Turkish Journal of Scientific Reviews 3(1): 55-71, 2010
ISSN: 1308-0040, www.nobel.gen.tr

Formation and Distribution of Gypsic Soils in Jordan

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Abstract

Gypsic soils often have good potential for both rainfed and irrigated cropping. In recent decades, there has been a significant increase in using gypsic soils because of a need to extend agricultural production into previously non-cultivated arid and semi-arid regions.

Gypsum is a common component in soils of arid areas of Jordan. The purpose of this paper is to investigate the processes of formation of gypsic horizons and their pedofeatures. The study area is located in the Azraq basin in the northeastern region of Jordan. Seven representative profiles were selected for laboratory analysis. Soil samples were taken from genetic horizons for the laboratory analyses.

Occurrence of gypsum in soils of the study area indicates that local climatic conditions with low rainfall do not allow leaching of weakly soluble gypsum. The pedogenetic processes are very slightly expressed and consist mainly of a slight bioaccumulation of humus and nutrients reflected in an ochric A horizon , and a slight migration of gypsum and accumulation of gypsum in a subsurface gypsic or petrogypsic horizon, clay illuviation and leaching of the soluble salts. The studied soils belong to the Haplogypsids (Haplic Gypsisols); Argigypsids (Argic Gypsisols); and Calcigypsids (Calcic Gypsisols) great groups.

Keywords: gypsic soils, aridic, soil maps, GIS.

INTRODUCTION

Gypsic soils contain significant quantities of gypsum and are found in arid and semi-arid areas, where rainfall is insufficient to leach the gypsum out of the soil mantle. Gypsum accumulation is a characteristic phenomenon in soils with an aridic or xeric moisture regime [9,11,16,32,37] similar to calcareous soils, but gypsic soils are much less widespread because a source of SO_4^{-2} may not always be available. Gypsic soils commonly also contain soluble salts and calcium carbonates, but $CaSO_4 .2H_2O$ accumulation in the soil occur almost exclusively in arid and semi-arid zones with less than 400 mm of annual rainfall [3].

The extent of soils containing gypsum around the world is difficult to establish, but [10] have estimated about 200 million hectares of soils with gypsic or petrogypsic horizons. The occurrence of gypsum in soils depends on many factors, including a source of SO_4^{-2} ions, the difference between annual precipitation and evaporation, porosity of the soil, and groundwater movement. The most common sources of Ca^{++} and SO_4^{--} are eolian or fluvial deposition, parent mineral weathering (sulfate salts and/or sulfide minerals), and atmospheric sources (seawater, industrial pollution, volcanoes) [18,7,31,26,33,5,27,6,4,24]. Once the necessary ions (Ca^{++} and SO_4^{--}) are present, various surface and groundwater processes can cause the redistribution of accumulated salts in the soil profile. In areas of greater effective precipitation, gypsum occurs deeper within the soil whereas a shallow or perched water table can result in gypsum accumulating at or near the surface [4]. In the case of in-situ weathering of gypsum parent materials, the non-gypsic (e.g. calcium carbonate) fraction can increase in the upper horizons as soil forming processes dissolve gypsum. The amount and placement of gypsum in a soil profile is a function of the source of Ca^{++} and SO_4^{--}ions, effective precipitation, location of perched water tables or the regional groundwater table, and the length of time in which pedogenesis occurs. Although gypsic soils contain sufficient quantities of calcium sulfate to affect plant growth and crop production [3], many gypsic soils still have a reasonably good potential for both rainfed and irrigated cropping.

In Jordan, most of the gypsum-enriched soils occur in the aridic regime in eastern and northeastern parts of the country [31]. The country, located in the eastern Mediterranean region, is predominantly arid to semiarid and characterized by dry hot summers and mild wet winters with extreme variability in rainfall within and among years. The highest rainfall zones, are restricted to the western and northern highlands and receive between 300 mm and 650 mm annual rainfall (Figure 1). Most of these areas have been urbanized [1]. Therefore, there is significant political and economic pressure in Jordan to find additional lands for agricultural production. Much of the remaining non-urbanized land in Jordan receives significantly less rainfall (Figure 1) and contains varying amounts of gypsum. Therefore, there is a need to understand the extent and behavior of these gypsic soils for use in irrigated cropping. One of the areas of highest interest is the region surrounding Azraq. In this study, we analyze existing soil maps to quantify the extent and types of of gypsic soils in this region, and investigate the processes of formation of gypsic horizons and their pedofeatures in the aridic regime of northeastern Jordan.

MATERIALS AND METHODS

Analysis of soil maps

Soil maps of Jordan were produced through the national soil map and land use project (NSMLUP) which was carried out by the Ministry of Agriculture (MoA) and other institutions and agencies during the period 1989-1995 [22,23]. The USDA classification system [35] was followed in this project and the existing soil maps included information on soil characteristics at the level of soil mapping unit at the following three levels: Level 1, characterizes soils at the reconnaissance level with a scale of 1:250,000 that covered the entire country (89,500 km^2) with an average sampling density of one observation per 7.6 km^2. Level 2, is semi detailed with a scale of 1: 50,000 and covers about 9,000 km^2 of the country (mainly the high rainfall zones) at a density of 3.5 observations/km^2, and Level 3 is highly detailed with a scale of 1: 10,000 that covers selected parts of the country (Total of 1,000 km^2) with a density of 15 observations/km^2.

The NSMLUP soil survey was based on aerial photography interpretation and field observations that were mainly based on described or analyzed profiles, and to a less extent described and/or analyzed profiles. All maps were available as hardcopy sheets (Atlases) while all profile and pit information was saved in the Jordan soil and climate information system (JOSCIS), held by the MoA. In this database, profile description of sampled sites is available. Detailed physical and chemical analysis is available for some profiles and sites of the third level. In this study, maps of level 1 were used to quantify the extent of gypsic soils in Jordan. The hardcopy maps of level 1 were converted to digital maps in GIS format. The corresponding legends were entered into spreadsheet and joined to the GIS software with the attributes of map unit. The legends were descriptive and provided information including the name and the code of the unit and the percent of each soil type. For further characterization of gypsic soils and their distribution in the country, a query function was applied to select the soil map units with gypsic soils. The selected set was converted to a map that shows the distribution of gypsic soils in the country (Figure 2). The proportion of each type of gypsic soil was summed to calculate the percent of gypsic soils in each soil map unit. The total area of gypsic soils was calculated by multiplying the percent of gypsic soil in each map unit with its area and summing the output area for all units.

Soil samples

The study area and the sampled pedons were in the Azraq basin in northeastern Jordan (Figure 1). Several soil profiles were studied in the field and seven representative profiles were selected for laboratory analysis. Three pedons of the NSMLUP were also considered in this study. Geographical positions and major properties of the studied soils are presented in Table 1. Both sets of pedons were described and classified according to the USDA Soil Taxonomy [36] and [12]. Morphological characteristics of the studied soil were described according to [15] and are presented in Table 2. Soil samples were taken from genetic horizons for the laboratory analyses. The bulk soil samples were air dried, crushed with a mortar and pestle, and sieved to remove coarse (> 2mm) fragments. Particle size distribution was determined by the hydrometer method [13]. Soil pH was measured on 1:1 soil to water suspensions [21]; soluble salts were determined by measuring the electrical conductivity of 1:1 soil to water extracts [29]; organic matter (OM) was determined using the Walkley-Black method [25]; calcium carbonate ($CaCO_3$) equivalent values were obtained using the acid neutralization method [30]. Cation exchange capacity (CEC) was determined by the sodium saturation method [8]. Gypsum content was determined using the acetone precipitation method [30].

A linear regression analysis was then applied between some soil properties to investigate the degree of correlation between gypsum and the analyzed soil properties. The procedure was carried out for all profiles and for all horizons and then was repeated for the data of the surface horizons. The coefficient of determination R^2 was calculated for the significant correlation at a probability level of 95%.

RESULTS

Distribution of gypsic soils

Analysis of the Level 1 reconnaissance soil maps show that at this scale, Jordan has 1595 soil map units. At the country level, eighteen land regions were identified by the NSMLUP (http://alic.arid.arizona.edu/jordansoils/index.html). Gypsic soils occur in 780 of these map units (Figure 2). Map units that contain some percentage of gypsic soils form 49% of the total area of the country. Considering the percent of gypsic soils within each map unit, the total area of gypsic soils in the country is more than 22% of the total country's area.

The distribution of gypsic soils within soil map units show that most of these soils are found in areas with rainfall less than 100 mm and are concentrated in the eastern and the northeastern regions of the country. Further analysis of the soil maps indicated that about five major types of gypsic soils are found in Jordan. These are Lithic Haplogypsids, Typic Haplogypsids , Lithic Calcigypsids , Typic Petrogypsids and Xeric Haplogypsids. All of these units are distributed in areas with an aridic moisture regime and in thermic and hyperthermic soil temperature regimes.

Analysis of soil profiles

Gypsum content increases with depth in all studied pedons resulting in the formation of gypsic horizons. Surface horizons contain less gypsum, ranging from 1.0 to 2.2% in the study profiles and from 2.7 to 3.8% for the NSMLUP profiles. In contrast, gypsum content increases up to 24.1 % in the subsurface horizons of the studied pedons (Table 3). In the studied pedons, gypsum occurs as stage I snowballs: white, spherical masses of fine crystalline gypsum 0.5 to 3 mm in diameter [5], which occur on ped surfaces, within the matrix, lining pores, and/or on the bottom of rock fragments. SEM analyses of the stage I snowballs show that they are composed primarily of euhedral, lenticular gypsum crystals (Figure 4). Additionally, powdery coatings (~ 1 mm thick) of fine-crystalline gypsum deposits are present on soil ped surfaces. These features occur mainly in the subsurface horizons.

Two stages of the development of calcic horizons were observed in the studied soils. These stages were: stage I, where thin discontinuous pebble and gravel coatings develop; stage II with continuous coatings (pendants) with weakly cemented matrix which appeared as few to common carbonate nodules with powdery and filamentous carbonate in places between nodules [14]. Calcium carbonate content decreases with depth in all studied pedons (Table 3). The linear regression results did not show a significant relationship between gypsum and $CaCO_3$, although a trend of decreasing gypsum was observed with increased levels of $CaCO_3$.

Clay content for pedons 1, 2, 3, 4 and 9 increased with depth (Table 3). Argillic horizons are present in pedons 2 and 3 (Table 3). In pedons 5, 6 and 7, the clay was uniformly distributed. For some soil profiles (2, 3, 4, 6, 7 and 10), maximum silt content was found in the surface layers. Sand fractions, on the other hand, were uniformly distributed throughout the soil pedons (Table 3). Gypsum content significantly decreases as clay content increases in the surface horizons (Figure 3).

Cation exchange capacity is highest in the surface horizons. There is a significant relationship ($P < 0.05$, $n = 10$) between gypsum and CEC for the surface horizons with an R^2 value of 0.50 (Figure 3). The CEC tends to decrease with the amount of gypsum in the soil surface. A siginficant relationship ($P< 0.05$, $n = 10$) occured between clay content and CEC for the data of all profiles and for all horizons with an overall R^2 value of 0.51. A similar relationship was observed for the surface horizons but with a higher correlation (R^2 = 0.87).

The studied soils were slightly to moderately alkaline (pH 7.3-8.3). Results also show that some of those soils contain soluble salts in the upper horizons. The EC values for the studied soils increase gradually with increasing depth, especially in pedons 5 & 7 (Table 3). The organic matter content of studied soils is highly variable (Table 3). Although it was generally low in such aridic environments, it is concentrated in the surface layers and decreases rapidly with depth for the profiles measured (Table 3). Organic matter content ranges from 0.01 in the subsurface layers of pedons 6 and 7 to 1.17 in the surface layer of pedon 2. The organic matter content of pedon 2 and 3 reaches one percent for the surface horizons, which meet the requirement of the mollic epipedon in organic matter content. However, they were not classified as mollic epipedons because of the lack of the thick dark color or soft consistency [36]. Significant correlations occurred between clay and organic matter contents in the surface and subsurface horizons (Figure 3) with R^2 values of 0.19 and 0.27 for surface and subsurface horizons, repectively.

DISCUSSION

Gypsum content increases with depth in all studied pedons and often forms the snowball morphology, which is in indicator of pedogenic gypsum development [4,5]. The snowball morphology, size and euhedral shape of the gypsum crystals indicates that pedogenic processes are dissolving gypsum from the upper horizons and precipitating pedogenic gypsum in the subsurface. The amount and placement of gypsum in the soil profiles is controlled by the soil texture, effective precipitation, and gypsum (and/or SO_4^{-2}) input through time (primarily from dust). Coarser-textured soils have lower porosities and therefore wetting fronts can move deeper into the profile. Increased effective precipitation during previous pluvial climates would move soluble gypsum deeper into the profile, whereas Holocene aridity and/or summer rainfall events would result in gypsum precipitating in shallower horizons. It is also more likely that Holocene aridity would increase SO_4^{-2} dust input to these soils. Capillary fringe evaporation from perched or high water tables can also precipitate gypsum, calcium carbonate or other soluble salts [4]. Gypsum that has precipitated through this processes often has a sharp upper boundary and can easily be distinguished in the field from gypsum precipitating from downward percolating waters.

The content and distribution of gypsum within the profile is affected by the chemical equilibria with other soluble components, in particular with $CaCO_3$ and soluble salts. In these profiles, calcium carbonate occurs as stage I gravel coatings and filaments indicating that the carbonate is pedogenic [14,17]. Calcium carbonate content decreases with depth in all studied pedons (Table 3), although the opposite trend was expected under aridic conditions. Although the linear regression analyses did not show a significant relationship between gypsum and $CaCO_3$, a trend of increasing gypsum was observed with decreasing levels of $CaCO_3$. This can be explained by the common ion affect: if gypsum is present, the solubility of $CaCO_3$ decreases, thus pedogenic accumulation of gypsum is preferred over $CaCO_3$ [28,19,5,4]. The increased $CaCO_3$ in the surface horizons (Table 3) reflects a combination of eolian $CaCO_3$ accumulation in dust and/or (in pedons 3, 4, 5, 10, and 11) a high water table associated with the Azraq oasis wherein capillary fringe evaporation has concentrated $CaCO_3$ and other soluble salts.

Soluble salts are present in many of these pedons, which is common in gypsic soils [4]. The EC values increase gradually with increasing depth (Table 3) indicating that the dominant pedogenic process for these soils is the accumulation of pedogenic minerals (gypsum, calcium carbonate, and soluble salts) from downward percolating waters. Depending upon the chemistry of these soluble salts, many of these gypsic soils could be problematic for agricultural production. For example, sodium salts can destroy soil structure, resulting in poor drainage and decreased crop production. Future studies to determine the mineralogy and chemistry of these soluble salts will aid in our understanding and management of these soils for agricultural production.

The studied soils were slightly to moderately alkaline (pH 7.3-8.3). The pH of soils containing mixtures of calcium carbonate, gypsum, and soluble salts can vary dramatically depending upon the type and relative amounts of salt minerals present. Sulfate minerals (including gypsum) tend to lower pH values below 8.0, whereas sodium minerals (sodium carbonates and/or chlorides) can promote extreme alkaline conditions (pH > 9). If calcium carbonate dominates the system, pH values usually are slightly alkaline (~ 8.0-8.3). The presence of gypsum (and likely other sulfates) in these soils results in slightly less alkaline pH values compared to soils dominated by calcium carbonate. Therefore, these soils should have fewer problems associated with pH-controlled nutrient deficiency problems commonly associated with alkaline soils.

Particle-size distribution varies between pedons. Sand fractions, were uniformly distributed throughout the soil pedons. Clay content for pedons 1, 2, 3, 4 and 9 increased with depth indicating illuviation. However, the difference in clay content between the surface and the subsurface horizons (Table 3) did not meet the requirement for an argillic horizon. The majority of clay illuviation occurred before the carbonate and gypsum accumulation because the pedogenic calcium carbonate and gypsum occur either as coatings on top of the illuviated clay and/or in horizons above. This, in addition to the significant depth of clay illuviation, suggests that the majority of pedogenic clay formation occurred during a previous pluvial climate. Later, Holocene aridity decreased the depth of wetting; and increased dust inputs containing soluble salts and gypsum. In contrast, pedons 6, 7 and 8, contain uniformly distributed clay. These pedons may have formed in Holocene alluvium and therefore have not experienced enough time and/or an appropriate climate for clay illuviation. For some soil profiles, maximum silt content was found in the surface layers, which is consistent with a desert pavement and vesicular A horizon development formed through eolian deposition [20].

The organic matter content of the studied pedons is highly variable. Organic matter content ranged from 0.01 in the subsurface layers of pedons 6 and 7 to 1.17 in the surface layer of pedon 2. The organic matter content of pedon 2 and 3 reached one percent for the surface horizons, which met the requirement of the mollic epipedon in organic matter content. However, they were not classified as mollic epipedons because of the lack of the thick dark color or soft consistency [36]. Organic matter tended to increase with clay content in surface and subsurface horizons. No significant relationship is present between gypsum and organic matter contenSurface layers have the highest CEC values, this was attributed to higher organic matter and lower gypsum. Gypsum and/or gypsum-coated particles have no negative charge and the total exchange capacity of gypsic soils therefore decrease with increasing gypsum content. This relationship between gypsum and CEC was significant for the surface horizons with an R^2 value of 0.50. The CEC was inversely correlated with the amount of gypsum in the soil. Therefore, soils with low gypsum contents exhibited higher CEC values and could be considered as moderately fertile. A siginficant linear relationship was observed between clay content and CEC for all horizons with an overall R^2 value of 0.51. A similar trend of increased CEC with clay content was observed for the surface horizons (Figure 3) with an R^2 value of 0.87.

CONCLUSIONS

Because there is a need to extend agricultural production into previously non-cultivated arid and semi-arid regions of Jordan, this study was undertaken to better understand these soils. We find that gypsum is a common component in these soils and mainly distributed in areas with annual rainfall amounts of less than 100 mm in the eastern and northeastern parts of the country. The dominant pedogenic process that has occurred in these soils is the subsurface accumulation of clay, calcite, and gypsum. Clay illuviation is primarily a process that occurred during a previous pluvial climate; whereas carbonate and gypsum accumulation occurred later and is a characteristic of the more arid Holocene climate. The amount of gypsum and soluble salts in many of these profiles is strongly controlled by the input of sulfate-rich dust. The presence of vesicular horizons rich in silt at the surface of many of the pedons indicates the importance of eolian processes on these soils [20]. The depth of gypsum and carbonate in these soils is controlled by the depth of wetting and amount of effective precipitation. Some pedons have argillic horizons suggesting their formation occurred during at least one pluvial period; whereas others lack an argillic horizon and probably formed during the

Holocene. The pedons studied also show a slight bioaccumulation of humus and nutrients that are reflected in an ochric *A* horizon.

The studied soils belonged to the Haplogypsids (Haplic Gypsisols); Argigypsids (Argic Gypsisols); and Calcigypsids (Calcic Gypsisols) great groups. These soils have a very deficient moisture regime due to the climate aridity unless they are irrigated. The agricultural value of these gypsic could be limited for controlled grazing and/or crops with shallow root depth to avoid the high salinity of the subsurface horizons. Irrigation will affect the soil properties as gypsum and soluble salts are mobilized within the soil profile. The high variations in soil chemical and physical properties among the different studied profiles emphasized the need for more intensive sampling and studies on these soils for planning their future land use and management.

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Table 1. General description of the study sites.

Pedon	Coordinates	Slope (%)	Geology [2]
1	32º 22′ N 37º 11′ E	Almost flat (0-1%)	Basalt
2	32º 22′ N 37º 12′ E	Almost flat (0-1 %)	Basalt
3	31º 46′ N 36º 41′ E	Almost flat (0-1%)	Chert
4	32º 03′ N 36º 59′ E	Gently sloping (1-2%)	Basalt
5	31º 58′ N 36º 46′ E	Gently sloping (1-2%)	Limestone
6	32º 24′ N 37º 22′ E	Flat (0 %)	Basalt
7	32º 29′ N 37º 24′ E	Gently sloping (2-3%)	Basalt
8	32º 25′ N 37º 13′ E	Flat (0 %)	Basalt
9	32º 02′ N 37º 07′ E	Gently sloping (1-2%)	Basalt
10	31º 46′ N 37º 01′ E	Gently sloping (1-2%)	Chert

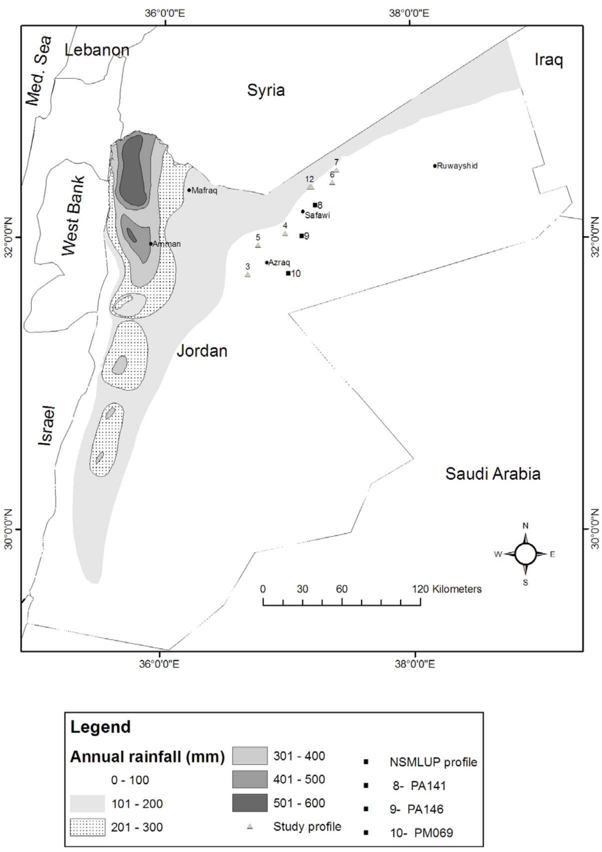

Figure 1. Location of the soil profiles in Jordan.

Table 2. Morphological characteristics of the studied sites (Abbreviations according to [34]).

Pedon	Horizon	Depth (cm)	Moist color	Structure	Consistence	Boundary	Remarks	Soil Classification
1	A	0-15	7.5YR 4/6	1fgr	mfr	g	-	
	By1	15-70	7.5YR 4/4	3cabk	mfr	d	fine gypsum crystals	USDA: Typic Haplogypsids
	By2	70-165	7.5YR 4/6	3cabk	mfi	d	fine gypsum crystals	WRB: Haplic Gypsisols
	Bty	165-190	5YR 4/6	3cabk	mfr	-	fine gypsum crystals, clay skins	
2	Ap	0-10	7.5YR 4/4	1fgr	mfr	g	-	USDA: Typic Argigypsids
	By1	10-40	7.5YR 4/4	3cabk	mfr	d	fine gypsum crystals	WRB: Argic Gypsisols
	By2	40-90	7.5YR 4/4	3cabk	mfi	d	fine gypsum crystals	
	Bty	90-155	5YR 3/4	3cabk	mfr	-	fine gypsum crystals	
3	A	0-20	7.5YR 4/6	1mgr,mpl	mfr	c	-	USDA: Calcic Argigypsids
	By	20-60	7.5YR 5/4	3msbk	mfi	g	few gypsum crystals	WRB: Argic Gypsisols
	Bky	60-100	7.5YR 3/4	3msbk	mvfi	-	stage II $CaCO_3$	

4	A	0-10	7.5YR 4/6	2 mgr	mvfr	g	gypsum crystals	USDA: Typic Calcigypsids
	Bky1	10-25	7.5YR 4/6	3 msbk	mvfr	d	Ca + gypsum	WRB: Calcic Gypsisols
	Bky2	25-60	7.5YR 4/6	3 mabk	mvfr	g	Ca + gypsum	
	Bky3	60-85	7.5YR 4/6	3 cabk	mvfr	d	gypsum crystals	
	Bky4	85-165	7.5YR 4/6	3 cabk	mvfr	-	gypsum crystals	
5	A	0-7	7.5YR 6/6	1 mpl	ml	d	-	USDA: Typic Haplogypsids
	B	7-20	5YR 5/6	1 fsbk	mvfr	d	soft gypsum crystals	WRB: Haplic Gypsisols
	By1	20-75	7.5YR 6/4	1 csbk	mvfr	d	hard gypsum crystals	
	By2	75-170	7.5YR 6/4	2 fsbk	mfi	-	hard gypsum crystals	
6	Ap	0-10	7.5YR 6/4	2 cpl	mfr	c	-	USDA: Typic Haplogypsids
	By1	10-25	7.5YR 6/4	3 msbk	mfr	c	irregular cracks	WRB: Haplic Gypsisols
	By2	25-60	7.5YR 6/5	2 csbk	ml	g	soft gypsum crystals	

	Bty	60-120	5YR 5/6	1 csbk	ml	g	soft gypsum crystals	
7	A	0-10	7.5YR 3/4	1 csbk	mfr	d	-	USDA: Typic Haplogypsids
	By1	10-25	7.5YR 3/4	2msbk	mfr	d	soft gypsum crystals	WRB: Haplic Gypsisols
	By2	25-60	7.5YR 4/4	2csbk	mfr	d	soft gypsum crystals	
	By3	60-165	7.5YR 4/4	2cabk	mfi	-	soft gypsum crystals	
8	A	0-8	7.5 YR 5/6	3vcpl	mfr	c	-	USDA: Typic Calcigypsids
	Bw	8-23	7.5 YR 4/6	3msbk	mfr	c	-	WRB: Gypsic Calcisol
	By	23-58	7.5 YR 4/6	1csbk	ml	c	soft gypsum crystals	
	By2	58-123	7.5 YR 4/6	1csbk	ml	d	soft gypsum crystals	
	By3	123-154	5 YR 4/6	1msbk	mvfr	-		
9	A	0-5	7.5 YR 4/5	2cpl	mfr	c	-	USDA: Typic Haplocambids

	Ay	5-17	7.5 YR 4/6	2msbk	ml	c	med. soft crystals	WRB: Yermic cambisol
	By	17-60	5 YR 4/6	3msbk	mfr	g	small soft crystals	
	Bw	60-98	5 YR 4/6	2csbk	mfr	d	med. hard crystals	
	By2	98-127	5 YR 4/6	3csbk	mfr	d	med. hard crystals	
	By3	127-160	5 YR 4/6	1msbk	mvfr	-		
								USDA: Lithic Calcigypsids
10	A	0-4	10 YR 5/6	1vfpl	mfr	c		WRB: Gypsic Calcisol
	C1y	4-30	10 YR 5/8	1 vfsbk	mfr	c		
	C2y	30-85	10 YR 7/6	-	-	-		

Table 3. Relevant soil properties of the studied sites

Pedon	Horizon	pH	Ec (dS.m-1)	O.M (%)	$CaCO_3$ (%)	CEC cmol (+) kg-1	Gypsum (%)	Sand (%)	Silt (%)	Clay (%)
1	A	8.3	8.5	0.63	15.1	33.6	1.8	16.5	30.0	53.5
	By1	7.5	12.1	0.67	13.5	30.4	9.6	6.5	35.5	58.0
	By2	7.6	14.9	0.66	12.1	26.1	16.1	9.0	31.0	60.0
	Bty	7.5	4.95	0.70	13.7	28.9	12.4	14.0	24.0	62.0
2	Ap	8.1	35.5	1.17	17.2	36.4	1.0	2.3	42.3	55.4
	By1	8.0	3.04	1.08	15.3	31.5	6.8	2.6	35.1	62.3
	By2	7.9	9.13	0.61	14.5	25.2	15.1	3.0	36.0	61.0
	Bty	7.8	11.5	0.95	14.8	25.0	15.7	2.5	31.9	65.6
3	A	7.8	36.3	1.01	32.0	24.3	1.7	17.0	49.5	33.5
	By	7.7	11.27	0.90	31.0	21.1	17.1	16.5	45.0	38.5
	Bky	7.8	43.2	1.10	29.1	20.9	15.3	16.4	32.6	51.0
4	A	8.2	3.2	0.98	28.9	28.5	1.2	15.6	42.9	41.5
	Bky1	7.8	19.7	0.75	26.4	25.7	7.6	16.9	39.0	44.1
	Bky2	7.7	24.5	0.75	25.1	20.8	18.2	9.1	31.2	59.7
	Bky3	7.5	25.3	0.75	24.8	20.5	18.4	9.7	30.6	59.7
	Bky4	7.6	25.4	0.70	24.6	19.5	14.2	9.5	31.7	58.8
5	A	8.0	75.6	0.33	45.6	29.1	1.4	10.0	36.7	53.3
	B	7.9	110.0	0.16	41.1	25.2	4.1	13.3	38.5	48.2
	By1	7.6	95.2	0.05	42.1	19.4	20.2	8.8	25.8	65.4
	By2	7.7	120.1	0.02	42.5	18.6	23.1	9.5	57.8	32.7

6	Ap	8.2	10.0	0.28	23.1	25.9	2.2	4.5	62.1	33.4
	By1	7.9	17.5	0.09	21.4	19.1	5.3	4.3	61.1	34.6
	By2	7.3	95.2	0.03	21.5	17.5	14.5	5.5	59.6	34.9
	Bty	7.3	78.9	0.01	18.1	13.8	24.1	5.8	60.8	33.4
7	A	8.1	36.1	0.17	13.1	11.5	2.1	16.1	57.0	26.9
	By1	7.9	78.1	0.10	12.5	6.3	15.2	16.7	56.3	27.0
	By2	7.9	121.1	0.04	9.0	8.1	7.1	16.9	55.9	27.2
	By3	7.8	123.2	0.01	9.1	6.1	11.1	17.5	50.7	31.8
8	A	7.8	6.9	0.49	21.3	19.0	3.8	4.5	62.1	33.4
	Bw	7.7	16.4	n/a	22.3	16.8	4.7	3.4	65.0	31.6
	By	7.5	90.3	n/a	22.3	14.0	13.8	3.5	67.3	29.2
	By2	7.3	71.7	n/a	17.5	17.2	23.4	5.8	60.8	33.4
	By3	7.3	71.6	n/a	16.5	20.0	6.1	0.9	64.7	34.4
9	A	7.5	1.0	0.38	32.4	13.2	2.7	45.5	40.0	14.5
	Ay	6.8	85.2	n/a	23.8	14.4	4.6	26.3	58.5	15.2
	By	7.1	61.7	n/a	26.2	16.8	1.1	15.4	50.7	33.9
	Bw	7.3	61.8	n/a	21.9	20.4	2.2	19.3	43.4	37.3
	By2	7.3	65.8	n/a	19.4	23.3	4.6	13.4	50.0	36.6
	By3	7.3	50.1	n/a	19.4	26.8	8.5	14.2	52.8	33.0
10	A	8.1	2.7	n/a	18.6	8.0	3.0	48.6	37.2	14.2
	c1y	7.8	12.5	n/a	8.4	4.8	3.0	73.6	15.8	10.6
	C2y	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

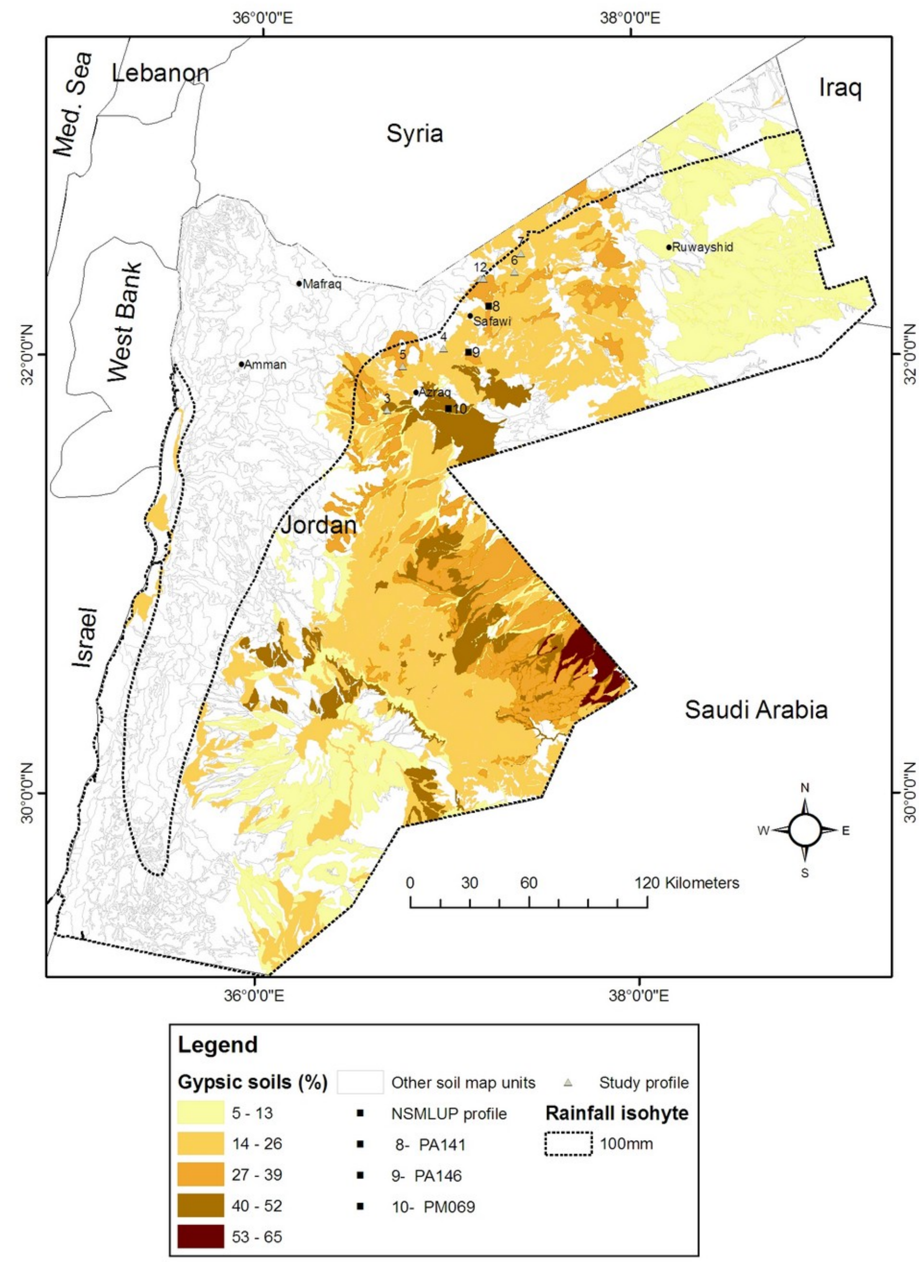

Figure 2. Distribution of gypsic soils in Jordan after aggregation of similar map units.

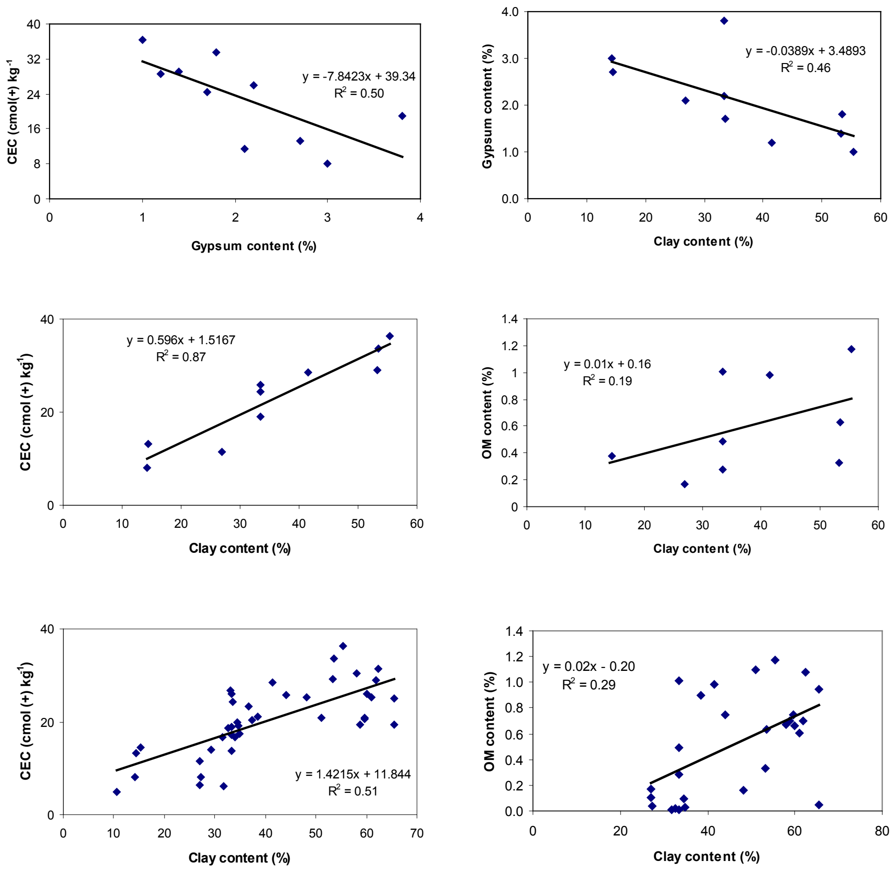

Figure 3: Relationships between: (a) gypsum content and CEC, (b) clay and gypsum contents, (c) clay content and CEC, (d) clay and OM contents for the surface horizons and between (e) clay content and CEC, (f) clay and OM contents for all horizons.

Figure 4. Euhedral lenticular gypsum crystal from the vesicular A horizon of Pedon