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).

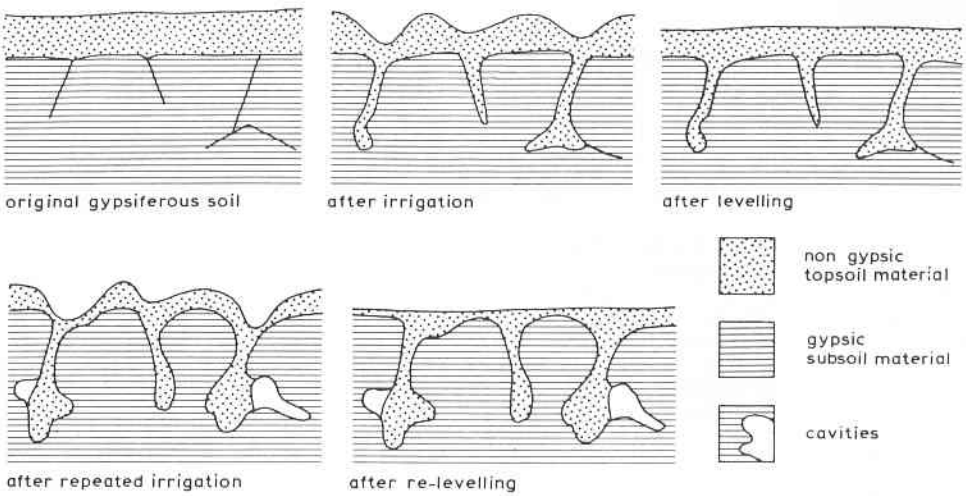

Fig. 3. Exposure of a gypsic subsoil layer and cavity formation as a consequence of prolonged irrigation of gypsiferous soils (schematically).

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.