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Formation and properties of aridic soils of Azraq Basin in northeastern Jordan

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Abstract

Aridisols occupy a wide and significant part of Jordan. The majority of soils in the Azraq Basin, northeastern Jordan, are aridisols. A database on aridisols and land characteristics in northeastern Jordan is needed to allow rational planning of land and water resources utilization.

The objectives of this paper are to: characterize the main soil types in the area, and identify the main processes contributing to their genesis and evolution. For this purpose eight representative profiles were selected for this study and soil samples were collected and their chemical and physical properties were examined in the laboratory.

The natural vegetation is desert shrubs and short grasses. The sparseness of the vegetation resulted in low SOM content and the presence of ochric epipedons in all of the studied soils. The genesis of these soils accounts for the accumulation of calcium carbonate, soluble salts, and gypsum in the subsoil.

Carbonate, clay eluviation–illuviation, and salt accumulation are the dominant pedogenic processes in these soils. Silt content increased toward the surface indicating eolian activity. Clay content increased with depth indicating illuviation of clay. Clay illuviation and argillic horizon development within these soils is assumed to be a relict feature from presumably more humid climates during the Quaternary.

Desert pavements cover the surfaces of these soils and provide a unique obstacle for agricultural development. The major restrictions to agricultural land use in the area are very

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low infiltration rate, low permeability, and high erodibility. Proper management practices should be adopted if such soils are to be cultivated.

Keywords: Aridisols; Calcic horizons; Salic horizons; Gypsum accumulation

1. Introduction

Aridisols are soils of the aridic moisture regime which occur normally in arid climates. Few are located in semi-arid climates. Aridisols are soils with one or more distinctive pedogenic horizons which have been either enriched or depleted of substances by moving water. They have at least a cambic horizon, or an argillic or natric horizon, or a calcic or petrocalcic horizon or a gypsic or petrogypsic horizon or a duripan, or a salic horizon (Soil Survey Staff, 1998). The arid and semi-arid lands of Jordan, locally known as the Badia, are one of the major dry areas in the world (Allison, 1997). Aridisols occupy a wide and significant part of Jordan. Soils in the Azraq Basin, where this study was carried out, cover an area of about 11,210 square kilometers (km^2) in northeastern Jordan and are classified as aridisols.

Most aridisols occur on stable land surfaces and probably formed under pluvial climates effectively more moist than the present ones (Wilding et al., 1983). Formation of aridisols was reported to be more rapid and effective in pluvial times than in the Holocene (Gile, 1975). Factors of soil formation in arid and semi-arid regions are the same as those in any other part of the world (Buol, 1965). The relative intensities of the various soil forming processes, however, result in some pedologic processes that are quite characteristic of those regions. The limited amount of water available for pedogenic processes is a factor that results in lowering of the intensity of many of these processes (Buol et al., 1997). Water movement in the soil profile is considered one of the most important processes leading to sorting of soil materials and profile differntiation (Mckeague and Arnaud, 1964; Jackson and Hole, 1969). Limited precipitation and shallow soil-moisture penetration dissolved some salts such as calcite and gypsum, which precipitate to form genetic horizons.

The most striking feature of soils in arid and semi-arid regions is the carbonate enriched layer that tends to develop at the bottom of the illuvial horizon soils derived from parent materials containing carbonate (Buol et al., 1997). The calcic horizon is a horizon of accumulation of calcium or of calcium and magnesium carbonate (Soil Survey Staff, 1998). Ca-horizons of desert soils differ widely in carbonate content, bulk density, consistence, texture, and manner of carbonate occurrence. Carbonate may be distributed throughout the horizon, or may be segregated within the horizon. They form in a developmental sequence which is related to time. Calcic horizon normally consists of several subhorizons each of which has a characteristic morphology (Gile, 1961).

Gypsum concentration occurs in the lower horizons of many kinds of profiles from relatively young to probably much older profiles. They are often associated with horizons that show some evidence of impeded drainage. Gypsic horizon forms where parent materials or dust fall have large gypsum content (Wilding et al., 1983). Petrogypsic horizon is a gypsic horizon that is strongly enough cemented with gypsum that dry fragments do not slake in water and that roots cannot enter. The gypsum content is far greater than the minimum requirements for the gypsic horizon. Petrogypsic horizons are restricted to arid climates and to parent materials that are rich in gypsum (Soil Survey Staff, 1998).

A database on aridisols and land characteristics in northeastern Jordan is needed to allow rational planning of land and water resources utilization; especially in setting priorities for the efficient use of the very limited surface water and groundwater reserves. Although the geomorphology and vegetation in the area have drawn some attention, no studies dealt with the morphology, genesis or classification of these soils, nor do they contribute to understanding the relationships observed between the strong variation in soil surface features and the soils beneath.

In order to provide an accurate and definitive soil database on aridic soils, and to evaluate and classify the parameters of soils in terms of their suitability for a wide range of agricultural uses. This paper aims to: (1) characterize the main soil types in the area; (2) identify the main processes contributing to their genesis and evolution.

2. Materials and methods

2.1. Study area

The study area (Azraq Basin) is located in the Jordan Plateau, in a tectonic depression associated with the Wadi Sirhan graben (Fig. 1). The basin covers an area of about 11,210 km^2 with an elevation of 533 m above sea level (a.s.l.) at Azraq, 800 m (a.s.l) at Al-Arityan, and 712 m (a.s.l) at Safawi (Dutton, 1998).

Based on previous studies, using satellite images of the area, several areas in the basin were identified as potential development areas for agricultural production. Eight representative profiles were selected for this study, excavated and described in the field. Soil samples were collected from each horizon in the studied profiles and were taken to the laboratory. These areas have also been important grazing lands for the local population over the years (Juneidi and Abu-Zanat, 1993).

Late Tertiary and early Quaternary basalt rocks are found in northeast Jordan. The basalt is part of the major North Arabian Volcanic Province. Basaltic flows cover about one-third of the total basin area (Allison et al., 1998). The soils have been developed from Quaternary alluvium, eolian, and geologic formations derived from basalt; fluvial deposits; colluvium limestone; eolian gypsum; marls and alluvium cherts.

2.1.1. Climate

The region falls in an arid climatic zone. Air temperature fluctuates widely from a daily mean minimum of 10 °C, mean maximum of 24.5 °C, and a mean daily temperature of 17.5 °C. Occasionally, absolute minimum and maximum temperatures might reach −5 and 46 °C, respectively.

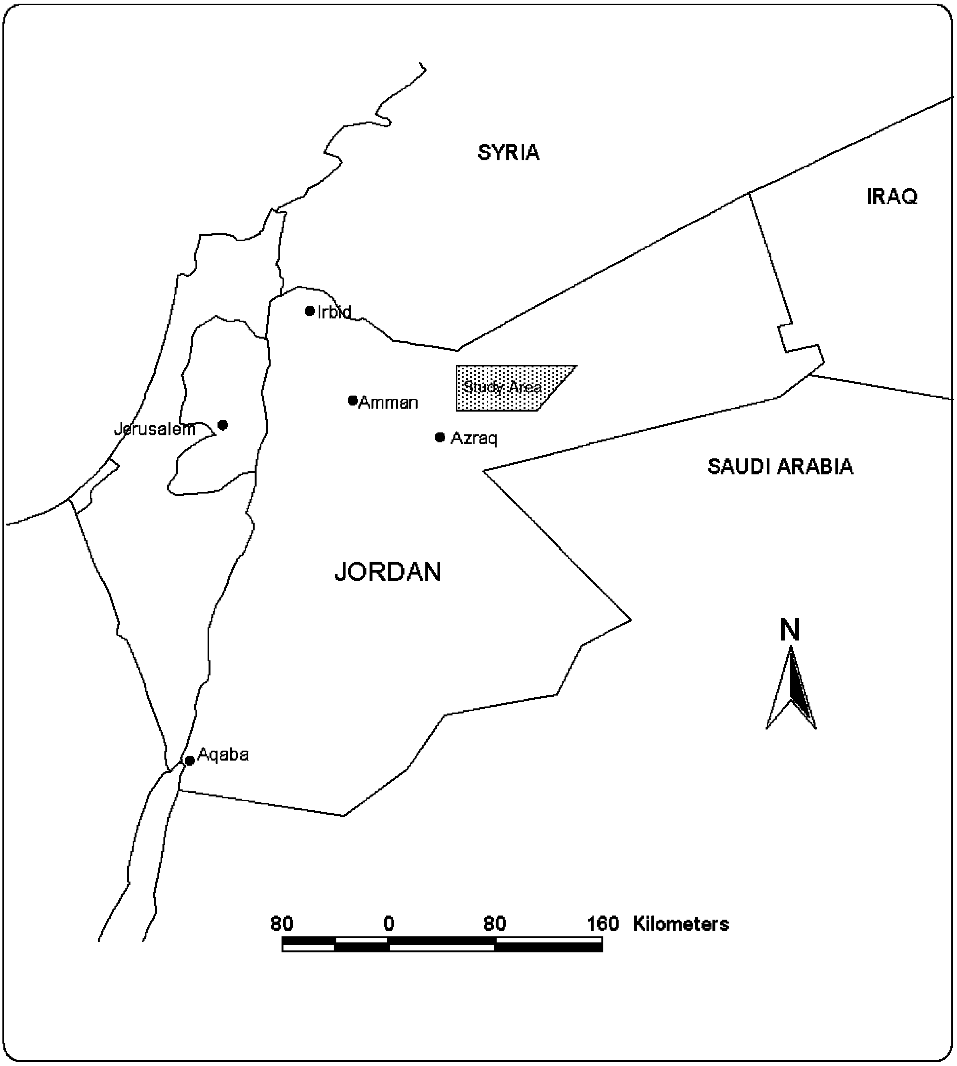

Fig. 1. Map of study area.

Rainfall is variable both spatially and temporally. There are seasonal variations, with summers tending to be hot and dry and winters cool and wet. The average annual precipitation in this area is 100–200 mm. This amount varies substantially from one year to another. The rainfall is basically irregular, sporadic, and unpredictable. Therefore, heavy showers cause tremendous losses of water through surface runoff which decreases the amount of water stored in the soil. Additionally, these showers can also result in high soil erosion events. A high evaporation demand is caused by strong wind gust and high temperature, thus substantially lowering the water available for plant growth in comparison with actual rainfall. The estimated potential evapotranspiration can be in excess of 50 times the mean annual rainfall (Burdon, 1982). This phenomenon is responsible for thinning out the plant cover that causes further erosion and accelerate the rate of soil fertility degradation.

Rainfall occurs mostly between the months of November and May, with 80% of the annual precipitation arriving between December and March with average annual rainfall of less than 70 mm. Individual storms frequently result in wadi flow since many of the rainstorms are of high intensity.

2.1.2. Methods

Each profile was then described using the methodology outlined in the Field Book for Describing and Sampling Soils (Schoeneberger et al., 1998) and soil color was defined using a Munsell Soil Color Chart. Unconsolidated soil and individual soil peds from each described horizon were collected. The bulk soil samples were air dried, crushed with a mortar and pestle, and sieved to remove fragments >2 mm. The site and morphological properties of each soil profile were studied. Particle-size analysis was performed on each horizon in the studied soil profiles using the hydrometer method described by Gee and Bauder (1986). Equivalent calcium carbonate was determined for all soil samples using acid neutralization method described by Richards (1954). Soil pH was measured on 1:1 soil:water suspensions (McLean, 1982). Soluble salts were determined by measuring the electrical conductivity (EC) of 1:1 soil:water extracts (Rhoades, 1982). Cation exchange capacity (CEC) was determined by the sodium (Na) saturation method (Chapman, 1965). Organic matter was determined using Walkley–Black method (Nelson and Sommers, 1982). Gypsum content values were obtained by precipitation with acetone method (Richards, 1954).

3. Results

3.1. Profiles description

3.1.1. Profile 1

Classification	Calcic Haplosalids
Location	(East of Shawmari Reserve)
Slope	0% flat
Parent material	Chert
Latitude	31°46′N
Longitude	36°41′E
Physiographic position	Basin floor
Elevation	520 m
Precipitation	50 mm
Land use	Grazing
Color	On moist basis

Remarks	Small chert fragments 25%, chert pavement
Hor. depth (cm)	
A1 0–4	Strong brown (7.5 YR 4/6); silty clay loam; weak medium platy + loose silty eolian additions; slightly hard; friable; moderately plastic; moderately sticky; no roots; violently effervescent; abrupt boundary
A2 4–20	Strong brown (7.5 YR 4/6); silty clay loam; weak fine to medium granular; moderately hard; friable; non-plastic; sticky; no roots; strongly effervescent; diffuse boundary
Btz 20–60	Brown (7.5 YR 5/4); silty clay loam; strong medium subangular blocky; few gypsum crystals; extremely hard; extremely firm; slightly sticky; non-plastic, strongly effervescent; gradual boundary
Bkz 60–100	Dark brown (7.5 YR 4/4); clay; strong medium subangular blocky; common stage II $CaCO_3$ nodules; violently effervescent, no roots, abrupt boundary

3.1.2. Profile 2

Classification	Typic Haplosalids
Location	Azraq
Vegetation	Sporadic vegetation
Slope	0%
Parent material	Lacustrine marl parent material
Latitude	31°48′N
Longitude	36°49′E
Physiographic position	Playa
Elevation	520 m
Precipitation	80 mm
Land use	None
Color	On moist basis
Profile description	
Hor. depth (cm)	
A1 0–12	Strong brown (7.5 YR 4/6), clay; strong medium coarse platy, few very fine vertical roots, hard, very firm, sticky, very plastic, violently effervescent; abrupt boundary
A2 12–22	Strong brown (7.5 YR 4/6), clay; strong medium platy, common fine roots, bottom of the horizon common charcoal presence; hard, very firm, sticky, very plastic, violently effervescent; very abrupt boundary

Bz 22–92	Strong brown (7.5 YR 4/6), clay; strong extremely coarse angular blocky; few fine roots, prominent clay skins; rare stage I carbonates; manganese oxides; very hard, firm, sticky, very plastic, violently effervescent; very abrupt boundary
Bg 92–150	1 gley 6/10y; clay; strong coarse prismatic; no roots; poor clay skins; very hard; firm; very plastic; sticky; violently effervescent

3.1.3. Profile 3

Classification	Typic Calciargids
Location	(Azraq-Safawi Hwy)
Slope	1% concave
Parent material	Alluvium derived from basalt
Latitude	32°00′N
Longitude	36°57′E
Physiographic position	Piedmont
Elevation	610 m
Precipitation	80 mm
Land use	Bare
Color	On moist basis
Coarse fragments	Stone cover 85%
Remarks	Desert pavement gypsum crystals
Profile description	
Hor. depth (cm)	
A 0–10	Strong brown (7.5 YR 4/6); silt loam; strong medium platy/lower part medium granular, very few very fine roots, slightly hard; very friable; moderately plastic; slightly sticky; violently effervescent; gypsum crystals; clear boundary
B 10–30	Strong brown (7.5 YR 4/6); silty clay; strong medium subangular blocky, few very fine roots; slightly hard; friable; plastic; sticky; few stage II calcium carbonate concretions, no roots, gypsum crystals; abrupt boundary
Bk 30–50	Yellowish red (5 YR 4/6); clay; strong medium subangular blocky, hard; very friable; moderately plastic; sticky; stage II $CaCO_3$; no roots, violently effervescent; gypsum crystals; gradual boundary
Btk 50–130	Yellowish red (5 YR 4/6); clay; strong fine subangular blocky, slightly hard; very friable; plastic; sticky; very faint clay skins; common stage II $CaCO_3$; no roots, violently effervescent; gypsum crystals; gradual boundary

3.1.4. Profile 4

Classification	Typic haplocalcids
Location	(Azraq-Safawi Hwy 20 km south-west Safawi)
Slope	2% concave
Parent material	Alluvium with basaltic desert pavement
Latitude	32°03′N
Longitude	36°59′E
Physiographic position	Playa
Elevation	610 m
Precipitation	100 mm
Land use	None
Color	On moist basis
Coarse fragments	Stone cover 85%
Remarks	Gypsum crystals
Profile description	
Hor. depth (cm)	
A 0–15	Strong brown (7.5 YR 4/6); silty clay loam; medium granular; no roots, few stage I $CaCO_3$ filaments, slightly hard; very friable; moderately plastic; moderately sticky; violently effervescent; gypsum crystals; gradual boundary
Bk1 15–30	Yellowish red (5 YR 4/6); silty clay loam; strong subangular blocky; slightly hard; very friable; moderately plastic; moderately sticky; few stage II calcium carbonate concretions, no roots; strongly effervescent; gypsum crystals; abrupt boundary
Bk2 30–41	Yellowish red (5 YR 4/6); silty clay loam; strong medium angular blocky, slightly hard; very friable; moderately plastic; moderately sticky; stage II $CaCO_3$ no roots, strongly effervescent; gypsum crystals; abrupt boundary
Bk3 41–70	Yellowish red (5 YR 4/6); silty clay loam; strong medium angular blocky, slightly hard; very friable; very plastic; very sticky; violently effervescent; gypsum crystals; abrupt boundary
Bk4 70–93	Yellowish red (5 YR 4/6); silty clay loam; strong very coarse angular blocky; slightly hard; very friable; very plastic; very sticky; stage II $CaCO_3$ no roots; violently effervescent; gypsum crystals; gradual boundary

3.1.5. Profile 5

Classification	Typic Haplocalcids
Location	(Deir Al-Kahf, 6 km north)

Slope	2–3% convex
Parent material	Alluvium with basalt clasts
Latitude	32°13′N
Longitude	36°50′E
Physiographic position	Playa
Elevation	905 m
Precipitation	150 mm
Land use	None
Color	On moist basis
Coarse fragments	Stone cover 40%
Remarks	Basalt desert pavement
Profile description	
Hor. depth (cm)	
Ap 0–20	Strong brown (7.5 YR 4/6); clay loam; upper 5 cm moderate medium platy; the rest of the horizon is angular blocky that breaks to strong fine subangular blocky; slightly hard; friable; very plastic; very sticky; few fine roots; earth warm cast; gradual boundary; violently effervescent; clear boundary
Bk 20–49	Strong brown (7.5 YR 4/6); silty loam; few fine nodules $CaCO_3$; strong fine angular blocky that breaks to subangular blocky, slightly hard; very friable; very plastic; very sticky; few fine medium roots, violently effervescent; gradual boundary
Btk1 49–69	Yellowish red (5 YR 4/6); clay; strong coarse angular blocky that breaks to subangular blocky; moderately hard; very friable; moderately plastic; moderately sticky; very few fine roots, prominent stage II $CaCO_3$, same as Bk, very few very fine roots, stage II Calcium carbonate, pebbles, strong fine subangular blocky, violently effervescent; diffuse boundary
Btk2 69–120	Yellowish red (5 YR 5/6); clay; stage II $CaCO_3$ plugged, very hard; firm; moderately plastic; moderately sticky; strong very coarse angular blocky to subangular blocky, no roots, strongly effervescent; possible gypsum

Note: Gypsum occurs at 80 cm. There is a lag of basalt clasts that occurs between 40 and 75 cm (probably a buried desert pavement).

3.1.6. *Profile 6*

Classification	Typic Haplocalcids
Location	(Bishriyah)
Slope	1% flat
Parent material	Alluvium derived from basalt

Latitude	32°08′N
Longitude	36°50′E
Physiographic position	Piedmont
Elevation	780 m
Precipitation	150 mm
Land use	Bare
Color	On moist basis
Coarse fragments	Stone cover 85%
Remarks	Basalt scattered boulders within 15 cm of the surface
Profile description	
Hor. depth (cm)	
A 0–15	Brown (7.5 YR 5/4); loam; upper 5 cm strong fine, slightly hard; friable; moderately plastic; moderately sticky; very few fine roots, strong medium subangular blocky; violently effervescent; gradual boundary
Bt 15–70	Strong brown (7.5 YR 4/6); loam; strong fine subangular blocky; moderately hard; firm; slightly plastic; slightly sticky; violently effervescent; gradual boundary
Bk 70–145	Strong brown (7.5 YR 4/6); clay; strong fine subangular blocky; hard; firm; very plastic; very sticky; stage II Calcium carbonate; no roots; violently effervescent; abrupt boundary

3.1.7. Profile 7

Classification	Typic Calciargids
Location	(Aritayn)
Vegetation	Bare
Slope	1% flat
Parent material	Alluvium with basalt clasts
Latitude	32°08′N
Longitude	36°51′E
Elevation	778 m
Precipitation	120 mm
Land use	None
Color	On moist basis
Coarse fragments	Pebbles, 75%
Remarks	Desert pavement
Profile description	
Hor. depth (cm)	
A 0–17	Strong brown (7.5 YR 4/6); clay loam; granular; slightly hard; friable; moderately plastic; moderately sticky; no filaments, common fine roots, strongly effervescent; gradual boundary

Btk1 17–70	Strong brown (7.5 YR 5/6); clay; moderate medium subangular blocky, moderately hard; friable; moderately plastic; moderately sticky; very few medium roots; stage II calcium carbonate; violently effervescent; gradual boundary
Btk2 70–140	Yellowish red (5 YR 4/6); clay; moderate medium subangular blocky, moderately hard; firm; very plastic; very sticky; more prominent stage II, strongly effervescent; clay skins, possible Fe and Mn oxides, no roots

3.1.8. Profile 8

Classification	Typic Haplocalcids
Location	(Aritayn)
Vegetation	Bare
Slope	2% concave
Parent material	Alluvium with basalt clasts
Latitude	32°07′N
Longitude	36°52′E
Physiographic position	Piedmont (north facing slope)
Elevation	800 m
Precipitation	120 mm
Land use	None
Color	On moist basis
Coarse fragments	Stone cover 60%
Remarks	Desert pavement
Profile description	
Hor. depth (cm)	
A 0–10	Brown (7.5 YR 5/4); clay loam; upper part platy; moderately hard; friable; moderately plastic; moderately sticky; strong coarse angular blocky; very few fine medium; violently effervescent; gradual boundary
Btk 10–30	Dark brown (7.5 YR 4/4); clay; strong coarse angular blocky; moderately hard; friable; moderately plastic; moderately sticky; no roots; violently effervescent; abrupt boundary
C 30–140	Light reddish brown (5 YR 6/4); sandy loam; non-plastic, non-sticky; violently effervescent; Dusty no $CaCO_3$

3.1.9. Particle-size distribution

Clay content distribution with depth did not show any clear trend. In profiles 1, 3, 6 and 7, clay increased with depth. In profile 8, it increased with depth until 70 cm

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depth then it slightly decreased. In profiles 2, 4, and 5, clay content distribution fluctuated with depth.

Silt content increased toward the surface in all studied profiles except for profile 5 (Figs. 2–9). Clay increase with depth is attributed to illuviation processes, while silt accumulation at the surface horizons indicates accretion by wind.

Argillic horizons and clay skins presence in profiles 1, 3, 5, 6, 7, and 8 is attributed to the stability of the soil surface where the presence of chert and desert pavement helped in stabilizing the soil and promoted illuviation process.

The accumulation of silt, indicative of drier climates, must have enhanced dissection processes and retarted pedogenic development. It seems that silt accumulation contributed to the formation of the thin surface vesicular horizons structure that was found in the study area. This results in slow permeability and low infiltration rates, which leads to higher erosion susceptibility. Also, this might have led to the obliteration of features such as clay and oxide coatings.

3.1.10. Soil pH

All profiles of studied soils exhibited a similar trend in pH with increasing depth. The upper horizons exhibited higher pH values than the subsurface horizons except for profiles 1 and 2 (Table 1), which is attributed to the higher EC values at the surface horizons for those profiles (Table 1). The pH of the studied soils is alkaline as a result of the presence of calcium carbonate. All the surface horizons, predominantly A horizons, had a higher pH, which is likely a result of the presence

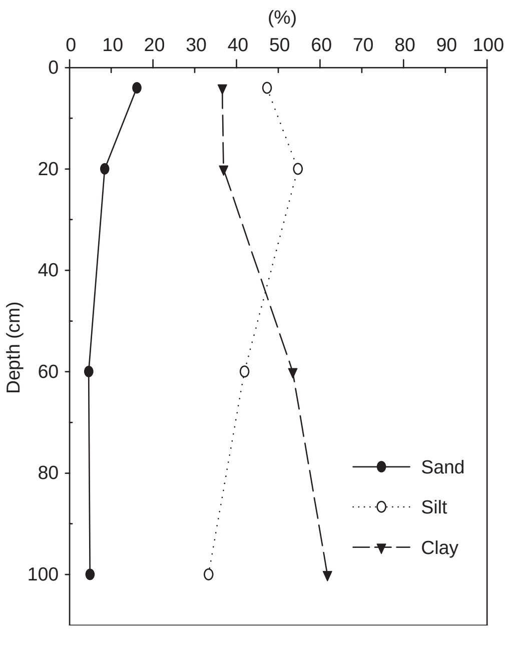

Fig. 2. Particle-size distribution in profile 1.

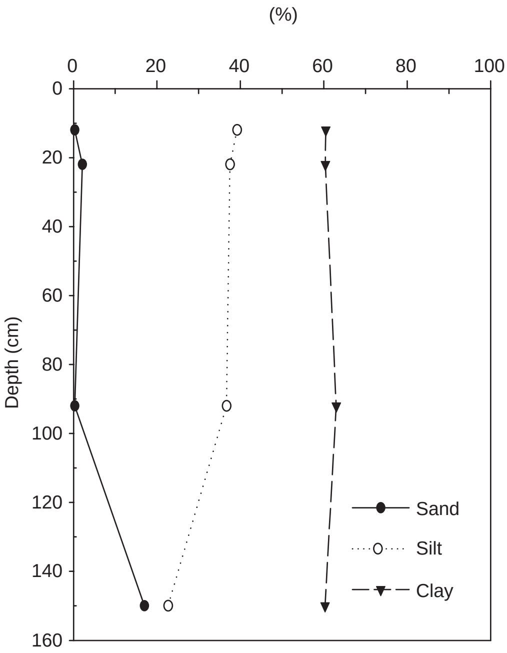

Fig. 3. Particle-size distribution in profile 2.

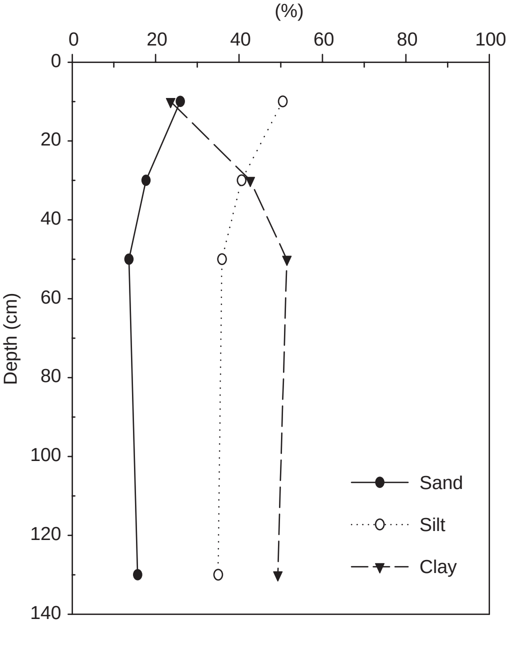

Fig. 4. Particle-size distribution in profile 3.

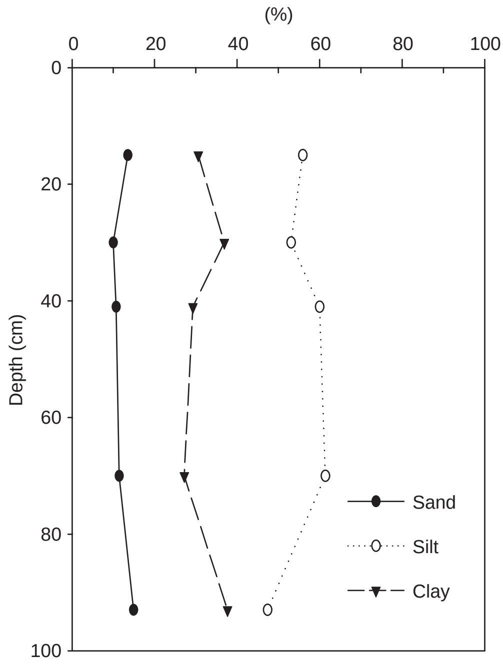

Fig. 5. Particle-size distribution in profile 4.

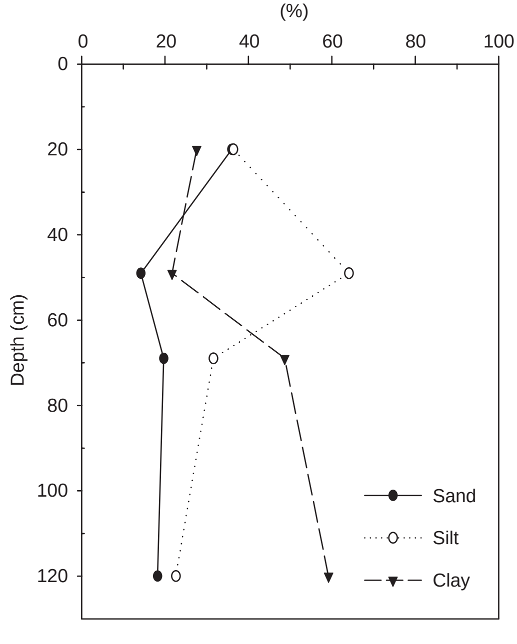

Fig. 6. Particle-size distribution in profile 5.

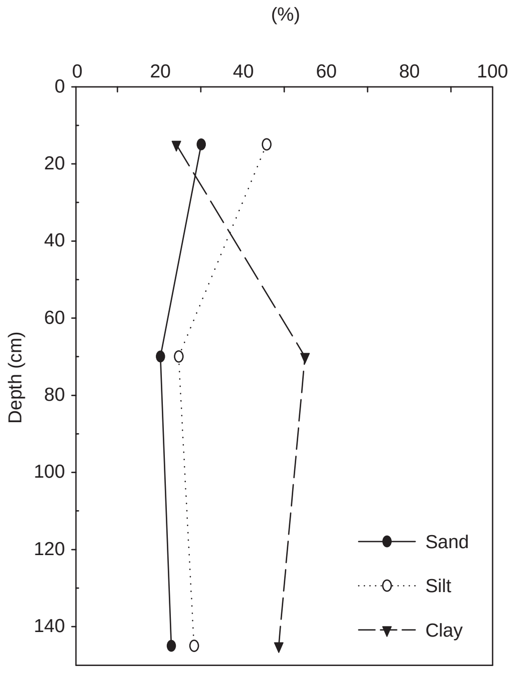

Fig. 7. Particle-size distribution in profile 6.

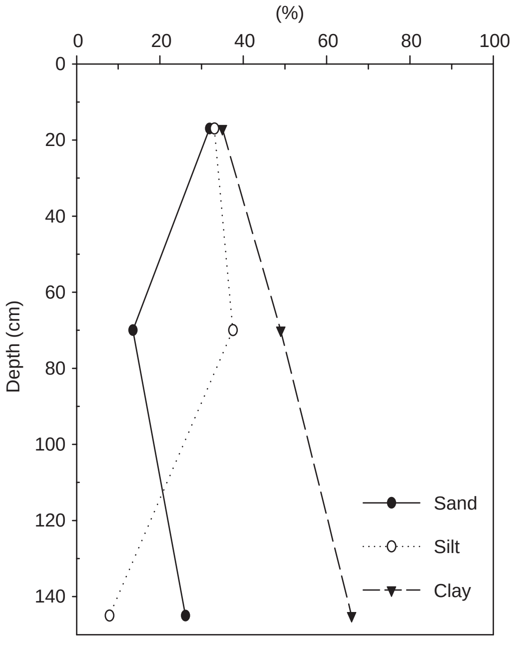

Fig. 8. Particle-size distribution in profile 7.

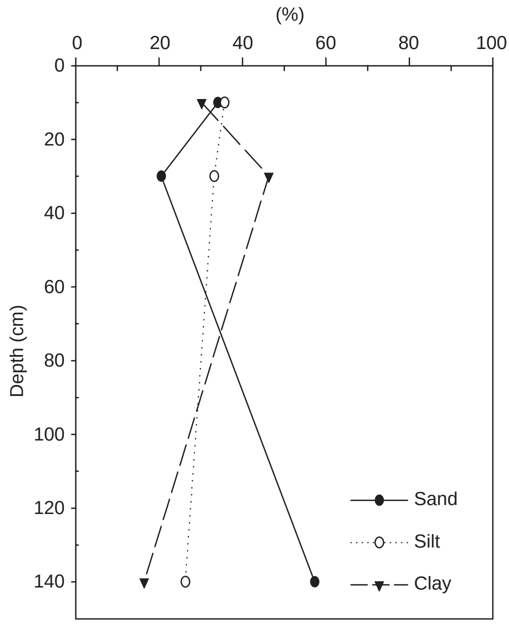

Fig. 9. Particle-size distribution in profile 8.

of calcareous surficial deposits. The area is characterized by wind-blown sediment deposits that represent the margin of an extensive sand sea in the Arabian Peninsula (Allison et al., 1998).

Also, typical of arid regions, those soils contain considerable amounts of carbonates (Table 1). This leads to alkaline reaction of the soils with pH values mostly above 8. This could result in low availability of certain nutrients like phosphorus and micronutrients. If such soils are to be cultivated, proper management practices should be adopted to ensure the availability of those nutrients to crops. Such practices include adding organic manure that will help lower the pH and increase the fertility status. Rawajfih et al. (2005) discussed several management practices for those soils in order to achieve sustainable agricultural production.

3.1.11. Electrical conductivity

EC values for the studied soils increased gradually with increasing depth suggesting very high evaporation within these soils. The highest EC value was observed in profile 1 where it reached 46.1 $ds\,m^{-1}$ at the bottom.

Profile 2 meets the requirement to have a salic horizon at the depth of 22 and 92 cm (Table 1). Profile 7 surface horizon exhibited the lowest EC value in the studied profiles, and it was very low compared with the horizons underneath (Table 1).

Soil salinity in the studied soils is relatively high and this produces volumetric changes in the soil mass which, along with the low organic matter content, does not favor aggregate stability. The repeated cycles of salt dissolution–crystallization, affect soil structure, making the soil more susceptible for erosion.

Table 1
Relevant soil chemical properties of the studied sites

Horizon	Depth (cm)	pH (1:1)	EC ($ds\,m^{-1}$)	OC (%)	$CaCO_3$ (%)	Gypsum (%)	CEC ($cmol\,kg^{-1}$)
Profile 1							
A1	0–4	7.79	36.3	0.28	28.9	0.20	21.0
A2	4–20	8.03	11.27	0.28	30.8	0.90	19.9
Btz	20–60	7.72	43.20	0.27	28.1	0.98	22.1
Bkz	60–100	7.75	46.10	0.25	29.8	0.98	21.0
Profile 2							
A1	0–12	8.27	26.10	0.57	28.0	1.03	26.3
A2	12–22	8.60	21.90	0.46	27.4	0.91	26.3
Bz	22–92	8.85	31.30	0.31	29.5	0.01	25.1
Bg	92–150	8.88	15.70	0.35	30.9	0.10	22.9
Profile 3							
Av	0–10	8.20	0.71	0.39	24.4	—	21.0
B	10–30	8.06	14.73	0.25	23.0	—	22.2
Bk	30–50	8.05	17.86	0.23	25.1	0.01	21.8
Btk	50–130	8.07	15.80	0.20	29.8	0.88	20.3
Profile 4							
A	0–15	8.18	3.16	0.30	26.8	0.08	24.4
Bk1	15–30	7.75	19.66	0.24	26.4	0.88	25.7
Bk2	30–41	7.73	24.49	0.20	25.3	0.90	27.1
Bk3	41–70	7.69	25.34	0.20	25.7	0.89	27.3
Bk4	70–93	7.73	25.37	0.20	24.6	0.55	27.7
Profile 5							
Ap	0–20	8.65	0.62	0.73	20.8	0.09	24.4
Bk	20–49	7.84	4.62	0.39	17.1	0.05	25.7
Btk1	49–69	7.84	16.68	0.37	30.4	0.05	28.1
Btk2	69–120	7.90	19.66	0.27	31.4	0.81	**27.4**
Profile 6							
A	0–15	8.75	1.25	0.37	24.7	0.03	24.9
Bt	15–70	7.99	10.19	0.23	21.1	0.55	30.2
Bk	70–145	7.88	16.07	0.20	29.7	1.57	30.1
Profile 7							
A	0–17	8.58	0.58	0.50	29.2	0.05	21.0
Btk1	17–70	7.84	14.01	0.30	31.3	0.03	20.5
Btk2	70–140	7.81	22.62	0.21	31.1	0.93	18.0
Profile 8							
A	0–10	8.92	0.84	0.46	23.7	0.06	25.5
Btk	10–30	8.07	7.52	0.36	24.7	0.03	32.3
C	30–140	7.68	21.38	0.38	31.1	0.10	39.0

Those soils contain soluble salts in the upper horizons in amounts enough to impede plant growth. Such salts would have to be leached using good quality water before successful growing of crops can be carried out.

3.1.12. Cation exchange capacity

The soil CEC was uniformly distributed throughout profiles 1and 3. CEC values were higher in profiles 2 and 4 (Table 1). The CEC of soils depends, in general, on the organic matter content, soil texture, and type of clay minerals. CEC was high in the studied soils; this is attributed to the dominance of smectite in the region (Irani, 1992).

3.1.13. Organic matter

Organic matter values for all the studied soils did not reach 1% (Table 1). The light plant cover in the studied sites, results in low organic matter content. *Artemesia herba-alba* and *Siedlitzia rosmarinifolia* are the major vegetative cover found in study sites 1, 5, 6, 7, and 8. *Retama raetam*, *Atriplex halmus*, and *Amygdalus spartioides* are the major vegetative cover found in study sites 2–4. The rather low organic matter content in the surface horizons (0.28–0.73%) becomes very low in the lower horizons (0.20–0.38%). This is a typical characteristic of the soils of arid regions reflecting the sparse vegetation of such areas and the rapid rate of organic matter decomposition and the grazing of the natural vegetation leading to minimal addition of organic residues to those soils.

3.1.14. Carbonates

The horizons of carbonate accumulation are one of the most common diagnostic features in the study area. Three stages of the development of calcic horizons are observed in the studied soils. These stages are: stage I, where thin discontinuous pebble and gravel coatings develop; stage II with continuous coatings with weakly cemented matrix which appears as few to common carbonate nodules with powdery and filamentous carbonate in places between nodules; and stage III plugged horizons.

The calcic horizons in the study area are of pathogenic origin since their distribution is parallel to the land surface and their shape is mainly disseminated and segregated filaments and threads, nodules and concretions. The depths at which the calcic horizons are found are deeper than that of the present leaching depth as described by Khresat and Taimeh (1998) and Irani (1992). This indicates that these soils were subjected to a previous climate wetter than the prevailing one as indicated by Khresat and Taimeh (1998). Upon weathering, the $CaCO_3$ is dissolved and the residue is a strongly calcareous clay or silty clay, which is an important soil forming material in East Jordan. In the wet areas this clay has a typical reddish brown color. In the drier areas, leaching of the lime is not completed and the clay contains numerous limestone debris and its lime content is generally higher than in the preceding case.

3.1.15. Gypsum

Gypsum content of the studied soils was low throughout the soil suggesting that these soils are in the early stage of gypsum development. Very fine grains of gypsum were observed in some horizons in different profiles indicating possible gypsic horizons presence. Maximum gypsum content obtained was 1.57%, which did not meet the requirements of gypsic horizon. Periods with low rates of soil deflation, usually strong in this region, promote surface stability and the concentration of the weathered gypsum into distinctive horizon (Taimeh, 1992).

Gypsum dissolves in the surface horizons and moves down with the percolating water until it reprecipitates at the depth of wetting. The illuviation of gypsum begins in the smaller voids and channels in association with capillary moisture movement and then proceeds to larger and still larger voids as the smaller voids are filled. Decalcification process seems to accompany gypsum formation. The zone around the pockets of gypsum may be decalcified, indicating that the calcite supplied the calcium for the gypsum.

3.1.16. Soil genesis

The unique feature of those soils is having desert pavements (wind-polished gravel) on their surfaces. Desert pavement is not strictly a soil horizon, but it is unique to the regions of arid environments. A desert pavement is formed as a deflation feature. Fine particles are removed from the soil surface leaving behind coarse fragments. Over time, as more and more fine material is removed, the coarse fragments form an interlocking 'pavement' on the surface, protecting it from additional wind erosion. Removal or disturbance of the rock pavements can initiate a new cycle of deflation by exposing the underlying soil to wind erosion.

The sparseness of the vegetation resulted in low SOM content and the presence of ochric epipedons in all of the studied soils. Enrichment of clay occurs in deeper Bt horizons, in which Ca-rich clays have been formed and have been translocated; in addition, diagnostic calcic or petrocalcic, and gypsic horizons have formed. Salinization was active in profiles 1 and 2 and salic horizons were formed.

4. Conclusions

Most of study area land surfaces are plains where eolian deflation has exposed loose gravels consisting predominantly of pebbles but with occasional cobbles forming desert pavement, a sheet-like surface of rock fragments that remains after wind and water have removed the fine particles. Desert pavements cover most of the land surface excluding the mud playas (locally known as Marabs) and are composed of basalt clasts.

Carbonate, clay eluviation–illuviation, and salts accumulation are the dominant pedogenic processes in these soils. Silt content increased toward the surface indicating eolian activity. Clay content increased with depth indicating illuviation of clay and argillic horizons were formed in most of the studied sites. Clay illuviation and argillic horizon development within these soils is assumed to be a relict feature from presumably more humid climates during the Quaternary.

Accumulation of eolian fine-grained silt has resulted in the formation of a vesicular horizon in profiles 2 and 3, and possibly in profile 1. In addition, much of the silt, clay, carbonates, and soluble salts that have accumulated in the studied soils could be attributed to incorporation of eolian materials rather than to chemical weathering of soil parent materials.

The results obtained from the physical and chemical analyses indicated that these soils were developed in a more humid climate and the climate changed gradually toward aridic. Weathering and soil development in the soils of Azraq Basin would be expected to be very limited due to the low annual precipitation and the shallow infiltration fronts restricting soil moisture.

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