soil is the most important in terms of expansion and agricultural use and is only found in limestone marl deposits and lakes in depressions emerging from Dead Sea rifts under conditions of saturation or poor drainage. These soils have a thick, dark moly horizon and a high organic matter content.

Keywords: semi-arid; black soils; rendzina; Chernozems; eastern Mediterranean

Citation: Hag Husein, H.; Bäumler, R.; Lucke, B.; Sahwan, W. Black Soils in the Eastern Mediterranean: Genesis and Properties. *Geographies* **2024**, *4*, 168–181. https://doi.org/10.3390/geographies4010011

Academic Editor: Jeroen Meersmans

Received: 19 December 2023
Revised: 14 February 2024
Accepted: 19 February 2024
Published: 27 February 2024

1. Introduction

Although black soils have a small contribution to the soil cover of the eastern Mediterranean, their occurrence and evolution in relation to the current prevailing geological, geomorphological, and climatic factors are controversial. The International Network of Black Soils (INBS) defines black soils as soils that have (i) black or very dark surface horizons, typically with a chroma of $\leq$3 moist, a value of $\leq$3 moist, and $\leq$5 dry; (ii) a high organic carbon content, as per the following: $\geq$1.2% for cold and temperate regions and $\geq$0.6% for tropical regions; and (iii) a thickness of very dark to black surface horizons not less than 25 cm [1,2]. The term "black soil" in this study refers to fine black soil that contains a layer of humus and rich organic matter content in the upper layer, regardless of whether it meets the requirements of the INBS. Its dark color is due to the abundant accumulation of soil organic carbon (SOC) [3–5]. The WRB Classification System [6] classified black soil as Chernozems, Kastanozems, and Phaeozems, whereas Soil Survey Staff [7] classified black soil as being mostly Mollisols, excluding Vertisols and dark Andosols [8]. Black soils are mostly found in cold and temperate northern latitudes, such as the 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]. They host the largest terrestrial carbon pool [11], and thus, they 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 to 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] and 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, 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. Whereas [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 were earlier referred to by Miklaszewski [23] as white rendzina. These soils contain a significantly higher content of $CaCO_3$ and P availability 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], and Chalabi [32] as well as by Ilaiwi [33]. The person who first mentioned black soils in Jordan was Moormann [34], who remarked that the (A) horizon is very weak and the organic matter content rarely exceeds 1 or 2% in the best cases. 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 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 Leptosols on limestone regolith in the Abila ruins in northern Jordan.

Despite the growing recognition of the significance of black soils as bread baskets due to their inherent high fertility as well as carbon sequestration reservoirs, particularly in marginal and fragile ecosystems like the eastern Mediterranean, available information regarding the characteristics of black soils and their utilization remains limited. Comprehending their properties and genesis is imperative for their conservation and sustainable management. Therefore, this study seeks to elucidate the attributes and determinants contributing to the formation of these soils by analyzing soil survey data obtained from 15 soil profiles.

2. Materials and Methods

First, areas expected to contain black soil based on previous research results [33,41] were investigated. Subsequently, 15 soil profiles in Syria, known for harboring the largest share of black soil in the region, were studied. The soil profiles were selected to represent the diverse environmental and topographic conditions of the eastern Mediterranean region; see Figure 1.

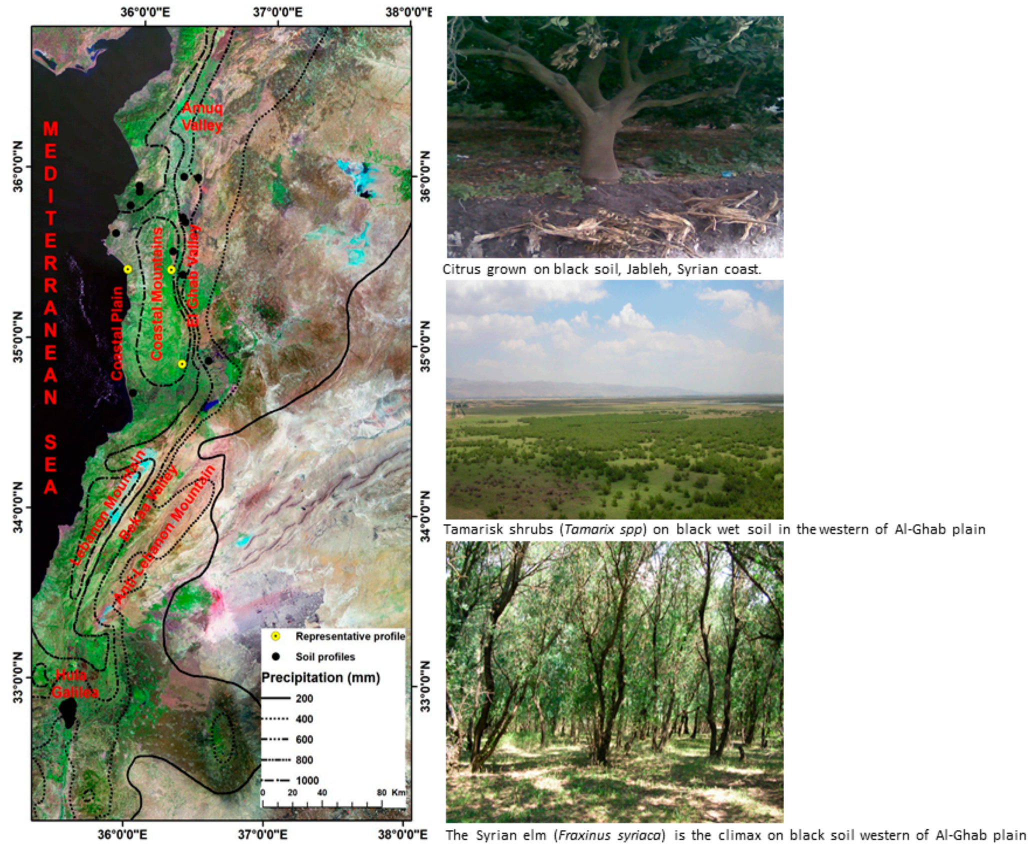


Figure 1. Illustrates the geographical distribution of the 15 studied black soil profiles across four bioclimatic stages in the eastern Mediterranean region.

The soil profiles are distributed across four bioclimatic stages, based on the pluviothermic quotient of Emberger [42]. These stages include the following:

i. Upper humid stage, cold.
ii. Lower sub-humid stage, fresh.
iii. Lower sub-humid stage, temperate.
iv. Upper semi-arid.

These stages receive annual precipitation ranging from approximately 500 to over 1000 mm. The climax vegetation consists of Pinus brutia forest, while the degraded stages were characterized by Maquis vegetation dominated by Quercus species, particularly in wetter stages. From among these soil profiles, three representative profiles were selected for soil sampling and analysis: Jableh (littoral plain), Al-Ghab (rift valley), and Barshin (littoral mountainous area).

Soil description and sampling were based on the procedures of the Soil Survey Division Staff [43]. The morphological study and soil profile description followed the guidelines provided in the Field Book for Describing and Sampling Soil [44], as well as the Keys to Soil Taxonomy [7]. All soil samples underwent air-drying at 95 °C for 24 h. Following the removal of gravel, stones, and vegetation, the samples were ground, sieved, and homogenized. The organic carbon ($C_{org.}$) content was determined using the Walkley–Black method [45], modified by Nelson and Sommers [46]. For samples with a high organic matter content, organic carbon was determined by loss on ignition (LOI) at 420 °C in the furnace for 6 h [47]. A particle size analysis was conducted using the hydrometer method [48]. The soil reaction (pH) was measured in suspensions of H_2O (1:1), (0.01 M) and $CaCl_2$ (1:2) [47]. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) were estimated using the Mehlich method ($BaCl_2$-TEA, pH = 8.2) [49,50]. Basic saturation (BS) was determined using the Soil Survey Staff method [51], and calcium carbonates were assessed using the Scheibler method [52]. The total nitrogen was determined following Kjeldahl's procedures [53] and McRae's methods [54]. Electrical conductivity (EC) was measured in a suspension of H_2O (1:2) [48]. The available phosphorus was estimated according to Olsen [55], and the total potassium was determined according to Jackson [56].

3. Results

The soil profiles revealed the presence of black soil in certain areas of the littoral plain, littoral high hilly areas, and rift depression valleys. These soils were distributed across multiple bioclimatic stages, originating from various parent materials, and situated within different rainfall zones, as outlined in Table 1.

Table 1. General description of soil profile features.

Profile Code	Coordinates and Elevation	Rainfall mm	Bio-Climate Stage	Physiographic and Topographic Position	Drainage Class	Vegetation	Parent Material	Classification	
								ST **	WRB ***
Jableh	35°25′10.67″ N 35°55′23.37″ E 28 m.a.s.l *	863	sub humid, hot	littoral undulating plain, very gentle slope	moderately well drained, very slow surface runoff	pinus brutia	Calcareous sandstone and conglomerates	Typic Ren-dolls	Rendzic Mollic Leptosols
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 gentle slope	moderately well drained, very slow surface runoff	cultivated olive trees	Pliocene marls and limestones	Typic Calcixe-rolls	Calcic Cher-nozems
Kassab Zanzaf	35°47′44.77″ N 35°55′46.52″ E 240 m.a.s.l	1248	humid temperate	littoral high hilly, footslope	well drained, rapid surface runoff, moderately slow permeability	pome trees	Undifferentiated complex of igneous rock predominated by serpentine of Mesozoic era	Typic Ren-dolls	Rendzic Leptosols
Kassab Nibh Al mur	35°52′41.93″ N 35°59′35.60″ E 380 m.a.s.l	1248	humid temperate	littoral high hilly, middle slope of mountainous area	well drained, rapid surface runoff, moderately slow permeability	pome and stone fruit trees	Undifferentiated complex of igneous rock predominated by serpentine of Mesozoic era	Entic Ultic Hap-loxe-rolls	Rendzic Leptosols
Kassab	35°54′47.54″ N 35°59′24.10″ E 800 m.a.s.l	1248	humid temperate	littoral high hilly, middle slope of high hills	well drained, rapid surface runoff, moderately rapid permeability	pinus brutia	Undifferentiated complex of igneous rock predominated by serpentine of Mesozoic era	Entic Ultic Hap-loxe-rolls	Rendzic Sekeletic Leptosols
Der Athman	35°58′22.8″ N 36°19′16.2″ E 325 m.a.s.l	679	sub humid temperate	inland mountainous area, back slope of undulating hills	well drained	cultivated olive and stone fruit trees	Limestone	Calcic Pachic Hap-loxe-rolls	Leptic Calcic Kas-tanozem
Drkosh-Al daher	35°58′04.8″ N 36°25′37.9″ E 530 m.a.s.l	679	sub humid temperate	inland mountainous area, back slope of undulating hills	Well drained	shrubs and cultivated olive trees	Dolostones and hard limestone	Entic Ultic Hap-loxe-rolls	Rendzic Humic Leptosols
Akkar-Zahed	34°41′38.66″ N 35°59′12.36″ E 1.0 m.a.s.l	1150	sub humid hot	littoral plain, flat plain	poorly drained, very slow surface runoff, slow permeability	irrigated vegetables and green-houses	Quaternary and recent colluvium and alluvium derived mainly from Neogene basalt	Vertic Hap-loxe-rolls	Vertic Cher-nozems
Barshin	34°52′20.60″ N 36°20′37.41″ E 930 m.a.s.l	994	humid temperate	littoral high hilly, back slope of high hills	moderately well drained, rapid runoff, slow permeability	pome trees	Pliocene basalt	Typic Hap-loxe-rolls	Cambic Skeletic Phaeozems
Houla	34°53′42.88″ N 36°32′11.59″ E 375 m.a.s.l	480	semi-arid temperate	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 Hap-loxe-rolls	Vertic Kastanozems

Table 1. *Cont.*

Profile Code	Coordinates and Elevation	Rainfall mm	Bio-Climate Stage	Physiographic and Topographic Position	Drainage Class	Vegetation	Parent Material	Classification	
								ST **	WRB ***
Al-Ghab-Joureen	35°31′58.92″ N 36°15′7.67″ E 180 m.a.s.l	871	sub-humid temperate	rift valley level to depression valley fills	moderately well drained, very slow surface runoff, slow permeability	elms trees	Quaternary or more recent marl diatomaceous, lacustrine deposition	Aquic Haploxerolls	Leptic Kastanozems
Al-Gab Enab	35°25′25.40″ N 36°14′41.89″ E 182 m.a.s.l	871	sub-humid temperate	rift valley level to depression valley fills	moderately well drained, very slow surface runoff, slow permeability	elms trees	Quaternary or more recent marl diatomaceous, lacustrine deposition	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

* Meters above sea level. ** Soil Taxonomy. *** World Reference Base.

We did not encounter any black soil in the Al-Ruj Plain, despite the indications provided by Ilaiwi [33]. Additionally, the presence of these soils was notably limited in Jabal Al-Arab, which is contrary to the findings of numerous studies [57,58]. This discrepancy arises from the surface horizon's darkness. The darkness here is primarily attributed to the decaying of basalt rather than the soil humification process.

3.1. Soil Morphology

The soil morphology of the representative profiles is listed in Table 2. The color of the topsoil varied from black to dark reddish brown (10YR 2/1-5YR 3/3 moist). Distinct color variations between the horizons were primarily observed in the soil profile with Rendzic properties (Jabla), which can be attributed to significant fluctuations in carbonate content in the sub-surface horizon and the diverse origins of parent materials. A thin layer of slightly de-composed forest litter was observed atop the rendzina (Oi) horizon. The soils exhibited considerable depth overall, except in cases where steep slopes, intervening undulating hills, and mountainous regions were present. In these areas, gully erosion posed a significant challenge, particularly on deforested plots.

Table 2. Soil morphology of representative soil profiles.

Horizon	Depth (cm)	Color		Structure	Consistence	Pores	Roots	Boundary	Special Features
		Dry	Moist						
Jableh, Typic Rendolls/Rendzic Mollic Leptosols									
Oi	5–0	dark gray brown 7.5YR3/3	very dark gray 7.5YR3/1	midrate medium fine granular	slightly plastic	-	abundant very fine to medium	abrupt smooth	slightly decomposed plant material frequent rounded stone constituting approximately 10%

Table 2. *Cont.*

Horizon	Depth (cm)	Color		Structure	Consistence	Pores	Roots	Boundary	Special Features
		Dry	Moist						
A	0–35	-	dark reddish brown 5YR3/3	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 reddish brown 2.5YR3/4	-	fine granular	sticky and plastic	few fine vertical in ped, simple, closed	few fine	very abrupt smooth	few small soft carbonate stones
C	50+	-	pale yellow 10YR8/3 and pink 7.5YR8/3	-	-	-	-	-	conglomerates calcareous sandstone
Al-Ghab, Aquic Haploxerolls/Vermic Chernozems									
A	0–26	dark brown 10YR3/3	black 10YR2/1	moderate 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 grayish brown 10YR3/2	fine granular	firm (moist) sticky and plastic	few fine vertical in ped, simple, closed	plenty fine	gradual wavy boundary	roots between peds
AC	55+	-	dark gray 10YR4/1	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, Typic Haploxerolls/Cambic Skeletic Phaeozems									
Ap	0–18	dark brown 7.5YR3/3	very dark grayish brown 10YR3/2	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 brown 10YR3/3	very dark grayish brown 10YR3/2	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%
C	40–75	-	grayish brown 2.5YR5/2	weak medium sub-angular 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 indicated that the texture ranged from clay to sandy clay loam to loam. The proportion of clay in the particle size distribution exhibited lower values than typical for Mediterranean soils. However, there was no definitive indication of illuviation observed in relation to the variation in clay content, clay/sand and clay/silt with depth, as shown in Table 3.

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

Table 3. *Cont.*

Soil	Horizon	Depth (cm)	Particle Size Distribution (%) Ø mm			Clay/Sand	Clay/Silt	Texture
			Sand	Silt	Clay			
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
	BC	55–115	12	39	49	4.08	1.25	clay
	R	115+	-	-	-	-	-	-

3.3. Soil Chemical Properties

Table 4 presents some soil chemical properties. The soil reaction (pH) generally ranged from slightly to moderately alkaline, with values influenced by the carbonate content and base saturation. However, the basalt-derived soil showed slight-to-moderate acidic reactions due to its non-carbonate igneous parent material and its exposure to leaching due to its location in an area with heavy rainfall.

Table 4. Some soil chemical properties.

Horizon	Depth (cm)	pH		Carbonates $CaCO_3$%		EC $mS.m^{-1}$	$C_{org.}$ %	Extractable Bases $meq.100\ g^{-1}$				Ext. P $mg.kg^{-1}$	Tot. N %	CEC $meq.100\ g^{-1}$	BS
		$CaCl_2$ 1:1	H_2O 1:1	<2 mm	<0.002 mm			Ca^{2+}	Mg^{2+}	K^+	Na^+				
Jableh, Typic Rendolls/Rendzic Leptosols															
Oi	0–5	7.4	7.5	2.2	ND	0.5	14.42	ND	ND	0.4	0.3	31.3	0.38	52.5	ND
A	5–35	7.6	7.8	16.4	ND	0.4	2.41	ND	ND	0.1	0.3	20.5	0.19	62.5	ND
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	ND
C	50+	7.4	7.5	44.0	ND	0.5	0.1	ND	ND	0.2	0.3	19.0	-	70.2	ND
Al-Ghab, Aquic Haploxerolls/Vermic Chernozems															
A	0–26		7.2	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		7.8	69.5	27.0	2.1	3.1	15.0	1.1	0.1	1.1	8.2	4 *	24	88.3
AC	55+		7.6	77.0	26.0	2.5	2.2	11.0	0.6	0.1	0.6	3.3	2 *	22	75.7
Barshin, Typic Haploxerolls/Somerirendzic Leptosols															
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 $mg.kg^{-1}$.

Contrary to expectations, the Barshin soil, supposed to be carbonate-free except for some nodules of secondary carbonates, exhibited fairly high and constant calcium carbonate content across solum and constituted a prominent chemical feature. In the marl diatomaceous lacustrine deposit, the calcium carbonate content showed no consistent trend, increasing to more than 77%.

Cation exchange capacities were not high; the Barshin soil profile exhibited the lowest CEC due to low carbonate content and soil reaction. Although trends to decrease or increase with depth were unclear, base saturation was generally high across all profiles.

4. Discussion

Our study found that black soils occur in the eastern Mediterranean in very small-scale areas, and they can be categorized into three types depending on evolution and genesis:

1. Calcareous black soils (rendzina) on littoral plains and hilly areas.
2. Hydromorphic black soils in depressions.
3. Black soil on basalt.

These soils can be present in both humid and sub-humid Mediterranean climates.

Calcareous black soils

These soils can develop on various parent materials such as limestone, sandstone, chalk, dolostones, serpentin, and similar calcareous materials; see Figure 2. The darker color of the surface horizon is attributed to the accumulation of organic matter in the (O-A) or (A) horizons. In contrast to Reifenberg's [20] assertion that these soil types were deficient in humus, our investigation revealed a high organic carbon content in these soils. The significant presence of calcium carbonate content keeps the soils almost entirely base saturated, which retards the weathering processes and subsequent release and redistribution of sesquioxides and silica [59]. Consequently, this soil typically exhibits a weakly developed, immature profile. The most prevalent soil type observed is Typic Rendolls (rendzina), which evolves from Brown Calcisols or directly from the calcareous regolith through humification processes.

(**A**) (**B**) (**C**) (**D**)

Figure 2. Calcareous black soils: (**A**) Al Qanjra, Calcic Chernozems on chalk material; (**B**) Kassab, Rendzic Skeletic Leptosols on serpentine; (**C**) Jableh, Rendzic Mollic Leptosols on sandstone; (**D**) Jableh, Cambic Skeletic Leptosols on calcareous materials.

The microrelief and parent materials play crucial roles in the development of this soil type. In some cases, the soil profile is subjected to intensive erosion, which rejuvenates the weathering profile [60,61]. The mollic horizon is often shallow, perhaps eroded on shoulders and slopes. In such scenarios, the soil tends to be relatively immature, characterized by a shallow mollic epipedon covering the calcareous regolith.

Occasionally, a litter layer can be observed above the mollic horizon, varying in depth from 5 to 30 cm. The typical soil horizon sequence comprises (O-A-C or A-C), occasionally including a transitional horizon (AC), but a proper illuvial horizon is typically absent.

The soil featured a high content of calcium or calcium and magnesium and a high base saturation throughout the soil profile. It seems that the high calcium content gives these soils a large potential for carbon sequestration, which should be verified and studied in detail in the context of the potential of these soils to reduce emissions [60].

Hydromorphic black soils

These soils are paramount in terms of their extent and agricultural utility. For instance, the agricultural land area in the Al-Ghab Plain alone spans 87,000 hectares. Hydromorphic black soils occur mainly in close depressions with annual precipitation ranges of 500 to 1000 mm. Hydrologic conditions play a key role in the evolution and development of this kind of soil. Unlike soils found in rainy mountainous regions that develop on basalt (Barshin soil) and exhibit relatively good drainage, the defining characteristic of hydromorphic black soil is its formation in areas with poor drainage conditions. Poor drainage is primarily attributed to the combination of location (depression) and topography (level), leading to a very slow water flow and the presence of heavy clay-textured soils, as observed in the soil of the Akkar plain between Syria and Lebanon, or the location within closed or semi-closed depression valleys (such as Al-Ghab, Hola, and 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, and El Amuq rift valley). The valley fills of these areas can tell a complicated story of erosion, sedimentation, and pedogenesis during periods of stability [62].

Water stagnation and poor drainage have affected the accumulation of organic matter on the topsoil to the extent that these soils were historically considered wetlands before reclamation and drainage efforts. The black soil in these areas developed on marl, freshwater organic, woody materials, and conglomerates of lacustrine deposits (e.g., Al-Ghab, El Amuq), as well as on marl, freshwater organic material of lacustrine deposits, and basalt (e.g., Houla Homs and Hola Galilea). Until recently, before reclamation and artificial drainage to dispose of excess water, ponding was a common occurrence, particularly from January to February. However, remnants of hydrophilic vegetation such as elms, willows, bulrushes, tama-risks, and acrocarpous mosses are still visible today [63]; see Figure 3.

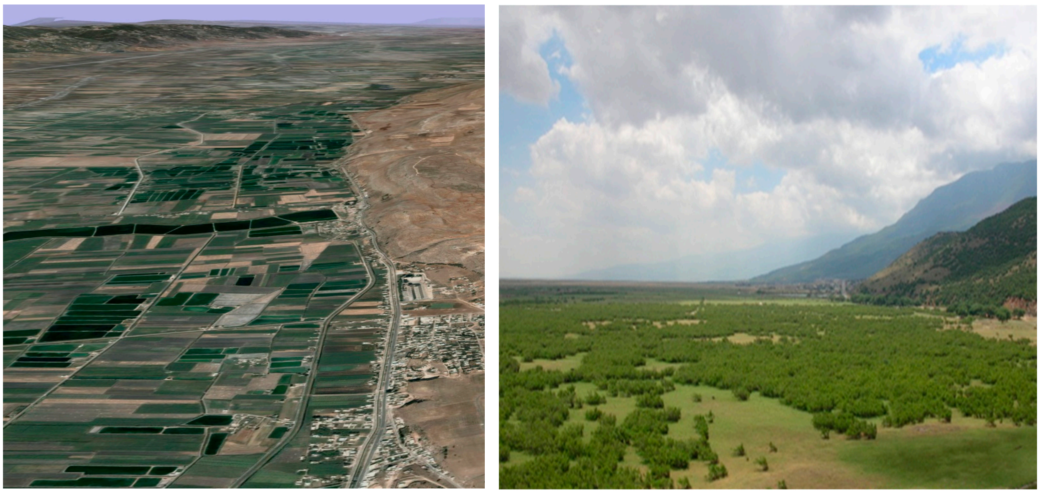
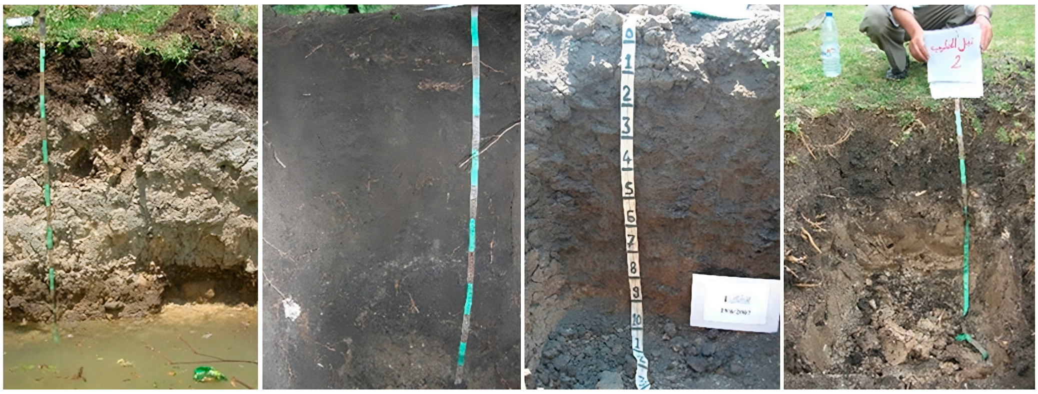

(A) (B)

Figure 3. (**A**) The landscape (Google earth), and (**B**) the natural vegetation of the Al-Ghab rift plain.

The black soil in the Al-Ghab valley exemplifies this soil type. Situated within a fragmented strip of a north-to-south fault of the Coastal Mountain Range, it occupies the wetland of the Al-Ghab depression. The poor drainage of the Al-Ghab is primarily attributed to a lava flow, which nearly obstructs the outlet of the Orontes River. Only a shallow passage has been worn through this impediment. In 1956, the basalt threshold in the northernmost part was breached to facilitate drying of the area. The landscapes of both areas bear striking similarities, 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 clay migration in these soils is a result of continuous soil cultivation and extensive agriculture rotation [64].

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 soil classification in the lower categories. However, Aquic, Cumulic, Pachic, Calcic Pachic, and Typic Haploxerolls are assumed to be largely represented; see Figure 4.



(**A**) (**B**) (**C**) (**D**)

Figure 4. Hydromorphic black soils of the Al-Ghab rift plain: (**A**) Joureen, (Aquic Haploxerolls/Mollic Stagnosols); (**B**) Ennab, (Cumulic Haploxerolls/Hortic Chernozems); (**C**) El Kreem, (Pachic Haploxerolls/Vertic Chernozems); (**D**) Nbel El Khateeb, (Calcic Haploxerolls/Clacic Chernozems).

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.

Black soil on basalt

Most of these black soils have undergone weathering from basic olivine basalts of the Pliocene age [65]. 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 satisfactorily explained by differences in their topographic positions and the progressive changes in topography.

These soils are shallow and have small and very dark grayish-brown epipedons. The epipedon is rich in fine roots and contains a high amount of organic material over an intensively weathered parent material (C) horizon. The texture is loam or clay loam with a crumb-to-fine blocky structure and high amounts from gravel of parent rocks through the profile. Soil colors are approximately similar and originate from humus accumulation and dark basaltic parent material. The dark color on the surface horizons primarily originates from the basalt parent material. However, the high amount of humus increases the intensity of the color. In addition to color, humus-accumulated horizons can be distinguished from ordinary horizons by the crumbly structure of the soil and the dense containment of thin roots. 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 [66].

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; see Figure 5. These soils are considered devoid of primary carbon 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.

(**A**) (**B**)

Figure 5. (**A**) Soil profile of Black soils on basalt, (**B**) landscape of weathered olivine basalt.

5. Conclusions

This study reveals that black soils are found in specific areas of the littoral plain, littoral high hilly areas, and rift depression valleys across the eastern Mediterranean region. Their distribution is influenced by multiple factors, such as parent materials, microrelief, and rainfall zones. These soils exhibit considerable variability in morphology and physical and chemical properties. Color variations, depth, texture, and chemical composition vary based on factors like parent material, erosion, and drainage conditions. The study classifies black soils into three main types: calcareous black soils, hydromorphic black soils, and black soil on basalt. Each type has distinct characteristics that are influenced by its evolution and genesis. Hydromorphic black soils, prevalent in depressions with poor drainage conditions, play a crucial role in agriculture despite historically being considered wetlands. Their formation is linked to water stagnation, organic matter accumulation, and drainage efforts. Calcareous black soils develop on various calcareous parent materials and are characterized by their skeletal, high organic carbon content epipedons, and significant presence of calcium carbonate. Their weakly developed profiles and high base saturation contribute to their unique properties. Black soil on basalt originating from basic olivine basalts, features dark grayish-brown epipedons rich in organic material. Despite being devoid of primary carbon, they contain secondary carbonates.

This study provides comprehensive insights into the diverse nature of black soils in the eastern Mediterranean region and underscores the importance of considering their unique properties and genesis for effective agricultural and environmental management strategies. However, the existence of these kinds of soils under arid and semi-arid conditions raises questions about the genes and forming processes, as well as the conditions associated with them, particularly paleosols and paleoclimate, which require further research.

Author Contributions: Conceptualization, H.H.H. and B.L.; Methodology, H.H.H. and R.B.; Formal Analysis, H.H.H. and B.L.; Investigation, H.H.H., W.S. and B.L.; Data Curation, B.L.; Writing—Original Draft Preparation, W.S.; Writing—Review and Editing, H.H.H., R.B. and B.L.; Visualization, H.H.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request. The data are not publicly available due to ongoing research using a part of the data.

Acknowledgments: Many thanks to the Soil Laboratory of the General Commission for Scientific Agriculture Research (GCSAR), Syria.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. FAO. DEFINITION | What Is a Black Soil? 2019. Available online: https://www.fao.org/global-soil-partnership/intergovernmental-technical-panel-soils/gsoc17-implementation/internationalnetworkblacksoils/more-on-black-soils/definition-what-is-a-black-soil/ru/ (accessed on 8 June 2023).
2. FAO. *Global Status of Black Soils*; FAO: Rome, Italy, 2022. [CrossRef]
3. Han, X.; Li, N. Research Progress of Black Soil in Northeast China. *Sci. Geogr. Sin.* **2018**, *38*, 1032–1041. [CrossRef]
4. Song, C.; Lu, W.; Du, H. Degradation of Black Soil Quality and Strategies of Prevention Control in Northeast Plain, China. In Proceedings of the 7th International Conference on Water Resource and Environment (WRE 2021), Online, 1–4 November 2022; Available online: https://www.scitepress.org/Papers/2021/110203/110203.pdf (accessed on 1 November 2022).
5. Andreeva, D.; Leiber, K.; Glaser, B.; Hambach, U.; Erbajeva, M.; Chimitdorgieva, G.; Tashak, V.; Zech, W. Genesis and properties of black soils in Buryatia, southeastern Siberia, Russia. *Quat. Int.* **2011**, *243*, 313–326. [CrossRef]
6. IUSS Working Group WRB. *World Reference Base for Soil Resources. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*, 4th ed.; International Union of Soil Sciences (IUSS): Vienna, Austria, 2022.
7. Soil Survey Staff. *Keys to Soil Taxonomy*, 13th ed.; U.S. Department of Agriculture, Natural Resources Conservation Service: Washington, DC, USA, 2022.
8. Sorokin, A.; Owens, P.; Láng, V.; Jiang, Z.-D.; Michéli, E.; Krasilnikov, P. "Black soils" in the Russian Soil Classification system, the US Soil Taxonomy and the WRB: Quantitative correlation and implications for pedodiversity assessment. *CATENA* **2021**, *196*, 104824. [CrossRef]
9. Liu, X.; Burras, C.L.; Kravchenko, Y.S.; Duran, A.; Huffman, T.; Morras, H.; Studdert, G.; Zhang, X.; Cruse, R.M.; Yuan, X. Overview of Mollisols in the world: Distribution, land use and management. *Can. J. Soil Sci.* **2012**, *92*, 383–402. [CrossRef]
10. Smreczak, B.; Jadczyszyn, J.; Kabała, C. Przydatnoœć rolnicza rędzin w Polsce. *Soil Sci. Annu.* **2018**, *69*, 142–151. [CrossRef]
11. FAO; ITPS. Status of the world's soil resources (SWSR)–main report. In *Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils*; FAO: Rome, Italy, 2015.
12. Lal, R. Soil carbon management and climate change. *Carbon Manag.* **2013**, *4*, 439–462. [CrossRef]
13. Hag Husein, H.; Lucke, B.; Bäumler, R.; Sahwan, W. Contribution to Soil Fertility Assessment for Arid and Semi-Arid Lands. *Soil Syst.* **2021**, *5*, 42. [CrossRef]
14. Achiba, W.B.; Gabteni, N.; Lakhdar, A.; Laing, G.D.; Verloo, M.; Jedidi, N.; Gallali, T. Effects of 5-year application of municipal solid waste compost on the distribution and mobility of heavy metals in a Tunisian calcareous soil. *Agric. Ecosyst. Environ.* **2009**, *130*, 156–163. [CrossRef]
15. Parras-Alcántara, L.; Lozano-García, B.; Keesstra, S.; Cerdà, A.; Brevik, E.C. Long-term effects of soil management on ecosystem services and soil loss estimation in olive grove top soils. *Sci. Total Environ.* **2016**, *571*, 498–506. [CrossRef]
16. Muñoz-Rojas, M.; Jordán, A.; Zavala, L.M.; De la Rosa, D.; Abd-Elmabod, S.K.; Anaya-Romero, M. Organic carbon stocks in Mediterranean soil types under different land uses (Southern Spain). *Solid Earth* **2012**, *3*, 375–386. [CrossRef]
17. Hag Husein, H.; Mousa, M.; Sahwan, W.; Bäumler, R.; Lucke, B. Spatial Distribution of Soil Organic Matter and Soil Organic Carbon Stocks in Semi-Arid Area of Northeastern Syria. *Nat. Resour.* **2019**, *10*, 415–432. [CrossRef]
18. Ahmet, C. Soil organic carbon losses by water erosion in a Mediterranean watershed. *Soil Res.* **2016**, *55*, 363–375. [CrossRef]

19. Tarzi, J.G.; Paeth, R.C. Genesis of a Mediterranean red and a white rendzina soil from Lebanon. *Soil Sci.* **1975**, *120*, 272–277. [CrossRef]
20. Reifenberg, A. *The Soils of Palestine*, 2nd ed.; Thomas Murbery and Co.: London, UK, 1947.
21. Durand, R.; Dutil, P. Experimental alteration of calcareous and dolomitic rocks-Importance of rock structure and its mineralogical nature. *Acad. Sci. Paris CR Ser. D* **1971**, *272*, 2423.
22. Geze, B. *Carte de Reconnaissance de Sols du Liban*; MinistCre de 1′Agriculture. Direction de 1′Enseignement et de la Vulgarisation: Beirut, Lebanon, 1956.
23. Miklaszewski, S. *Mémoire Relatif à la Pologne, Mémoires sur la Nomenclature et la Classification des Sols*; Imprimerie de l'État Finlande: Helsinki, Finland, 1924; pp. 245–255.
24. Sayegh, A.H.; Salib, A.J. Some physical and chemical properties of soils in the Beqa'a plain, Lebanon. *J. Soil Sci.* **1969**, *20*, 167–175. [CrossRef]
25. Çepel, N. *Sedir Yetisme Muhiti Tanitinimin Pratik Esaslari ve Orman Yetisme Muhiti Haritaciligi*; Kurtulus Matbaasi: Istanbul, Turkey, 1966.
26. Darwish, T.M.; Zurayk, R.A. Distribution and nature of Red Mediterranean soils in Lebanon along an altitudinal sequence. *CATENA* **1997**, *28*, 191–202. [CrossRef]
27. Muir, A. Notes on the Soil of Syria. *J. Soil Sci.* **1951**, *2*, 163–187. [CrossRef]
28. Nahal, I. Contribution à l'étude de la végétation dans le Baer-Bassit et le Djebel Alaouite de Syrie. *Webbia* **1962**, *16*, 477–641. [CrossRef]
29. Nahal, I. The Mediterranean climate from a biological viewpoint. In *Mediterranean-Type Shrublands. Ecosystem of the World*; Di Castri, F., Goodall, W., Specht, R.L., Eds.; Elsevier Scientific Publishing Company: Amsterdam, NL, USA, 1981; Chapter 3; Volume 11, pp. 63–86.
30. Van Lier, W.J. *Classification and Rational Utilization of Soils*; Report to the Government of Syria; FAO: Rome, Italy, 1965; p. 141.
31. Zain al Abdeen, A.N. *Principles of Soil Science*; University of Aleppo: Aleppo, Syria, 1978; pp. 250–270.
32. Chalabi, M.N. Analyse Phytosociologique, Phytoécologique, Dendrométrique et Dendroclimatologique des Forêts de Quercus Cerris Subsp. Pseudocerris et Contribution à l' Étude Taxinomique du Genre Quercus L. en Syrie. Ph.D. Thesis, Université d' Aix, Marseille, France, 1980; pp. 137–141, III 342p. + annexes de 171 p. Ecologia Mediterranea T.VIII, (Fascicule 1/2). Marseille.
33. Ilaiwi, M. Contribution to the Knowledge of the Soils of Syria. Ph.D. Thesis, Ghent University, Ghent, Belgium, 1983; p. 259.
34. Moormann, F. *The Soils of East Jordan: Report to the Government of Jordan (Expanded Technical Assistance Program No. 1132)*; FAO: Rome, Italy, 1959.
35. Ministry of Agriculture, Jordan (MoA). *The Soils of Jordan: Level 1 (Reconnaissance Survey)*; Report of the National Soil Map and Land Use Project; Ministry of Agriculture: Amman, Jordan, 1993; Volume 1.
36. Ministry of Agriculture, Jordan (MoA). *The Soils of Jordan: Level 2 (Semi Detailed Studies)*; Report of the National Soil Map and Land Use Project; Ministry of Agriculture: Amman, Jordan, 1995; Volume 3.
37. Khresat, S.E.A. Nature and properties of mollisols in a semiarid region in northern Jordan. *Commun. Soil Sci. Plant Anal.* **1999**, *30*, 2429–2436. [CrossRef]
38. Lucke, B.; Schmidt, M.; al-Saad, Z.; Bens, O.; Hüttl, R.F. The Abandonment of the Decapolis Region in Northern Jordan—Forced by Environmental Change? *Quat. Int.* **2005**, *135*, 65–81. [CrossRef]
39. Lucke, B. Demise of the Decapolis. Past and Present Desertification in the Context of Soil Development, Land Use, and Climate. Ph.D. Thesis, BTU Cottbus, Cottbus, Germany, Omni Scriptum, Saarbrücken, Germany, 2008.
40. Lucke, B.; Kemnitz, H.; Bäumler, R. Evidence for isovolumetric replacement in Terrae Rossae of Jordan. *Bol. Soc. Geol. Mex.* **2012**, *64*, 21–35. [CrossRef]
41. *Soil Atlas of El-Zawia and El-Wstani Mountains, Hussam Hag Husein, General Commission for Scientific Agricultural Research*; Damascus: Douma, Syria, 2012; p. 255. ISBN 978-9933-9238-5-3. Available online: https://www.researchgate.net/publication/366185616_SOIL_ATLAS_OF_El-ZAWIA_El-WASTANI_MOUNTAINS (accessed on 18 December 2023).
42. Emberger, L. *Une Classification Biogeographique des Climates*; Recueil, travaux de laboratoire géolo-zoologique, Faculté des sciences; Scientific Research: Montpellier, France, 1955; Volume 7, pp. 3–43.
43. Soil Survey Division Staff. *Soil Survey Manual*; U.S. Department of Agriculture Handbook 18; U.S. Government Publishing Office: Washington, DC, USA, 1993; p. 510.
44. U.S.D.A-NRCS. *Field Book for Describing and Sampling Soils. v 1.1*; USDA-NRCS: Lincoln, NE, USA, 1998; p. 182.
45. Walkley, A.; Black, A. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **1934**, *37*, 29–38. [CrossRef]
46. Nelson, D.W.; Sammers, L.E. Total carbon and organic matter. In *Methods of Soil Analysis, Part 2*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; ASA-SSSA: Madison, WI, USA, 1982; pp. 539–579.
47. Soil Survey Staff. *Soil Taxonomy: A Basic System of Soil Classification for Making an Interpreting Soil Survey*; U.S. Department of Agriculture Handbook 436; U.S. Government Publishing Office: Washington, DC, USA, 1975; p. 503.
48. Soil Conservation Service. *Soil Survey Laboratory Methods*; Soil Survey Investigations Report No 42; U.S. Department of Agriculture: Washington, DC, USA, 1992; p. 400.
49. Mehlich, A. Use of Triethanolamine Acetate-Barium Hydroxide Buffer for the Determination of Some Base Exchange Properties and Lime Requirement of Soil 1. *Soil Sci. Soc. Am. J.* **1939**, *3*, 162–166. [CrossRef]

50. Soil Survey Staff. *Kellogg Soil Survey Laboratory Methods Manual*; Soil Survey Investigations Report No. 42, Version 5.0; Burt, R., Soil Survey Staff, Eds.; U.S. Department of Agriculture, Natural Resources Conservation Service: Washington, DC, USA, 2014.
51. Soil Survey Staff. *Keys to Soil Taxonomy*, 12th ed.; U.S. Department of Agriculture, Natural Resources Conservation Service: Washington, DC, USA, 2014.
52. Turski, R.; Domżał, H.; Borowiec, J.; Flis-Bujak, M.; Misztal, M. *Gleboznawstwo. Ćwiczenia dla Studentów Wydziałów Rolniczych*; Polish Scientific Publishers PWN: Warsaw, Poland, 1986; pp. 1–278.
53. Kjeldahl, J. Neue Methodezur Bestimmung des Sticksoffs in organischen Körpern. *Z. Anal. Chem.* **1883**, *22*, 36–382. [CrossRef]
54. McRae, S.G. *Practical Pedology Studying Soils in the Field*; Ellis Horwood Limited: Chichester, UK, 1988; p. 253. ISBN 0-85312-918-5.
55. Olsen, S.R.; Cole, F.; Watanabe, S.; Dean, L.A. *Estimation of Available Phosphorus in Soil by Extraction with Sodium Bicarbonate*; U.S. Department of Agriculture Circular 939; U.S. Department of Agriculture: Washington, DC, USA, 1954; p. 18.
56. Jackson, M.L. Instrument in soils and waters. *J. Agric. Food Chem.* **1956**, *4*, 602–605. [CrossRef]
57. Habib, H. Genesis, surface charge and classification of soil developed on lcanic ashand basalt in an arid climate (Syria). Ph.D. Thesis, Ghent University, Ghent, Belgium, 1986; p. 192.
58. Habib, H. Pedological study of soil topo-sequence on Daher Al-jabal, Swieda Governorate. *Univ. Damascus Syr.* **2006**, *22*, 181–209. (In Arabic)
59. Arnold, R.W. Multiple Working Hypothesis in Soil Genesis 1. *Soil Sci. Soc. Am. J.* **1965**, *29*, 717–724. [CrossRef]
60. Kabała, C. Rendzina (rędzina)-Soil of the Year 2018 in Poland. Introduction to origin, classification and land use of rendzinas. *Soil Sci. Annu.* **2018**, *69*, 63–74. [CrossRef]
61. Miechówka, A.; Drewnik, M. Rendzina soils in the Tatra Mountains, central Europe: A review. *Soil Sci. Annu.* **2018**, *69*, 88–100. [CrossRef]
62. Lucke, B.; Hag Husein, H.; Sahwan, W.; Bäumler, R. A preliminary survey of soils and sediments in the Dead Cities region, northwestern Syria. In *The "Dead Cities" of Northern Syria and Their Demise*; Riis, T., Ed.; Verlag Ludwig: Kiel, Germany, 2015; pp. 33–59.
63. Erdağ, A.; Kirmaci, M.; Tizini, I.; Kashlan, A.; Addine, B.C. Contributions to the moss flora of the Al-Ghab plain (north-west Syria). *Turk. J. Bot.* **2013**, *37*, 369–374.
64. Hag Husein, H.; Kalkha, M.; Al Jrdi, A.; Bäumler, R. Urban Soil Pollution with Heavy Metals in Hama Floodplain, Syria. *Nat. Resour.* **2019**, *10*, 187–201. [CrossRef]
65. Technoexport. *The Geological Map of Syria. Scale 1:1,000,000: Explanatory Notes*; Ministry of Industry: Damascus, Syria, 1966; 111p.
66. Hag Husein, H.; Nammora, T.; Zaghtiti, I.; Al-Khateeb, A.; Zenyah, E. Soil Catena Properties of Daher Al-Jabal IN south Syria. *Int. J. Environ.* **2017**, *6*, 87–107. Available online: http://www.nepjol.info/index.php/IJE/article/view/16870/13714 (accessed on 18 December 2023). [CrossRef]