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Morphological, physical and chemical properties of selected soils in the arid and semi-arid region in north-western Jordan

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The morphological features and physico-chemical properties of four pedons representing the major soil types in the arid and semi-arid region in north-western Jordan were studied. Soils of this area show a wide variation in their morphological, physical and chemical properties as a result of differences in mean annual precipitation, soil parent material, vegetation and topography. The studied soils developed in a wetter climate than the prevailing one and were subjected to different paleoclimates ranging from humid to the prevailing arid conditions. The major pedogenic processes are calcification and illuviation. Soils in the area belong to the orders Aridisols and Vertisols.

Keywords: pedology; paleoclimate; Vertisols; Aridisols; arid and semi-arid environment

Introduction

Soils of north-western Jordan show a wide variation in their characteristics, covering five of the USDA's soil orders. These are Aridisols, Entisols, Inceptisols, Vertisols and Mollisols (Ministry of Agriculture, 1993). There is a need for detailed soil characterization in many areas of north-western Jordan which is one of the major rain-fed agricultural areas in the country. Four sites of different lithology and annual rainfall were studied. The main objectives of this investigation were to characterize the soils of the area, to classify the soils according to the Soil Taxonomy System (Soil Survey Staff, 1975) and to provide basic information about the soils for agricultural development.

The soils have been developed from Quaternary alluvium, colluvium and loess deposits derived from basalt or limestone. The general relief varies from gently undulating to flat and gently sloping plains. The area has a Mediterranean climate with an average annual precipitation ranging between 200 and 500 mm (Meteorological Department, 1988), with the rainy season extending from November to March. This climatic region is in the 500–600 m elevation zone and is considered the major farming area in north-western Jordan. Two soil moisture regimes are recognized in the study area. The western half has a xeric regime and the eastern half has a xeric aridic transitional regime. Thermic is the dominant temperature regime in the study area. Mean winter air temperatures range from 5 to 9°C, and mean summer air temperature ranges from 22 to 29°C.

Materials and methods

Soil samples were collected from four soil sites representing the semi-arid–arid zone border (Fig. 1). The pedons were described according to Guthrie & Witty (1982) before taking the samples. The bulk soil samples were air-dried, crushed with a mortar and pestle and sieved to remove coarse (> 2 mm) fragments. Particle-size distribution was determined by the hydrometer method (Gee & Bauder, 1986). Soil pH was measured on 1:1 soil:water suspensions (McLean, 1982); soluble salts were determined by measuring the electrical conductivity of 1:1 soil:water extracts (Rhoades, 1982); organic matter was determined using the Walkley–Black method (Nelson & Sommers, 1982); and calcium carbonate equivalent values were obtained using the acid neutralization method (Richards, 1954). Free iron oxides were extracted with sodium

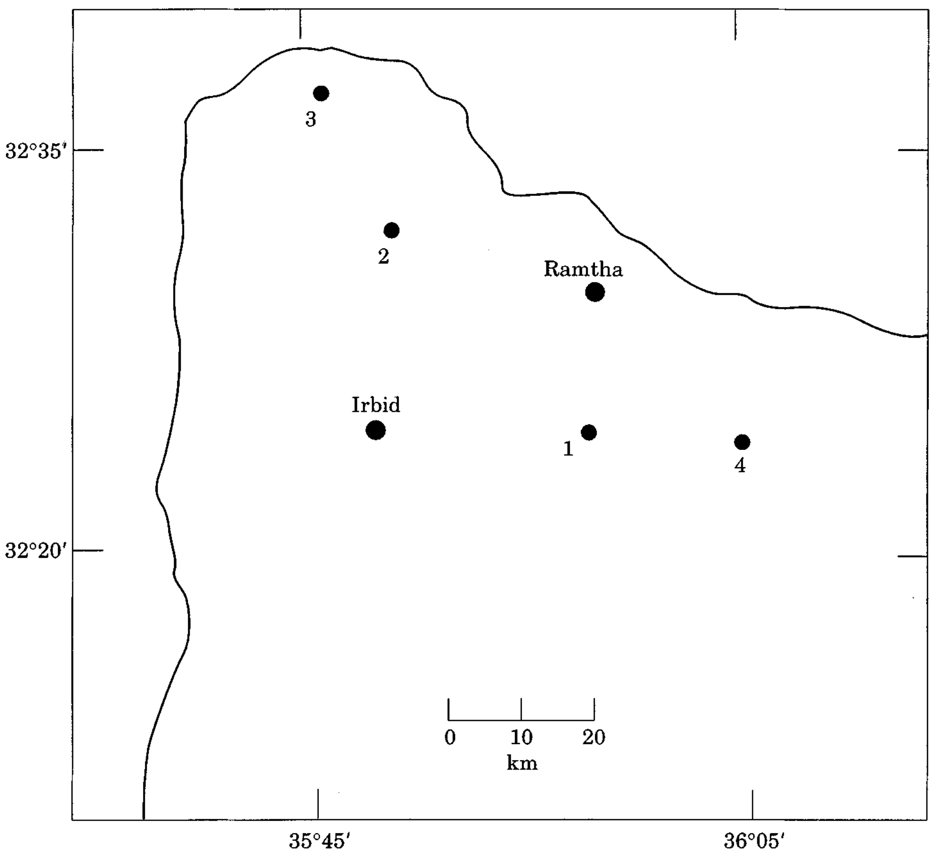

Figure 1. Location of study sites. 1 = Jordan University of Science and Technology (JUST); 2 = Amraweh; 3 = Thnaibeh; 4 = Khanasri.

dithionite-citrate-bicarbonate and measured using the orthophenanthroline colorimetric method (Jackson, 1973). Exchangeable bases were determined following displacement with 1 M NH_4OAc (Thomas, 1982). Cation exchange capacity was determined by the sodium saturation method (Chapman, 1965).

Profiles description

Pedon 1

Classification	: fine-loamy, mixed, thermic, Calcic Paleargid
Location	: 200 m north-west of the Agricultural Research centre at Jordan University of Science and Technology
Vegetation	: barley
Landscape position	: alluvial plain
Slope	: 1–2% concave position
Parent material	: alluvium derived from limestone
Elevation	: 580 m a.s.l.
Colour	: on moist basis

Horizon depth (cm)

Ap 0–28	Reddish brown (5YR 4/4), silty clay loam, moderate medium granular and strong medium subangular blocky structure, slightly hard; friable, sticky, plastic; common medium roots; strongly effervescent; gradual boundary
Bk1 28–55	Yellowish red (5YR 4/6), silty clay loam, strong coarse angular blocky structure; very hard, firm, sticky, plastic; few fine roots; strongly effervescent; clear boundary
Bk2 55–90	Yellowish red (5YR 4/6), silty clay loam, strong coarse angular blocky structure; very hard, firm, sticky, plastic; very few fine roots; stage I calcium carbonate filaments, strongly effervescent; gradual boundary
Btkb1 90–115	Strong brown (7·5YR 4/6), silty clay loam, strong coarse angular blocky structure that breaks to strong medium subangular blocky; very hard, firm, very plastic, sticky; stage II calcium carbonate nodules; common thick clay films; no roots; violently effervescent; clear boundary
Btkb2 115–170	Reddish brown (5YR 4/3), silty clay loam, moderate medium subangular blocky structure; slightly hard, firm, slightly sticky, slightly plastic; stage II calcium carbonate; many thick clay films; violently effervescent; gradual boundary
Btkb3 170–220	Strong brown (7·5YR 5/6), clay, moderate medium angular blocky structure that breaks to moderate fine subangular blocky; hard, friable, sticky, plastic; violently effervescent; many thick clay films

Pedon 2

Classification	: fine, smectitic, thermic, Aridic Haploxererts
Location	: Amraweh
Land use	: bare land

Slope : 0–1% level
Parent material : alluvium derived from Basalt
Landscape position : alluvial plain
Colour : on moist basis

Horizon depth (cm)

Ap 0–25 Dark reddish brown (5YR 4/4), clay, moderate medium granular and strong coarse subangular blocky structure, slightly hard, firm, slightly plastic to plastic, slightly sticky to sticky; common fine and few medium roots; strongly effervescent; clear boundary

Bw 25–70 Dark reddish brown (5YR 3/3), clay, strong coarse subangular blocky structure; hard, firm, sticky, plastic; stage I calcium carbonate filaments; few medium and very few fine roots; strongly effervescent; diffuse boundary

Bssk1 70–100 Dark reddish brown (5YR3/4), clay, strong coarse angular blocky structure that breaks to strong medium subangular blocky; very hard, extremely firm, very sticky, very plastic; parallelped structure; slickensides, stage II calcium carbonate nodules; strongly effervescent; very few fine roots; gradual boundary

Bssk2 100–160 Dark reddish brown (5YR 3/4), clay, strong coarse angular blocky structure; extremely hard, extremely firm, very plastic, very sticky; parallelped structure, slickensides, stage II calcium carbonate nodules; strongly effervescent; no roots

Pedon 3

Classification : very fine, smectitic, thermic, Aridic Haploxererts
Location : Thnaibeh
Land use : wheat
Landscape position : alluvial plain
Slope : 1–2% concave
Parent material : alluvium derived from Basalt
Colour : on moist basis

Horizon depth (cm)

Ap 0–10 Dark reddish brown (5YR 4/3), clay, moderate medium granular structure; slightly very hard, firm, slightly plastic, slightly sticky; many fine and few medium and coarse roots; strongly effervescent; gradual boundary

Bwl 10–35 Dark reddish brown (5YR 3/4), clay, strong coarse angular blocky structure that breaks to subangular blocky; extremely hard, extremely firm, very plastic, very sticky; strongly effervescent; few medium roots, diffuse boundary

Bssl 35–100 Dark reddish brown (5YR 3/4), clay, strong coarse angular blocky structure; extremely hard, extremely firm, very sticky, very plastic; parallelped structure, slickensides; strongly effervescent; few medium roots; gradual boundary

Bss2	100–140	Dark reddish brown (5YR 3/4), clay, strong coarse angular blocky structure; extremely hard, extremely firm, very plastic, very sticky; parellelped structure, slickensides; strongly effervescent; no roots

Pedon 4

Classification	: fine loamy, mixed, thermic, Typic Haplocambid
Location	: Khanasri
Vegetation	: bare
Landscape position	: alluvial plain
Slope	: 1% plain
Parent material	: alluvium derived from limestone
Elevation	: 570 m a.s.l.
Colour	: on moist basis

Horizon depth (cm)

A	0–10	Brown (7·5YR 4/3), silty clay loam, strong fine granular structure; hard, friable, sticky, plastic; common fine and very fine roots; violently effervescent; clear boundary
Bwl	10–25	Brown (7·5YR 4/4), silty clay loam, strong fine subangular blocky structure; hard, friable, sticky, plastic; common fine roots; strongly effervescent; gradual boundary
Bw2	25–60	Brown (7·5YR 4/4), silty clay loam, strong medium angular blocky structure; slightly hard, friable, sticky, plastic; very few fine roots; stage I calcium carbonate filaments; strongly effervescent; clear boundary
2Bw3	60–70	Brown (7·5YR 3/4), silty clay, strong subangular blocky structure; hard, friable, very plastic, very sticky; no roots; strongly effervescent; clear boundary
2Bwt	70–100	Reddish brown (5YR 4/4), silty clay loam, strong medium angular blocky structure; very hard, firm, sticky, plastic; strongly effervescent; clear boundary
2Btk	100–140	Reddish brown (5YR 4/4), silty clay loam, strong medium angular blocky structure; hard, friable, very sticky, very plastic; stage II calcium carbonate nodules; common clay skins; violently effervescent; no roots

Results and discussion

Soil pH values slightly increased with depth in nearly all of the studied soils (Table 1). Most pH values of the surface layers are around 7·8. The similarity of the pH values throughout the soil horizons and in the different sites indicate limited leaching and slow rates of weathering and soil development in these arid and semi-arid regions.

The lack of significant differences in the values of electrical conductivity (EC) and soluble cations between the horizons of each pedon indicate little leaching, eluviation and illuviation have taken place in the studied soils. Electrical conductivity values show that the highest value was 4·47 dS m^{-1} in pedon 4. The average electrical conductivity of the other soils is 0·38 dS m^{-1} indicating that these soils are not saline.

Table 1. *Relevant soil chemical properties of the studied sites*

Horizon	Depth (cm)	pH*	EC (dS m^{-1})	OC	$CaCO_3$	Fe_2O_3
					%	
Pedon 1						
Ap	0–28	7·33	0·51	1·00	14·0	0·26
Bk1	28–55	7·91	0·28	0·55	19·4	0·24
Bk2	55–90	7·85	0·26	0·31	32·3	0·23
Btkb1	90–115	7·92	0·28	0·29	34·3	0·22
Btkb2	115–170	7·96	0·26	0·18	44·1	0·20
Btkb3	170–220	7·64	0·26	0·14	45·2	0·20
Pedon 2						
Ap	0–25	7·82	0·53	0·50	18·6	0·80
Bw	25–70	8·12	0·26	0·42	19·6	0·80
Bssk1	70–100	8·25	0·35	0·39	19·6	0·85
Bssk2	100–16	8·20	0·55	0·26	20·3	0·84
Pedon 3						
Ap	0–10	7·88	0·30	0·50	23·9	0·79
Bw	10–35	8·03	0·34	0·48	23·9	0·77
Bss1	35–100	8·27	0·45	0·38	24·0	0·83
Bss2	100–140	8·36	0·62	0·29	24·0	0·79
Pedon 4						
A	0–10	7·94	0·74	0·87	24·0	0·10
Bw1	10–25	8·10	0·35	0·64	24·0	0·11
Bw2	25–60	8·17	1·35	0·35	23·9	0·11
2Bw3	60–70	8·16	2·30	0·31	24·0	0·11
2Bwt	70–100	8·10	3·45	0·40	23·9	0·11
2Btk	100–140	7·94	4·47	0·32	23·9	0·11

* Soil pH was measured on 1:1 soil water suspensions.
EC = electrical conductivity; OC = organic carbon.

The horizons of carbonate accumulation in the studied profiles are pedogenic. This was concluded from their distribution pattern that parallels the land surface, and the filamental and nodular shape of the illuvial carbonate (Wilding *et al.*, 1990). Calcium carbonate content showed an increase with depth in pedon 1 from 14·0% at the surface to 45·2% below 170 cm depth (Table 1), and from 18·6 to 20·3% in pedon 2. The carbonate content was uniform in pedons 3 and 4. This suggests that during wetter periods the carbonate was removed from upper parts of the soil profile and translocated and re-deposited in the deeper soil layers in pedon 1. In pedons 2 and 3 which were classified as vertisols, the pedoturbation contributed to a more uniform distribution of $CaCO_3$. In pedon 4 translocation was not active. This is attributed to the stratification in this alluvial soil.

Clay content in pedon 1 (Fig. 2) increases from 35·4% at the surface to 44·8% below 170 cm depth. The difference in clay content between the surface and subsurface horizons accounts for the presence of a buried argillic horizon at a depth of 90 cm and below. This argillic horizon is deep and has calcareous material above it indicating that it was formed during pluvial times. In pedons 2 and 3 (Figs 3 and 4) the clay was uniformly distributed. Uniform clay content suggests that clay illuviation was not a

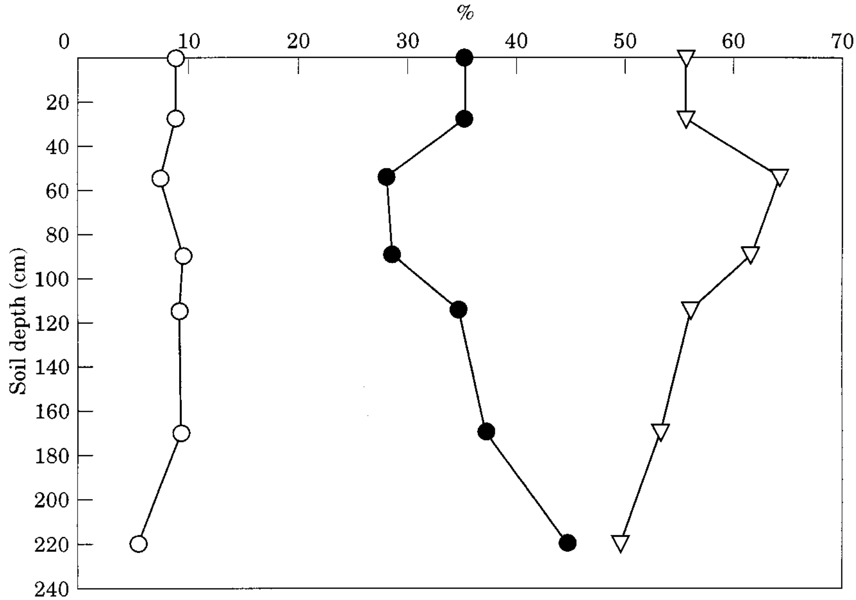

Figure 2. Particle-size distribution for pedon 1. (○) = sand; (●) = clay; (▽) = silt.

dominant process in the upper horizons. This is attributed to the flocculating influence of $CaCO_3$ which inhibits clay movement. Maximum silt content was found in the surface layers. This is attributed to increased aeolian activity. Sand fractions were uniformly distributed throughout the soil pedons.

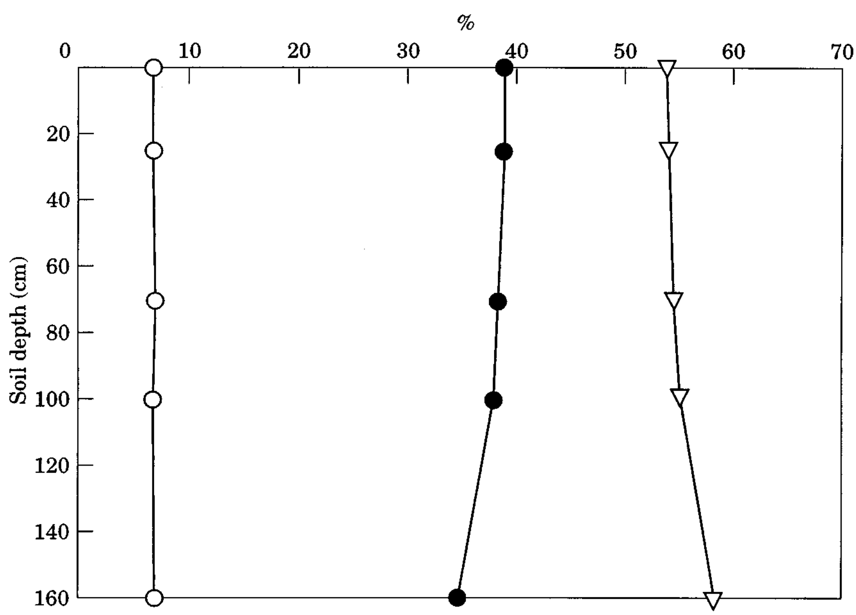

Figure 3. Particle-size distribution for pedon 2. (○) = sand; (●) = clay; (▽) = silt.

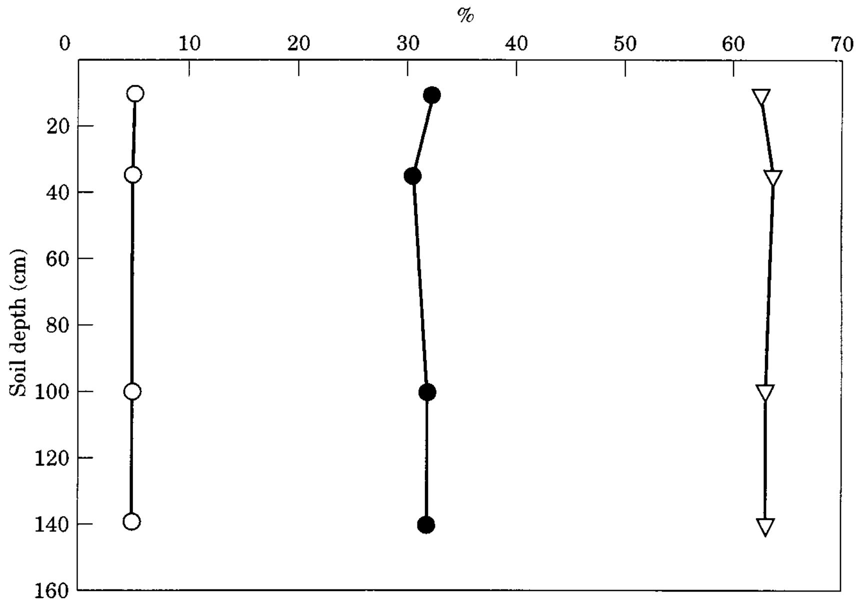

Figure 4. Particle-size distribution for pedon 3. (○) = sand; (●) = clay; (▽) = silt.

There was evidence of illuvial clay in pedon 4 (Fig. 5) but the illuviation was not enough to meet the requirements of an argillic horizon. Lithological discontinuity was observed in pedon 4 at a depth of 60 cm.

Free iron oxides were uniformly distributed throughout all the studied sites indicating slow weathering processes. The lowest amount (0·10%) was observed in pedon 4

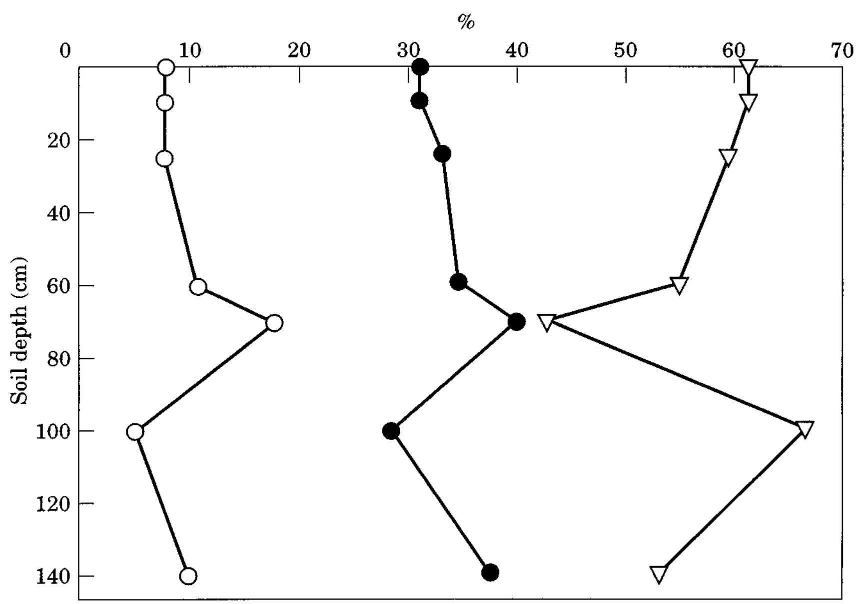

Figure 5. Particle-size distribution for pedon 4. (○) = sand; (●) = clay; (▽) = silt.

indicating very slow weathering. Pedons 2 and 3 have larger contents of free iron oxides reflecting the more basaltic parent materials.

Organic carbon is generally low and decreases with depth in all studied soils (Table 1). The lowest amount was observed (0·14%) in the subsurface horizons in pedon 1. Higher organic carbon values were observed at the surface horizons in pedons 1 and 4. This is attributed to their concave position where more water is concentrated and organic matter oxidation is less. Also, these sites are uncultivated. The organic carbon content of pedon 1 exceeded the 1% required for mollic epipedon for the surface horizons, but due to dryness and dark colour requirements for the mollic epipedon (Soil Survey Staff, 1994) it was not classified as mollic.

The soil cation exchange capacity (CEC) was high at the soil surface (Table 2) and decreased with depth for pedon 1. This is due to the effect of the higher organic matter in the surface horizons. For pedons 2 and 3, the cation exchange capacity was about the same for all horizons. This could be related to the homogeneity in clay amounts as a result of pedoturbation. The cation exchange capacity showed different values among soil pedons (Table 2). This variation is attributed to different amounts of dominant clay minerals (lithology).

Calcium was the most dominant extractable cation followed by magnesium, sodium and potassium (Table 2). Calcium was highest in the surface horizons for all studied

Table 2. *Extractable cations and cation exchange capacity (CEC) of the studied sites*

Horizon	Depth (cm)	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	CEC
		cmol(+)kg^{-1}				
Pedon 1						
Ap	0–28	20·8	0·8	2·31	0·62	37·8
Bk1	28–55	19·1	1·6	1·13	0·66	37·9
Bk2	55–90	17·3	0·5	0·64	0·75	38·5
Btkb1	90–115	18·0	0·7	0·54	0·97	30·8
Btkb2	115–170	18·3	1·5	0·51	0·93	29·2
Btkb3	170–220	14·2	1·1	0·36	0·84	28·5
Pedon 2						
Ap	0–25	37·0	10·1	2·07	1·06	48·5
Bw	25–70	33·3	12·6	1·38	2·55	47·5
Bssk1	70–100	30·8	13·6	1·23	5·50	46·0
Bssk2	100–160	27·2	14·3	1·20	7·60	48·5
Pedon 3						
Ap	0–10	35·1	10·4	1·08	0·88	45·8
Bw	10–35	34·0	10·4	0·77	1·28	46·3
Bss1	35–100	29·8	13·0	0·59	3·60	44·5
Bss2	100–140	26·8	13·4	0·77	4·40	44·5
Pedon 4						
A	0–10	15·0	1·1	2·22	1·14	24·0
Bw1	10–25	15·4	0·4	1·64	1·06	24·3
Bw2	25–60	15·7	0·5	1·28	1·41	27·8
2Bw3	60–70	14·5	1·0	0·60	3·26	25·5
2Bwt	70–100	15·7	0·4	0·85	5·81	25·7
2Btk	100–140	15·1	0·5	0·86	6·34	26·0

soils. This is attributed to possible calcium additions at the surface by wind. There were slight differences between surface and subsurface horizons. Extractable sodium increased with depth, while extractable potassium decreased with depth.

Soil genesis and classification

The physical, chemical and morphological properties were used in hypothesizing that the studied soils developed in a wetter climate than the prevailing one and were subjected to different paleoclimates ranging from humid to the prevailing arid conditions. The buried argillic horizon in pedon 1 indicates the climatic change from moist to dry. The major pedogenic processes during this period are calcification and illuviation. Magaritz & Goodfriend (1987) indicated that the eastern Mediterranean was subjected to a sequence of wet and dry climatic periods during the late Pleisocene–early Holocene (15,000–8000 years B.P.).

Vertisols are most extensive in the western part of the arid zone in Jordan and are associated with alluvial parent materials. These parent material types are derived from mainly sedimentary rocks such as limestone and igneous rocks including basalt which forms smectites upon weathering. Haploxererts is the major great group in these soils.

The Aridisols are most common in the eastern part of northern Jordan. This is related to the amount of rainfall which decreases eastward. These soils are formed on alluvial limestone. Haplocambids and Paleargids are the major great groups in these soils.

All the soils have ochric epipedons. Only one soil had organic matter to meet the mollic epipedon requirement but the lack of dark colour and dryness moved it to the ochric.

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