GYPSIFEROUS SOILS

NOTES ON THEIR CHARACTERISTICS AND MANAGEMENT

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1 INTRODUCTION

The acreage of irrigated lands in arid and semi-arid areas is steadily increasing. Gypsum ($CaSO_4.2H_2O$) is a soil component common to such areas. When present in small quantities, gypsum is favourable for plant growth, since under sustained irrigation without adequate drainage it tends to prevent the formation of an Alkali Soil. Alkali soils containing gypsum are relatively easy to reclaim. Soils with high percentages of gypsum, however, show relatively low yields, one reason for this being an unbalanced uptake of nutrients by the plant roots. The presence of gypsum in soils may cause problems in other fields. Civil Engineers often face severe predicaments when building hydraulic structures in gypsiferous soils and rocks. When water seeps through cracks in hydraulic structures, gypsum dissolves, thus causing a subsidence of the ground-level. The subsidence phenomenon is irregular and erratic in nature and often leads to a collapse of the hydraulic structures. Moreover, sulphate ions, present in irrigation water or in the soil solution, have a corrosive effect on concrete structures. The aim of this paper is to review what is known of gypsiferous soils, placing emphasis on their characteristics and management.

The paper is based on observations made by the authors in Spain, Syria and Tunisia, and on the study of recent literature.

The term 'gypsiferous soil' as used in this paper refers to soils containing more than 2 % gypsum. The lower part of such soils usually contains a layer with more than 14 % gypsum. Such individual layers are called 'gypsic', in accordance with Soil Survey Staff (1967) in its definition of a gypsic mineralogic class.

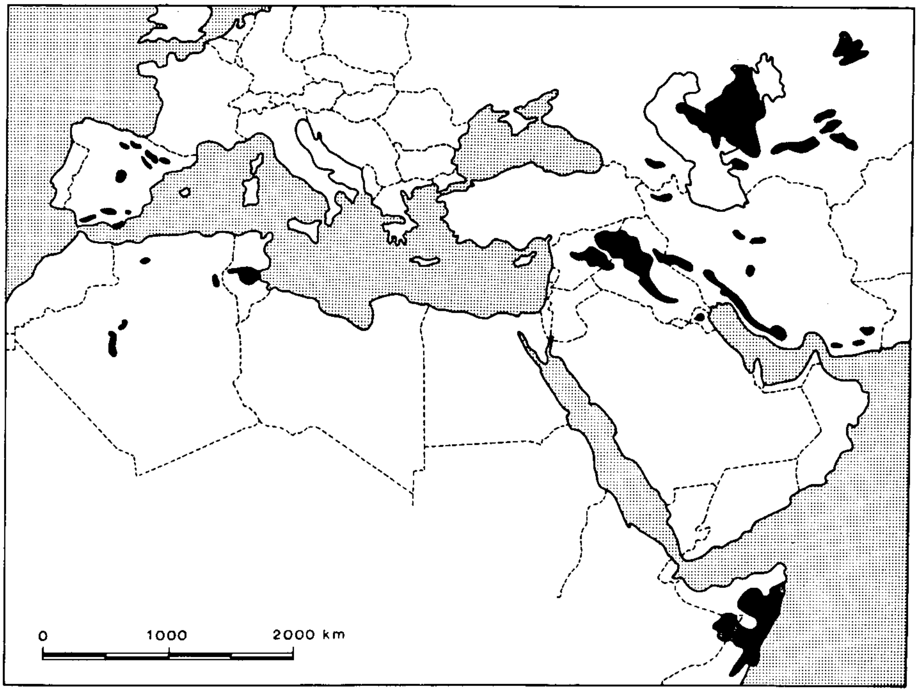

Fig. 1. Distribution of gypsiferous soils in North and East Africa, Southern Europe and South-West Asia

2 GENERAL ASPECTS OF GYPSIFEROUS SOILS

2.1 REGIONAL DISTRIBUTION

Gypsiferous soils are found in arid or semi-arid areas where gypsiferous rocks or sediments are present and rainfall is too scanty to leach gypsum out of the soil profile. The gypsiferous areas known to the authors from literature and from their own studies, are roughly indicated on the map (Fig. 1). Their estimated surface is 850,000 km^2. Gypsiferous soils are located in south-west Siberia (Soviet Geography, 1964; Momotov, 1965), in east Syria (van Liere, 1965), in north and central Iraq (Buringh, 1960) and in south-east Somalia (d'Hoore, 1964).

Gypsiferous soils can also be found in Spain (Riba Arteriu and Macau Vilar, 1962), Algeria (Durand, 1959; d'Hoore, 1964), Tunisia (Bureau, 1960; d'Hoore, 1964), Iran (Dewan and Famouri, 1964), the Soviet Republics of Georgia and Transcaucasia (Minashina, 1956; Akhvlediani, 1962, 1965) and in southern central Australia (Jackson, 1958; Jessup, 1960).

2.2 ORIGIN OF GYPSIFEROUS DEPOSITS

Gypsiferous rocks and sediments of different origin are found throughout various countries in North Africa and south-west Asia. A provisional map showing the distribution of gypsiferous rocks and sediments in Iraq has been given by Buringh (1960).

Gypsum rocks may consist of hydrated calcium sulphate, i.e. gypsum proper ($CaSO_4.2H_2O$), but also of anhydrite ($CaSO_4$). Both are crystalline; a non-crystalline form is alabaster.

Outcrops of gypsum-bearing clays or marls, as well as massive gypsum or anhydrite rocks, are known in Spain, Tunisia and Iraq. They are of Triassic, Jurassic and Cretaceous age.

During the Eocene and Oligocene, but mainly during the Miocene, solid deposits of gypsum and gypsum deposits interbedded in marls or clays, silt and sandstones, were formed in Spain, North Africa, the Middle-East and south-west Siberia. Interbedded Miocene gypsum deposits of the Lower Fars formation, are frequently found in east Syria, west and central Iraq and in south-west Iran.

In Spain, solid and interbedded gypsum deposits of the Sarmantien (Upper Miocene), and of the Ludien (transition-period Oligocene-Eocene) are found in the Ebro Valley. Gypsum deposits probably dating from the Lower Miocene are found in the Tajo Valley, south-west of Madrid.

During the Pliocene and Pleistocene, the gypsiferous rocks and sediments weathered and eroded. The debris was displaced by aeolian or fluviatile action. In some instances, the gypsum in primary deposits dissolved and was precipitated in younger formations. Sediments with such detrital or preprecipitated gypsum accumulations, either crystalline or amorphous, are called secondary gypsum deposits (Buringh, 1960). Their formation is still continuing.

Gypsum deposits of aeolian origin can be found in Tunisia (Trichet, 1963), while those in various terraces of the Euphrates and Tigris Rivers in Syria and Iraq are most likely also of this origin (Buringh, 1960; Mulders, 1969). Wind-blown gypsiferous deposits, derived from lacustrine sediments, are found in south-east Australia (Jessup, 1960).

Gypsum is transported a great distance from its origin along with the river water in which it is dissolved or broken up into particles, and is precipitated along with clay, silt and sand. Some gypsum precipitates when the river water is diverted for irrigation purposes. In sloping terrains, fragments of gypsum rocks are transported in torrential floods and deposited close to their origin (Mulders, 1969).

When the capillary fringe of gypsum-bearing groundwater is located close to the surface, gypsum may precipitate if evaporation is high. This process explains the formation of gypsum incrustations overlying water-bearing sands in the Qued R'hir and the Souf Oasis in Algeria (Durand, 1959), and would also account for part of the secondary gypsum deposits in Iraq (Buringh, 1960).

Pleistocene and Holocene salt and gypsum deposits of lacustrine origin can be found along parts of the Shotts in Algeria (Durand, 1959) and in former inland lakes in western USA.

A particular petrographic composition of the rock sometimes leads to the formation of gypsum. In large areas of south-west Siberia, a gypsiferous layer is found at depths extending from 20 to 150 cm below the soil surface.

The parent rocks are rich in sulphur compounds, e.g. pyrite. Upon oxidation, sulphuric acid is formed, which subsequently reacts with the $CaCO_3$ abundant in the rock (Rozanov, 1961). Gypsum is likewise formed in the Kirovabad Massif, Transcaucasia (Minashina, 1956) and locally in east Georgia, USSR (Akhvlediani, 1965).

The reaction of Na_2SO_4 and $CaCO_3$ may account for the formation of gypsum deposits in the Kura Valley, Georgia, USSR (Klopotovsky, 1949). The Na_2SO_4 is leached from saline soils bordering the valley; the $CaCO_3$ originates from weathering dolorite.

From the descriptions given it can be deduced that gypsum deposits can be either pedogenetic or geogenetic. The translocation and deposition of gypsum in a soil profile as a result of percolating rainwater or capillary rise and evaporation apparently is a pedogenetic phenomenon; the formation of the Miocene gypsum deposits is a geogenetic process. Gypsum deposits originating from groundwater evaporation may be called hydrogenic.

2.3 SOIL CHARACTERISTICS

The morphology and the chemical and physical characteristics of gypsiferous soils depend to a great extent on the origin of the gypsum deposits, but also on the depth at which a proper gypsic layer occurs in the soil profile. When this layer is located 30 cm or more below the surface, the top layer of the soil often has morphological and physico-chemical characteristics similar to those of the non-gypsiferous soils encountered in the same pedogenetic condition, e.g. Chestnut, Chernozem or Sierozem soils (Rozanov, 1961, Kurmangaliev, 1966).

The characteristics of gypsiferous soils are also determined by the fact that gypsum is easily re-distributed within the soil profile as a result of the alternating influence of rainfall and evapotranspiration. When a gypsic layer is situated close to or at the soil surface, dew formation can also play an important role in the migration of gypsum (Bureau and Roederer, 1960).

The varying origin of gypsiferous deposits and the easy re-distribution of gypsum in the soil may result in a great variance in the morphology of the soil profile, as is illustrated by the descriptions of two different soil profiles from the Euphrates Basin (see Annex).

A gypsic layer can have either a powdery or a sandy appearance, depending on the size of the gypsum crystals, which may vary from 50 to over 2,000 microns. Gypsum deposits formed by the oxidation of sulphur components present in parent rocks are often composed of very fine crystals (Rozanov, 1961). When gypsum redistributes within the soil profile, it may take the form of pockets composed of very fine gypsum crystals, lumps consisting of sand and soil particles cemented by gypsum, gypsum rosettes, or hard horizontal crusts. Vertical gypsum crusts also occur (Buringh, 1960). These have a polygonal pattern and consist of two vertical plates of pure gypsum, extending to a depth of sometimes up to one meter and separated by a thin layer of soil. The genesis of such crusts is not fully understood. In contrast with horizontal gypsum crusts, vertical crusts are very resistant to disintegration.

Powdery gypsic layers are characterized by a low bulk density and a soft consistence. The low bulk density is due to a relatively low specific weight of gypsum, e.g. 2.3 gr per cm^3, in combination with an occasional high porosity. Lumps and crusts, however, are hard and can have a low porosity. The porosity of the crusts probably depends on the degree of wetting and drying during crust formation (Mulders, 1969).

Gypsum accumulations are seldom composed of pure gypsum, but are usually a mixture of gypsum, $CaCO_3$ and or soil particles. Gypsum crystals are sometimes coated with a precipitate of $CaCO_3$.

Gypsiferous soils cannot always be discerned visually during field work. (See for instance Profile 1 in the Annex). The gypsum content is often difficult to estimate and should be determined in the laboratory. The quantitative acetone method, as proposed by Richards et al. (1954), is appropriate for this purpose. As the solubility of gypsum is only about 2.6 gr/1, (although the solubility varies somewhat with the concentration and the composition of the soil solution), a 1:1 soil-water extract would dissolve only about 0.25 weight % of gypsum in a soil sample. The soil-water extract should therefore be very dilute when high gypsum percentages are involved, e.g. 40 % gypsum, the ratio soil-water should be at least 1:160. The acetone method can also be used to determine gypsum qualitatively. It can be applied in the field as a quicktest on the presence of gypsum in the soil.

2.4 SOIL CLASSIFICATION

Many publications on soil classification mention gypsiferous soils. It would appear, however, that in the various systems, gypsum in the soil is often considered a criterion only at lower levels of the classification. Four different types of gypsiferous soils in Spain were described by Kubiena (1953), who classified them as sub-groups of some great soil groups, viz.. Solonchaks, Desert Soils, Rendzinas and Sierozems. In the 'gypsum Solonchak' the gypsum has precipitated by evaporation from shallow groundwater. The 'gypsum crust yerma', a Desert Soil, is a raw mineral soil with a hard crust on the soil surface, the chief cementing agent being gypsum. The 'gypsiferous Xerorendzina' is formed primarily in mountainous areas on solid gypsiferous rocks, whereas 'gypsiferous Sierozems' are formed on loose, gypsum-bearing parent material.

Gypsiferous soils in the Ebro Valley, Spain, were grouped by Albareda et al. (1961) with the Sierozems and Rendzinas: 'marly gypsum Sierozem' and 'gypseous Xerorendzinas'. In the 'marly Sierozem' the decomposing gypsum marl is found at a depth of 40 to 50 cm below soil surface and in the 'gypseous Xerorendzinas' at a depth of approximately 20 cm.

Bureau and Roederer (1960) studied soils in the area around Gabès (Tunisia) and grouped gypsiferous soils either with the Calcimorphic or with the Hydromorphic soils. Le Houerou (1960) included gypsiferous soils in southern Tunisia with the 'Well-developed Soils', 'Non- or slightly developed Soils' and 'Paleosoils', respectively.

In Iraq, gypsiferous soils are found within the great soil groups of the Sierozems, Reddish-brown soils, Lithosols, Regosols and occasionally among the Alluvial Soils (Buringh, 1960).

In the USSR, gypsiferous soils have been classified as 'gypsum-bearing Sierozems' (Rozanov, 1961; Kurmangaliev, 1966) and as 'structural Sierozems' (Rozanov, 1961). On the soil map of Georgia, USSR, shallow soils on solid gypsum rock are named 'gahza' (Akhvlediani, 1962).

In the 'Seventh Approximation', the newest soil classificaton system in the USA (Soil Survey Staff, 1960), a 'gypsic horizon' is defined as a layer secondarily enriched with calcium sulphate. The 'gypsic horizon' should have a thickness of at least 15 cm and contain at least 5 % more than the underlying layer; the product of the thickness of the gypsum enriched layer in centimeters and the percentage of gypsum should be more than 150. Evidently a shallow soil on solid gypsum rock will not normally contain a 'gypsic horizon', even if it contains considerably more than 10 % gypsum. Nor does a 'gypsic horizon' in sedimentary soils lead to a special classification. Its presence is indeed diagnostic at the lower levels of classification, but then it is used indiscriminately with a similarly defined 'calcic horizon'. Thus most gypsiferous sedimentary soils belong to the Aridisol order of classification, forming part of the Calciorthid great group. Mulders (1969), in his classification of the soils in the Balikh Basin (Syria), introduces the name Gypsiorthids.

In a recent supplement to the 'Seventh Approximation' (Soil Survey Staff, 1967), however, the term 'gypsic' is also applied to a mineralogical class for the grouping of soils at 'family' level. In this case the gypsum content should be more than 35 % of the sum of carbonates and gypsum, and this sum itself more than 40 % by weight. Neither the depth of occurrence, the thickness of the layer concerned, nor the 'enrichment' aspect reappears in this definition. In practice 14 % is the critical value. This value is used in the present paper to distinguish between 'gypsic' and 'non-gypsic' layers.

The present classifications of gypsiferous soils do not give adequate recognition to the characteristics determining the agricultural value of gypsiferous soils. These characteristics, as will be shown in the following chapters, are the depth at which a gypsiferous layer is found, its percentage of gypsum and its consistence (powdery, crusty, stony).

A gypsiferous soil in the Euphrates valley, Syria.
The surface contains less than 1 %; the gypsum content below a depth of 37 cm is 45 % (see description profile no 2 in Annex).

3 SOIL PROPERTIES

3.1 PHYSICAL PROPERTIES

3.1.1 *Texture*

A great variety is evident in the texture of gypsiferous soils. In the Ebro Valley, Spain, samples taken from the non-gypsic surface layer[1]) of gypsiferous soils showed the clay content to range from 2 to 40 %, and in the Euphrates Basin, Syria, from 2 to 35 %. Gypsic subsoil layers do not, in general, contain more than 15 % clay. The texture depends largely on the nature of the parent material from which the soil is derived, e.g. clays, silts, sands or marls, and on their degree of interbedding in gypsum deposits.

3.1.2 *Soil moisture retention*

Some data on the soil moisture retention of gypsiferous soils of the Kirovabad Massif, Azerbaidzhan, USSR, were published by Minashina (1965). She found that the 'available' moisture retained in the non-gypsic surface layer amounted to 11-22 volume %; in the gypsic subsoil layer, containing up to 80 % gypsum, the 'available' moisture was 13-22 volume %.

In gypsiferous soils in the Ebro Valley, Spain, much more 'available' moisture was recorded in non-gypsic surface layers: 23-38 %. The clay content in the surface layers was about 40 % and the gypsum content varied between 1 and 9 %. In the gypsiferous soils of the Oasis of Gabès, Tunisia, a volume of 10-12 % of moisture is retained in the moisture tension stretch between pF 2.3 and 4.2 (El Amami et al., 1967). The soil in this region contains about 20 % gypsum and 10 % clay.

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1) Surface layer refers to the part of the soil profile that is ordinarily moved in tillage (0-20 cm, often coinciding with the pedogenetic A horizon); subsoil layer refers to the part below the surface layer in which roots can normally penetrate (20-100 cm, often coinciding with the pedogenetic B and/or C horizons).

The soil moisture retention curves of undisturbed samples of gypsiferous soils in the Euphrates Basin, Syria, were determined according to the method described by Stakman, Valk and van der Harst (1969, I, II) (Fig. 2). To avoid dehydration of gypsum, the samples were dried at a temperature of 50° C, instead of 105° C. The curves show that in these soils an important volume of water can be retained in the moisture tension stretch between pF 1.5 and 2.7. Assuming the water available for plant growth to be retained in the moisture tension stretch between pF 2.0 and 4.2, it can be concluded from the data in Table 1 that 13-22 % by volume of water can be retained in the non-gypsic surface layer, and 15-31 % by volume in the gypsic subsoil layer.

In the gypsiferous soils of the Kirovabad Massif, Azerbaidzhan, USSR (Minashina, 1956) and the Euphrates Basin, Syria, the gypsic subsoil layer has a powdery appearance. Gypsum is present in these soils in the form of fine crystals, the size of silt or fine sand. When gypsum occurs as crystals in the size of coarse to very coarse sand, however, a much lower 'available' moisture content is recorded: 5-15 % by volume (Stakman, private communication concerning the Quatif oasis in Saudi-Arabia).

It may be concluded that the storage capacity of 'available' water in layers with powdery gypsum accumulations depends both on the percentage of clay and on the grain size of the gypsum crystals.

3.1.3 *Hydraulic conductivity*

The hydraulic conductivity measured in gypsiferous soils of the Kirovabad Massif, Azerbaidzhan, USSR, varies between 20 and 100 cm/day for the gypsic subsoil layer and between 120 and 190 cm/day for the non-gypsic surface layer. In Iraq Smith and Robertson (1962) found a hydraulic conductivity of 75 cm/day in the gypsic subsoil layer and

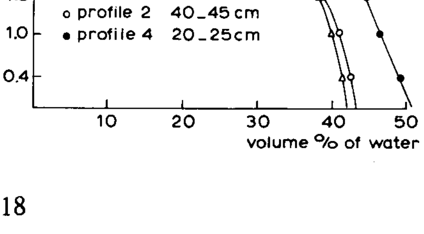

Fig. 2. Soil moisture retention curves of some gypsiferous soils in the Euphrates Basin, Syria.

TABLE 1

Soil moisture retention and hydraulic conductivity of some gypsiferous soils in the Euphrates Basin, Syria1)).

Profile	depth in cm	bulk density gr/cm^3	vol. % of moisture at			'available' moisture in vol. %	hydraulic conductivity in cm/day	weight % of gypsum	Texture
			pF 0.4	pF 2.0	pF 4.2				
1	32-37	1.44	46.9	32.4	10.8	21.6	185	1	sandy loam
	64-69	1.49	42.0	31.6	10.5	21.1	41	23	sandy loam
	94-99	1.49	38.8	31.5	7.3	24.2	29	32	sandy loam
2	5-10	1.46	45.6	29.8	11.0	18.8	170	0.1	sandy loam
	40-45	1.41	42.5	29.1	5.5	23.6	130	47	sandy loam
	83-88	1.42	44.2	27.8	10.4	17.4	180	20	sandy loam
3	10-15	1.07	47.3	19.4	7.6	11.8	820	14	loam
	24-29	1.20	41.3	21.5	4.5	17.0	475	35	sandy loam
	38-43	1.36	32.2	19.7	4.6	15.1	200	55	–
4	11-16	0.97	51.7	32.3	19.1	13.2	160	1	sandy loam
	20-25	1.15	49.3	37.2	6.4	30.8	220	54	gypsum powder
	crust						5-10		

1) Descriptions of Profiles 1 and 2 are given in the Annex.

30-45 cm/day in the non-gypsic surface layer. In soils of the Oasis of Gabès, Tunisia, the hydraulic conductivity in the gypsum-bearing surface varies between 200 and 250 cm/day, and in the gypsum-incrusted subsoil layer between 60 and 150 cm/day (El Amami et al., 1967). A great variation in hydraulic conductivity value was observed in gypsiferous soils of the Euphrates Basin: 30-475 cm/day in the subsoil layer and 160-820 cm/day in the surface layer (Table 1).

Where the soil is incrusted with gypsum, however, a low hydraulic conductivity was found: 5-10 cm/day.

It can be concluded from these data that the internal drainage of gypsiferous soils is normally moderate to rapid, but that it may be impeded by the presence of a gypsum-incrusted layer.

3.2 CHEMICAL PROPERTIES

3.2.1 *Gypsum content*

The gypsum content in gypsiferous soils of the Kirovabad Massif (Minashina, 1956) varies from a trace to 1 % in the surface layer and from 36 to 88 % in the subsoil layer. The majority of samples from the surface layer of gypsiferous soils in the Euphrates Basin, Syria, contain less than 2 % gypsum; the gypsum content in the subsoil layer generally amounts to 30 % or more (up to 75 %). Only in the ultimate surface layer of some deeply eroded soil profiles is a very high gypsum content found: 35-70 %. The gypsum content in gypsiferous soils in the Ebro Valley, Spain, varies from 1 to 9 % in the surface layer and from 16 to 55 % in the subsoil layer. Here too, exceptions occur, with the gypsum content in the surface layer sometimes amounting to 50 %, when deep erosion has taken place.

It can be concluded from these data that in the majority of the samples the gypsum content in the subsoil layer amounts to more than 35 %, and in surface layers usually to less than 5 %, except when deeply eroded soil profiles are concerned.

3.2.2 *Composition of exchange complex and soil solution*

The average percentages of exchangeable magnesium and potassium (in percentages of the cation exchange capacity), in samples of surface and subsoil layers of non-saline gypsiferous soils, do not differ markedly (see Table 2). The total quantity of magnesium and potassium stored in the exchange complex depends, of course, on the cation exchange capacity.

TABLE 2

Exchangeable magnesium and potassium in non-saline[1]) gypsiferous soils from various regions (average figures).

	% gypsum	% of CEC exchangeable Mg^{++}	% of CEC exchangeable K^{+}	Cation exchange capacity meq/100 gr of soil	Exchangeable Mg^{++} meq/100 gr of soil	Exchangeable K^{+} meq/100 gr of soil
Surface layer	0- 4	7.0	3.8	20.8	1.45	0.8
Subsoil layer	16-73	5.0	2.7	11.0	0.55	0.3

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1) Very high percentages of exchangeable magnesium were sometimes found in saline gypsiferous soils in the Euphrates Basin, Syria, and in the Ebro-Valley, Spain.

This capacity is about inversily proportional to the gypsum content. When the gypsum content increases, the amount of the non-gypsiferous components, including clay, decreases.

It can be assumed that the soil solution in the gypsic subsoil layers is almost saturated with gypsum. Consequently, low Mg/Ca and K/Ca ratios can be expected. This was partly confirmed in the following column experiment:
A column was filled with samples from a gypsic subsoil layer with a gypsum content of about 45 %, and from a non-gypsiferous surface layer containing 0.1 % gypsum. The gypsic sample was packed in the bottom half of the column, the non-gypsiferous sample in the top half.
Umbrella plants (Cyperus sp.) were grown to transpire part of the water applied. The amount of water used in the experiment equalled a depth of 590 mm 'irrigation' water and 70 mm was collected at the bottom end of the column as drainage water.
Very low K/Ca ratios were found in the drainage water (Table 3). The Mg/Ca ratios were somewhat higher probably because of slightly soluble Mg compounds in the soil.

TABLE 3

K/Ca and Mg/Ca ratios of 'irrigation water' applied on, and drainage water collected from, an artificial column of a packed gypsiferous soil.

	Date	K/Ca	Mg/Ca
Irrigation water		1: 32	1:4
Drainage water	21/7	1:250	1:4
	4/8[1]	1:135	1:6
	16/8	1:160	1:6
	25/8	1:270	1:5
	5/9	1:330	1:5

1) On 3/8 K-fertilizing took place, equivalent to 130 kg of potassium per ha.

Datepalm cultivation on a gypsiferous soil in the Oasis of Tozeur, Tunisia.

4 SOIL MANAGEMENT

4.1 GYPSUM CONTENT AND PLANT GROWTH

Little has been published on the relation between plant growth and the gypsum content of the soil. It was found in pot experiments that the yield of maize (Hernando et al., 1963) was lower only when the gypsum content was increased to 50 % or more.

Agricultural production on gypsiferous Chernozem and Chestnut soils did not decrease when the gypsum content was no more than 15-30 % (Akhvlediani, 1965). In North Iraq (Smith and Robertson, 1962), soils containing more than 25 % gypsum in the rootzone showed poor plant growth. In Tunisia (Bureau and Roederer, 1960) soils containing more than 30 % gypsum appeared to be toxic for plant growth. Field evidence in the Ebro Valley, Spain, has shown that 20-25 % gypsum in the soil lowered crop yield.

It can be concluded from these data that only when the gypsum content in the rootzone is above 25 % are lower yields to be expected in a number of important agricultural crops.

The hardness of a gypsic layer is one of the factors limiting crop yield on gypsiferous soils. When cementation by gypsum and a subsequent induration of a shallow gypsic layer takes place, mechanical resistances impede roots from growing deeper, thus limiting the depth of the rootzone. The poor K and Mg status of soils containing a high percentage of gypsum probably also accounts for a reduced crop yield. Cations are taken up by the roots either through exchange reactions between plant roots and soil particles, or from the soil solution itself. The column experiment (Table 3) shows that the K/Ca and Mg/Ca ratios in the soil solution are very low when the gypsum content is high. This may result in a very low uptake of potassium and magnesium from the soil solution. The uptake of potassium and magnesium through exchange depends not only on the total amount of exchangeable potassium and magnesium in the soil, but also on the total plane of contact between plant roots and clay particles. Both are smaller when the gypsum content in the soil is higher.

Very high gypsum percentages in the rootzone are not always detrimental to crop growing. High yields of irrigated alfalfa, wheat and apricots are being recorded on gypsiferous soils in the Ebro Valley, Spain; a gypsic subsoil layer is often found in these soils at a depth of 30-60 cm. In the oasis of Tozeur, Tunisia, good results have been obtained in the cultivation of alfalfa and date palms; the surface layer in this area contains 50 % gypsum.

Yields of 10 tons/ha of alfalfa hay were reported by Amami et al., 1967, on gypsiferous soils containing about 20-25 % gypsum in the surface layer. Minashina (1956) reported excellent growth and yields of grapevines on gypsiferous soils with a gypsic layer at shallow depth.

Admittedly, in all these cases the gypsic surface or subsoil layer has a powdery appearance, so that there are no mechanical resistances to rootgrowth, and further of these crops, at least alfalfa is known to grow well under strongly varying ion ratios.

4.2 SOIL FERTILITY AND FERTILIZATION

4.2.1 *Soil fertility*

Surface layers of gypsiferous soils in Spain, whether irrigated or non-irrigated, generally contain less than 250 mg N (determined according to Kjeldahl) per 100 gr soil. The surface layer of gypsiferous soils in the Euphrates Basin, Syria, contains only 50-140 mg N (Kjeldahl) per 100 gr soil. In the surface layers of gypsiferous soils in the Kirovabad Massif, USSR (Minashina, 1956), the nitrogen content amounts to 70-260 mg N (Kjeldahl) per 100 gr soil.

These data indicate that the total nitrogen content in the surface layer of gypsiferous soils is low to moderate, and that a beneficial effect can be expected from the application of nitrogenous fertilizers.

As regards phosphorus, surface layers of gypsiferous soils in Iraq contained 120 mg P_2O_5 (extractable in concentrated HCl) per 100 gr of soil, a content which is considered low. The gypsic layer occurred at a depth of more than 60 cm (Smith and Robertson, 1962). Gypsiferous soils found in the Ebro Valley, Spain, are also characterized by a low phosphate content. The surface layer of recently irrigated soils, in which the gypsic layer is at a depth of more than 60 cm, contained 70-110 mg P_2O_5 (extractable in 20 % HCl) per 100 gr soil or 6 mg P_2O_5 (extractable in 1 % HCl) per 100 gr soil. The phosphate content is lower still in soils where the gypsic layer occurs at a depth of less than 60 cm. The surface layer of these soils contains about 30 mg P_2O_5 (extractable in 20 % HCl) per 100 gr soil when irrigated, and about 10 mg P_2O_5 per 100 gr soil when non-irrigated.

These data on the phosphate content indicate that the surface layer of gypsiferous soils is low in phosphorus. This surface layer, while usually containing little or no gypsum, often does contain a great deal of calcium carbonate. In the presence of calcium carbonate, the solubility of calcium phosphates increases. However, at a pH above 7.0, phosphorus is mainly present as HPO_4 ions, which are difficult for plant roots to absorb. Hence the application of phosphate fertilizers could be beneficial to crop production.

A survey on the potassium content of gypsiferous soils has produced the following figures: In the surface layer of newly irrigated soils with a deep-lying gypsic layer, low values of extractable potassium in NH_4Cl were found: less than 45 mg per 100 gr soil (Ebro Valley, Spain).
On the other hand, the available potassium of these soils (water soluble K, soil-water ratio 1:5) amounted to an average of 4.7 mg per 100 gr soil, a value which is considered adequate. Similar data were found in some surface and subsoil samples of gypsiferous soils in the Euphrates Basin, Syria.
In soils in the Ebro Valley containing 15-50 % gypsum within a depth of 30 cm, the potassium content amounted to more than 200 mg potassium (extractable in 20 % HCl) per 100 gr soil, which is considered high. Similar potassium contents were found in samples of surface layers of soils in northern Iraq, where the gypsic layer was more than 60 cm below soil surface (Smith and Robertson, 1962); these samples contained 650-750 mg of potassium (extracted in hot concentrated HCl) per 100 gr soil.
As is evident from these data, the potassium content in the surface layer of gypsiferous soils is usually high to moderate, independent of the depth at which the gypsic layer occurs.

Data on magnesium and micro-nutrient contents in gypsiferous soils are scarce. Dobrovalskiy (1965) found that samples from gypsiferous layers contain very small amounts of Mn, Cu, Zn and Mo. Results of pot or field experiments, however, are not mentioned.
On irrigated gypsiferous soils in the Ebro Valley, Spain, neither a magnesium nor a micro-nutrient deficiency was observed in wheat, barley or alfalfa. On the other hand, chlorosis phenomena were often noticed in apricots and peaches. This chlorosis was, however, at least partly caused by the application of too much irrigation water.

From the available data it may be concluded that, except when the gypsic layer occurs at shallow depth, there is no essential difference between the soil fertility of gypsiferous and non-gypsiferous soils in the same pedogenetic condition, e.g. that of Chestnut, Chernozem or Sierozem soils. The same was found by Rozanov (1961) and Kurmangaliev (1966).

With a gypsic layer at shallow depth, the volume of soil containing the essential elements for plant growth is limited. Even when plant roots can penetrate into the gypsic layer, the available amount of plant-nutrients will not increase substantially. Nitrogen is normally in short supply in subsoil layers and high concentration of Ca ions in the soil solution results in an adverse K/Ca ratio and in a low availability of phosphorus.

4.2.2 *Fertilization*

Data on the application of fertilizers on gypsiferous soils are based on farming practices, since no results of field experiments are available. In the irrigation scheme 'El Burgo de Ebro' in the Ebro Valley, Spain, the following amounts of nitrogenous fertilizer are being applied. Before wheat, maize and sugarbeets are sown, 70 kg N per ha is applied, mainly in a mixed fertilizer form. Sugarbeets receive an additional 400 kg ammonium nitrate (26 %) per ha. For wheat and maize, a topdressing of 200-250 kg ammonium nitrate or 300 kg ammonium sulphate per ha is applied.

Cotton is fertilized with 40 kg N per ha, applied in a mixed fertilizer form; a small quantity of ammonium nitrate is sometimes added. Apricot trees receive 3 kg 'ferticros' (7-8-5) per tree in autumn, and 2 kg ammonium sulphate per tree in spring.

In the Sierra de Alcubierre, a gypsiferous mountainous area north-east of Zaragoza, Spain, no nitrogenous fertilizer is applied to dryland wheat and barley. On gypsiferous soils elsewhere in Spain, however, dryland wheat and barley are treated with 50 kg N per ha.

In the Sierra de Alcubierre, dryland wheat and barley on soils with a gypsiferous layer at shallow depth receive 150 kg of superphosphate (17 %) per ha. South-east of Madrid superphosphate applied to dryland wheat and barley on gypsiferous soils may total 300 kg per ha.

In the irrigation scheme 'El Burgo de Ebro', wheat, barley and sugarbeets receive a dressing of 80 kg P_2O_5 per ha in a mixed fertilizer form to which 100 kg superphosphate per ha is sometimes added. Cotton, on the other hand, receives only 50 kg P_2O_5 per ha. For the cultivation of irrigated alfalfa heavy dressings of up to 1000 kg of superphosphate per ha have been recorded. In Tunisia, dressings of 300 kg of superphosphate per ha on irrigated alfalfa have been reported by El Amami (1967).

In the Ebro Valley potassium fertilizer is not being applied to dryland wheat and barley on soils with a gypsic layer at a depth of less than 60 cm, since sufficient organic matter is available in this area. In a gypsiferous area south of Madrid, where no organic matter is available, 75 kg KCl 50 % is being applied to the same crops.

On newly irrigated soils in the Ebro Valley, which have gypsic layers at a depth of more than 60 cm 30 kg K_2O per ha is generally applied to various crops, such as wheat, maize and alfalfa. In the old irrigation scheme 'El Burgo de Ebro' in the Ebro Valley, sugarbeets, wheat and maize receive 50 kg K_2O per ha and cotton 30 kg K_2O per ha.

To overcome iron deficiency, fruit trees in the Ebro Valley are given small dressings of $Fe_2(SO_4)_3$ around the trunks.

4.3 SOIL MANAGEMENT

4.3.1 *Dry farming*

Dry-farming on gypsiferous soils in Spain is practised in areas of eroded and hilly uplands where the total depth of the soil varies from about 40-50 cm in narrow valleys to less than 10 cm at the upper end of the slope. Gypsiferous soils are prone to erosion due to their low cohesive forces. To control this erosion some gypsiferous terrains have been terraced and the soils are cropped with wheat and barley once every two years. After harvesting, the land is harrowed to improve infiltration and thereby the conservation of rainwater (In the regions in Spain where gypsiferous soils occur the annual precipitation varies between 250-450 mm).

Experiments are being undertaken to increase the organic matter content and the fertility of the soil by growing a leguminous crop for green manuring during the fallow period.

In the Jezirah, north-east Syria, dry-farming is practised on a large scale (van Liere, 1965). In the southern part of this area, where annual precipitation amounts to 200-300 mm, gypsiferous soils are being used for barley and wheat. The gypsiferous soils are very irregular as a result of erosion. In some soils the gypsum content in the surface layer is negligible, whereas in eroded soils the gypsum content in the surface layer can be as high as 80 %. To improve root-development, the often cemented gypsic subsoil layer may be loosened mechanically. In this way susceptibility to drought is reduced. Further, phosphate fertilizers are applied, which are thought to have a favourable effect on the nitrification and on the decomposition of the stubble of the previous crop.

4.3.2 *Irrigated farming*

For irrigated farming on gypsiferous soils, it is very important that the land be correctly prepared, so as to ensure the efficient and uniform application of water. Excess water filtrating beneath the root zone will penetrate into the gypsum-rich layer and will cause the gypsum to dissolve.

The average subsidence of the ground level, as a result of the dissolution of gypsum, can be roughly estimated at 0.1-0.2 mm per year per 100 mm depth of percolation water. The following may serve as an illustration:

> The solubility of gypsum being 2.6 gr/l, a percolation loss of 100 mm (= 1000 m^3/ha) will dissolve approximately 2.6 tons of gypsum per ha. Dividing the weight of the gypsum dissolved by the bulk density of the soil in a gypsiferous layer, say 1.5 gr/cm^3, this wil result in a total volume of 1.7 m^3 gypsum dissolved. The loss of gypsum evenly distributed over 1 ha therefore results in a subsidence of 0.17 mm per 100 mm water loss.

The subsidence, of course, will vary with the bulk density and the percentage of gypsum in the soil. In irrigated fields, percolation losses may amount to some hundreds of mm's per year. Consequently the average subsidence of the ground level is in order of 0.5 mm per year. Percolation losses from unlined irrigation canals and field ditches are even higher and the subsidence of the ground level underneath an unlined main canal may well reach 30 mm per year.

In the above estimate of the subsidence of the ground level, it was assumed that the water losses were evenly distributed over the area. In practice, however, the excess water percolating through the subsoil and substratum tends to flow through fissures, holes and cracks. Hence, gypsum is dissolved locally, the small holes and fissures being widened until finally cavities in the subsoil and substratum are formed. Evidence of the presence of such subterranean cavities is found in escarpments of river terraces and in embankments of terraced irrigated fields. The tendency of the water to flow through these subterranean cavities can have an advantageous effect on the drainage of the area. However, the same process of cavity formation often causes the collapse of the embankments of terraced irrigated fields, may bring about erosion in escarpments of river terraces and can lead to severe subsidence phenomena in the field as well.

Irregularity in the thickness of the non-gypsiferous surface layer will gradually develop because surface soil material is transported, either by the irrigation water or by levelling implements, to holes in the subsoil formed by the dissolution of gypsum. Here, surface soil material accumulates, resulting in the exposure of the gypsic subsoil layer on nearby spots (Fig. 3). On the other hand, the thickness of the original surface layer may increase by the addition of the non-gypsiferous residue of the originally gypsic subsoil layer, after its gypsum has been dissolved. This phenomenon was observed by Gorbounov (1962) on irrigated gypsiferous soils in Middle Asia, and by the second author on irrigated gypsiferous soils in the Ebro Valley, Spain.

The impression prevails that much depends on the consistence of the gypsic layer. Where the gypsum is present in soft, powdery form and is evenly distributed throughout the layer, the thickness of the non-gypsic surface layer may gradually increase. Incrusted layers, especially those where the distribution of the gypsum is uneven, would tend to become exposed.

To restrict any subsidence of the ground level, irrigation water should be applied as efficiently as possible notably by avoiding excessive water gifts which cause downward leaching. This implies the necessity of levelling the land carefully before irrigation, and of relevelling it annually.

4.4 CROPS AND YIELDS

4.4.1 *Dry farming*

Wheat and grapes are cultivated on gypsiferous soils in the Kirovabad Massif, Azerbaidzhan, USSR (Minashina, 1956). In general; approximately 2,000 kg/ha of wheat grain per annum are harvested from soils with a non-gypsiferous surface layer of about 20-25 cm. Wheat is cropped on gypsiferous soils in North Iraq, but local farmers do not cultivate soils in which a gypsic layer occurs at a depth of less than 30 cm (Smith and Robertson, 1962).

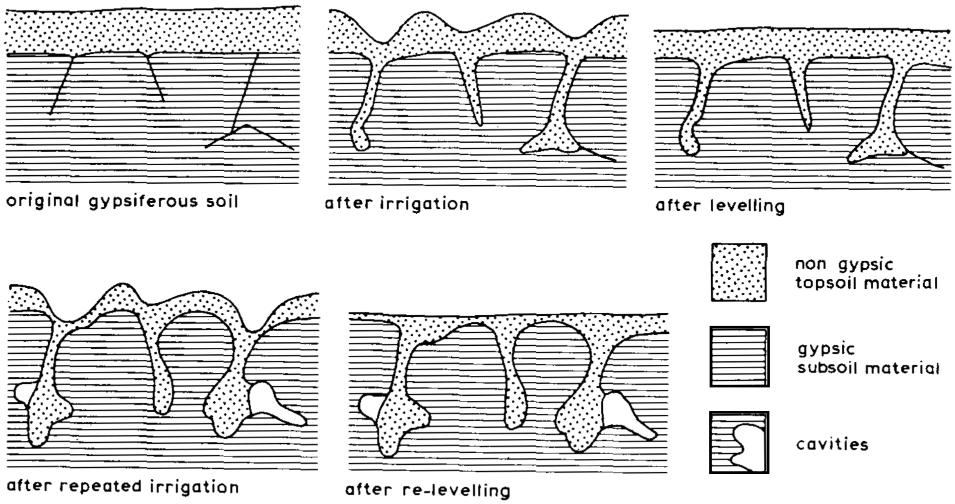


Fig. 3. Exposure of a gypsic subsoil layer and cavity formation as a consequence of prolonged irrigation of gypsiferous soils (schematically).

On gypsiferous soils in Spain, wheat and barley are cultivated once every two years. Locally, grapes are also grown. The yield of wheat varies between 1,000 and 2,000 kg/ha; yields of barley are somewhat higher. Obviously the variation in yield depends on the annual rainfall. The water retaining capacity of the soil in the rootzone is also a factor. If the surface layer is shallow, the nature of the gypsic subsoil layer may limit the depth of the rootzone and thus restrict the volume of water available for the plants. It was observed that if the subsoil consists of gypsum powder, crop yield will not differ much whether the non-gypsiferous surface layer is 5 or 30 cm thick. However, if the subsoil consists of incrusted gypsiferous material or of lumps of disintegrating gypsum rock, a proportional relation is evident between the crop yield and the thickness of the non-gypsiferous surface layer.

4.4.2 *Irrigated farming*

Gypsiferous soils are being irrigated in the Ebro Valley on a relatively large scale. A list of the crops cultivated is given in Table 4.

On newly irrigated land, high alfalfa yields are obtained even during the first year of irrigation. A satisfactory yield of wheat and maize is obtained only after several years. The low nitrogen content of the soil could account for the poor initial growth of wheat and maize.

TABLE 4

Crops (1965) grown on gypsiferous soils in various districts of the Ebro Valley.

	Old irrigation scheme El Burgo de Ebro	New irrigation scheme Valsalda	 Artasona
	Percentage of the area cultivated		
Winter wheat	35.6	–	–
Winter grains	–	56.8	64.7
Maize	41.8	8.6	4.5
Alfalfa	5.9	23.9	24.7
Sugarbeets	1.2	0.6	1.1
Cotton	2.4		
Fruit trees	9.0		
Vegetables	1.5		

Under the prevailing conditions of soil management and fertilization, the yields of the various crops are as follows (Table 5):

TABLE 5

Average crop yields in kg/ha in the Ebro Valley.

	Old irrigation scheme El Burgo de Ebro	New irrigation scheme Valsalda	 Artasona
Wheat	4,000 (up to 5,000 kg)	2,100	3,200
Barley	5,000		
Maize	5,200	4,400	5,400
Alfalfa	16,000	11,200	12,500
Cotton	2,000		
Apricots	8,000		

The differences between crop yields from the old and new irrigation schemes may be explained by the depth at which the gypsic subsoil layer occurs. In the old irrigation scheme 'El Burgo de Ebro' this layer generally occurs at a depth of more than 50 cm, whereas it occurs less deeply in the new irrigation schemes of Valsalda and Artasona. Due to prolonged irrigation in the 'El Burgo de Ebro' area (this scheme is more than 100 years old), the depth of the original surface layer has been increased by the non-gypsiferous residue of the subsoil, whose gypsum has dissolved.

5 IRRIGABILITY OF GYPSIFEROUS SOILS

In the classification of land for purposes of irrigability, the basic physical factors to be considered are soil, topography and drainage. As regards the soil, the following points are of primary importance for irrigated agriculture:

- the depth of a layer limiting root penetration
- the water-holding capacity of the root zone
- the intake rate
- excess salts or excess exchangeable sodium, if any.

Where gypsiferous soils are concerned, special attention must also be given to the gypsum content in the various layers of the soil profile, the depth to a proper gypsic layer and the physical appearance of this layer. These factors are decisive whether – with an estimated water application efficiency – the dissolution of the soil, leading to possible subsidence and cavity formation, will be acceptable.

If a gypsic layer occurs at a depth of more than 60 cm, the application of irrigation water could be equilibrated with the water-holding capacity of the non-gypsic surface layer, thus avoiding great percolation losses seeping into the subsoil.

If the depth to the gypsic subsoil is less than 60 cm the quantity of water that can be stored in the root zone may become marginal. A lower water-holding capacity within the root zone makes it more difficult to apply irrigation water efficiently. Consequently, the percolation losses into the gypsic subsoil tend to increase.

Cavities may form in this subsoil layer causing local subsidence of surface material. Subsequent levelling will gradually expose the gypsic layer to the surface.

In the irrigation scheme 'El Burgo de Ebro' in the Ebro Valley, medium-deep gypsiferous soils in which the gypsic layer starts at a depth of 30-60 cm are considered moderately suitable for irrigation provided the surface layer is finely textured. If the texture of the surface layer is medium to coarse, the suitability of such gypsiferous soils for irrigation is considered poor. If a gypsic layer occurs at a depth of less than 30 cm, the soil is considered unsuitable for irrigated agriculture. In view of the experience gained by Ebro Valley farmers, it is considered that gypsiferous soils with a gypsic layer at a depth of 60 cm or more can be used for irrigated agriculture, on the condition that a high efficiency of water application on the farm is assured. When the efficiency is less, the depth at which the layer occurs should be correspondingly greater if soil degradation is to be avoided. Because a low farm application efficiency is often encountered in irrigation projects, Buringh (personal note) considers a gypsiferous soil suitable for irrigation only if the depth to a gypsic subsoil layer exceeds 1 meter.

The experience gained in the Ebro Valley also reveals that the costs of proper soil and water management on gypsiferous soils, together with the expenditure for fertilization, are approximately 20 % higher than those for deep, non-gypsiferous alluvial soils elsewhere in the valley.

6 CONSTRUCTION OF IRRIGATION WORKS

Civil engineers face two severe problems when constructing irrigation works on and in gypsiferous soils and rocks, i.e.:

- the corrosive effect of sulphates on concrete
- deformation in hydraulic structures due to caving-in of the subgrade.

6.1 CORROSION OF CONCRETE

The free CaO in concrete reacts with sulphates dissolved in irrigation water under formation of etringite (calcium aluminium sulphate). Etringite contains 31 molecules of crystal water, and its formation leads to swelling and eventual slow disintegration of the concrete (Durand, 1956, Llamas Madurga, 1962, Beutelspacher and van der Marel, 1966). The corrosion of concrete by sulphates is a relatively easy problem to overcome. When the concentration of sulphates in the irrigation water is more than 300-400 mg SO_4/liter, sulphate-resistant cements such as ferrari cement or sulfadur should be used in the construction of irrigation works.

In a recent paper, Hobson (1968) correlated the sulphate content in the soil with the degree of corrosion of concrete structures. When the content of soluble sulphates (as SO_4^{--}) in the soil is higher than 1000 ppm (0.1 weight %), a corrosion hazard is considered to exist, and above 7000 ppm (0.7 %) the hazard is considered high. These values would correspond to about 1.7 g/l and 12.2 g/l soluble gypsum. Since the solubility of gypsum is only 2.6 g/l, it is clear that sulphates from gypsiferous soils, even when proper gypsic horizons are concerned, are only of minor importance as a cause of corrosion in concrete. Only when the more soluble Na- or Mg sulphates are present, as in coastal soils, can corrosion be serious

6.2 DEFORMATION IN HYDRAULIC STRUCTURES

If the ground on which the hydraulic structures are built consists of gypsiferous bedrock or gypsum-bearing alluvial or colluvial deposits the filtration of water through cracks in the canal lining or other irrigation structures, and the subsequent formation of cavities in the sub-grade, presents a serious problem. The suitability of gypsiferous rocks as a foundation for hydraulic structures depends largely on their lithology. Gypsiferous rocks may be stratified or solid, folded or unfolded, crystalline or amorphous, with or without intercalating layers of marl and fissures, weathered or unweathered. The rock may consist of gypsum or anhydrite. Fissured bedrock and bedrock with water-bearing layers are unsuitable as foundations because seepage water filtrates into the cracks in the rock. These cracks grow wider as the gypsum dissolves. As a consequence, the sub-grade is weakened and the hydraulic structures are undermined.

The use of gypsiferous deposits of alluvial or colluvial origin as foundations can constitute a real danger. Gypsum is often the cementing agent in such deposits, supplying the material with stability and cohesion. However, upon dissolution of even minute amounts of gypsum the sub-grade material loses its cohesion and stability, resulting in a collapse of the hydraulic structure. In the Ebro Valley much damage to hydraulic structures was encountered on loess deposits, containing only 3.5 % of gypsum. (Llamas Madurga, 1962).

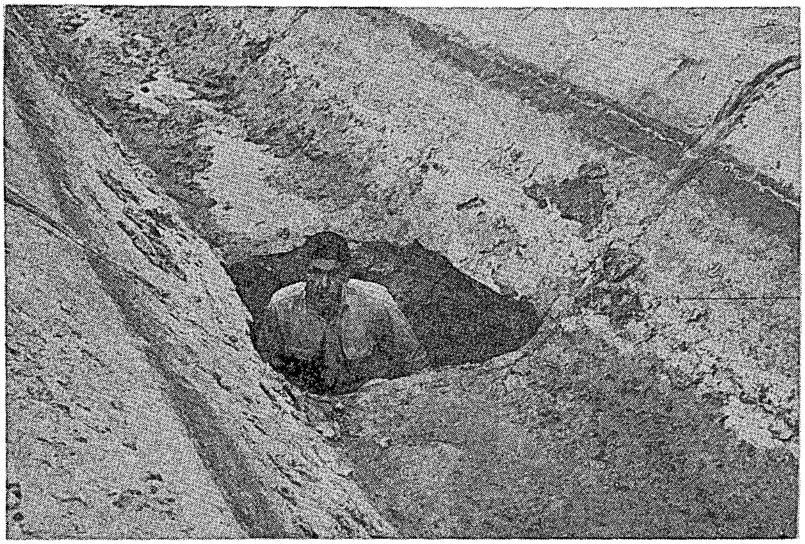
Breakdowns have occurred in several large irrigation canals in the Ebro Valley, e.g. in the Imperial, Aragon y Cataluña, Monegros and Violanda Canals, the capacities of which range from 15-90 cubic meter/sec. The Imperial Canal, one of the oldest canals in the valley, originally had a concrete-lined bottom and plastered side slopes. A section of the canal had to be abandoned due to frequent breakdowns, which naturally caused considerable problems to the farmers. Serious breakdowns in the Aragon y Cataluña Canal have been described by Herrero (1957) and in the Lodosa, Monegros, Violanda and Flumen Canals by Llamas Madurga (1962).

Undermining and breakdowns of irrigation works have also been observed in the USSR (Terletskaya, 1955). She proved in a laboratory experiment that cavities are formed in the subgrade by water seeping from irrigation canals and structures and that this process eventually causes the deformation of the canals and structures.

In general it can be said, that unsuitable for the foundation of hydraulic structures are not only gypsum rock and gypsic layers proper, but also any gypsiferous soils with more than 2 % of gypsum.

6.3 RECENT IMPROVEMENTS IN IRRIGATION STRUCTURES

In the Ebro Valley reinforced concrete was used in an attempt to improve the lining of canals and excellent results were obtained during the first 10-20 years of operation.



Breakdown of an irrigation canal in a gypsiferous soil.
Quatif Experimental Farm, Saudia-Arabia (Photograph by courtesy of ILACO, Arnhem, The Netherlands).

However, after this period serious breakdowns once more occurred. Better results were achieved by constructing the reinforced concrete canal linings on pillars forced deeply and strongly into the soil.

A more satisfactory solution recently introduced is to use a lining which is both flexible and impermeable. When the lining is flexible, any filtration and subsequent caving-in of the sub-grade are immediately noticed and repairs can be carried out as soon as they are needed and before the lining collapses. A flexible lining usually consists of an asphalt or plastic membrane covered by a layer of concrete slabs. When a filtration is noticed, immediate measures are taken to prevent a collapse of the canal lining, which would otherwise interrupt the transport of irrigation water. A metal tube with an internal diameter of 4.5 cm is inserted into the soil, parallel to the side slope of the canal. A mixture of clay, cement and water is injected into the soil under a low overpressure (less than one atmosphere) thereby plugging the filtration channel.

Irrigation canals of small dimensions were originally constructed – unlined – in the ground itself. This method, however, resulted in exceptionally high water losses, particularly in gypsiferous terrains. Seepage water percolating through the subsoil formed large subterranean cavities which emerged at terrace escarpments and local saggings occurred on the land surface. Where visible filtrations in the bottom of the smaller irrigation canals occur, a mixture of sand, clay and gravel is used to plug the filtration channel.

However, when the unlined irrigation canals are damaged too frequently a special technique is applied to repair the canal. The canal bottom is covered with concrete upon which concrete slabs of 50x50x6 cm are placed vertically along the canal sides and connected to the bottom with a light cementing agent. If breakdowns occur the concrete slabs can be disconnected and re-used. In more recent irrigation schemes in the area, use is made of elevated flumes, i.e. independently supported concrete canals of smaller dimensions, which are constructed overground. In the first overground constructions, the junction between two elements of the channel was placed upon the supporting pillars. Despite this special provision the pillar often subsided due to water filtrating through the junction and weakening the subsoil under the pillar. Nowadays, therefore, two canal elements are joined midway between two pillars.

ANNEX

SOIL PROFILE DESCRIPTION OF GYPSIFEROUS SOILS

Profile 1 (number refers to number in Table 1, p. 19)

Location:	Euphrates Basin, Syria, 50 meters west of Wadi Ogla, 800 meters north-west of Mata'b.
Author:	van Alphen.
Date of description:	April, 1966.
Topography:	Flat
Vegetation:	Fallow after cotton

0- 5 cm:	Sandy loam, light yellowish brown (10 YR 6/4)[1] when dry, moderate fine platy, to:
5-22 cm:	Sandy loam, light yellowish brown (10 YR 6/4) when dry, moderate coarse prismatic breaking to moderate medium sub-angular blocky, slightly hard, many roots, clear and wavy boundary, to:
22-36 cm:	Sandy loam, light yellowish brown (10 YR 6/4) when dry, spongey structure, small pores (0.1-0.7 mm in diameter) in all directions, very friable, lime mycelium, few pockets of gypsum powder, many roots, clear and wavy boundary, to:
36-62 cm:	Fine sandy loam, light yellowish brown (10 YR 6/4) when dry, spongey structure, small pores (0.1-0.7 mm in diameter) in all directions, very friable, lime mycelium, pockets of gypsum powder, many roots, diffuse and wavy boundary, to:
62-90 cm:	Sandy loam, yellowish brown (10 YR 5/4) when slightly moist, spongey structure, very friable, some lime mycelium, pockets of gypsum powder, few large roots, clear and wavy boundary, to:
90-110 cm:	Sandy loam, yellowish brown (10 YR 5/4) when slightly moist, spongey structure, very friable, some lime mycelium, pockets of gypsum powder and gypsum mycelium, few pockets of reddish clay (Miocene red clay), diffuse wavy boundary, to:
+ 110 cm:	Sandy loam (10 YR 5/3) when moist, spongey structure, friable, pockets of gypsum powder and gypsum mycelium.

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[1] Colour notations according to Munsell's Soil Color Charts.

By augerhole	
130 cm:	Silt loam, pale brown (10 YR 6/3) when moist, gypsum crystals, few iron mottles.
170 cm:	Silt loam, pale brown (10 YR 6/3) when moist, decreasing amount of gypsum crystals.
180 cm:	Very fine loamy sand, few faint iron mottles.
220 cm:	Sand, light olive brown (2.5 Y 5/4) when moist.

Note: In the field, no high gypsum content could be discerned. However, laboratory analyses revealed:

5- 15 cm	trace
25- 35 cm	1.5 %
45- 55 cm	41.5 %
70- 80 cm	29.0 %
95-105 cm	43.5 %
115-120 cm	41.0 %
150-160 cm	19.0 %
180-200 cm	2.0 %
220-240 cm	1.3 %

Profile 2 (ref. Table 1, p. 19)

Location:	Euphrates Basin, Syria, 1 km east of Wadi Ogla, 1.5 km north east of Mata'b.
Author:	van Alphen.
Date of description:	April, 1966.
Topography:	Nearly flat.
Vegetation:	Fallow

0- 8 cm:	Sandy loam, light yellowish brown (10 YR 6/4) when dry, 0-1 cm strong medium platy, 1-8 cm moderate medium sub-angular blocky, slightly hard, some gravel, many small roots, clear and wavy boundary, to:
8-37 cm:	Loamy sand, light yellowish brown (10 YR 6/4) when dry, weak coarse prismatic breaking to weak-medium to fine sub-angular blocky, very friable, many pores (0.1-0.5 mm in diameter), small lime mottles, few small roots, some gravel, abrupt and wavy boundary, to:
37-82 cm:	Gypsum powder, very pale brown (10 YR 7.5/3) when dry, structureless and massive, very hard when dry, friable when moist, no roots, few pores (0.1-0.5 mm in diameter), below 68 cm re-crystallisation of gypsum, clear and wavy boundary, to:

82-98 cm:	Sandy loam, brown (10 YR 5.5/3) when dry, structureless, some gravel, pockets of gypsum and gypsum mycelium, clear and wavy boundary, to:
+ 98 cm:	Gravelly loamy sand, yellowish brown (10 YR 5/4) when dry, structureless, few pockets of gypsum.

Laboratory analyses

Depth	Gypsum content
2- 5 cm	–
20- 30 cm	0.1
45- 55 cm	52
85- 95 cm	23
105-115 cm	7

SUMMARY

Gypsum is a component common in soils of arid and semi-arid areas. Its presence in small percentages, up to 2 % or so, is favourable for plant growth. Higher percentages, up to about 25 %, have little or no adverse effect on crops, provided the gypsum is present in powdery form.

At still higher values the yield of most crops decreases substantially, due at least in part to imbalanced ion ratios.

Often, however, the gypsum occurs concentrated in more or less cemented and indurated layers. At gypsum percentages of anywhere between 14 and 80 %, such layers form a mechanical impediment to root growth, and the water-holding and water-transmitting properties are adverse.

When gypsiferous soils are used for irrigated agriculture, water should be applied with the utmost care. Gypsum may dissolve in the excess water percolating beyond the rootzone through the gypsum-rich subsoil, and this often results in surface subsidence. The subsidence pattern will be very irregular, which makes it necessary to re-level the land yearly.

The construction of hydraulic structures in gypsiferous soils and rocks poses severe problems to civil engineers. Water seeping through cracks in the structure gradually dissolves gypsum in the subgrade. Hence, this subgrade is weakened, leading to final collapse of the hydraulic structure. A flexible lining should be used when constructing canals of larger dimensions. Under these conditions, curative measures can be taken as soon as the canal lining subsides. Canals of smaller dimensions should preferably be constructed overground.

RESUMEN

El yeso es un componente común de los suelos de áreas áridas y semi-áridas. Su presencia en pequeños porcentajes, hasta 2 % o algo similar es favorable para el crecimiento de las plantas. Cuando el yeso se encuentra en forma de polvo a mayores porcentajes, hasta 25 % aproximadamente, tiene poco o ningún efecto adverso sobre los cultivos. Pero a más altos contenidos de yeso, las cosechas de muchos cultivos decrecen substancialmente, entre otros debido al desbalance de la relación de iones. Sin embargo frecuentemente, el yeso se encuentra concentrado en capas endurecidas y más o menos cementadas. En cualquier punto entre 14 y 80 % de yeso tales capas dan lugar a impedimentos mecánicos para el crecimiento de la raíz, incluso para el almacenamiento del agua y propiedades adversas de trasmisibilidad.

Cuando se utilizan para la agricultura bajo riego suelos con altos contenidos de yeso el agua debe ser aplicada con mucho cuidado. El yeso podría ser disuelto por el exceso de agua que percola más alla de la zona de raíces, a través de sub-suelo rico en este elemento, que frecuentemente da lugar a subsidencias en la superficie. El patrón de subsidencia va a ser muy irregular y sería necesario nivelar anualmente los campos.

La construcción de las estructuras hidráulicas en suelos y rocas con mucho yeso causa grandes problemas a los Ingenieros Civiles, el agua que filtra a través de las rajaduras de las estructuras gradualmente disuelve el yeso de la zapata debilitándola, lo que da lugar al colapso final de la estructura hidráulica.

Cuando se construyen canales de gran dimensión debe ser usado revestimientos flexibles de tal manera que tan pronto el revestimiento del canal sufre una subsidencia, se pueden tomar medidas de corrección. Canales de pequeña dimensión deben ser construídos preferiblemente sobre el terreno mismo.

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