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Soil salinity and alkalinity in the Great Konya Basin, Turkey

Türkçe özetli:
Türkiye'nin, Orta-Anadolu bölgesinde bulunan
Büyük Konya Havzasında Toprak Tuzluluğu ve Alkaliliği

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This is the third report in a series of studies on the soils of the Great Konya Basin.

The complete series to be published by Pudoc, Wageningen, will consist of the following publications.

1. Driessen, P. M. en T. de Meester: Soils of the Çumra Area, Turkey (published in 1969).
2. Meester, T. de (Ed.): Soils of the Great Konya Basin, Turkey (published in 1970).
3. Driessen, P. M.: Soil salinity and alkalinity in the Great Konya Basin, Turkey (this report).
4. Janssen, B. H.: Soil fertility of the Great Konya Basin, Turkey (in preparation).
5. Meester, T. de: Lacustrine carbonatic soils of the Great Konya Basin, Turkey (in preparation)

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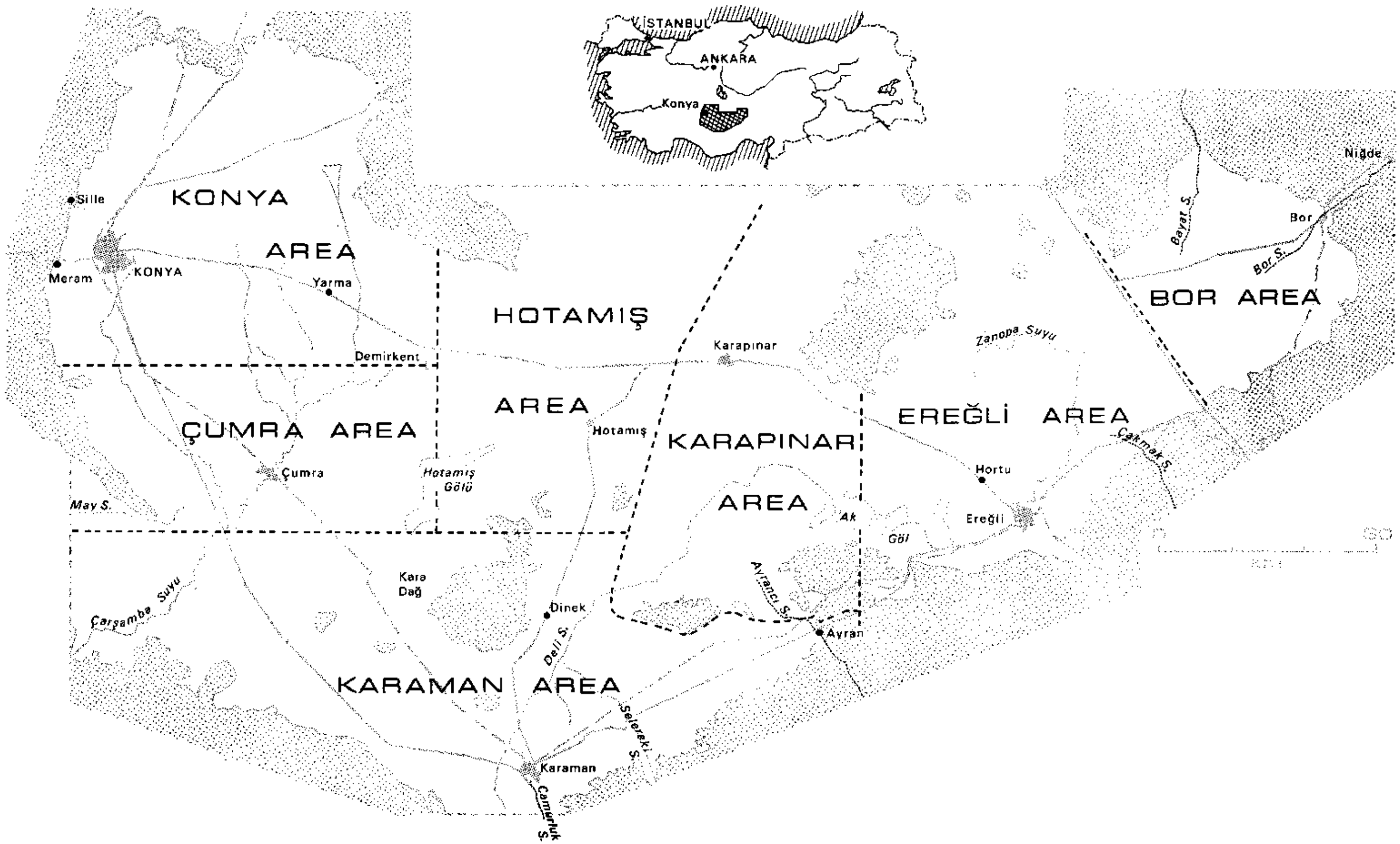


Şekil 1. Büyük Konya Havzası'nın genel haritası.

Introduction

Konya, in Central Anatolia, some 300 km south of Ankara, at an altitude of about 1000 m, was called Ikonion by the ancient Greeks, later Iconium by the Romans. Its importance lay, and still lies, in agriculture; the region satisfies most of Turkey's need for wheat.

The city of Konya is located in the west of a plateau of about 10 000 square kilometres, known as the Great Konya Basin because it is surrounded by mountains. It has long been an important administrative and trade centre. In the Thirteenth Century, under the Seljuk dynasty, it became the regional capital, but its splendour decreased during Ottoman times. Today it is still the administrative centre of Turkey's largest province.

For over 50 years, parts of the Basin have been irrigated. This is indeed the obvious way to combat aridity, but unless proper irrigation techniques are used and the soil is drained as well, aridity will eventually be replaced by an even worse problem: accumulation of soluble salts in the soil. This has indeed happened in the last decades, and salt affection and alkalinity have become a major problem in the Basin. Measures to combat this situation are already being taken by Devlet Su İşleri (DSI) and by Topraksu, the Turkish authorities in charge of the technical and the agricultural aspects of irrigation affairs, respectively, to improve the irrigation system, and by the Ministry of Agriculture and some semi-governmental institutions in teaching adequate irrigation techniques to the farmers.

Investigations into the cause and the extent of salt affection of soil in relation to irrigation have been made by the Food and Agriculture Organization of the United Nations (FAO Report, No 1975, 1965) and by the International Engineering Company (IECO, 1967).

The aim of the present study was to gain a better insight into salinity and alkalinity in the Great Konya Basin. Besides semi-quantitative studies, it attempts to trace the origin, composition and location of the salts. It has been carried out within the scope of the Konya Project, a research and training project on soils, established by the Department of Tropical Soil Science in the Agricultural University, Wageningen, the Netherlands, in co-operation with Turkish soil scientists and governmental institutions. It has been possible to study the scientific background of phenomena, which would be too time-consuming and laborious for a purely commercial project. In addition, the investigations at or in collaboration with various institutions and universities, have yielded some new methods for the study of soil salinity and alkalinity.

Exploratory work started in 1964. Various types of salt accumulation in soil were studied. Soil samples were brought to the Netherlands for further investigations during 1965 at a new laboratory, established specially for salinity research and for training students in analysing salt-affected and alkali-affected soils. In 1966, salinization types were further studied in the field and a mobile laboratory was tested for necessary routine analysis. Again many soil samples were brought to Wageningen.

In the spring and autumn of 1967, salinity was surveyed throughout the Basin and was recorded on sketch maps giving location of salt and indications of its composition and quantity. Alkalinity was studied too, and various single-parameter maps were compiled.

In 1968, further field data were collected to complete parts of the study.

The study and the analysis of some 2500 soil samples, and over 1000 water samples, has taken three years in the laboratory. Co-operation with colleagues and final year students considerably speeded up the work and its accuracy, as the data could be checked by replicate analysis of random soil samples.

It is hoped that the laboratory results and field observations gathered during four 6-month field seasons will contribute to the improvement of agriculture in the Great Konya Basin, which is a major policy objective of the Turkish Government.

1 General characteristics of the area

1.1 Physiography

Most of the population of the Great Konya Basin live in some 225 villages scattered all over the area and in a few towns, in particular Konya, Karaman, Karapınar, Ereğli and Niğde (Fig. 1).

The Basin is traversed by the highways Konya-Karaman, Konya-Adana and Ankara-Adana. Many secondary roads and tracks provide ready access to the hinterland. A railway runs from Konya in the west along the southern border of the Basin to Ereğli and Niğde.

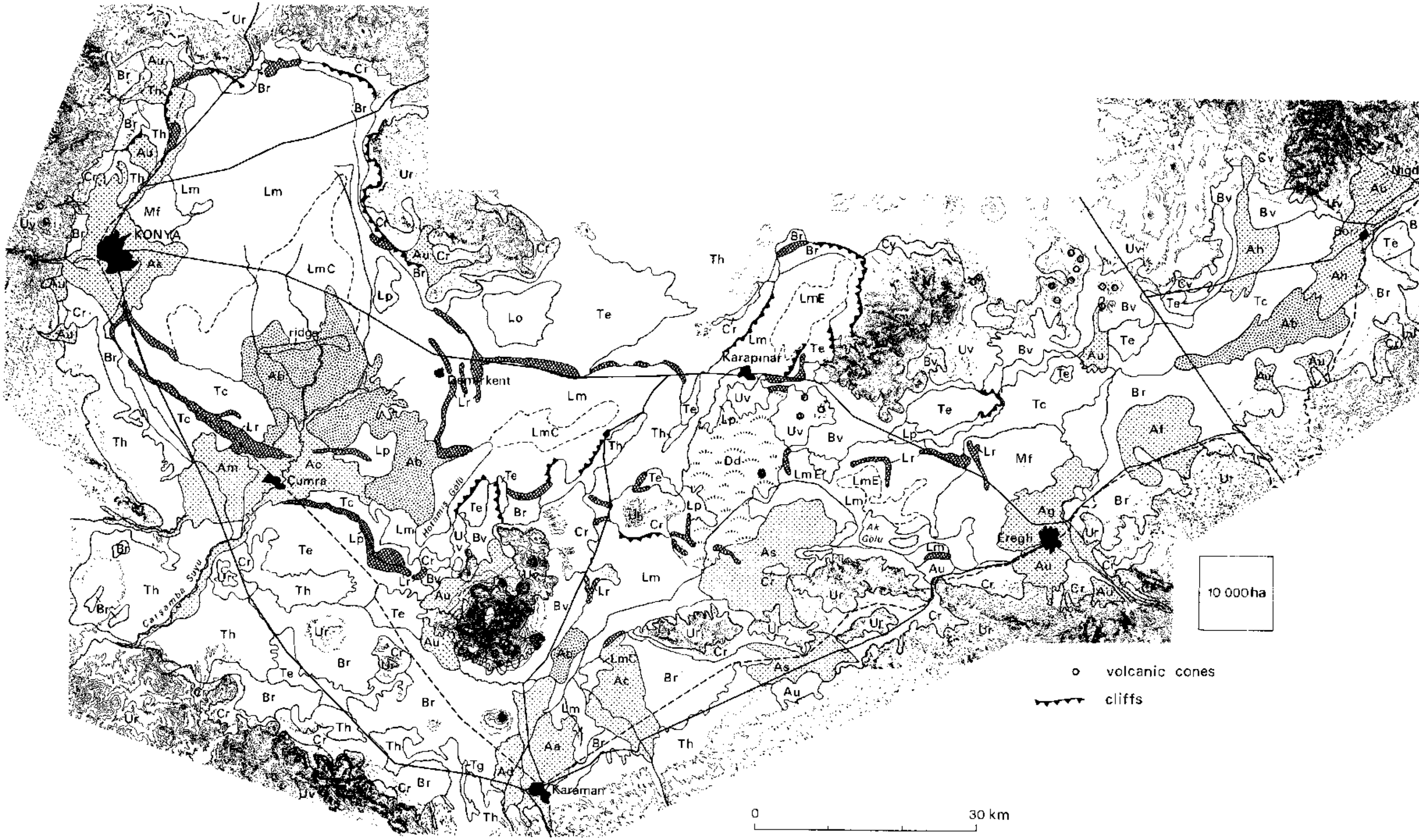
The Basin is enclosed by the Toros Mountains in the south and the Anatolides in the west and north. The Toros Mountains consist chiefly of marine sediments of Miocene age and older (Ketin, 1966). Alkaline intrusions of Peridotite and Serpentine have occured during the Upper Cretaceous. During the Oligocene Epoch, the strata have been folded and in the Miocene the massif rose to it present level. The Anatolides consist of Palaeozoic limestone and schists. Their greater age is reflected by their more rounded and eroded form.

In the Basin and along its fringes, there are Miocene volcanoes (Westerveld, 1957) of andesitic and basaltic material. They are located along a fault traversing the Basin from the south-west towards Niğde and Bor in the far east of the area. Although they are quiet now, numerous sulphur-containing mineral springs remain. Along the fringes of the plain, there are Mio-Pliocene freshwater limestones with faults and structural terraces. The Great Konya Basin itself is covered with Tertiary and Quarternary sediments. Near Konya clastic sediments have been found to be over 400 m thick.

During the late Pleistocene Epoch until the Würm Epoch, most of the Basin was covered by a shallow lake fairly constant in level. This is witnessed by a number of sandy beach ridges and sand plains located roughly at the 1010 m contour. On top of the soft-lime lake bottom a large variety of other sediments were deposited, resulting in various physiographic units. As these units are important in the appreciation of the hydrology of the area, and consequently for the distribution of salinity and alkalinity, their location and approximate extent are indicated on a sketch map (Fig. 2).

The *Uplands* (U) include part of the mountains surrounding the Basin and a number of volcanoes in the Basin. The first consist of limestone and volcanic material and reach up to 2000 m. The highest peak in the Basin is Karadağ, a volcanic and limestone massif, 2390 m high. The mountains include only small areas suitable for crops or grazing.

Fig. 2. Physiography of the Great Konya Basin (from De Meester, 1970).



Şekil 2. Büyük Konya Havzası'nın fizyografisi.

The *Colluvial Slopes* (C) are the taluses of limestone or volcanic material from the mountains. They consist of an unconsolidated mixture of soil material and rock fragments accumulated at the base of the mountain slopes primarily by gravity. They are very stone and are of only limited importance for agriculture. The Colluvial Slopes cover about 7% of the area.

The *Terraces* (T) of flat Neogene limestone are located along the fringes of the Basin. They slope gently (< 8%) towards the centre and are locally dissected by erosion gullies so much that only a shallow solum has remained. Their agricultural value is mainly determined by the thickness of this solum. The Terraces cover about 26% of the area.

The *Bajadas* (B) or piedmont plains are found at the base of the Uplands and consist of the finest material carried from the Uplands towards the Basin by combined action of gravity and water. This material is transported through small gullies dissecting the Bajadas radially towards the centre of the Basin. These Bajadas consist of heavy clay and clay-loam of volcanic or limestone origin and are nearly flat or only gently sloping. They make excellent arable land and cover about 18% of the area.

The *Alluvial Plain* (A) comprises the river sediments of some ten rivers debouching into the Basin near Çumra (rivers Çarşamba and May), near Konya (rivers Sille and Meram), near Karaman (rivers Deli and Selereki), near Ayrancı (Ayran river) and near Ereğli and Niğde (rivers Zanopa, Çakmak and Niğde). Depending on the geological and climatic conditions of their catchment areas, these rivers differ very much in seasonal flow and in the properties of their deposits. They cover 19% of the area and form alluvial fans or inland deltas consisting of sediments ranging from coarse sand (fan apices) to heavy clay (former backswamps). In general they are very suitable for crops.

Locally very saline clays occur that behave like sand in forming dunes which are, of course, quite unsuitable for agriculture.

The *Lacustrine Plains* (L) are mainly flat and level, and are up to 90% carbonates. They have been deposited under water and cover vast areas in the centre of the Basin. They include the old sandy beach ridges and shores at 1010 to 1020 m altitude formed by continual washing by the former Pleistocene lake. Their value for agriculture varies, but large parts are suitable only for sheep ranging. They make up about 26% of the area, excluding the 2% covered by inaccessible marshes.

The *Aeolian Plain* (D) consists of sand dunes, either still shifting or stabilized, in the very centre of the Basin near Karapınar. It has only recently formed; it is due to severe overgrazing of very sandy deposits. A special wind erosion control camp has been established to develop measures for the protection of the Town of Karapınar against these sands.

They cover only about 1% of the area.

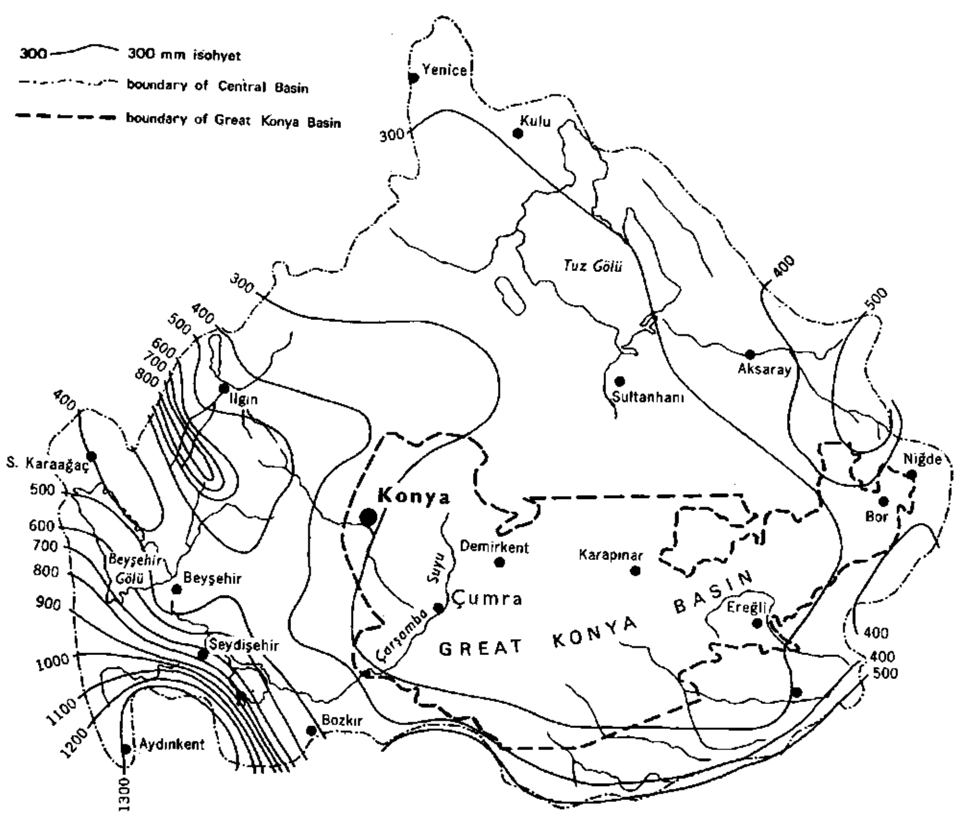
1.2 Climate

The climate of the Great Konya Basin is semi-arid, with a dry hot summer and a cool relatively wet winter. The annual precipitation only fortuitously exceeds 300 mm, since both the prevailing northerly wind and the common southerly are dry; the first comes from a dry area; the latter loses its burden of moisture in the Toros mountains so that in the Basin its relative humidity is below 50%. In the Basin's catchment area the precipitation often considerably exceeds 300 mm (Fig. 3).

The effectiveness of this rainfall for the Basin itself will be discussed later. Here suffice it to say that the low rainfall and the favourable conditions for evapotranspiration cause high water deficits in the Basin (Fig. 4).

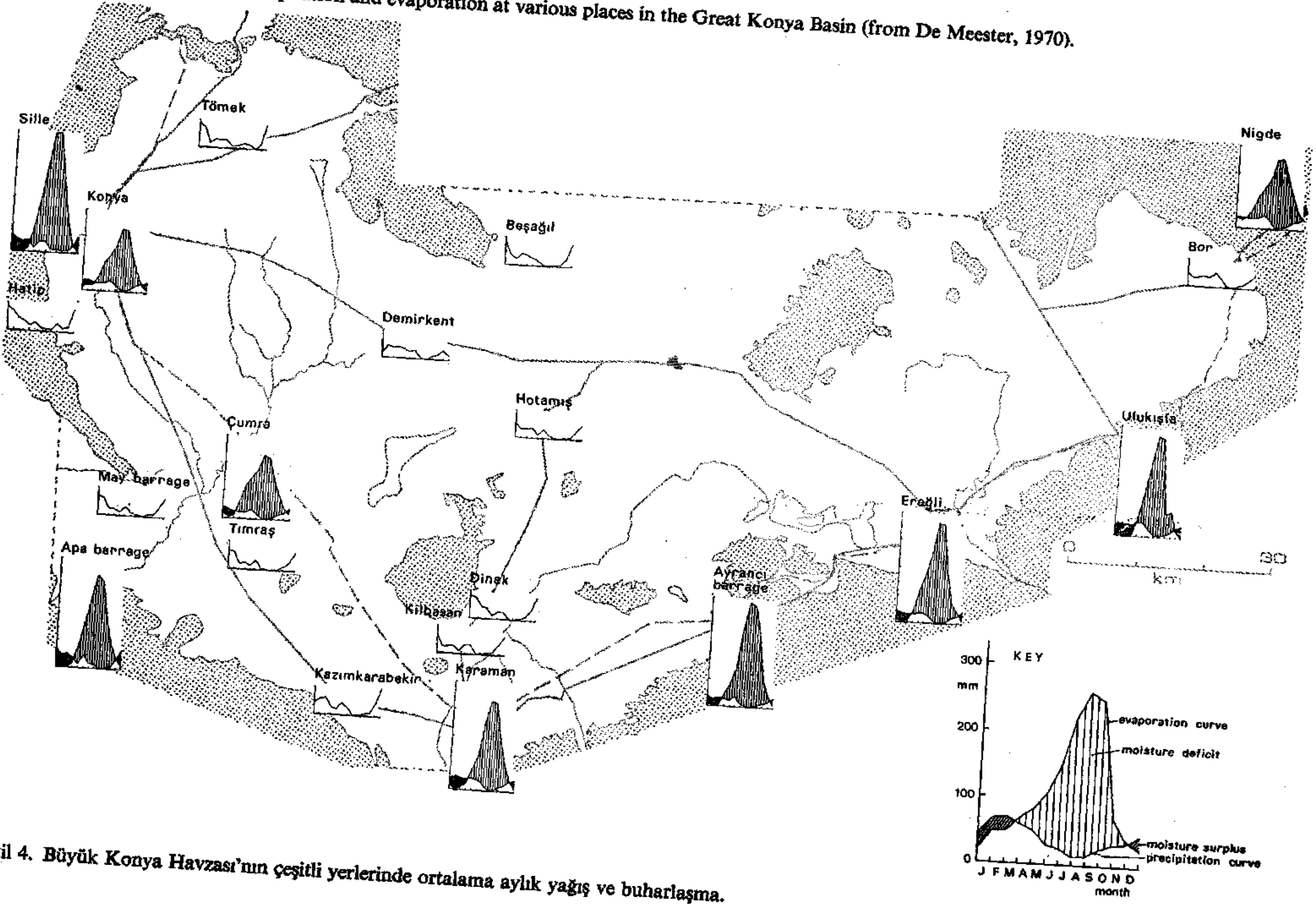
Temperatures are high in summer and often below freezing in winter (Fig. 5). In summer, nights are cool.

Fig. 3. Average annual precipitation (mm) in the Great Konya Basin and its surroundings (from DSI).



Şekil 3. D.S.İ. kayıtlarına göre Büyük Konya Havzasında ve çevresinde mm olarak ortalama senelik yağış.

Fig. 4. Average monthly precipitation and evaporation at various places in the Great Konya Basin (from De Meester, 1970).



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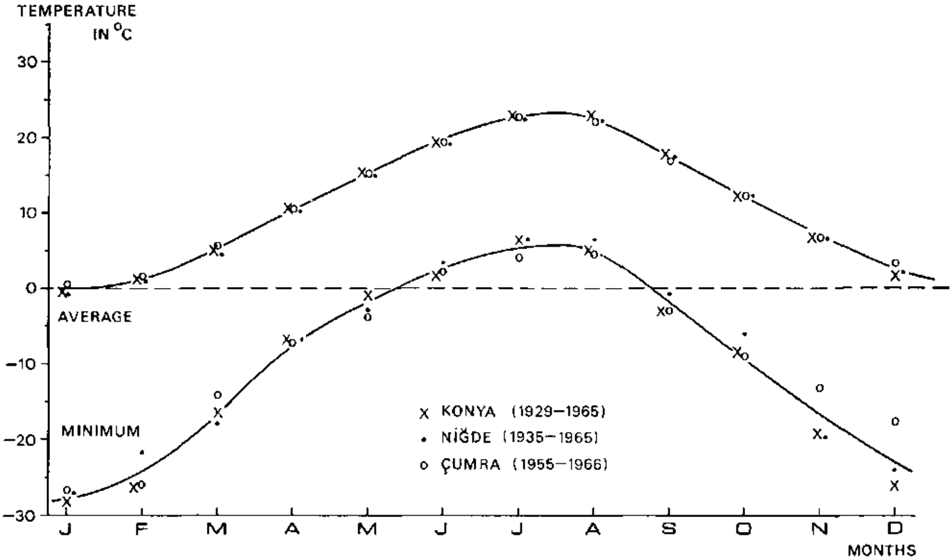

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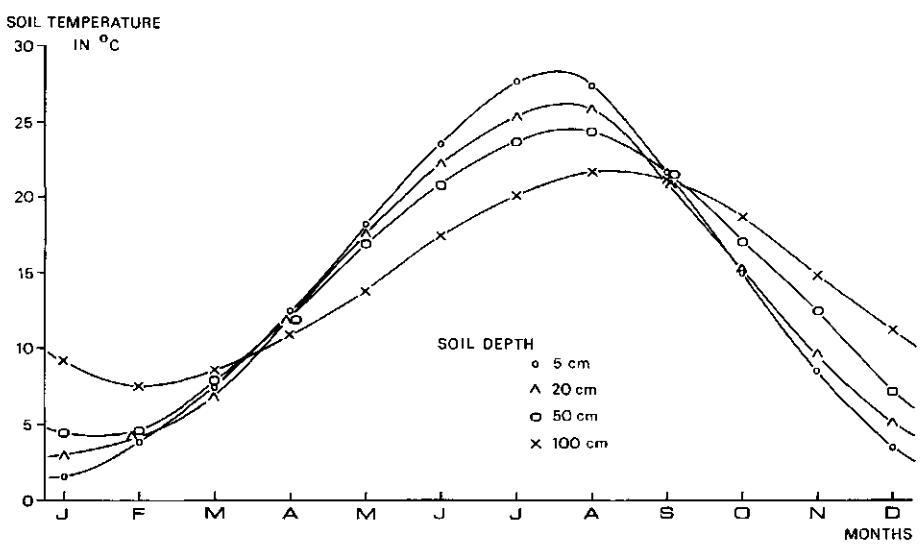
Fig. 6. Soil temperatures at various depths in the Çumra Experimental Station.



Şekil 6. Çumra Deneme İstasyonu'nda çeşitli derinliklerdeki toprak sıcaklıkları.

Soil temperatures, which very much affect the solubility of the salts in the soil, are given for the Çumra Experimental Station in Figure 6. They are also important for the classification of soils into soil families according to the 1967 Supplement of the 7th Approximation.

1.3 The vegetation

Except on very wet and very saline or alkali soils, the original vegetation of the Basin (some thousand years ago) must have been some kind of forest. This forest has almost entirely disappeared by cutting for house building and fuel, and by clearance for agriculture. At present, heavy grazing by sheep prevents regrowth and only a poor cover of drought-resistant grasses and weeds is found, both on saline or alkali soils and elsewhere.

The clearance of forest and subsequent grazing have caused heavy erosion, particularly on slopes. Soil conservation trials have been set up, e.g. near Konya, where small plots have been fenced to enable the vegetation to recover.

During the summers of 1966 and 1967, the vegetation of the Basin was studied by de Wit; the results will be published in a report of the Department of Tropical Soil Science of the Agricultural University at Wageningen.

Section 4.2 gives some particulars on the vegetation.

1.4 Hydrology

The total catchment area of the Great Konya Basin covers about 22 000 sq. km. As shown by Figure 3, its precipitation is considerably higher than of the Basin itself, since its southern border is less than 50 km from the Mediterranean.

The water flows into the Basin as subsurface seepage, artesian water and surface water, both controlled and run-off. Figure 7 gives the Basin and its catchment area. The magnitude of hydrological processes can be gauged from a balance sheet for supply and losses of water in the Basin.

The supply of water can be expressed as

$$S = A \times N + \Sigma Q + V_{ss} + A_s$$

where

S = total supply to the Basin (m^3 per yr)
A = surface of the area (m^2)
N = precipitation (m per yr)
ΣQ = sum of the yearly inflow of all rivers entering the Basin (m^3 per yr)
V_{ss} = subsurface inflow (m^3 per yr)
A_s = surface runoff (m^3 per yr)

The drainage from the Basin is

$$D = A \times E + Dr + A\mu\Delta s + A\Delta s_m$$

where

D = total loss of water from the Basin (m^3 per yr)

E = evapotranspiration (m^3 per yr)

Dr = subsurface drainage (m^3 per yr)

μ = specific yield

Δs = change in watertable (m per yr)

Δsm = change in soil moisture (m per yr)

If supply and losses over a year are equal ($S = D$),

$$A \times N + \Sigma Q + V_{ss} + A_s = A \times E + Dr + A\mu\Delta s + A\Delta s_m$$

or

$$\Sigma Q + V_{ss} + A_s = A\,(E - N + \mu\Delta s + \Delta s_m) + Dr$$

where

$$\Sigma Q + V_{ss} + A_s = S_c = \text{total inflow from the catchment area.}$$

Recent investigations (Int. Inst. Ld Reclam. Improv., 1965) show that natural drainage, if any, from the Basin is very low, so that Dr can be assumed to be zero.

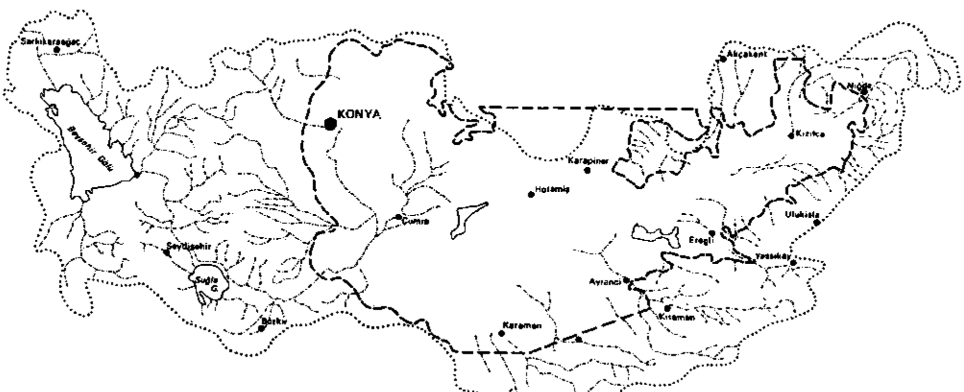
In the above formula, the total surface of the Basin, A, is about 10 000 km^2 or 10^{10} m^2.

Potential evapotranspiration, E, is a function of evaporation E_e as measured in the US Weather Bureau's class A pan, defined by $E = K_eE_e$, where K_e is an empirical coefficient. It can be found from Penman's formula

$$E = K_p\,E_o$$

where K_p is another empirical value and E_o is the evaporation from a free water surface. Kohler (1955) has found that $E_o = 0.7\ E_e$, which implies that $K_e = 0.7\ K_p$. Here for K_p, summer and winter values of 0.8 and 0.6, respectively, have been taken, as recommended for England by Penman, which have given fair results under Iraqi circumstances (Dieleman *et al.*, 1963). This leads to $K_e = 0.56$ for summer crops and to $K_e = 0.42$ for winter crops.

Fig. 7. The Great Konya Basin and its catchment areas (from Driessen & Van der Linden, 1970).



Şekil 7. Driessen ve Van der Linden göre Büyük Konya Havzası ve havzadaki su toplama bölgeleri.

Values for E_e are known from a number of meteorological stations in the Basin. Those measured at the Çumra Experimental Station may be considered representative for the whole Basin; they amount to

E_e-summer = 1405 mm, E_e-winter = 317 mm, E_e-total = 1722 mm

Substitution of these values in the equation $E = K_e E_e$ gives an annual evapotranspiration of 820 mm.

Precipitation N is not the same all over the Basin, but an average of 300 mm per year seems reasonable.

Watertables and moisture stored in the soil remained constant from year to year. This means that both Δs and Δsm can be considered zero. Thus for a period of 12 months inflow into the Basin can be written as

$$\Sigma Q + V_{ss} + A_s = A (E - N)$$

and combination with the formula $\Sigma Q + V_{ss} + A_s = S_c$ gives

$$S_c = A (E - N)$$

Substitution with the above values in the last formula gives potential annual inflow, as the substituted evapotranspiration value is based on a well watered crop that completely covers the surface. The actual evapotranspiration is largely determined by complex local circumstances, so that accurate enough calculation is impossible (Int. Inst. Ld Reclam. Improv., 1965).

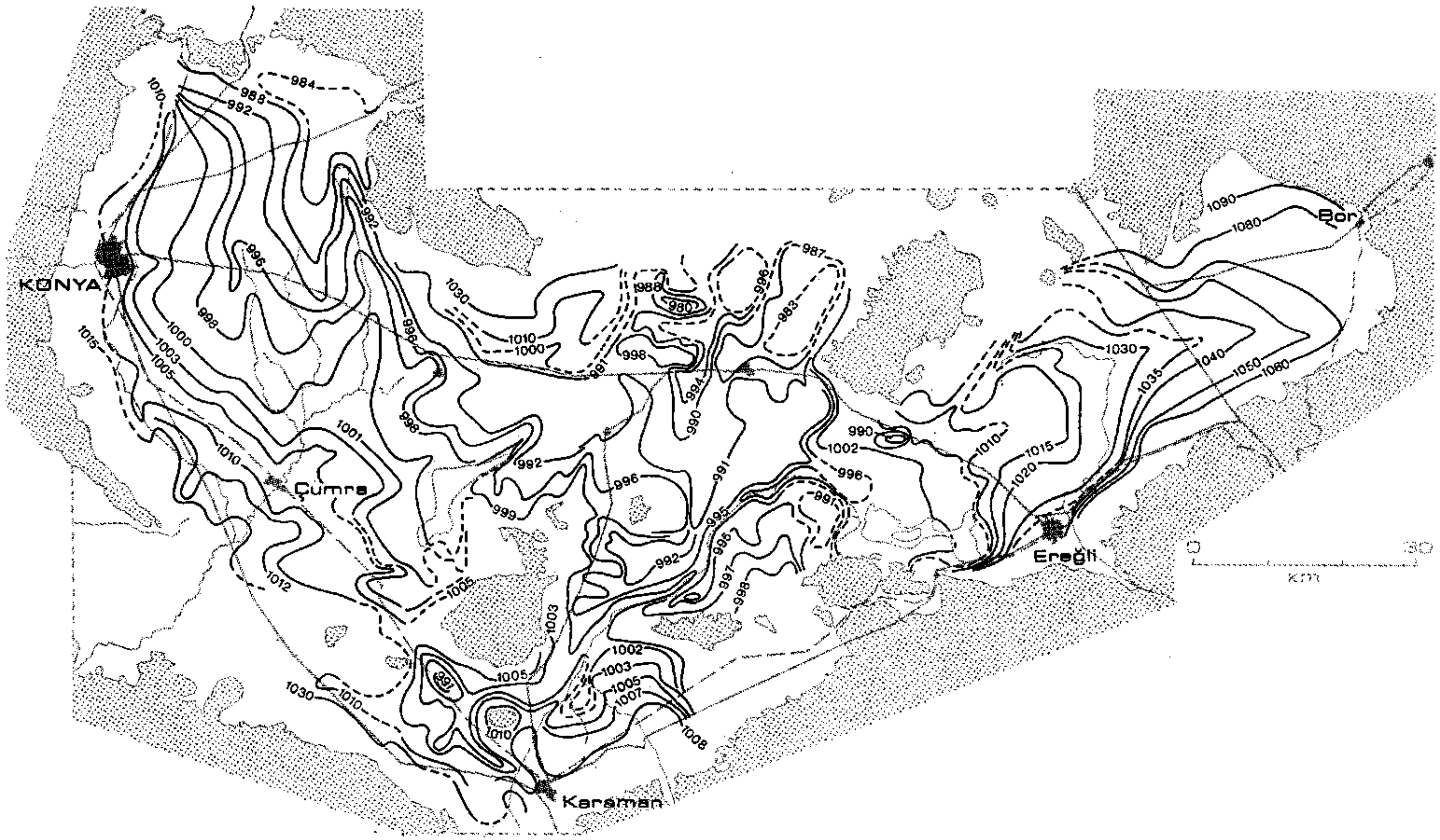
Actual general evapotranspiration must be somewhere between 45% and 85% of potential evapotranspiration. If actual evapotranspiration is 0.65 E, the formula $S_c = A (E - N)$ gives an annual inflow into the Basin of 10^{10} (0.65 × 0.82 — 0.30) = 0.23 × 10^{10} m^3. This corresponds with 0.63 mm per day. But obviously this value is very speculative and indicates only the magnitude of the actual annual inflow.

As subsurface drainage is negligible, inflow collects at the Basin's lowest spots, as far as topography and subsurface stratification allow. To study this process, watertables were measured at some 500 points in spring and autumn 1967 establishing the exact heights of these points above sea-level; these sites were plotted on a scale of 1 : 200 000 (Fig. 8).

Figure 9 shows the depths of the watertable in May and September 1967. In considering these data it should be remembered that the hydrology of the Basin has been substantially influenced by human activities. Dams have been constructed at several places, e.g. near Konya, Ayrancı and Karaman, and a vast network of irrigation and drainage canals covers much of the alluvial deposits near Çumra and Ereğli and, locally, the better soils of the southern part of the Basin (Fig. 45).

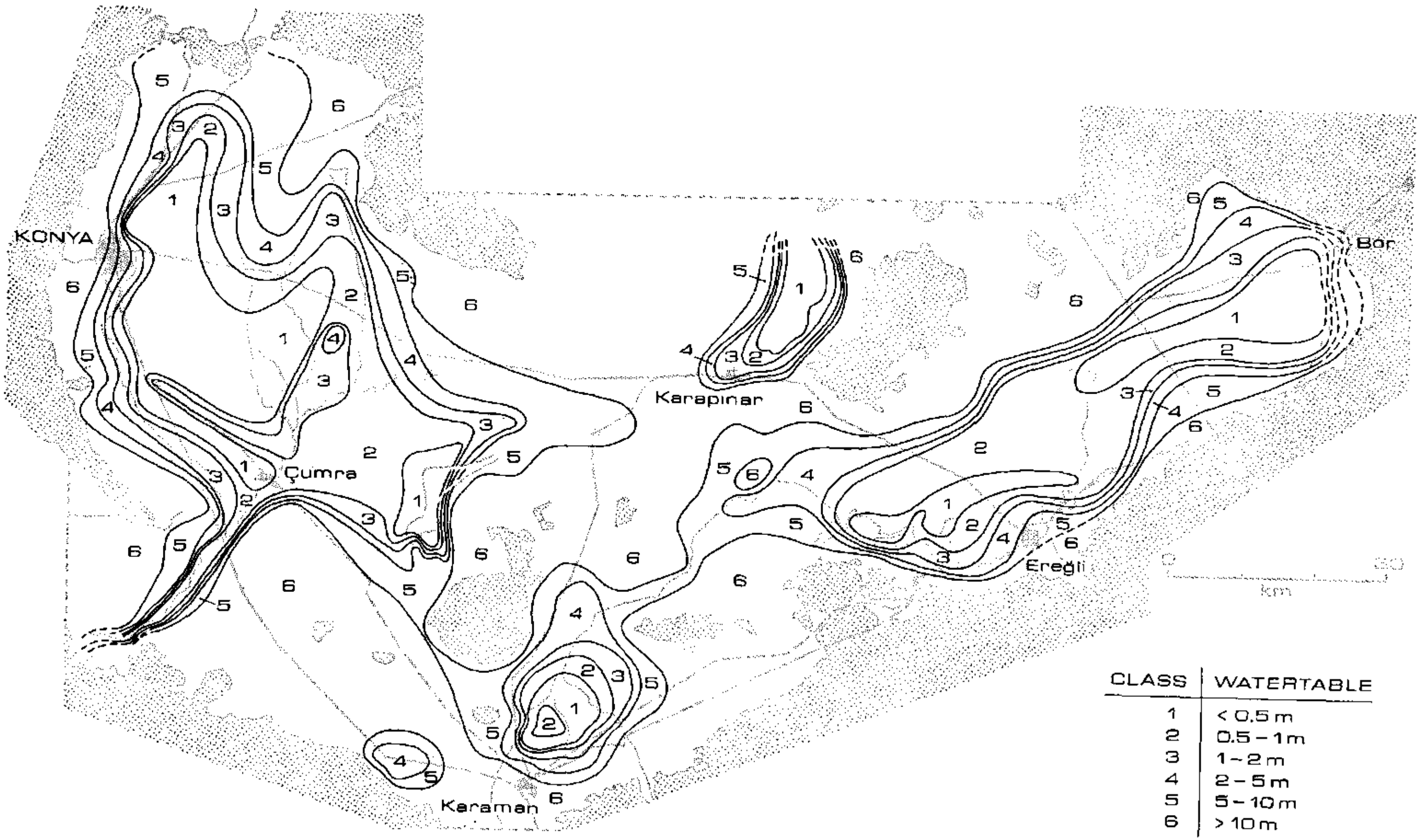
Although in May and September the pattern is similar, there are striking differences, In autumn, the agriculturally important upper two metres of soil are considerably drier: in spring 10% of the area has a watertable less than 50 cm, in autumn it is only occasionally less than one metre; in spring 30% of the area has water within two metres of the surface; in autumn 24%. This decrease causes an increase in the group with watertables between 2 and 5 m from 7.4% in May to 13% in September.

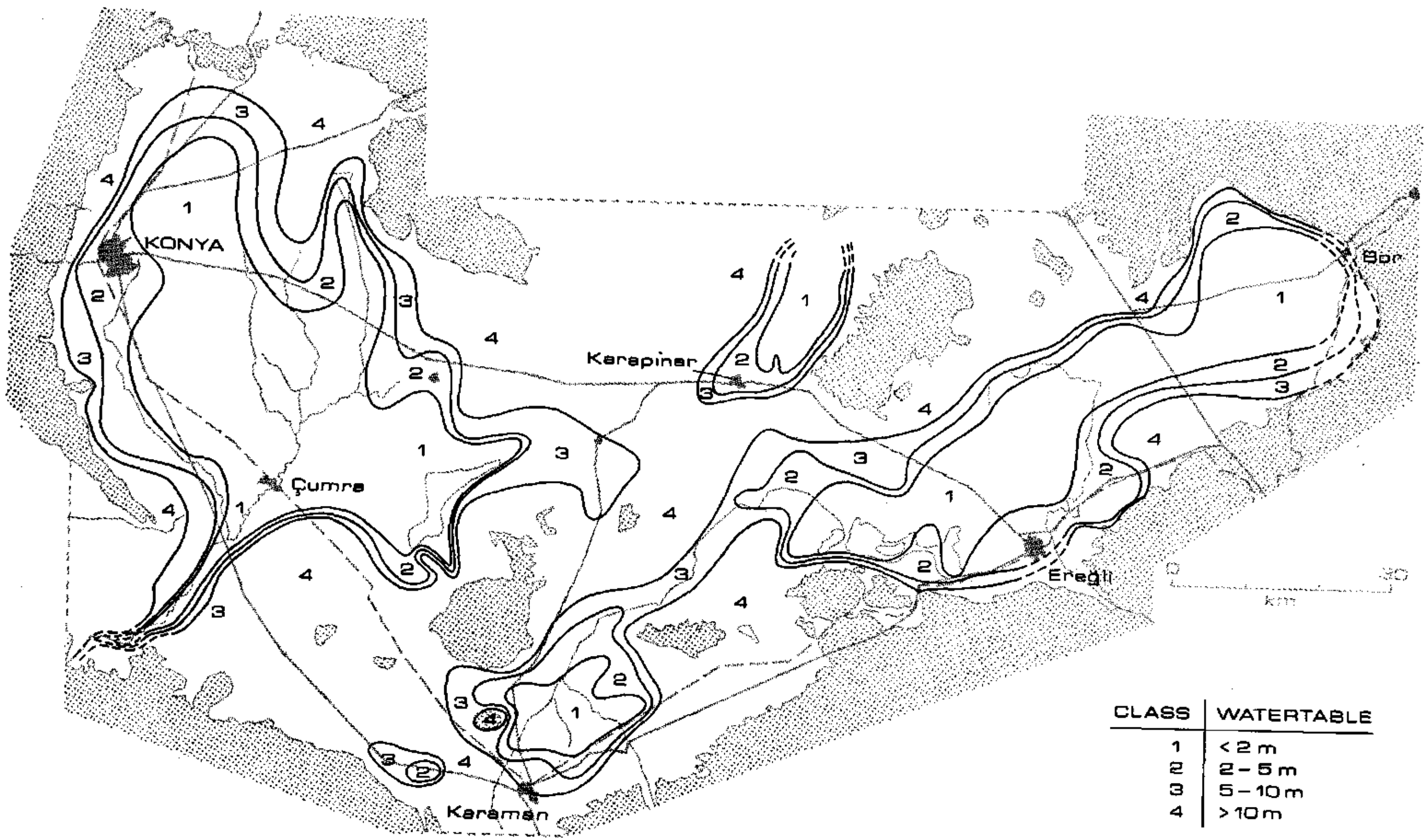
Fig. 8. Sketch map of the isohypses in the Great Konya Basin in May (above) and in September 1967 (below). From Driessen & Van der Linden (1970).



Şekil 8. Driessen ve Van der Linden göre Büyük Konya Havzası'nda Mayıs (üstteki şekil) ve Eylül (alttaki şekil) aylarında kaba izohips'len haritası.

Fig. 9. Depth of watertables in the Great Konya Basin in May (above) and in September (below).





Şekil 9. Büyük Konya Havzası'nda Mayıs (üstteki şekil) ve Eylül (alttaki şekil) aylarında taban suyu derinlikleri.

Physiographic unit	Map unit		Main taxonomic classes
Ac Çarşamba Fan Soils	AcA	clayey	
	AcB	loamy, locally sandy	
	AcC	loamy over sandy subsoil	
Ad Deli Fan Soils	AdA	clayey	
	AdB	loamy	
Ae Selereki Fan Soils	AeA	locally shallow clayey over marl	
	AeB	loamy	
Af Çakmak Fan Soils	AfA	clayey	
	AfB	loamy	
Ag Zanopa Fan Soils	AgA	clayey	
	AgB	loamy or sandy	Calciorthids, Camborthids, Haplargids, Xerochrepts and locally Xerorthents. Typic subgroup
	AgC	hydromorphic clayey	
Ah Bor Fan Soils	AhA	clayey	
	AhB	loamy or sandy	
Ak Meram and Sille Fan Soils	AkA	clayey	
	AkB	loamy, locally sandy	
Am May Fan Soils	AmA	loamy, locally clayey	
	AmB	shallow loamy, locally sandy over soft lime and limestone	
	AmC	gravelly or sandy	
An Bayat Fan Soils	AnA	clayey and loamy	
As Ayrancı Fan Soils	AsA	clayey, locally complex and sandy	
	AsB	sandy and gravelly	
Au Soils of the Medium Sized Fans	AuA	clayey and loamy	
	AuB	gravelly and sandy	
	AuC	volcanic angular-cobbly	

Physiographic unit	Map unit		Main taxonomic classes
Lm Marl Soils	LmA	clayey, with shell fragments	
	LmB	locally stratified loamy with shell fragments	
	LmC	clayey with shell fragments, shallow dark-gray organic surface soil	Calciorthids and Natrargids. Aquic and Salic subgroups
Lm Marl Soils (cont.)	LmD	predominantly salt-affected clayey, periodically flooded playa	
	LmE	strongly salt-affected clayey, periodically flooded playa	
	LmF	hydromorphic, locally gypsiferous and cemented, clayey	Calciorthids. Aquic and Salic subgroups
Lr Sandridge Soils	LrA	high	Calciorthids and Calcixerolls.
	LrB	low	
Lp Sandplain and Beach Soils	LpA	dark-grayish-brown	Calciorthids and Calcixerolls.
	LpB	pale-brown stratified carbonatic with shell fragments	Calciorthids and Camborthids. Stratic subgroup
	LpC	carbonatic with dark volcanic surface soil	Vitrandepts or Andic Calciorthid.
	LpD	reworked complex and stratified	Calciorthids. Typic subgroup
Lo Old Sandplain Soils	LoA	undulating, deep	Xeropsamments. Typic subgroup
	LoB	nearly flat shallow over terrace	
Mf Marsh Soils	MfA	carbonatic clay or soft lime with dark surface soil	Humaquepts and Haplaquepts. Mainly Typic subgroup
	MfB	carbonatic clay with organic surface soil, deep black in many creeks	

Physiographic unit	Map unit		Main taxonomic classes
	MfC	soft and crusted calcareous tufa	Haplaquepts.
	MfD	soft gypsum	
Dd Sand Dunes	DdA	complex of mainly shifting sand dunes	Mainly Calcareous Sands. Locally Calciorthids, or complex of Normipsamments and Calciorthids. Typic subgroup
	DdB	stabilized sandy, locally shallow over carbonatic clay	

1.6 Soil conditions and agriculture

Direct effects of low precipitation Salinity and alkalinity of the soils in the Great Konya Basin are determined by climate (rainfall and temperature), influx of water from other areas and soil. Where rainfall is insufficient for growth of crops, water has to be added by irrigation from the rivers, from groundwater, or from reservoirs in which surplus supplies are stored. In the Basin some 25% of the area can be irrigated, mainly in the Alluvial Plains, the Lacustrine Plain, and in some small patches of the Terraces and Bajadas.

In a third of the area, irrigation is marginal: only in wetter years is sufficient water available there. On many of the small river fans, irrigation is only possible at the beginning of the rainy season.

The unirrigated parts consist of higher soils used for dry farming (most Bajadas and Terraces, parts of the Alluvial Plain), whereas the wet Marls and Soft Lime Soils in the centre of the Basin are used for pasture.

Where the soil is not irrigated and no lateral subsurface flow supplies water, the necessary water for plant growth comes from rainfall and from moisture stored in the soil. But most rain falls in showers, so that its effect is substantially reduced.

The water used by the plants if water supply is optimum (the 'consumptive use' CU, in m) can be expressed as follows:

$$CU = \mu \Delta s + T \Delta s_m + f\,(N)$$

where

μ = specific yield
Δs = change in watertable, in m
T = depth in m
Δs_m = change in soil moisture
f = effectivity factor
N = precipitation in m

For very deep groundwater (Bajadas, Terraces), $\mu \Delta s$ equals zero as it is of no significance for plant growth.

The effect of low precipitation and high evaporation during growth is enhanced by

Table 1. Water consumption in mm (consumptive use, *CU*) under optimum conditions during a year or a cropping period for various crops (data supplied by Çumra Experimental Station).

Barley	460	Tomato	629	Cauliflower	447
Wheat	682	Beans	622	Maize	833
Rye	561	Pasture	1017	Lettuce	541
Oats	621	Hemp	763	Potato	803
Sugar-beet	874	Melon	480	Onion	564
Sunflower	605	Flax	739	Lucerne	1201

Tablo 1. Normal şartlar altında mm olarak çeşitli ürünler için bir yıl boyunca veya yetişme süresi içinde su tüketimi (tüketilen miktar, *CU*). Kayıtlar Çumra Deneme İstasyonu'ndan temin edilmiştir.

a high salt content of the soil. There often occur moisture tensions exceeding pF 4.2, which means that the plants take up only part of the water reaching this layer; 20% seems a reasonable average for the total effectivity of rainfall in the Basin (f = 0.20). According to measurements by Niemann & Poulsen (1967), in experiments with French beans and cotton, dew is of only minor importance for the plant's water supply (the equation does not account for this influence).

In soils with deep watertables, the plants must obtain water that had been accumulating in the soil from rainfall in spring. Measurements of unirrigated cultivated soils revealed a decrease in this water during summer of 5 or 10% of soil weight. According to the depth of the rooting zone this is between 60 and 240 mm available water, which is far less than CU, which varies from 450 to 1200 mm between crops (Table 1).

Length of the growing season The growing season in the Great Konya Basin is only short because of the high altitude. This limits the cultivation of various crops common in other areas of the same latitude.

As apparent from Figure 5, night frosts occur in spring and autumn, and only between early May and the second half of August is a frost-free period assured. This excludes the cultivation of such crops as cotton, rice, tobacco and citrus.

Land use Few crops are grown on the dry soils in the Great Konya Basin. Wheat and some other cereals are by far the most important. Under irrigation, there is a wider range of crops. Most common are cereals, sugar-beet and melons; locally gardens occur with vegetables and fruit trees. Poplars are grown to cover the local need for fuel and building. Data on crop yields are given by de Meester (1970).

The land not used for arable cultivation serves as range for sheep, goats, horses, water buffaloes and cattle. Here poor-quality grasses are found together with clumps of *Juncus sp.* and other weeds. Experiments are under way with newly introduced species resistant to drought and salinity. In the Uplands only very extensive ranging of sheep and goats is possible.

Fertilizers are not yet widely used. Experiments are carried out, however, in various experimental stations and substations and information on their use is given to the farmers by sugar factories and governmental institutions. On a small scale, green manure (lucerne) is introduced into the crop rotation.

2 Soil salinity

2.1 General classification of saline soils

Saline soils contain such a quantity of water-soluble salts that their harmful effects make commercial crops impossible. As a rule the limit is taken as 1%. This is only a general criterion; some crops are more tolerant, others less; effects can already be observed with 0.1%. Not all salts are equally harmful: sodium salts are more so than chlorides and magnesium sulphate. Calcium carbonate and bicarbonate and gypsum can be tolerated at much higher levels, but as a rule they are not considered in salinization problems. The same applies to nitrates, which may be harmful in high concentrations. In the following only chlorides, sulphates and soda (sodium carbonate) are considered.

The Russian pedologists have devised various classifications based on the total levels of these salts in soils; three examples are given in Table 2. However the American soil scientists make no distinction between sulphates, chlorides and soda, and consider only the total level estimated from electrical conductivity of a saturation extract (ECe), expressed in mmho per cm at 25° C. This method is less accurate than the Russians' as the conductivity is not only determined by the concentration but also by the characteristics of the ions. But it has the advantage of rapid and reliable estimation, bypassing a complicated laboratory analysis.

Table 2. Classifications of saline soils based on anion ratios as proposed by Russian soil scientists (the last two columns from Janitzky, 1957).

		Pljusnin	Rosanov	Sadovnikov
Sulphate soils	Cl/SO_4	<0.5	<0.2	<0.2
Chloride-sulphate soils	Cl/SO_4	0.5—1.0	0.2—1.0	0.2 —1.0
Sulphate-chloride soils	Cl/SO_4	1.0—5.0	1.0—2.0	1.0 —5.0
Chloride soils	Cl/SO_4	>5.0	>2.0	>5.0
Soda soils	CO_3/SO_4			<0.05
Sulphate-soda soils	CO_3/SO_4			0.05—0.16
Soda-sulphate soils	CO_3/SO_4			>0.16

Tablo 2. Anyon oranları esas alınarak Rus toprakçıları tarafından teklif edilen tuzlu toprakların sınıflandırılmaları (son iki kolon Janitzky, 1957' den alınmıştır).

Table 3 gives a comparison between the Russian and the American classifications for saline soils.

As well as the total level of salts, their distribution over the profile is important. Here, too, the Russian and American outlooks differ, as apparent from Table 4.

Apart from the rare cases in which salt-containing rocks or deposits are directly involved, salinity is caused by evaporation of salt-containing water. This water may occur above the surface (e.g. in lakes), or on the surface (where the watertable reaches it), or at some depth from where it is carried to the surface layer by capillary action. Or it may remain at some depth but within reach of normally developing plant roots.

Table 3. Russian and American classifications of saline soils (concentrations as weight percentages).

	Russian classification (from Pljusnin) salt content of upper 1 m layer				American classification total salt content
	mainly chlorides		mainly sulphates		
	total	of which chlorides	total	of which chlorides	
Non-saline	<0.25	<0.01	<0.3	<0.01	0—0.15
Weakly saline	0.25—0.50	0.01—0.04	0.3—1.0	0.01—0.04	0.15—0.35
Moderately saline	0.50—1.00	0.04—0.20	1.0—2.0	0.04—0.20	0.35—0.65
Strongly saline	>1.00	>0.20	>2.0	>0.20	>0.65

Tablo 3. Rus ve Amerikalı'lara göre tuzlu toprakların sınıflandırılmaları (ağırlık yüzdesine göre konsantrasyonlar).

Table 4. Russian and American classifications of internal solonchaks.

	Depth (in cm) at which salinity starts	
	Russian classification	American classification
Non-saline	>150	>120
Deeply saline	100—150	80—120
Less deeply saline	70—100	40— 80
Saline	30— 70	< 40
Solonchak	5— 30	

Tablo 4. Rus ve Amerikalı'lara göre iç solonçakların sınıflandırılmaları.

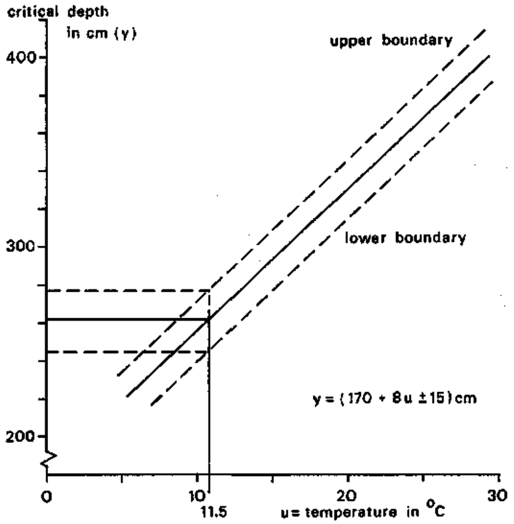


Fig. 10. Critical depth of the water-table according to Polynov.

Şekil 10. Polynov'a göre taban suyunun kritik derinliği.

Several investigators have attempted to compute the highest admissible watertable (the critical depth). It depends partly on physical characteristics of the soil but largely also on temperature, which is taken as a measure of evaporation. Polynov (according to Janitzky, 1957) has calculated the critical depth (y) from

$y = (170 + 8\ u \pm 15)$ cm, in which

u is the average temperature in ° C (Fig. 10).

For the Çumra Area (u = 11.5° C), the critical watertable is 262 ± 15 cm.

The US Department of Agriculture (1951) defines the critical depth of saline groundwater as follows: 'If a saline watertable occurs within a depth of 6 feet, salt may rapidly accumulate in the solum, especially if the surface is barren and capillary rise is moderate to high'. Although surface conditions and characteristics of the solum are taken into account here, this statement is only a rough approach to what really happens.

Talsma (1963) considers a somewhat higher watertable admissible. His opinion is based on the consideration that capillary rise of groundwater cannot completely keep up with evapotranspiration. This results in a dry crumb surface layer hampering evaporation and preventing rapid accumulation of salts at the soil surface.

It is of importance to trace what the exact relation is between capillary rise and depth of the watertable under the conditions of the Great Konya Basin. In Section 2.3 this relation will be elaborated.

2.2 Types of saline soil

Saline groundwater may occur at various depths, which gives rise to different types of saline soils.

Fig. 11. Flooded solonchak (white parts) near the Village of Kaşınhan (Site 3, Fig. 49).

Şekil 11. Kaşınhanı yakınlarında istila solonçaklar (beyaz kısımlar) (Yer 3, Şekil 49).

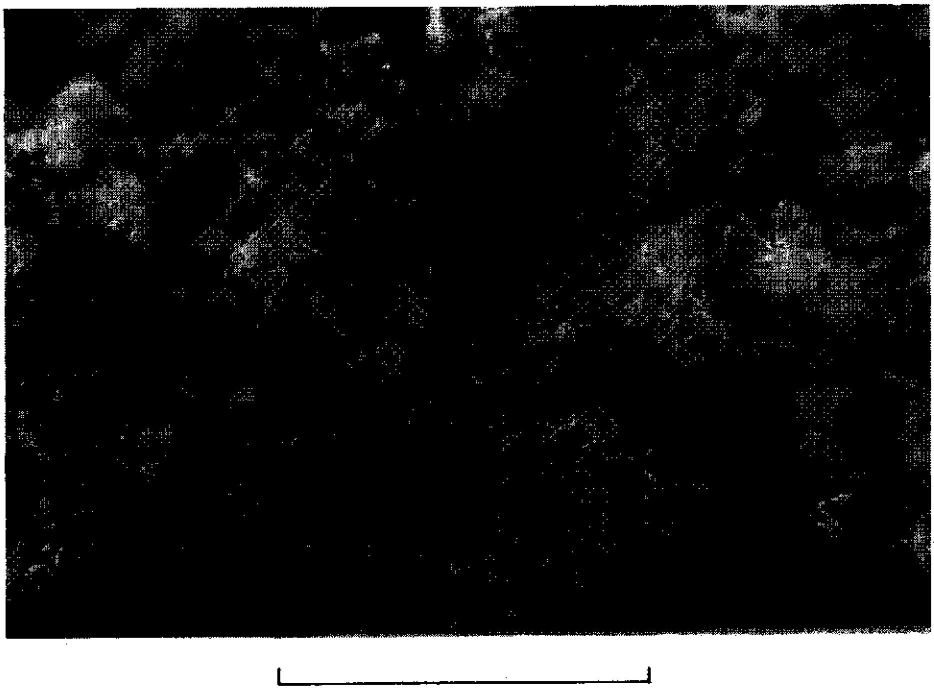
In *temporary ponds* or along the *shores of permanent lakes*, the salt may accumulate at the soil surface by evaporation of the water to form external solonchaks.

Of the ponds only a nearly flat depression may remain covered with a white crust. Such flooded solonchaks are found in the low central part of the Basin, e.g. near the Village of Kaşınhanı, near Ak Göl and near Konya (Fig. 11).

External solonchaks are formed too where *groundwater reaches the surface*. They result from evaporation accompanied by accumulation of salts on or in the uppermost soil layer, in the Basin chiefly sodium sulphate and sodium chloride. Accumulation of sodium sulphate gives rise to puffed solonchaks, characterized by a fluffy surface layer consisting of a thorough mixture of soil particles and needles of $Na_2SO_4.10H_2O$ (Buringh, 1960). These crystals are formed overnight when air moisture is relatively high. Their needle shape disrupts the soil particles which consist mainly of fine crumb aggregates owing to the saltiness of this layer (Fig. 12).

According to Janitzky (1957) sodium sulphate accumulates because of its temperature-related solubility product, dropping from 400 to 550 g per litre at 34° C to 50 to 90 g per litre at 0° to 10°. Its accumulation is therefore dependent on soil temperature at different depths throughout the year (Fig. 6). Thus sodium sulphate accumulates

Fig. 12. Fluffy mixture of needle-shaped $Na_2SO_4.10H_2O$-crystals and soil particles in a puffed solonchak (Site 1, Fig. 49).



1 cm

Şekil 12. Bir kabarık solonçak'ta iğne şeklinde $Na_2SO_4.10H_2O$ kristalleri ile toprak parçalarının tüy şeklindeki karışımı (Yer 1, Şekil 49).

during summer and is not effectively leached during the wet winter, whereas other soluble salts are easily removed in winter. The accumulation of sodium sulphate in the top of the profile amounts to 20 to 60% $Na_2SO_4.10H_2O$ (w/w).

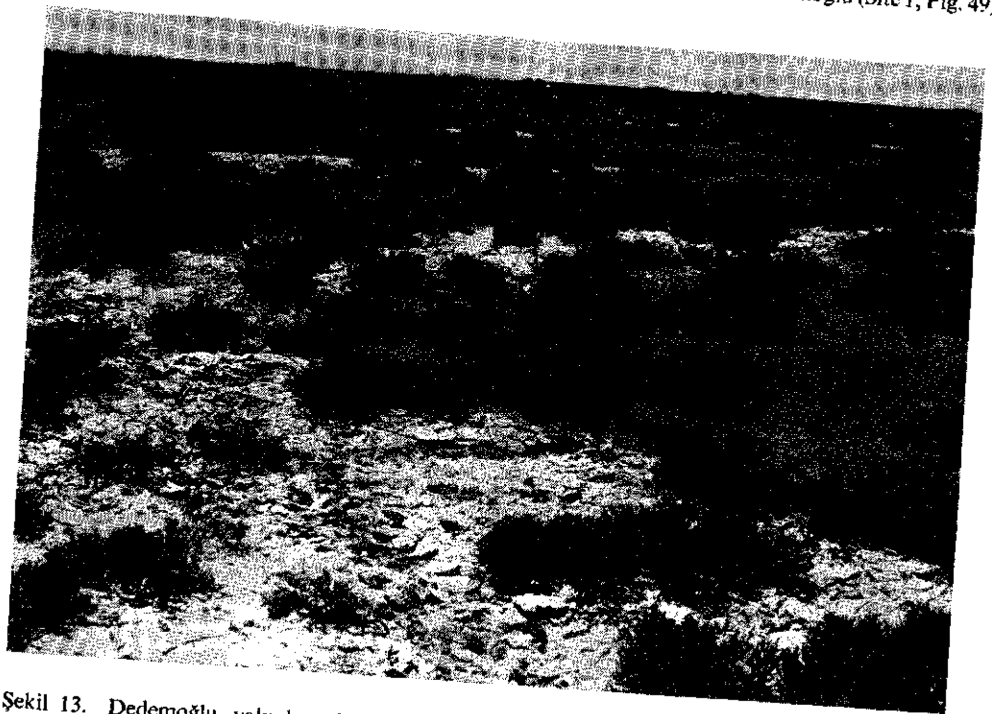
In the Basin such puffed solonchaks are common. They occur in particular near Ereğli, near Ak Göl, north of Çumra, and near Konya. Near Konya they are rich in magnesium sulphate too, because of the occurrence of magnesite, which is even quarried.

The puffed solonchaks tend to occur in patches (Fig. 13), but the study of the soil profiles has shown almost identical characteristics for both puffed and unpuffed patches (Profile 1 pp. 90-91). The only difference that might be significant is that unpuffed patches have slightly more carbonate.

Between 1966 and 1968 no change was detected in distribution of puffed patches.

Soils with an *accumulation of hygroscopic salts* in the surface soil are generally called 'sabbakh'. These salts attract moisture from the air, especially in the early

Fig. 13. Patchy distribution of puffed solonchaks (the white patches) near Dedemoğlu (Site 1, Fig. 49).



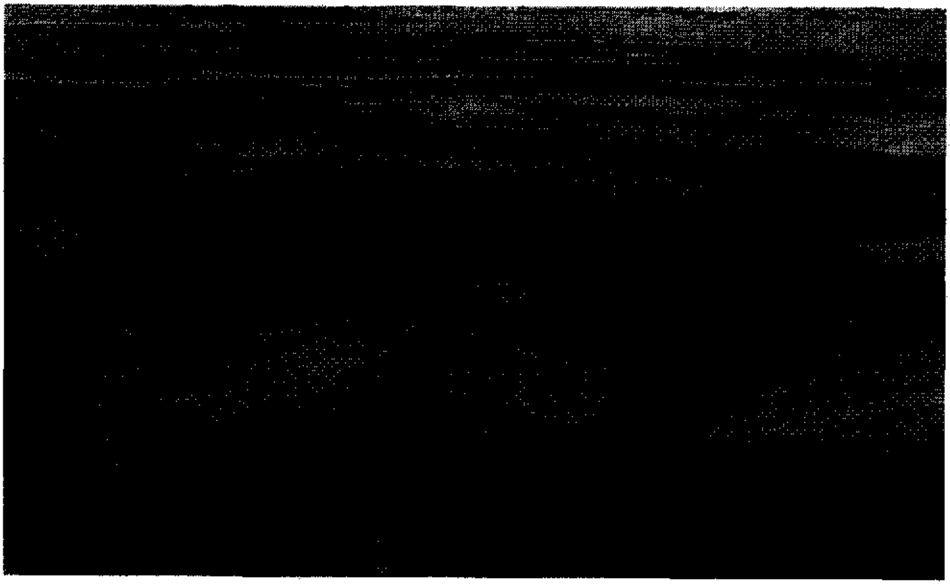
Şekil 13. Dedemoğlu yakınlarında kabarık solonçaklar'ın benekler halinde görünüşü (beyaz kısımlar) (Yer 1, Şekil 49).

morning when relative humidity is high (Buringh, 1960) and turn the surface into a muddy mixture of salt and soil, often making the sabbakh soils slippery and inaccessible. This type of salinity is characterized by the occurrence of darker patches in the field (Fig. 14).

In general the hygroscopic salts are calcium and magnesium chlorides. In the Great Konya Basin, however, hygroscopic nitrates are important too, particularly north of Karapınar, where a macrochromatographic differentiation of the salts gives rise to zones, each with one type of salt dominant. In the strip in which nitrates predominate and sabbakhs occur, local crusts are formed which are pushed upwards by gases escaping from the underlying mud. The same phenomenon has been recorded north of Ereğli.

Another form of an external solonchak found all over the Basin is characterized by a glass-like crust of salt, sealing the underlying sodden and saline surface soil from the air. Probably this crust consists of sodium magnesium sulphate (Bloedite); it considerably hampers evaporation. Thus the soil remains wet. This phenomenon, too, occurs irregularly, so that wet patches are usually surrounded by very hard, dry and cracked soil (Fig. 15).

Fig. 14. Patchy distribution of sabbakh soil (the darker parts) near Karapınar (Site 2, Fig. 49).



Şekil 14. Karapınar yakınlarında sabbakh toprağın benekler halinde görünüşü (koyu renkli kısımlar) (Yer 2, Şekil 49).

Fig. 15. Glass-like salt seal at the surface (in the middle of the photograph) preventing the surface soil drying out (Site 3, Fig. 49).

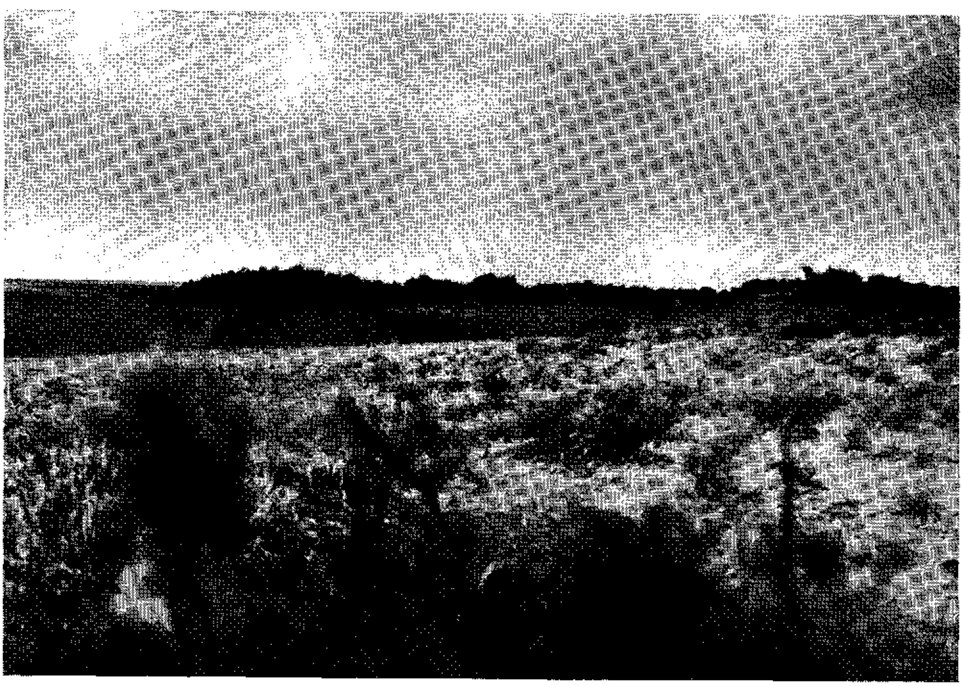
Şekil 15. Toprak yüzeyinden buharlaşmayı önleyen cam gibi tuz öbekleri (fotoğrafın orta kısımlarında).

Evaporation is commonly decreased in external solonchaks. Salt efflorescence at the surface considerably reduces the influence of temperature fluctuations, wind and humidity.

The most common form of efflorescence is a loose structure of salt crystals with different amounts of water built in the crystal. The upper zone of this crust is exposed to the air and is reduced to a powdery partly undifferentiated mass, the deeper layers having fully intact crystals. This type of loose salt crust is often found along canals, in waterlogged areas and in the flooded solonchaks (Fig. 11).

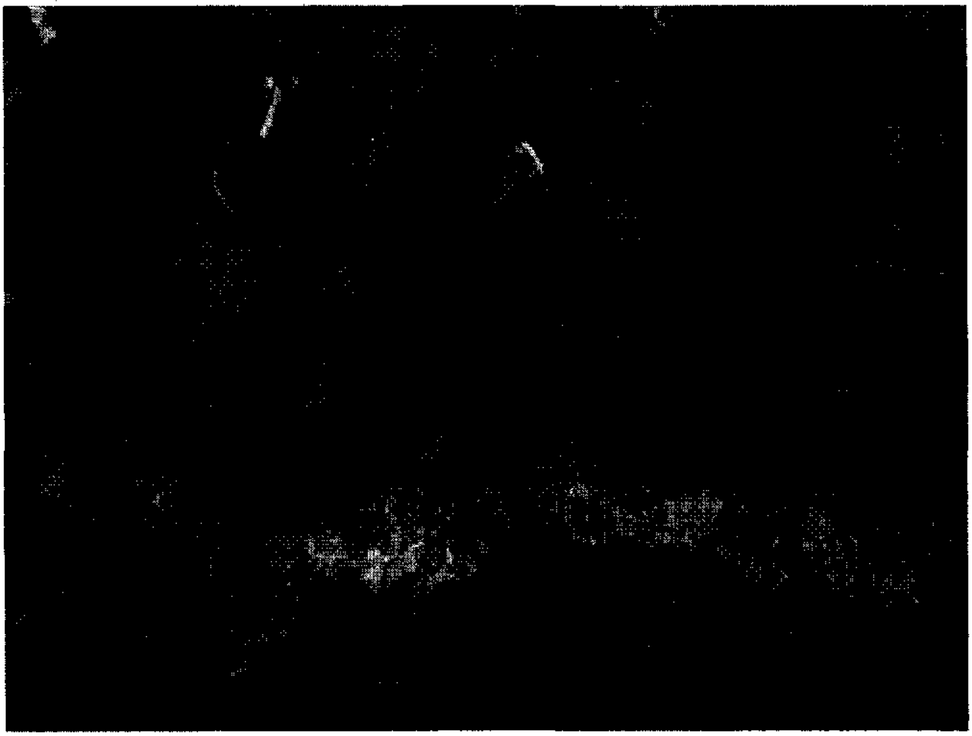
Not *all* external solonchaks show any of these characteristics. Especia*ll*y in heavy self-mulching Vertisols very saline surface layers may exist without any clear salt efflorescence. But if so an examination with a lens reveals tiny salt crystals at the surfaces of the crumb or granular structure elements. Here and there in these saline soils the formation of clay dunes has been observed. They consist of well flocculated, very salines particles of heavy clay, behaving like sand grains when exposed to the wind.

Fig. 16. Clay dunes on severely salt-affected Vertisol north of the Village of Küçük Köy (Site 4, Fig. 49).



Şekil 16. Küçük Köy'ün kuzey kısımlarında çok fazla tuz etkişinde kalmış Vertisol üzerinde kil kümeleri (Yer 4, Şekil 49).

Fig. 17. Accumulation of salts in an internal solonchak (Site 5, Fig. 49).



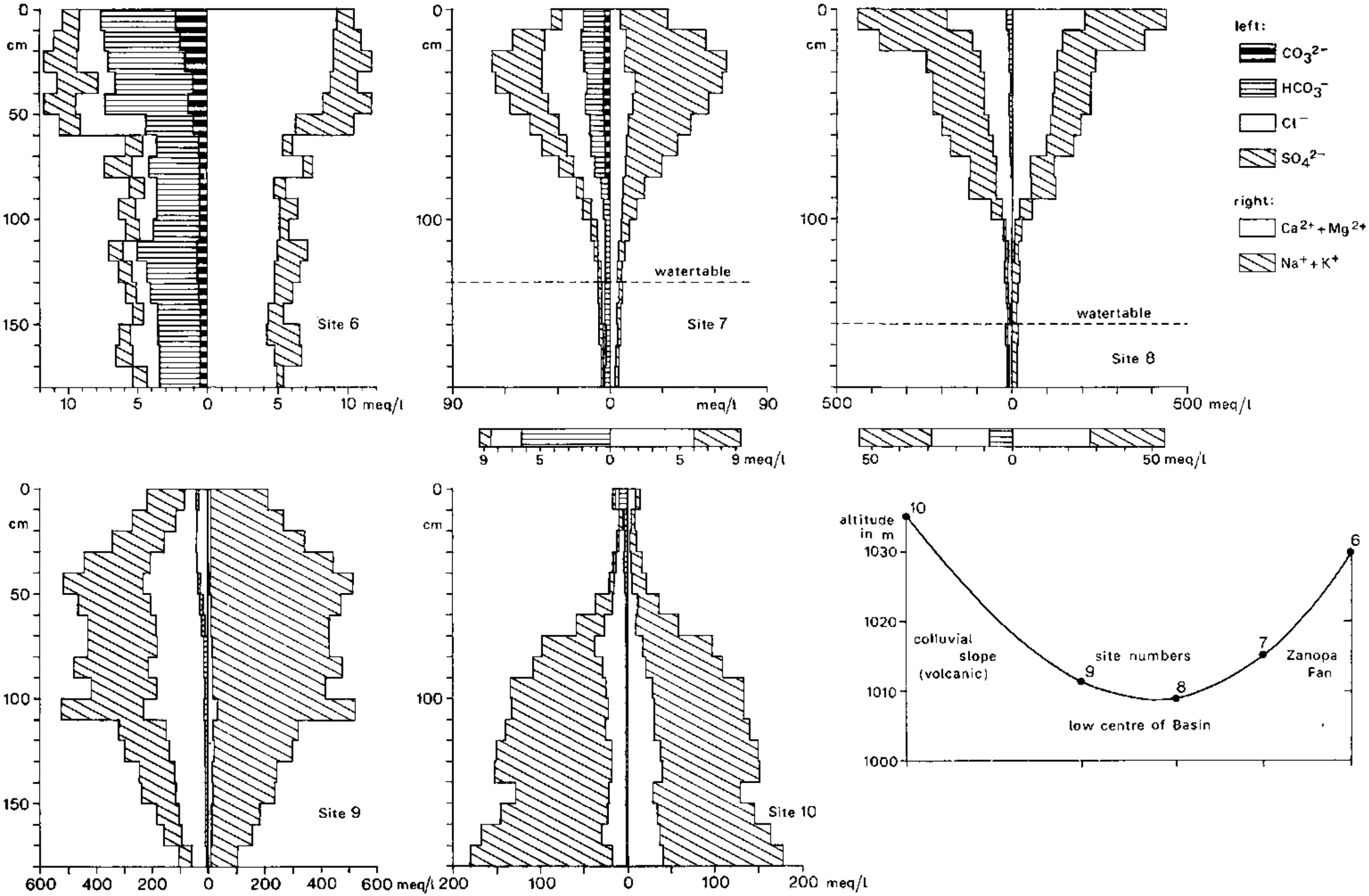
Şekil 17. Bir iç solonçak'ta tuz birikmesi (Yer 5 Şekil 49).

Such claydunes occur mainly on the heavy backswamp soils where they attain heights of 4 metres. Much smaller claydunes are found north of Karapınar. Most dunes are now stabilized by a vegetation of tamarix (Fig. 16).

Where only *deep groundwater* is present, no external solonchak is formed. Internal solonchaks may however form by leaching of the surface soil or accumulation of salt by evaporation of capillary water (Fig. 17), especially in heavy alluvial deposits where horizontal cracking and very slow capillary rise hinder surface evaporation. If salt accumulation exceeds 2% of the weight of the soil mass over a distance of 6 inches or more and if the product of the thickness in inches and percentage salt by weight exceeds 24 percent-inches a 'Salic horizon' is formed, which is of importance in classification by the 7th Approximation (1960).

Internal solonchaks are difficult to trace in the field. Yet they influence agriculture by their effect on root development and thereby on growth and yield of crops. Only laboratory analysis can indicate their type and degree of salinity.

Fig. 18. Salinity patterns as related to topography (Sites 6, 7, 8, 9 and 10, Fig. 49).



Şekil 18. Topoğrafya ile ilgili olarak tuzluluk patternleri (Yer 6, 7, 8, 9 ve 10, Şekil 49).

2.3 Regional distribution and composition of salts

2.3.1. Introduction

Composition and regional distribution of salts in the soils of the Basin are known from the field work and many analyses. The concentrations of ions (in meq. per litre) have been translated into symbols plotted on the map, and they have been represented in graphs for a cross-section along the Ereğli-Karapınar highway (Fig. 18). This cross-section links the Zanopa Fan with the volcanic slopes of the northern mountains and includes three major salinity types of the Basin.

The well drained Alluvial Fan Soils are non-saline. The waterlogged centre of the Basin (Site 8) consists of severely saline external solonchaks. The very porous volcanic slopes (Site 10) are well drained and internally saline by leaching in winter and subsequent reaccumulation.

In general the soils have been sampled to a depth of 1.20 m.

2.3.2 Salinity in the soil associations

The *Upland soils* (U) are in general non saline. The *Limestone Upland Soils* (Ur) are often shallow and sloping with sufficient natural drainage to prevent salinization. The *Volcanic Upland Soils* (Uv) are locally very deep, in particular near the volcanic cones where thick layers of non-saline surface soil covered the salty subsoil as shown by the examples in Table 5. There chlorides predominate.

The Upland soils are not cultivated. They are used by nomads for cattle ranging, for instance in the main crater of Karadağ during summer.

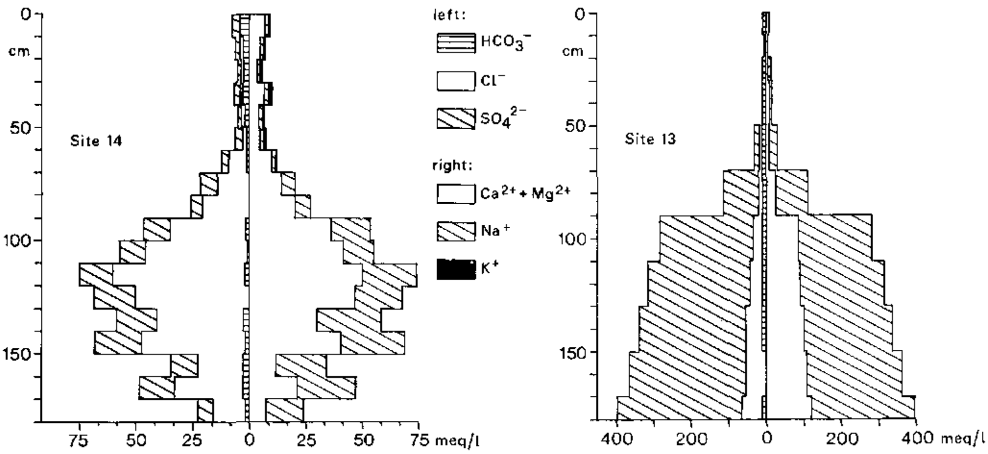
The *Colluvial Slope soils* (C) are in general apparently salt-free. They are probably to some degree saline at a great depth, especially on the slopes of volcanic material: north of Karapınar salt contents of over 1% have been found a metre below the surface (Fig. 19). The salt consists mainly of sodium sulphate. In the south, e.g. near

Table 5. Electrical conductivity (ECe. 10^3) of three deep Volcanic Upland Soils (Uv; Mekke Tuzlası).

Depth in cm	Crater centre (Site 11)	Inner slope of crater (Site 11)	Crater edge (Site 11)
0— 10	1.98	1.40	0.82
30— 40	0.60	0.68	0.68
70— 80	0.68	1.00	0.74
110—120	0.70	14.2 (!)	0.72

Tablo 5. Üç derin volkanik yüksek arazi topraklarının (Uv), elektriki geçirgenlik (ECe . 10^3) değerleri.

Fig. 19. Salinity patterns of a Colluvial Slope Soil near Dinek (Site 14, Fig. 49) and of a Volcanic Colluvial Slope Soil north of Karapınar (Site 13, Fig. 49).



Şekil 19. Dinek yakınlarında bir kolluviyal etek toprağının (Yer 14, Şekil 49) ve Karapınarın kuzeyinde volkanik diğer bir kolluviyal etek toprağının (Yer 13, Şekil 49) tuzluluk patternleri.

Dinek, internal salinity is far less pronounced; there chlorides predominate.

The *Terrace soils* (T) are salt-free, except for the soft limes that locally contain over 1%. The higher *Flat* and *Undulating Terrace Soils* (Te, Th) drain their excess water, mainly from winter rains, towards the lower *Soft Lime Soils* (Tc) in the centre of the Basin. There external solonchaks have developed, whereas in parts of the other Terrace soils weak internal solonchaks are present (Fig. 20). In the eastern Soft Lime Soils chlorides predominate; in the western, sulphates are more common.

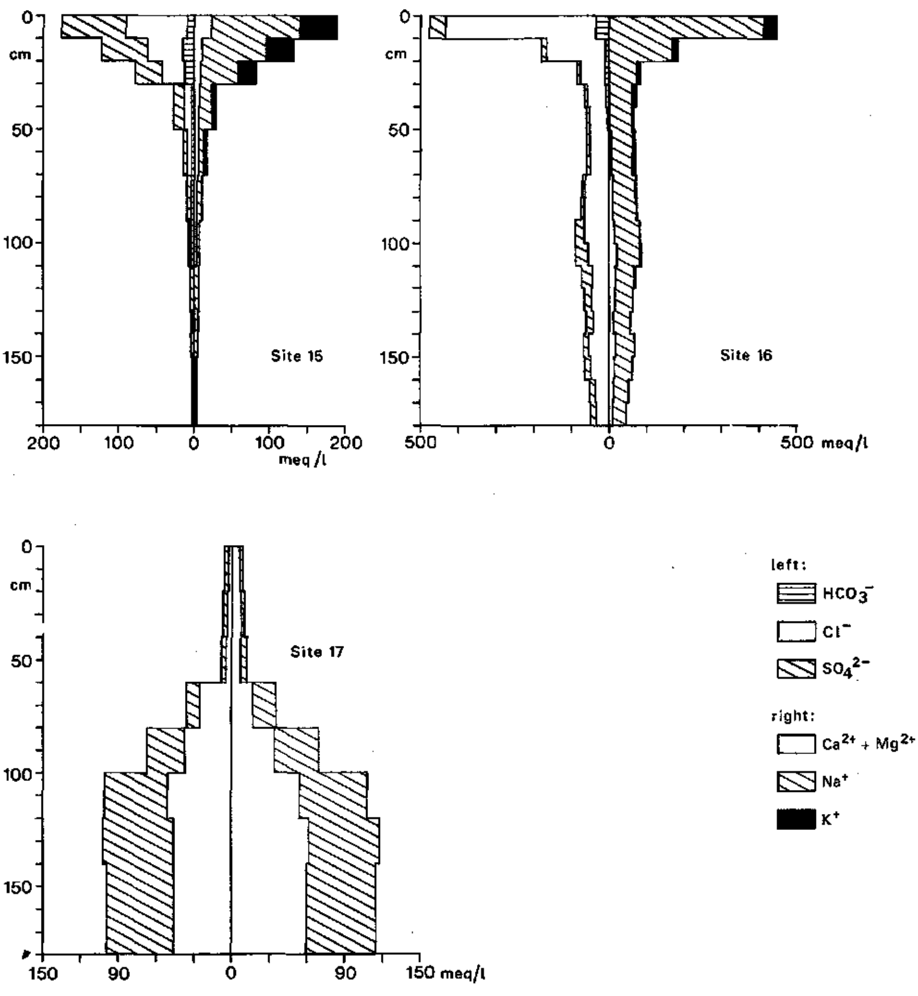
The *Bajada soils* (B) are not salt-affected, except at depths of two metres or more. For agriculture this may be of importance, as field trials (Janssen, 1970) have shown that the roots of cereals penetrate to such a depth. Table 6 gives the conductivity of some Bajada profiles near Karaman and Ereğli.

Table 6. Electrical conductivity ($ECe.10^3$) of three Bajada Soils (B).

Depth in cm	Site 18	Site 19	Site 20
0— 10	0.51	3.34	0.61
30— 40	0.49	2.59	1.11
70— 80	0.40	1.88	1.46
110—120		3.96	3.51

Tablo 6. Üç bajada toprağının (B) elektriki geçirgenlik ($ECe.10^3$) değerleri.

Fig. 20. Salinity patterns of three Terrace soils different in elevation and hydrology. A: near Türkmencamili (Site 15, Fig. 49), B: north of Hortu (Site 16), C: in High Terrace Soil near Okçu (Site 17).



Şekil 20. Değişik yükseklik ve hidroloji'ye sahip üç teras toprağında tuzluluk patternleri. A: Türkmencamili yakınlarında (Yer 15, Şekil 49), B: Hortu'nun kuzey kısımları (Yer 16), C: Okçu yakınlarında yüksek teras toprağında (Yer 17).

In the *Alluvial Plain soils* (A) severe salinity occurs here and there. The salinity depends on the composition of the river water and hence on the characteristics of the catchment area. Therefore each fan must be treated separately.

The *Çamurluk Fan Soils* (Aa) are not or only internally saline at great depth (Table 7). They drain towards the central depression and are, therefore, salt-free, despite a steady supply of salt-containing water from the south.

Table 7. Electrical conductivity (ECe . 10³) of some Alluvial Fan soils (A).

Depth in cm	Çamurluk Fan (Site 21)	Selereki Fan (Site 22)	Zanopa Fan (Site 23)	Meram Fan (Site 24)	Ayrancı Fan (Site 25)
0— 10	0.64	0.69	0.74	58.6	0.88
30— 40	0.55	0.60	0.53	54.0	0.49
70— 80	0.72	0.80	0.50	64.0	0.72
110—120	0.54	0.92	0.54	90.0	

Tablo 7. Alluviyal yelpaze topraklarının (Aa, Ae, Ag, Ak, As) elektriki geçirgenlik (ECe . 10³) değerleri.

The *Former Backswamp Soils* (Ab) are heavy-textured deposits from the rivers May and Çarşamba. According to their moisture status, they are more or less saline, mainly internally.

The lower *Çarşamba Fan Soils* (Ac) are locally strongly saline; both external and internal solonchaks occur. Well drained sites, mainly near the river bed, are an exception.

The *Deli Fan Soils* (Ad) are probably non-saline since they are well drained. Very weak internal salinity at a depth might occur but as yet there are no analytical data to prove this.

The *Selereki Fan Soils* (Ae) are efflorescent at their surface but profile analysis has shown that the soil itself is non-saline. No difference in salinity was noted between the apex and the base of the fan.

The *Çakmak Fan Soils* (Af) are non-saline. They drain towards the Soft Lime Soils.

The *Zanopa Fan Soils* (Ag) behave as the preceding but near the fringes of the fan evaporating seepage water causes accumulation of salts.

The *Bor Fan Soils* (Ah) are locally very saline as either internal and external solonchaks but no analytical data are available.

The *Meram and Sille Fan Soils* (Ak) are non-saline at the fan apex but very saline at the base. Stagnation of seepage water against the marl deposits causes a high watertable and rapid accumulation of salts by evaporation.

The *May Fan Soils* (Am) are non-saline at the fan apex, and at the base patches are moderately saline (Fig. 21).

The *Bayat Fan Soils* (An) are located in the very east of the Basin. They are well drained and not at all salt-affected. No analyses are available.

The *Ayrancı Fan Soils* (As) are not salt-affected (Table 7). Drainage is excellent towards the central depression.

The *Soils of the Medium-Sized Fans* (Au), deposited by various minor streams, are in general non-saline. They consist mainly of coarse material which enables rapid drainage of seepage water to lower areas. But locally deep internal salinity may be expected.

The *Marl Soils* (Lm) are locally very saline, in particular east of Konya, in the

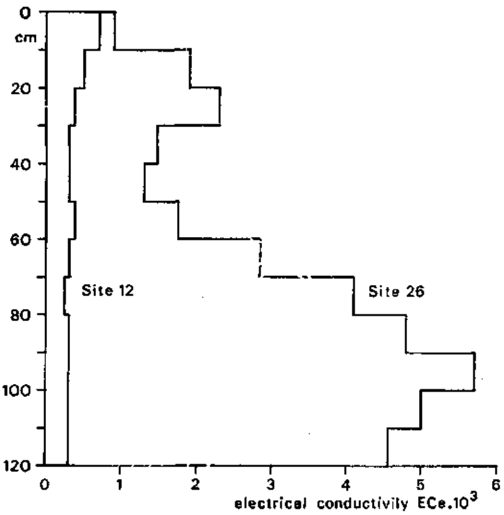


Fig. 21. Electrical conductivity (ECe. 10^3) of May Fan Soils from the apex (Site 12) and base (Site 26).

Şekil 21. May nehri yelpazesinin yüksek (Yer 12) ve alçak (Yer 26) topraklarında elektriksel geçirgenlik değerleri (ECe. 10^3)

playas north of Karapınar, and in the east of the Basin between Karapınar and Ereğli. Those in the centre of the Basin are a bit less saline; there sulphates predominate, whereas near Ak Göl most of the salts are chlorides. Both internal and external solonchaks occur (Table 8), their occurrence being governed by the local hydrological conditions.

The *Sandridge Soils* (Lr) are so porous and they occur at such heights that rapid drainage of rainwater is common. Even in those of irrigated ridges not the slightest salinity could be observed (Table 9).

The *Sandplain and Beach Soils* (Lp) are locally internally saline at great depth (Table 10). Because of their high permeability, the sandy surface is strongly leached. Only where the subsoil consists of heavy (mostly very carbonatic) material, stagnation

Table 8. Electrical conductivity (ECe.10^3) of two Marl Soils near Ak Göl.

Depth in cm	Internal solonchak (Site 27)	External solonchak (Site 28)
0— 10	3.40	101.0
30— 40	12.2	14.4
70— 80	24.6	15.0
110—120	27.4	12.0

Tablo 8. Ak Göl yakınlarında iki marn toprağının elektriki geçirgenlik (ECe.10^3) değerleri.

Table 9. Electrical conductivity (ECe.10^3) of two Sandridge Soils (Lr).

Depth in cm	Site 29	Site 30
0— 10	0.52	0.81
30— 40	0.35	0.44
70— 80	0.33	0.61
110—120	0.37	0.53

Tablo 9. İki kum bendi toprağının (Lr) elektriki geçirgenlik (ECe.10^3) değerleri.

Table 10. Electrical conductivity ($ECe.10^3$) of two Sandplain Soils (Lp).

Depth in cm	Site 31	Site 32
0—10	0.75	1.02
30—40	0.41	1.38
70—80	0.32	3.20
110—120	0.89	2.30

Tablo 10. İki kumlu ova toprağının (Lp) elektriki geçirgenlik ($ECe.10^3$) değerleri.

Table 11. Electrical conductivity ($ECe.10^3$) of two Old Sandplain Soils (Lo).

Depth in cm	Site 33	Site 34
0—10	1.24	0.64
30—40	0.72	0.43
70—80	0.62	0.42
110—120	—	0.41

Tablo 11. İki eski kumlu ova toprağının (Lo) elektriki geçirgenlik ($ECe.10^3$) değerleri.

Table 12. Electrical conductivity ($ECe.10^3$) of two Marsh Soils (Mf).

Depth in cm	Site 35	Site 36
0—10	17.2	58.0
30—40	7.8	35.2
70—80	7.0	25.6
110—120	4.4	33.4

Tablo 12. İki bataklık toprağının (Mf) elektriki geçirgenlik ($ECe.10^3$) değerleri.

of water and accumulation of salt may occur. These soils cover a small part of the Great Konya Basin and are of little importance for agriculture.

The *Old Sandplain Soils* (Lo) are not saline, though, *very* deep, internal solonchaks may occur. The two soils in Table 11 combine high permeability with high elevation and are therefore very well drained.

The *Marsh Soils* (Mf) are generally very saline, especially near Ak Göl, north of Konya (Aslım swamps) and near Ereğli. They cover the lowest parts of the Great Konya Basin and serve as a reservoir for (saline) seepage water from the surrounding areas. Near Konya, zones of hydromorphic soft gypsum occur. Table 12 gives data on their electrical conductivity.

The *Sand Dunes* (Dd) are not saline in the upper 120 cm. The deep subsoil has not been analysed. Sand dunes are of no importance for agriculture, even after being stabilized.

2.3.3 Relation between hydrological conditions and soil salinity

A careful consideration of the salinity described in Section 2.3.2 for each of the soil associations points at a distinct relation between the hydrology of the physiographic units and the salinity of the soils. To study this subject, the watertable was measured late in May and early in September 1967 in some 500 open village wells and water samples were collected for analysis in the mobile laboratory. As wells occur all over the area, the results supply a fair survey of the whole area and they could be plotted on scale 1 : 200 000 (Fig. 22).

A comparison of these maps with Figure 9, shows that places with a high watertable are usually saline because water containing dissolved salts gathers from the higher surroundings towards the depressions, where it partly evaporates so that its high salt content increases even more, especially in the centre of the Basin, where electrical conductivity has been found to be highest.

From spring to autumn the salinity of the groundwater hardly changed except for a slight increase due to higher evaporation. The area northwest of Karaman is a good example: in May the groundwater was non-saline but became slightly saline in September. In general, however, the pattern of the maps is identical.

Table 13 also shows that the changes were insignificant, in it are recorded the number of times (expressed as a percentage) various EC values were found in the well water.

A study of the various data from the wells suggests that in the eastern part of the Basin the area with values of 2-4 mmho per cm distinctly increases in summer but that near Konya the increase is only slight because the irrigation water from the River Çarşamba has a low electrical conductivity throughout the year (only 0.4 mmho/cm).

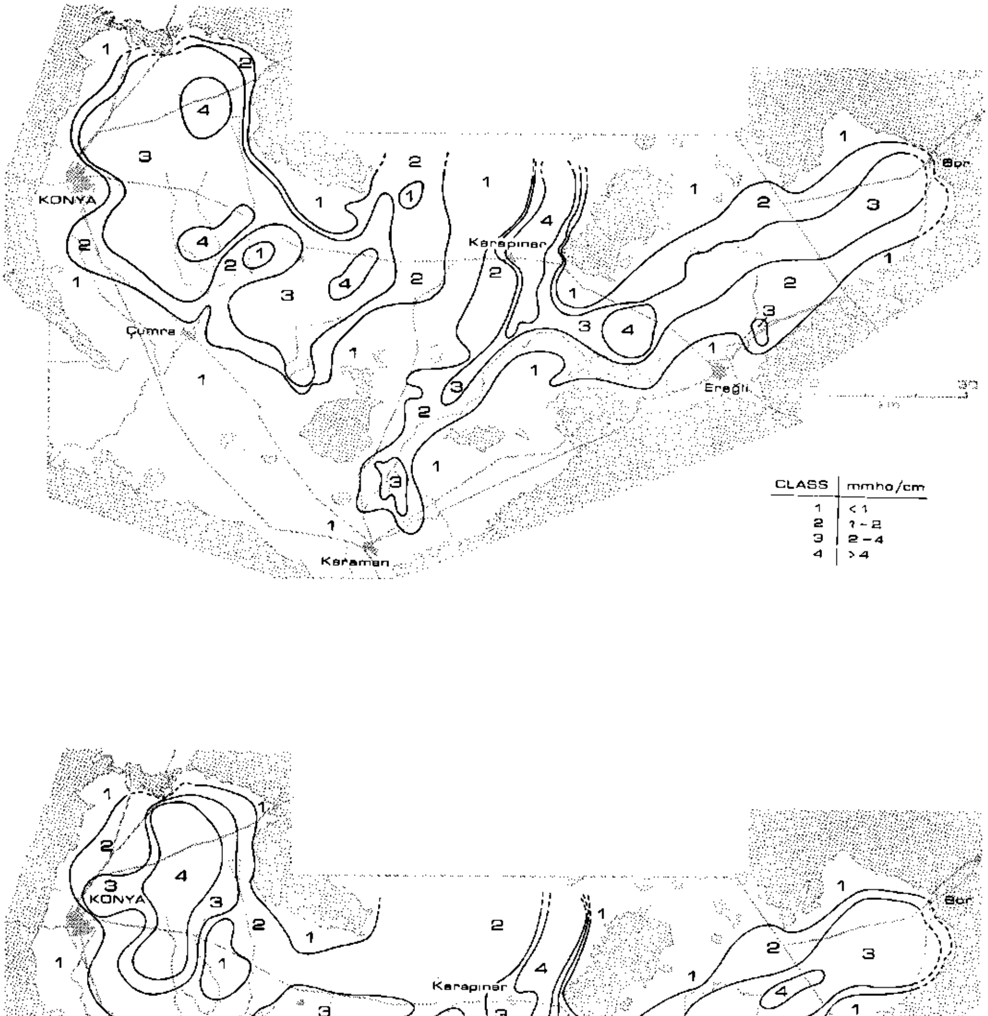
The group with conductivity values of less than 1 mmho per cm slightly decreased. The small extent of this decrease is explained by the deep watertable that is hardly subject to evaporation.

Table 13. Frequency of occurrence (%) of various EC values in spring and autumn over all water samles.

EC of groundwater	May 1967	September 1967
0—1 mmho/cm	49	48
1—2 mmho/cm	25	29
2—4 mmho/cm	22	16
>4 mmho/cm	4	7

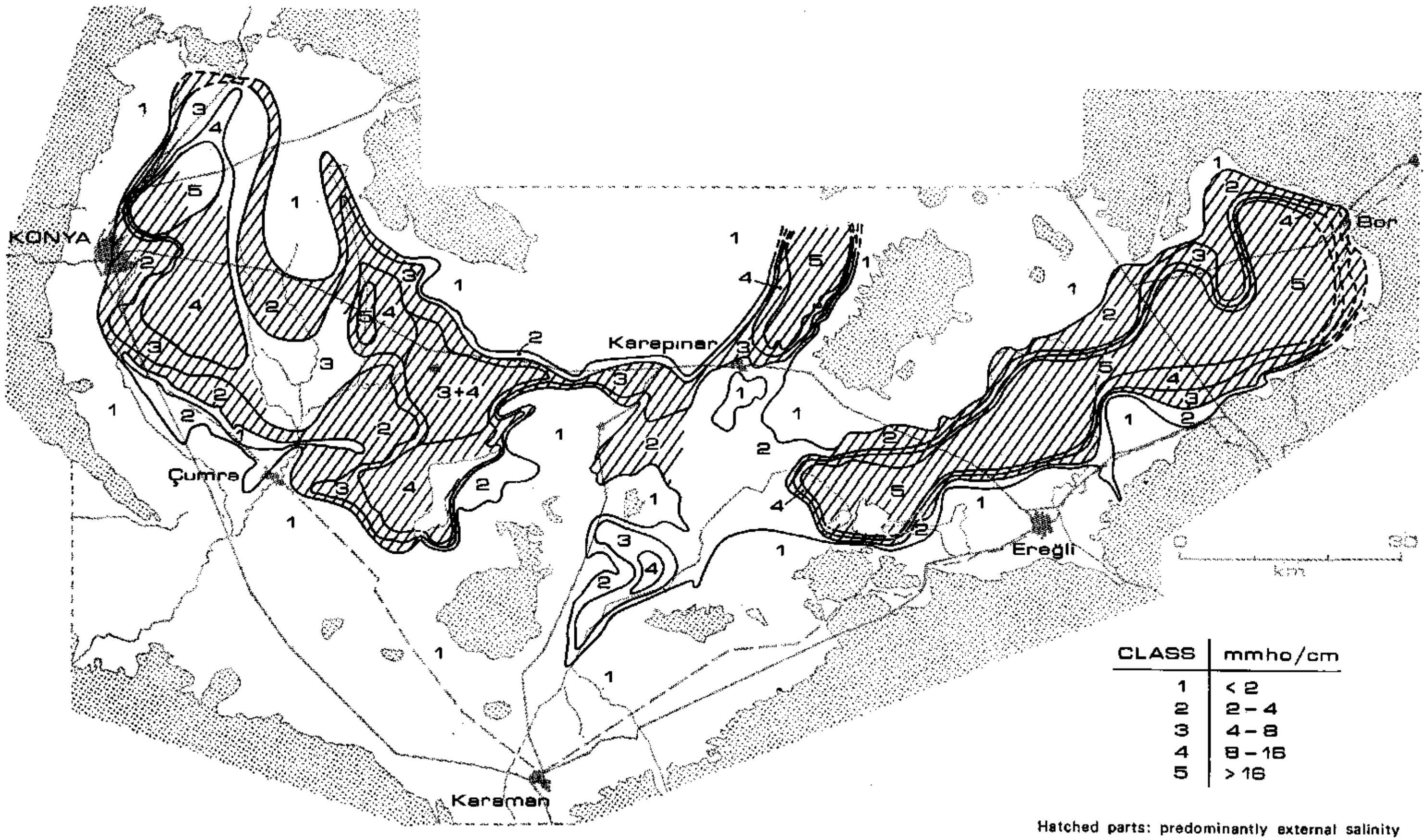
Tablo 13. Bütün su örneklerinde ilkbahar ve sonbaharda EC değerlerinin % olarak tekerrürü olayı.

Fig. 22. Sketch maps of electrical conductivity (EC. 10^3) of the groundwater in the Great Konya Basin in May (above) and in September 1967 (below).



Şekil 22. Büyük Konya Havzasında Mayıs (üstteki şekil) ve Eylül (alttaki şekil) aylarında taban sularının kaba-taslak elektriksel geçirgenlik (EC. 10^3) haritaları.

Fig. 23. Sketch map of the distribution of electrical conductivity (ECe. 10^3) for the soils in the Great Konya Basin in September 1967.



Şekil 23. Büyük Konya Havzası'nda Eylül 1967'de elektriksel geçirgenlik (ECe. 10^3) değerlerinin dağılışlarını gösteren kaba-taslak harita.

2.3.4 Distribution of salts over the Basin

To study the distribution of salts over the Konya Basin, some 200 soils were sampled in September 1967, at representative places at depths of 10, 40, 80 and 120 cm. The ECe values were plotted on the map (Fig. 23), and the places where salinity became apparent at depths of less than 40 cm were hatched. For each of the five salinity classes mentioned in Table 14 the predominant salinity figure was considered, so that internal solonchaks with a non-saline surface layer were grouped together with those with a slightly saline surface, provided their average salinity was the same, because this is in general more important than slight salinity of the upper 40 cm.

Basically, the areas are the same as those revealed by the study of groundwater. In the eastern part of the Basin, and north of Karapınar, the externally saline soils show the highest conductivity. In the southern part, near Karaman, saline soils do not occur or only rarely, despite the presence of (moderately) saline groundwater rather close to the surface. In the western part of the Basin the salinity distribution is more complicated, probably due to influx of salt by subsurface seepage from the western mountains, and to leaching by water from the River Çarşamba which feeds the irrigation system north of Çumra.

Table 14 shows the percentage distribution over the Great Konya Basin of the five salinity classes: the strongly and extremely saline areas are almost all externally saline. This agrees with the assumption that in the corresponding places salt accumulates from evaporating groundwater.

Table 14. Percentage of internally and externally saline soils in the total area of the Great Konya Basin.

Salinity class	% of total area	Internal solonchaks	External solonchaks
0—2 mmho/cm (non-saline)	61.0	—	—
2—4 mmho/cm (weakly saline)	15.0	7.0	8.0
4—8 mmho/cm (moderately saline)	8.5	4.0	4.5
8—16 mmho/cm (strongly saline)	7.0	2.0	5.0
> 16 mmho/cm (extremely saline)	8.5	0.5	8.0

Tablo 14. Büyük Konya Havzası'nda yüzde olarak içten ve dıştan tuz etkisinde kalmış toprakların dağılışları.

2.3.5 Composition of salts

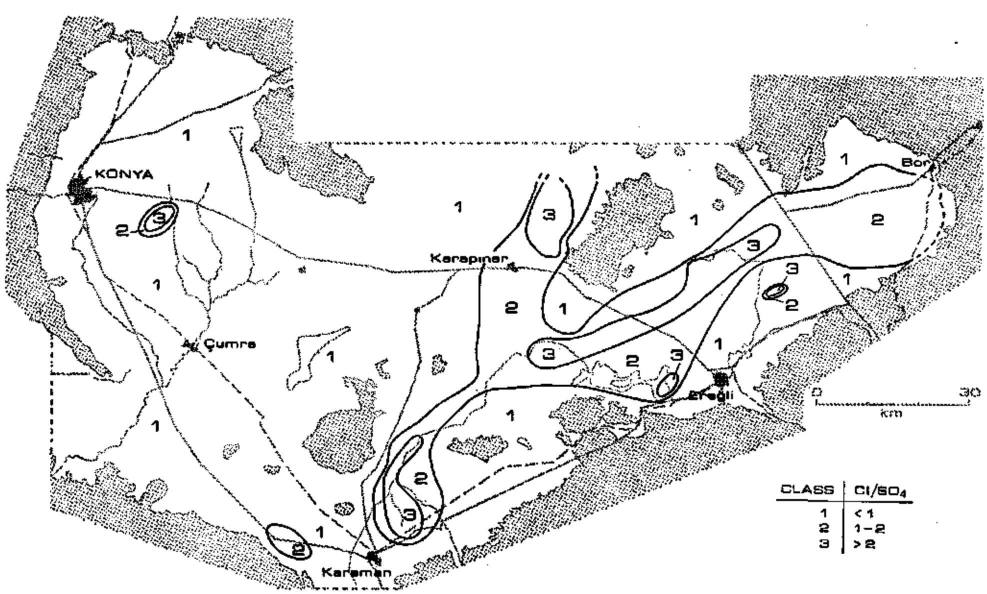
Besides the measurement of ECe, the 800 soil samples were analysed for the most important cations and anions. They included sodium, potassium, calcium, and magnesium, and for some samples carbonate, bicarbonate, chloride and sulphate (all in meq/l saturation extract). Though at first sight the number of samples and analyses may seem considerable (800 and over 7000, respectively), the data was insufficient for detailed classification. Moreover the data on anions may be inconclusive because of the presence of nitrates, and because estimates of chloride and bicarbonate, being based on colour changes, are rather unreliable (U.S. Salinity Laboratory Staff, 1954).

Thus two other methods were applied to characterize the soil samples: the Russian classification based on the Cl/SO_4 quotient, and a procedure which relates the sum of the cations in meq per litre with the electrical conductivity (ECe) in mmho per cm, assuming solvent and temperature to be the same.

The Cl/SO_4 quotient was calculated for all analysed samples. The data were plotted on a map (Fig. 24), which shows a striking difference between the western and eastern halves of the Basin: in the western half, sulphates predominate over chlorides (Cl/SO_4 province); east of the line Karapınar-Karaman, chloride is the most important anion (SO_4/Cl province).

The pattern in Figure 24 may have been influenced by differences in composition of the groundwater in the catchment areas from which the water originates. Presumably in the eastern half of the Basin, where it passes through marine sediments, it is rich in chlorides, though locally sulphates may predominate. The western mountains supply more sulphates, although spots with almost pure chloride salinity have been recorded, in particular in Vertisols with deeper watertables (below 1.80 m). They are probably

Fig. 24. Sketch map of the distribution of Cl^-/SO_4^{2-} quotients in the soils of the Great Konya Basin.



Şekil 24. Büyük Konya Havzası'nda kaba-taslak Cl^-/SO_4^{2-} oranlarının dağılışları haritası.

Table 15. Percentages of the Great Konya Basin occupied by three Cl/SO_4 classes.

Cl/SO_4	⩽1	1—2	⩾2
Percentage of the area	81.3	14.4	4.3

Tablo 15. Üç Cl/SO_4 sınıfın Büyük Konya Havzası'nda kapladığı saha yüzdeleri.

due to the greater mobility of chloride ions. Deeper in the profile, sulphates become more important.

Table 15 shows the areas of the Cl/SO_4 classes in percentages of the whole Basin. Obviously the Basin as a whole belongs to the Chloride-Sulphate Province. Really strong predominance of chlorides over sulphates occurs in only 4.3% of the Basin. The behaviour of a mixture of salts with different characteristics is not exactly known and interactions of the ions may influence the relation between EC and the sum of the cations in a solution. Yet it seems reasonable to assume that different mixtures have different Σ meq-ECe relations. For this reason the calculated Σ meq/ECe quotients (called IC quotients) have been plotted on the map. This has resulted in three sharply delimited areas for quotients below 9, between 9 and 11, and above 11 (Fig. 25). IC quotients higher than 11 occur mainly in the wet parts such as the centre of the eastern half of the Basin, the low-lying partly irrigated area of Konya and the zone bordering the southern mountains. West of Karapınar a north-south strip is found in which values below 9 occur. The other parts of the Basin have quotients between 9 and 11; it is therefore assumed, that in these parts none of the salts is predominant, i.e. predominant in the mobility of the total ion mixture. This may be important in leaching processes, for soil improvement and perhaps even for the effect of the salts on plant growth.

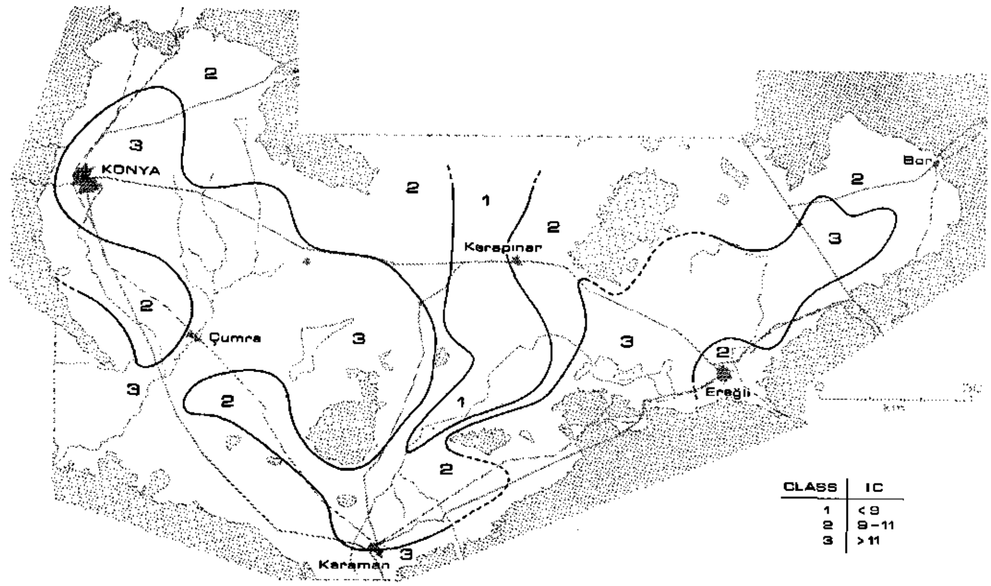
The explanations of the actual distribution of the three ranges of IC quotients over the Basin (Table 16), may be the following. In wet areas (IC quotient over 11) even

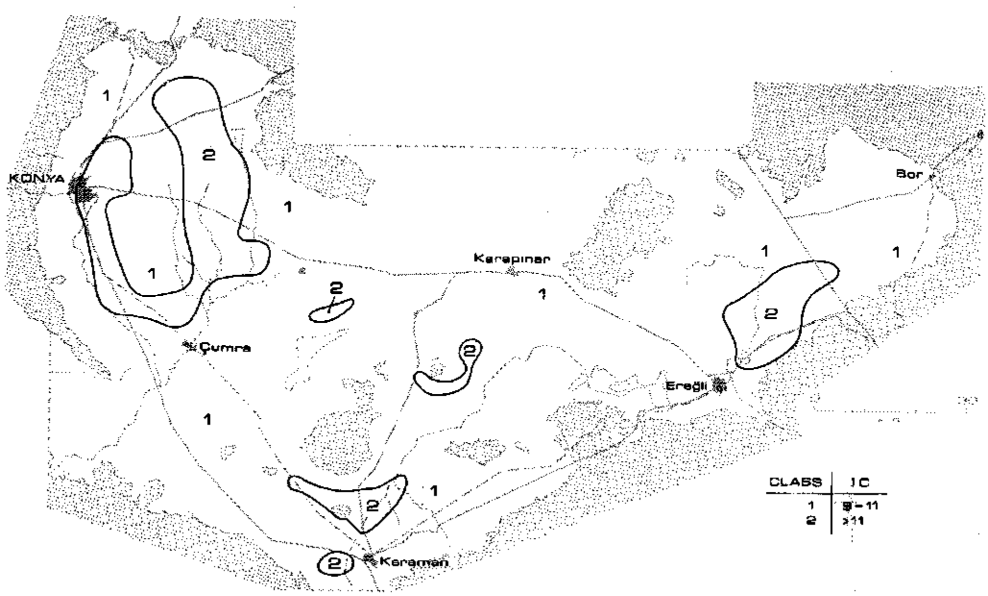
Table 16. Percentages of the Great Konya Basin occupied by three ranges of IC quotient.

IC quotient	% from soil analysis	% from analysis of groundwater
⩽9	3.7	87.9
9–11	41.6	
⩾11	54.7	12.1

Tablo 16. Üç ayrı İC-oranlarının Büyük Konya Havzası'nda kapladığı saha yüzdeleri.

Fig. 25. Sketch maps of the distribution of the IC quotients in the soils (above) and in the groundwater (below) of the Great Konya Basin.





Şekil 25. Büyük Konya Havzası'nda İC oranlarının, topraklarda (üstteki şekil) ve taban sularında (alttaki şekil) dağılışlarını gösteren kaba-taslak haritaları.

the less mobile ions are able to move to and from the upper 120 cm of the soil along with the more mobile constituents. In drier areas, to which, according to Groneman (1968), the strip west of Karapınar (the driest part of the Basin) belongs, capillary rise is slow over large distances (over 5 m), resulting in macrochromatographic differentiation of the salts and predominance of mobile constituents in the upper soil layer.

Alternatively one may consider that a shallow watertable ensures a rapid supply of water. Thus precipitation of salts with relatively low solubility products is not likely to occur deeper in the profile. With deeper watertable, precipitation of salts may occur during transport to the upper 120 cm by evaporation and water uptake by roots. This may result in a change in the composition of the salts and the predominance of the more easily soluble constituents.

To check the possible influence of the composition of groundwater, which is for much of the Basin considered the major suppliers of salts to the soil, the IC quotient of the groundwater was estimated as well (Fig. 25). No sharply defined areas can be distinguished for quotients below 9 or between 9 and 11 in groundwater, as they are distributed in an intricate pattern all over the plain. There are, however, distinct areas with ratios exceeding 11: in the east near Ereğli; in the south near Karaman and east of Konya, in the west of the Basin.

East of Ereğli gypsum formations occur (Fig. 26); near Karaman the soils are rich in gypsum at depths over 2 m, so that the groundwater must also be rich in gypsum. Near Konya magnesite occurs with the gypsum, and locally magnesium sulphate is found in large quantities, probably formed from gypsum reacting with magnesium carbonate. Gypsum is also abundant north of Konya and in the Aslım Swamps and occurs locally in great quantities in the marls of the centre of the Basin. These facts may explain the pattern shown in Figure 25 and confirm the conclusion that the IC quotient of the soil is not so much determined by the composition of the groundwater as by accumulation and redistribution of the salts in the soil according to soil factors and hydrological and climatic conditions.

2.4 Origin and dynamics of salts

2.4.1 Origin of salts

The salts in the Great Konya Basin are of different origin. The major groups are those from marine sediments, from volcanic deposits, and from weathering of rocks.

Old marine sediments occur everywhere around and under the Basin. They are Upper Eocene, Oligocene or Miocene in age and contain highly soluble salts, or gypsum, or both. At the surface of the Basin itself they are present east of Ereğli near the Village of Bahçeli Köy. Near Bahçeli Köy they consist of pure gypsum (Fig. 26) with very shallow Brown Soils.

Volcanic activity has occurred along a huge fault crossing the Basin from the Karadağ Massif in the centre towards the Town of Bor, and the chain of volcanoes is associated with many forms of soil salinization. Many of the volcanoes have saline

Fig. 26. Soil profile in almost pure gypsum near Bahçeli Köy (Site 37, Fig. 49).

Şekil 26. Bahçeli Köy yakınlarında hemen hemen saf jips üzerinde bir toprak profili (Yer 37, Şekil 49).

crater lakes. Their high salt content is due to accumulation of salt leached out of the surrounding volcanic ash and pumice soils. In particular near Karapınar this is seen clearly along the borders of the volcanic lakes where white salt crusts have formed (Fig. 27).

Near Akhüyük, volcanic activity is obvious from saline springs with an electrical conductivity of 49.6 mmho per cm, to which a curative effect is ascribed (Fig. 28). The water of these springs is very rich in bicarbonates, turning to carbonates when exposed to the air, and in sulphur compounds with a pungent smell of H_2S. Precipitation of carbonates has formed hills 10-20 m high with still active mineral springs at their apex. Other saline springs are found in the far east of the Basin, where those of the ancient city of Tiara are still visited by patients suffering from internal diseases.

Near the Town of Karapınar so much nitrate occurs in the soils that in the past it has been used for manufacturing gunpowder of an excellent quality on a commercial scale for the Ottoman Empire (Hamilton, 1842). Old inhabitants of Karapınar still recall the process of boiling the nitrate-rich soil and can show the ruins of the factory.

According to the late Mr B. Üstan of the Soils and Fertilizer Research Institute in Ankara, damage is done to the crops near Bor in the far east of the Basin by boron, present at toxic levels in the volcanic deposits. To study this phenomenon, a special experimental station has been established.

Fig. 27. Salt efflorescences at the borders of a crater lake near Mekke Tuzlası (Site 11, Fig. 49).

Şekil 27. Mekke tuzlası yakınlarındaki kraterin sınırları boyunca tuz tezahürleri (Yer 11, Şekil 49).

Fig. 28. Salt stalactites, up to 20 cm long, formed by evaporation of saline water from a spring near Akhüyük (Site 38, Fig. 49).

Şekil 28. Akhüyük yakınlarındaki bir tuzlu pınardan suyun buharlaşmasıyle 20 cm 'ye kadar uzunluklarda oluşan tuz sarkıtları (Yer 38, Şekil 49).

Part of the salts is washed out from the higher soils and accumulates in the low parts of the Basin or is stored in the deep subsoil of bajadas and terraces. This redistribution is governed by climatologic, topographic and hydrologic conditions.

The following discusses the influence of the different sources of salt either entering the Basin from the catchment areas outside (2.4.2) or from deposits in and under the Basin (2.4.3).

2.4.2 Dynamics of salts entering the Basin from outside

From the Basin's catchment areas, salt is carried into the Basin in three ways: by rivers, by subsurface seepage and by surface run-off. Apart from a few minor rivers, the annual contribution of the rivers amounts to about 760×10^6 m^3 (Table 17). Assuming a total inflow (rivers + seepage + run-off) of 2300×10^6 m^3 (Section 1.4), the annual seepage and run-off is $2300 \times 10^6 - 760 \times 10^6 = 1540 \times 10^6$ m^3.

To separate subsurface seepage and run-off is a complicated problem. Assumed that the subsurface inflow (V_{ss}) into the Basin is about the same in summer (V_s) and in winter (V_w) because of the buffering of the porous limestone formations, the soil layers and the forest vegetation in the catchment areas, the water balance over the summer season for the whole area (A m^2), with $V_s \approx V_w \approx \frac{1}{2} V_{ss}$, can be written as

$$A.N_s + \Sigma Q_s + 0.5\, V_{ss} = A.E_s + A.\mu.\Delta s_s + A\Delta sm_s + Dr_s$$

where

N_s = precipitation in the Basin in summer (m)

ΣQ_s = total inflow from rivers in summer (m^3)

E_s = evapotranspiration in the Basin in summer (m)

μ = specific yield

Table 17. Annual discharge and salt content of the most important rivers entering the Great Konya Basin (after DSI).

River	Annual discharge in 10^6 m^3	Salts in ppm	Salts in 10^6 kg/yr
Çarşamba	400	260	104
Sille	3.5	290	1.01
May	73.4	190	13.9
Camurluk	17.6	320	5.6
Ayrancı	31.7	190	6.0
Zanopa	168	190	31.9
Niğde	8.99	250	2.2
Meram	55	190	10.4
Total	758		175

Tablo 17. Büyük Konya Havzasına ulaşan önemli nehirlerin senelik boşaltımları ve tuz miktarları.

Δs_s = change in watertable in summer (m)

Δsm_s = change in soil moisture in summer (m)

Dr_s = subsurface drainage during summer (m^3)

As there is no outlet, subsurface drainage (Dr_s) is zero, the annual subsurface inflow V_{ss} can be written as

$$V_{ss} = 2\,A\,(E_s - N_s + \mu\Delta s_s + \Delta sm_s) - 2\Sigma Q_s$$

If surface run-off in summer is considered zero, which seems reasonable since the small rivers not mentioned in Table 17 do not contain any water in that season and uncontrolled surface flow is restricted to the winter months and early spring, the parameters of this formula are as follows:

$A = 10^{10}\ m^2$

$E_s = 0.85 \times 0.7 \times K_p \times Ee_s = 0.36 \times 0.18 = 0.42$ m

with Ee_s as the evaporation from a class A pan in summer

$N_s = 0.08$ m

$\mu = 0.10$ (Kessler *et al.*, 1965)

$\Sigma Q_s = 340 \times 10^6\ m^3$ (data from DSI *et al.*, 1964)

The estimation of Δs_s and Δsm_s offers special problems as not all parts of the Basin are affected in the same way. In the depression the losses caused by evaporation are partly replenished from other parts of the Basin, whereas in the higher areas with a deep watertable the lowering of the watertable has nothing to do with local evaporation.

Based on field observations Δs_s has been estimated at a metre; for Δsm_s 0.20 m has been accepted. Then the total annual subsurface flow into the Basin is

$$V_{ss} = 2 \times 10^{10}\,(0.42 - 0.08 - 0.1 \times 1.00 - 0.20) = 800 \times 10^6\ m^3$$

and the total run-off, including surface run-off, gully run-off and unknown river flows amounts to $1540 \times 10^6\ m^3 - 800 \times 10^6\ m^3 = 740 \times 10^6\ m^3$.

It is obvious that this only indicates its magnitude. Though it clearly shows that subsurface flow into the Basin is very important for annual input of salts, it does not allow an exact estimate of the annual salt supply.

Almost everywhere along the fringes of the Basin, there are springs fed by subsurface flow, many of which have been sampled and analysed in 1967. Table 18 gives the electrical conductivity (including some for springs near the mountains in the

Table 18. Electrical conductivity ($EC.10^3$) of some springs along the fringes of the Great Konya Basin.

Aslım swamps (Site 36)	10 km N of Karapınar	Acıpınar (Site 39)	Narazan (Site 40)	Karapınar	Pınarbası (Site 41)
2.22	0.90	1.10	2.12	0.90	0.64

Tablo 18. Büyük Konya Havzası boyunca çok sayıdaki su kaynaklarının elektriki geçirgenlik ($EC.10^3$) değerleri.

Basin). It accords with the assumption that subsurface flow in winter and summer is more or less buffered by soil layers and limestone formations serving as reservoirs, that the conductivity values hardly changed during the summer of 1967 (as confirmed by repeated measurements).

Except for a few saline springs, conductivity was commonly about 1 mmho per cm, corresponding to about 640 ppm salt. This leads to a total input of $800 \times 640 \times 10^3$ kg or about 510×10^6 kg.

In spring 1967 surface run-off was analysed. Allowing for run-off with a possible uptake of salt, accumulated in the Basin in previous years electrical conductivity was fairly constant at 0.7 mmho per cm, corresponding to 450 ppm. These values are higher than those measured in the rivers (Table 17) but lower than those of subsurface flow. This may be explained by the variably intimate contact of the water with salt-containing strata. Added to the quantities mentioned above, it brings the salt input into the Basin by surface run-off and by unanalysed minor rivers to about $740 \times 450 \times 10^3$ kg $\approx 330 \times 10^6$ kg.

These considerations suggest a total annual input of salts from outside the Basin of $(175 + 510 + 330) \times 10^6 \approx 10^9$ kg as a tentative estimate.

2.4.3 Dynamics of salts in the Basin

The salts already present in the Basin are redistributed and accumulated in some very saline areas in two ways: by lateral transport, and by vertical transport.

Lateral transport is by the wind over short distances and in relatively small quantities, and by groundwater flowing from higher areas near the Basin's fringes towards the centre. Vertical movement, within the profile, is in general downwards in winter (rainfall excess) and upwards in summer (rainfall deficit). It is the upward flow that causes salt accumulation in the upper two metres of the soil.

As mentioned in Section 2.1, several investigators have tried to provide a mathematical description of the relation between the upward movement and the watertable. Since this transport is the most important factor in salinization, a thorough discussion is indispensable.

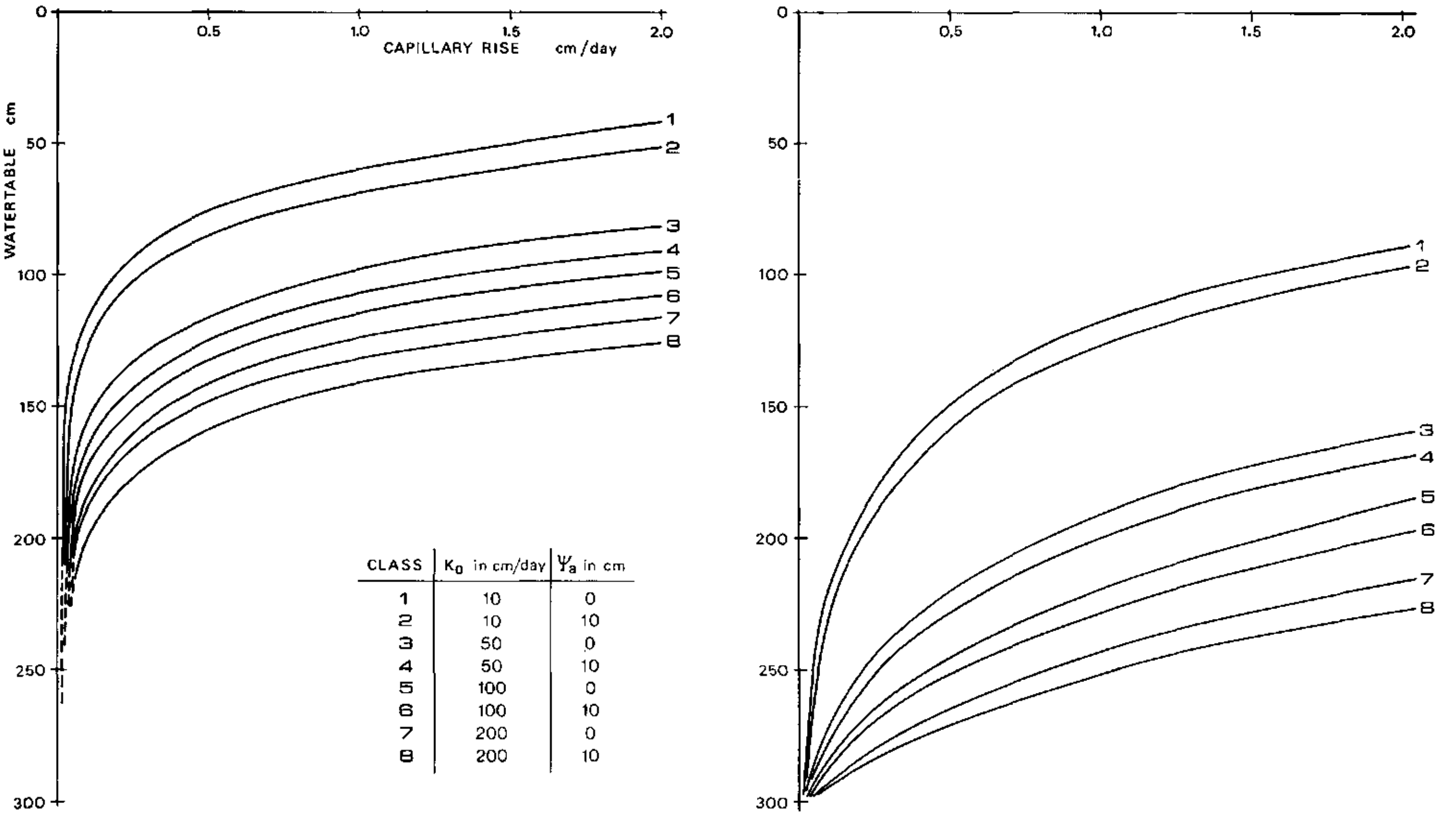
Upward capillary flow is determined by soil properties, watertable and moisture tension.

Rijtema (1965) considers two intervals in the moisture tension for the relation between flux (rate of flow) q and watertable z, separated by the value ψ_a, the moisture tension at which air just starts to enter the pores. They are

$\psi \leqslant \psi_a$ and
$\psi_a < \psi < \psi_{max}$

In the first interval there is no change in permeability, and as ψ_a is very low, this situation is found only when the saturated zone immediately above the watertable reaches the soil surface.

Fig. 29. Theoretical relation between watertable and capillary rise for conditions as present in the Great Konya Basin. Left: at assumed $\alpha = 0.04\ cm^{-1}$, right: at assumed $\alpha = 0.02\ cm^{-1}$.



CLASS	K_0 in cm/day	Ψ_a in cm
1	10	0
2	10	10
3	50	0
4	50	10
5	100	0
6	100	10
7	200	0
8	200	10

Şekil 29. Büyük Konya havzasında mevcut şartlarda taban suyu derinliği ile kılcal yükselme arasındaki teorik bağlantı. Solda $\alpha = 0.04\ cm^{-1}$, sağda $\alpha = 0.02\ cm^{-1}$ olarak hesaba alınmıştır.

For the Great Konya Basin, the other situation is common.[1]
Then the relation between q and z can be expressed in

$$z = \frac{1}{\alpha} \ln \frac{q + k_o}{q + k_o\, e^{-\alpha\,(\psi - \psi_a)}} + \frac{k_o\, \psi_a}{q + k_o}$$

where

z = depth of groundwater (cm)
q = capillary transport (cm/24h)
k_o = conductivity at saturation (cm/24h)
α = a constant factor (cm^{-1})
If $\psi_a = 0$,

$$z = \frac{1}{\alpha} \ln \frac{q + k_o}{q + k_o\, e^{-\alpha\psi}}$$

Rijtema quotes Visser in stating that k_o is only slightly lower than the hydraulic conductivity under saturated conditions. Also there was considerable variation of the saturated permeability over the different soils in the Basin (DSI *et al.*, 1965). So that values ranging from 10 to 200 cm per day can be introduced into the calculations.

The parameter α depends on the soil. Data given by Talsma (1963) and Rijtema (1965) indicate that, with the exception of two soils unimportant for crops in the Basin (coarse sand and peat), α ranges from 0.02 to 0.04 cm^{-1}. Both values have been used in the calculations.

The moisture tension at which air entry starts in the capillary (ψ_a) is determined by soil properties. However Rijtema gives only values of 0 and 10 cm for soils with considerable differences in texture, pore volume, and probably also in pore distribution.

The parameter ψ_{max} also varies with the soil. With the exception of 'knip clay', Chino clay and Pachappa loam, moisture tensions of 300 mbar could still be used for the calculations. Then the term $e^{-\alpha(\psi-\psi_a)}$ is very low; assumed that $\alpha = 0.04$, its value is 6.14×10^{-6}. Thus the relation at a moisture tension of 300 cm is almost identical with that calculated for an even higher tension. Indeed Talsma (1963) states that the relation between capillary rise and watertable is nearly the same at pressures of 1000 cm and 15 000 cm. This suggests that the value for $\psi = 300$ cm holds for the whole range important for plant growth, i.e. from pF 2.3 to 4.2.

The relations calculated with these parameters are presented in Figure 29. Obviously small variations in a deep watertable do not significantly alter capillary transport to the surface, whereas with shallow watertable, fluctuations in depth have a considerable effect on salinization.

1. In the central depression of the Basin, where groundwater is most saline, lateral supply keeps the watertable almost constant for most of the dry period. Hence for a considerable period evaporation of the capillary soil moisture does not cause an important change in the watertable.

The maximum height of capillary rise (H in cm) depends inversely on the radius r (in cm) of the capillaries. If the walls of the capillary are completely wetted, Rode (1962) gives the relation

$$H = \frac{15}{r}$$

For homogeneous soils, the diameter of the capillaries may be replaced by the average radius of the soil particles (d, in cm), so that

$$H = \frac{75}{d}$$

Rode has compared his observations with the values calculated by Atterberg (1908) for various textures (Table 19). The agreement is satisfactory.

The formula $H = 75 / d$ is not valid for heavy-textured soils. Even in clayey soils capillary rise seldom exceeds 5 to 6 m instead of the 37.5 m calculated for clay particles with a diameter of 2 μm. This is due to the merging of the films of sorbed water on opposite pore walls, making capillary rise impossible.

Combination of the given values with the computed relation between watertable and capillary rise suggests the danger of salt accumulation in the soil.

For the development of 'groundwater solonchaks', supply of (saline) groundwater to the soil profile is not the only factor determining nature and depth of salinization. During its vertical flow, water is lost by evaporation or uptake by plant roots, and conditions at the soil surface determine salinization as well. Rode (1959) supplies

Table 19. Observed and calculated maximum capillary rise in mm as related to particle size of homogeneous soils (Atterberg, 1908).

Particle size (mm)	Max. capillary rise (mm)	
	observed	calculated
5—2	25	21
2—1	65	50
1—0.5	131	100
0.5—0.2	246	210
0.2—0.1	428	500
0.1—0.05	1055	1000
0.05—0.02	2000	2100

Tablo 19. Homojen toprakların tane büyüklüğüne bağlı olarak rasatta ve hesapla bulunan en yüksek kılcal yükselme (mm olarak) (Atterberg, 1908).

some information on evaporation, obtained from the Russian team led by Morosov. However no detailed information could be given as the amounts depend on the uneven plant cover and on soil morphology. Losses of several millimetres per day are very well possible. The general rule is that external solonchaks are likely to develop if q exceeds L_T, the total loss of water during upward transport.

The depth in the profile at which q equals L_T is the depth at which internal solonchaks are formed, provided no salt precipitates at greater depths by the solubility product of one or more of the constituents being exceeded. Even if the capillary rise equals the total water loss in the soil, unlimited efflorescence at the soil surface is unlikely to occur, because of crust formation.

2.5 Mineralogical composition and morphology of some salt efflorescences

The extent of salt efflorescence at the surface of the soil is governed by the composition and other properties of the salts as well as by climatic and hydrological factors. Mineralogical research on this subject has to include chemical and X-ray analysis of crust samples and detailed study by electron-microscopy.

In almost all salt-affected soils of the Great Konya Basin, both sodium chloride and sodium sulphate occur. Magnesium compounds may be important as well.

In the west of the Basin, where sulphates predominate, an Na_2SO_4-H_2O system develops in puffed solonchaks and in parts of the flooded solonchaks. In the puffed solonchaks sodium sulphate continues to accumulate in the wet and cold winter relative to other salts; it is not completely leached during that period. In the Na_2SO_4-H_2O system mirabilite ($Na_2SO_4.10H_2O$) and Thenardite (Na_2SO_4) are the stable components, alongside the metastable $Na_2SO_4.7H_2O$ (Braitsch, 1962). In an NaCl-free system the mirabilite/Thenardite conversion point is situated at 32.383° C. If NaCl is present, as is generally so in the Basin, both solubility and conversion point of these minerals are lower; in an NaCl-saturated environment the conversion temperature is as low as 17.9° C (Fig. 30).

Where magnesium compounds have been introduced, an NaCl-Na_2SO_4-$MgCl_2$-H_2O system develops in which, besides mirabilite, Thenardite, halite and hydrohalite, the minerals Epsomite, hexahydrite, Leonhardtite, Kieserite, Bloedite, Loewite, Vanthoffite, D'Ansite, pentahydrite, Bischofite, Sanderite and a nameless magnesium sulphate with 1.25 molecules H_2O may occur.

Halite (NaCl) is the most common form of sodium chloride. If precipitated from natural solutions, it contains almost always less than 0.05% impurities in its crystal grid.

Hydrohalite ($NaCl.2H_2O$) is found locally in Siberian salt lakes. It probably forms in winter only.

Mirabilite ($Na_2SO_4.10H_2O$) is formed from sulphate-rich solutions in salt lakes, particularly in winter. It does not occur in typically oceanic salt deposits.

Thenardite (Na_2SO_4) represents the modification of sodium sulphate with warmth. It occurs only rarely in marine salt deposits.

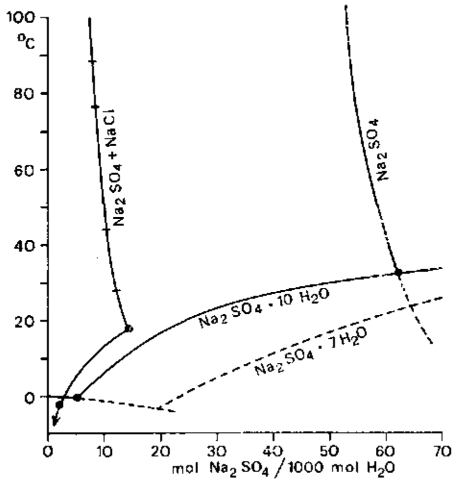


Fig. 30. Phase diagram of minerals formed in an Na_2SO_4-H_2O system, with and without NaCl saturation. Dotted line indicates metastable $Na_2SO_4.7H_2O$ (derived from Braitsch, 1962).

Şekil 30. NaCl doygunlu ile doygunluk olmadan (her iki şekilde). Na_2SO_4-H_2O sisteminde oluşan minerallerin faz eğrisi. Noktalı çizgiler Braitsch'e göre $Na_2SO_4.7H_2O$ (metastable) işaret etmektedir.

Epsomite ($MgSO_4.7H_2O$), common in salt deposits, is secondarily formed from Kieserite. The loss of one molecule of water of crystallization causes the formation of hexahydrite ($MgSO_4.6H_2O$).

Leonhardtite ($MgSO_4.4H_2O$) is a metastable primary precipitate indicating recent efflorescence.

Kieserite ($MgSO_4.H_2O$) is the most important magnesium sulphate in the soils of arid and semi-arid regions. It is, however, seldom present as crystals.

Bloedite ($Na_2Mg(SO_4)_2.4H_2O$) is present only as secondary salt, but it may be formed primarily from sea-water. It also occurs in a fairly pure state in salt lakes under natural conditions. (Eady, 1966)

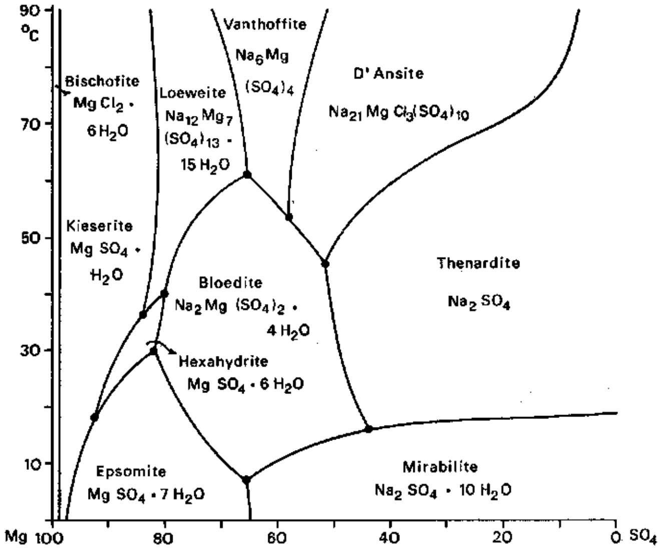
The other minerals mentioned above need no further comment here. They are of no importance in the Basin or act only during synthesis (e.g. pentahydrite). No attention has been paid to potassium compounds either; they are a minor constituent relative to sodium and magnesium compounds.

Figure 31 presents a phase diagram of the minerals in an NaCl-saturated solution. It demonstrates that the minerals most likely to occur in the Basin are Epsomite, hexahydrite, Bloedite, Thenardite and mirabilite. In the west of the Basin, where sulphates predominate, Thenardite, mirabilite and Bloedite are present as would be expected. Where magnesium compounds are important as well, Epsomite and hexahydrite may also occur. Furthermore the diagram shows that with decreasing temperature (in winter) Bloedite separates into its two components, sodium sulphate and magnesium sulphate. In the east of the Basin, halite predominates.

This general information will be sufficient to study the efflorescences observed in the Basin, and the effects of these efflorescences on salinization.

As said, efflorescence at the surface substantially diminishes accumulation in the surface soil. Essentially this can be traced back to a reduction of the evaporation from

Fig. 31. Phase diagram of minerals in an NaCl-saturated NaCl-Na_2SO_4-$MgCl_2$-H_2O system (derived from Braitsch, 1962).



Şekil 31. NaCl ile doymuş NaCl-Na_2SO_4-$MgCl_2$-H_2O sisteminde minerallerin faz eğrileri, Braitsch (1962) ye göre.

the surface. To what degree this happens depends partly on the chemical and mineralogical composition of the salt crust, partly on its morphology.

Three methods were used to study the effect of efflorescence in the Basin.

First chemical analyses were made of crust samples dissolved in ample water. Next, the resulting data were combined with those of X-ray analysis of the salts, which supplied an estimate of the quantitative mineralogical composition of the salts. Though these methods were not sufficiently refined to trace small quantities of a certain mineral, they were adequate for the purpose. Thereupon the morphology of the minerals was studied under a scanning electron microscope. As electric charging of the salt crystals, when exposed to the beam of electrons scanning their surface, seemed impractical, the usual treatment of the samples with carbon and gold under vacuum was followed by the application of an antistatic fluid.

The X-ray analyses of the Hotamış samples proved the presence of very pure Thenardite. A chemical analysis resulted in sodium sulphate (Thenardite) as well as some carbonates and bicarbonates. In samples from near Dedemoğlu, the Thenardite was accompanied by a little gypsum, halite, a few magnesium compounds and phosphates.

These efflorescences form porous continuous crusts of needle-shaped crystals or fragments. They alter the microclimate immediately above the soil surface by reducing evaporation. Within these crusts, two zones can be distinguished: a zone about 1 cm

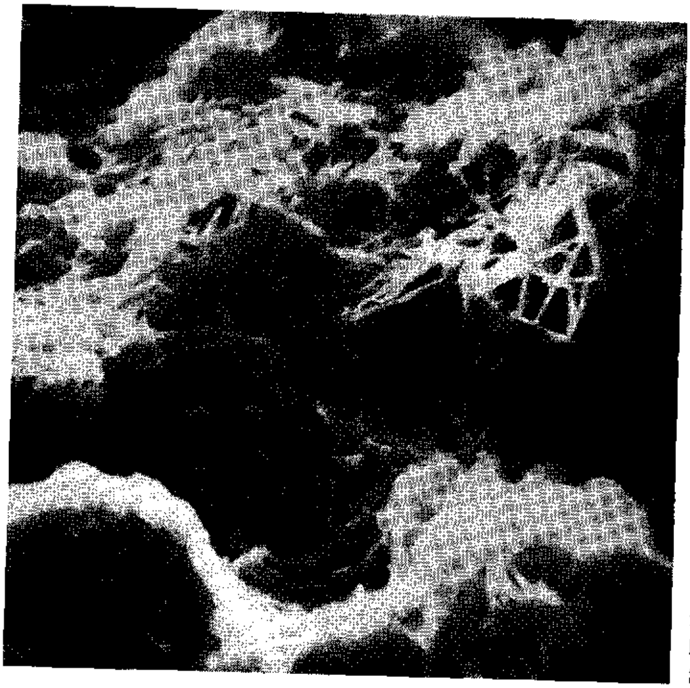


Fig. 32. White Thenardite efflorescence near Lake Hotamış (x3000) at Site 42 (Fig. 49).

Şekil 32. Hotamış yakınlarında beyaz Tenardit tezahürleri (x3000) (Yer 42, Şekil 49).

Fig. 33. Brown Thenardite efflorescence near Lake Hotamış (x2500) at Site 42 (Fig. 49). The dark colour is caused by the presence of mobile humus in the crust. Note coarser crystals than in previous figure, where humus was absent.

Şekil 33. Hotamış yakınlarında 42 numaralı yerde (Şekil 49) kahverengi Tenardit tezahürleri (x2500). Koyu renk hareketli humusun kabukta mevcudiyetinden dolayı meydana gelmiştir. Humusun mevcut olmadığı daha önceki şekille karşılastırarak daha büyük kristallere dikkat ediniz.

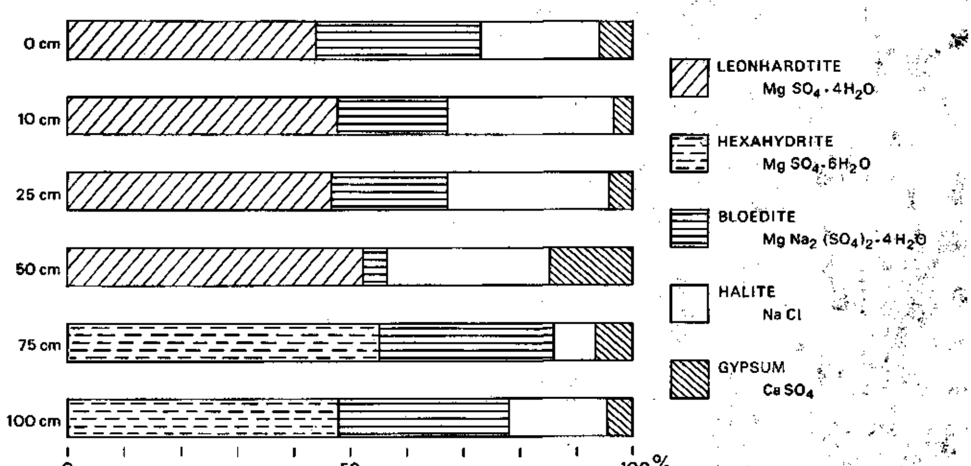
thick consisting of intact and distinctly needle-shaped mirabilite crystals, covered by a zone of varying thickness in which Thenardite predominates.

Mirabilite crystals could not be transported from Turkey to the Netherlands for further investigation. Even when completely submerged in xylol or toluol, they lose water and therewith change their crystal structure. Only immediately after their removal from the surface soil could they be photographed. As Thenardite crystals do not contain any water of crystallization they travelled considerably better.

In areas where the cation is almost exclusively Na^+, ESP is very high, and clay and humus are likely to turn mobile. Locally the clay and the humus discolour the salt crust brown. Figures 32 and 33 demonstrate the micromorphology of such crusts, as revealed by the electron-microscope. The photographs show that the brown crusts containing organic matter have the same structure as the white crusts, apart from the coarser appearance of the first.

In part of the Basin magnesium ions are important as well, introducing Epsomite, hexahydrite, Leonhardtite and Bloedite into the salt crusts. The relation between the moisture content of the soil and the mineralogical composition of the magnesium sulphates was studied in efflorescences from a fresh pit wall, where the watertable was at 1.40 m, about 3 km north-east of Konya. Figure 34 shows an abrupt change of hexahydrite into Leonhardtite between 50 and 75 cm. Probably the hexahydrite is formed by loss of water from Epsomite. Further loss of water yields Leonhardtite,

Fig. 34. Composition of efflorescences sampled in the vertical wall of a profile near Konya (Site 43, Fig. 49). Note change of hexahydrite into Leonhardtite between 50 and 75 cm, accompanied by a sudden decrease in the soil's moisture content.



Şekil 34. Konya yakınlarında düşey toprak profilinden toplanan tuz tezahürlerinin bileşimleri (Yer 43, Şekil 49). 50-75 cm'ler arasında toprağın rutubet miktarının aniden değişmesine bağlı olarak Hexahydrit'ın Leohardtit'e dönüşmesine dikkat ediniz.

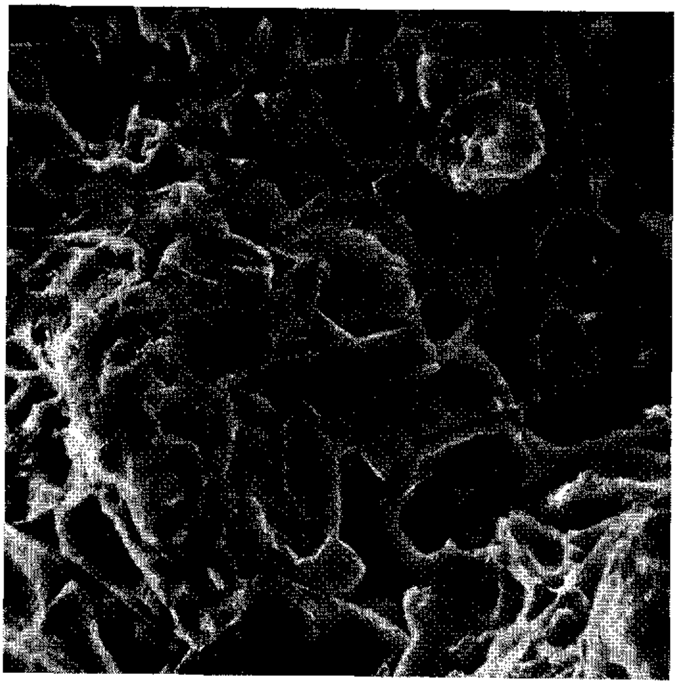


Fig. 35. Surface crust in flooded solonchak near Kaşınhan (Site 3, Fig. 49). Note crust structure caused by Bloedite crystals partly overlapping each other (x770).

Şekil 35. Kaşınhanı yakınlarında istila solonçak'ları (Yer 3, Şekil 49). Bloedit kristallerinin kısmen birbin üzerini örtmesiyle meydana gelen kabuk strüktüre dikkat ediniz (x770).

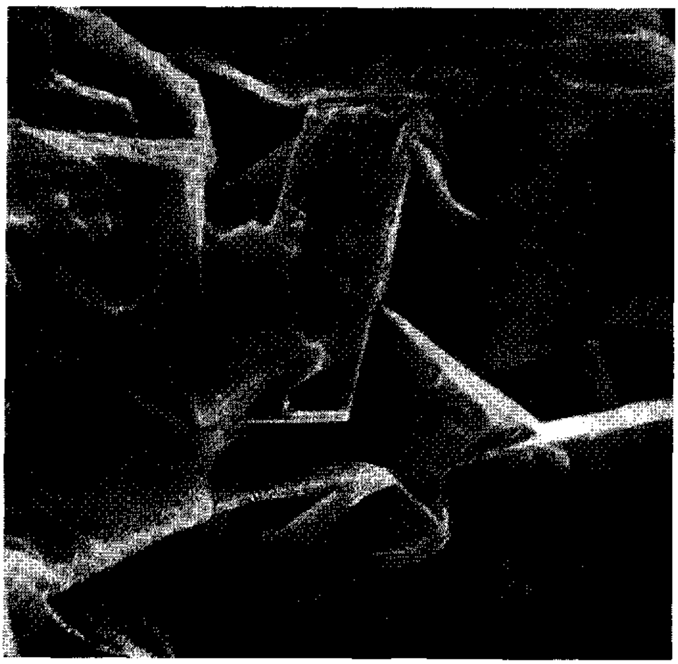


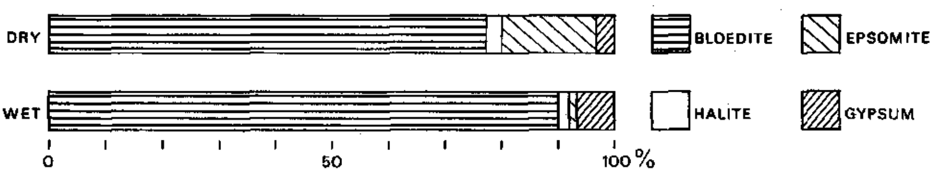
Fig. 36. Detail of Fig. 35 (x3000).

Şekil 36. Şekil 35'in daha detaylı görünüşü (x3000).

which is metastable and would probably change into another form of magnesium sulphate after continued drying.

In this profile Bloedite is also present. It is important for the formation of surface crusts, almost completely sealing the underlying soil; it is abundant at several places in the west of the Basin, occurring in spots surrounded by hard cracked dried soil. In these cases the crust is glass-like and consists for over 90% Bloedite. The high reduction in evaporation is also shown by microscopic study of the crust: the angular platy Bloedite crystals are imbricate (Fig. 35, 36 and 37) and holes in the crust close up by crystal growth from the edges (Fig. 38). When there is less Bloedite, Epsomite, hexahydrite, halite and gypsum interfere with the build-up of the crust. Then transitional forms occur, resulting in a loose and porous structure in which the platiness of the Bloedite crust is still easily recognizable.

Fig. 37. Mineralogical composition of glass-like salt seals near the Village of Kaşınhan (Site 3, Fig. 49).



Şekil 37. Kaşınhanı köyü yakınlarındaki cam gibi tuz öbeklerinin mineralojik bileşimi (Yer 3, Şekil 49).

Fig. 38. Hole in a Bloedite surface crust, closing up by crystal growth from the edges towards the centre of the pore (x720).

Şekil 38. Bloedit'ten oluşmuş bir yüzey kabuğundaki por'da kenardan merkeze doğru gelişen kristaller.

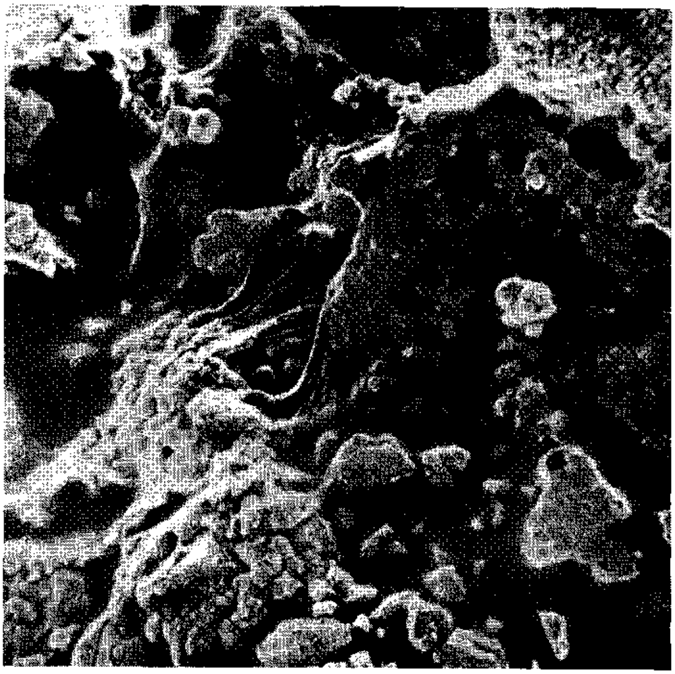


Fig. 39. Halite sealing the soil particles from the air (x115; Site 44, Fig. 49).

Şekil 39. Halit tarafindan toprak parçaları arasındaki hava boşluklarının doldurulması (x115; Yer 44, Şekil 49).

In the east of the Basin, chlorides are important. Locally they form a surface crust strongly resembling the Bloedite crusts but microscopically the soil particles are covered with angular halite crystals.

An almost complete sealing of the surface soil by halite has been observed in the playa north of Karapınar. Here the crust consists of almost pure NaCl (91.6%) surrounding the soil particles as a thin but continuous film (Fig. 39). The same phenomenon, though less pronounced, is found almost everywhere in the eastern central parts of the Basin.

The effect of these salt crusts is obvious: the soil becomes anaerobic with very low hydraulic permeability, hard to leach and difficult to reclaim.

The cause of their patchy distribution is less obvious. Vegetation cannot be the only influence, as barren parts of the playas are equally patchy. Very small variations in microrelief may be responsible, because contact with groundwater is maintained over a longer period in depressions and because the water covering the whole area in winter collects into the depressions while it is drying up, and the dissolved salts form an initial salt crust protecting the surface from drying out immediately. Such depressions are very shallow and hardly detectable without detailed measurements. In any case the field studies have revealed, beyond doubt, that differences within the soil profile that might be responsible for the patchiness of efflorescence are absent.

3 Soil alkalinity

3.1 ESP and SAR: general information

The percentage occupation of the soil's adsorption complex by Na^+, expressed as the Exchangeable Sodium Percentage (ESP), is widely used to characterize alkali and saline-alkali soils. In the American classifications, 'alkali' soils are soils with ESP exceeding 15. Russian soil scientists (Janitzky, 1957; Ivanova, 1963; Kovda, 1961, 1964) also consider the depth of an illuvial horizon or a salic horizon, the water regime and the stage of profile development important.

The amount of Na^+ adsorbed on the soil complex is a function of the chemical composition of the soil solution in equilibrium with the soil. Especially important are the amounts of monovalent and divalent ions (in meq per litre saturated extract), expressed as the Sodium Adsorption Ratio (SAR):

$$SAR = \frac{Na^+}{[(Ca^{2+} + Mg^{2+})/2]^{0.5}}$$

The US Salinity Laboratories (1954) give the following relation between SAR and ESP, based on analysis of American soils:

$$ESP = \frac{100\ (-0.0126 + 0.01475\ SAR)}{1 + (-0.0126 + 0.01475\ SAR)}$$

This formula is considered universally applicable, and it is in use all over the world. It agrees closely with the theoretical relation given by Bolt (1967):

$$\frac{ESP}{100 - ESP} = \frac{K}{1000}\,SAR$$

For illite K = 0.5 (meq per litre)$^{-0.5}$
For smectite and kaolinite, values of 1.5 (meq per litre)$^{-0.5}$ and 0.75 (meq per litre)$^{-0.5}$, respectively, are given.

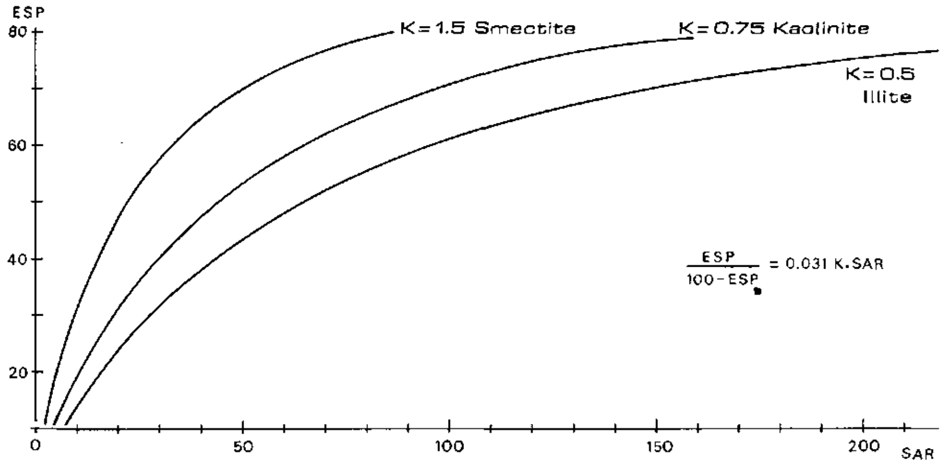
Analysis of Turkish soil samples has shown deviations of the relation if SAR exceeds 8, probably caused by errors in ESP analysis of soils rich in calcium and magnesium.

Estimates of ESP are unreliable, chiefly because:

exchangeable Na = extractable Na — soluble Na

So that if the amounts of extractable Na and soluble Na are high, the resulting value

Fig. 40. Theoretical relation between SAR and ESP for smectite, kaolinite and illite.



Şekil 40. Smektit, Kaolinit ve İllit için SAR ve ESP değerleri arasındaki teorik bağlantı.

for exchangeable Na is uncertain (Allison, 1964). Procedures are described in Richards (1954).

Moreover this method requires an estimate of the cation exchange capacity (CEC) of the soil, which depends on saturation of the exchange complex with Na^+. Especially for soils rich in Ca^{2+} (gypsum), this is difficult because incomplete saturation results in too high an ESP. Anyway estimation of ESP is very laborious and timeconsuming.

For all these practical reasons, it is more attractive to express alkalinity in SAR instead of ESP. Figure 40 gives the relation between ESP and SAR for different types of clay. For a reliable estimate of ESP, the composition of the clay fraction in the soil has to be known.

For alkali soils to develop, the chemical composition of the groundwater and of irrigation water is very important. Here SAR of the water is used to denote its sodium (alkali) hazard:

SAR $<$ 10	low alkali hazard
SAR 10-18	medium alkali hazard
SAR 18-26	high alkali hazard
SAR $>$ 26	very high alkali hazard

For classification of irrigation waters, SAR is combined with electrical conductivity (μmho/cm).

In the field, alkali soils are recognizable by their dispersed organic matter and by the presence of a 'Natric subsurface horizon' (7th Approximation, 1960) which has in addition to clay illuviation a prismatic, columnar or rarely blocky structure with tongues of a covering eluvial horizon extending into it, and an ESP of over 15%. If there is little clay and organic matter, recognition is possible only by laboratory analysis. According to some authors, a high percentage of exchangeable Mg exerts the same effect as a high sodium percentage. Van Es & van Schuylenborgh (1967) have found that in some soils of West Irian weathering releases large quantities of magnesium, which are adsorbed on the soil particles and saturate the exchange complex with Mg^{2+}, resulting in solonetz-like soils.

A high ESP is harmful to crops in three ways: it is toxic for some species; it interferes with the structure of the soil in impeding with the rooting of the plant; it hampers the plant's ion uptake.

In saline-alkali soils the harmful effects of salinity have to be added to those mentioned above.

Usually these soils carry a poor grass vegetation and are only suited to extensive cattle-ranging.

3.2 Regional distribution of alkali-affected soils

3.2.1 Introduction

In the Great Konya Basin, soils with a high alkali content but no salinity are almost absent. Hence severely alkali-affected soils are also found in the low centre of the Basin and it is difficult to trace them in the field. Consequently the survey of alkalinity involves extensive chemical analysis of many soil samples. Fortunately the same samples may be used as for salinity studies; included are soil samples from some 200 profiles and about 500 water samples, all collected during the survey of the Basin in August and September 1967. Alkalinity of the various land types and soil associations mentioned in Section 1.5 will be reviewed briefly.

3.2.2 Alkalinity in the soil associations

The *Upland soils* (U) are not affected, except for some deep profiles on or near the volcanic cones south and east of Karapınar. There the salts, mainly consisting of sodium compounds, are leached towards the subsoil where ESP may be high more than 2 m below the surface (Table 20). The coarseness and porousness of these soils prevents them from collapsing; no visible alkaline properties are found there.

The *Colluvial Slope soils* (C) are not alkali-affected either, except for fans of volcanic material in which SAR may reach very high values at depths of 60 cm or more (Table 21). Here, too, the structure is hardly affected by the high sodium adsorption because of the coarse texture of the soil.

Of the *Terrace soils* (T) the low *Soft Lime Soils* (Tc) are strongly affected, contrary to the high *Flat Terrace Soils* (Te) which are not affected at all. On the terraces ESP is difficult to estimate because of the high gypsum content, which interferes with proper measuring of CEC (Table 22).

Table 20. SAR of Volcanic Upland Soils (Uv).

Depth in cm	Inner slope of crater (Site 11)	Crater centre (Site 11)	Crater edge (Site 11)	Pumice and ash (Site 45)
0— 10		3.5	5.1	1.4
30— 40	0.6	1.7	0.5	
70— 80	0.3	2.4	0.3	
110—120	0.8	15.0	0.5	
190—200				19.2

Tablo 20. Volkanik yüksek arazi topraklarının (Uv) SAR-değerleri.

Table 21. SAR of two Volcanic Colluvial Slope Soils (Cv).

Depth in cm	Volcanic fan (Site 13)	Dinek (Site 14)
0— 10	0.37	0.2
30— 40	0.85	1.1
70— 80	24.4	2.1
110—120	34.6	5.0
150—160	23.6	9.5
190—200	26.2	5.5

Tablo 21. İki volkanik kolluviyal toprağın (Cv) SAR-değerleri.

Table 22. SAR of Low (Tc, lime) and High (Te) Terrace Soils

Depth in cm	Soft Lime Soil (Site 15)	High Flat Terrace Soil (Site 17)
0— 10	36.1	0.56
30— 40	8.3	1.5
70— 80	5.6	5.9
110—120	2.1	10.4
150—160	0.85	10.0

Tablo 22. Alçak (Tc) ve yüksek (Te) teras toprağında SAR-değerleri.

None of the *Bajada soils* (B) are alkali-affected, because of the deep watertable and good drainage. But below 1 m some indications have been found of moderate alkalinity especially in Bajadas containing volcanic material (Table 23).

The alkalinity of the *Alluvial Plain soils* (A) differs for each of the fans, as it depends closely on the chemical composition of the river water.

The *Çamurluk Fan Soils* (Aa) are not alkali-affected at all (Table 24), because of the fair quality of the water originating from the limestone formations covering the river's catchment area.

The *Former Backswamps Soils* (Ab) are like river basins. They are low-lying and frequently wet, so that natural drainage is poor and, especially deeper in the profile, they may be severely salt-affected. Laboratory analysis has shown that much of the adsorption complex may be occupied by sodium, as apparent from the high SAR.

As Table 25 shows, not all Former Backswamp Soils are alkali-affected. The highest Vertisols are close to the true river fans and they are not or only slightly affected.

Table 23. SAR of Bajada soils (B).

Depth in cm	Site 18	Site 19	Site 20
0— 10	0.21	0.38	0.39
30— 40	0.30	0.47	0.59
70— 80	0.28	0.98	1.03
110—120		5.21	6.52

Tablo 23. Üç bajada toprağının (B) SAR-değerleri.

Table 24. SAR of a Çamurluk Fan Soil (Aa).

Depth in cm	Site 21
0— 10	0.40
30— 40	0.48
70— 80	2.10
110—120	0.37

Tablo 24. Çamurluk çayı yelpazesini temsil eden bir toprağın (Aa) SAR-değerleri.

Table 25. SAR of Former Backswamp Soils (Ab).

Depth in cm	Site 48	Site 47	Site 46
0— 10	9.3	0.58	1.48
30— 40	21.4	0.75	
70— 80	36.9	2.3	1.04
110—120	34.7	4.2	0.82
150—160	32.5		

Tablo 26. Üç eski bataklık ardı toprağında (Ab) SAR-değerleri.

Table 26. SAR of well drained and watei-logged Çarşamba Fan Soils (Ac).

Depth in cm	Well drained (Site 49)	Waterlogged (Site 50)
0— 10	0.72	4.3
30— 40	0.94	6.9
70— 80	2.2	7.5
110—120	1.2	6.5

Tablo 26. Bir iyi drenajlı ve bir suyla doymuş Çarşamba çayı yelpazesi toprağında (Ac) SAR-değerleri.

In general the Backswamps of the River May are not alkali-affected at all.

The *Çarşamba Fan Soils* (Ac) are locally affected, but near the river bed and on other well drained sites only a low SAR has been measured (Table 26). Very high SAR is not common because of the higher elevation of the fan and the good quality of the Çarşamba irrigation water.

EC of the Çarşamba water near Çumra has been checked weekly during the five months May to October 1967. It was almost constant, on average 0.41 mmho/cm, probably by the buffering action of Lake Beyşehir, 160 km upstream from Çumra. It seems therefore reasonable to assume that the composition of the salts (and hence the SAR of the water) should be constant too, at least in summer.

The *Deli Fan Soils* (Ad) are probably not alkali-affected but no profile analysis is available.

The *Selereki Fan Soils* (Ae) are not affected either, because of their excellent natural drainage and the good quality of the water of the River Selereki (Table 27).

The *Çakmak Fan Soils* (Af) are probably not alkali-affected. Though no SAR data are available for the soil, that of a groundwater sample (at about 20 m) had a value of 5.4.

The *Zanopa Fan Soils* (Ag) are alkali-affected only near the base of the fan, whereas the higher parts are alkali-free. High SAR values occur in the upper part of the profile, where salinity is also most pronounced (Table 28).

The Zanopa Fan is fed with water from a number of springs near the Village of İvris, some 10 km east of Ereğli. According to analyses provided by DSI (1964), this water is of good quality.

The *Bor Fan Soils* (Ah) are locally strongly affected but no analytical data are available.

The *Meram and Sille Fan Soils* (Ak) are not alkali-affected, except for a strip along the bases of the fans, where high SAR has been measured in both the groundwater and the soil (Table 29). As the quality of the water of both rivers is good, it is assumed that their water takes up salts from the soil strata during percolation.

Table 27. SAR of Selereki Fan Soil (Ae).

Depth in cm	Site 22
0— 10	0.52
30— 40	0.70
70— 80	0.58
110—120	0.51

Tablo 27. Selereki çayı yelpazesinin bir toprağında (Ae) SAR değerleri.

Table 28. SAR of Zanopa Fan Soils (Ag).

Depth in cm	Midway (Site 23)	Base (Site 51)
0— 10	0.55	15.5
30— 40	0.17	19.1
70— 80	0.32	9.3
110—120	0.69	2.4
150—160	1.50	0.76

Tablo 28. Zanopa çayı yelpazesinin iki toprağında (Ag) SAR-değerleri.

The *May Fan Soils* (Am) are affected here and there near the base of the fan, though never severely and only on places with a high watertable. The chemical composition of the River May water is of no consequence because of the low annual flow (only in winter) and because the adjacent lands are irrigated with water from the River Çarşamba (Table 30).

For the *Bayat Fan Soil* (An), no data are available. Probably they are hardly affected, if at all.

The *Ayrancı Fan Soils* (As) have good internal drainage and are fed with water of excellent quality, so that no alkalinity of the soil occurs. SAR above 0.40 has never been measured.

For *Soils of Medium-Sized Fans* (Au), no analytical data are available. Their high elevation and their relatively coarse material would ensure rapid internal drainage, prevent Na-containing salts from accumulating and keep SAR low.

All rivers originating from a catchment area with limestone formations are rich in bicarbonates of calcium and magnesium. Even after exposure of their water to the air and precipitation of the carbonates, the quality of the water remains fair.

The *Marl Soils* (Lm) are locally strongly alkali-affected. In particular in the playa north of Karapınar and near Ak Göl, where salt accumulation at the surface is com-

Table 29. SAR of alkali-affected Meram Fan Soil (Ak).

Depth in cm	(Site 52) Base of fan
0—10	55.2
20—30	31.8
50—60	39.2
80 (groundwater)	58.8

Tablo 29. Alkalilik etkisindeki bir Meram çayı yelpazesinde (Ak) SAR-değerleri.

Table 30. SAR of May Fan Soils (Am).

Depth in cm	(Site 12) Apex	(Site 26) Base
0— 10	0.40	0.86
30— 40	0.67	1.50
70— 80	0.82	4.3
110—120	1.54	5.1

Tablo 30. May çayı yelpazesinin iki toprağında (Am) SAR-değerleri.

Table 31. SAR of Marl Soils (Lm).

Depth in cm	Demirkent (Site 53)	Ortakonak (Site 54)	Site 27	Ak Göl (Site 28)
0— 10	5.2	1.86	20.0	510.9
30— 40	23.5	15.3	37.4	51.7
70— 80	25.8	20.5	107.3	53.3
110—120	30.4	21.8	120.7	44.2

Tablo 31. Dört marn toprağında (Lm) SAR-değerleri.

mon, SAR is high in the upper metre of the profile. In drier parts SAR is high deeper in the profile; examples have been found near Ortakonak and Demirkent (Table 31).

The *Sandridge Soils* (Lr) are not alkali-affected, even in the irrigated parts, because of their good drainage and coarse texture (Table 32).

The *Sandplain and Beach Soils* (Lp) are locally slightly alkali-affected, in particular where the underlying material consists of calcareous marl or soft lime of low permeability. But even then, alkalinity is not very pronounced and occurs only at great depths (Table 33).

The *Old Sandplain Soils* (Lo) are not alkali-affected, except here and there deeper than 2 m (Table 34). But this alkalinity does not influence plant growth.

The *Marsh Soils* (Mf) are here and there considerably alkali-affected, in particular near Konya (Aslım Swamps) and north of Ereğli, where salinity causes high SAR. In these wet soils, the highest salt content, and hence the highest SAR, is found in the surface soil; efflorescence has been observed here and there (Table 35). In the profile itself, the morphological characteristics of a solonetz are not very pronounced. Eluviation of organic matter and accumulation at a depth between 40 and 100 cm is common.

The *Sand Dunes* (Dd) of the Aeolian Plain are not alkali-affected at all, though in the deep subsurface soil (> 2 m) alkalinity might be found. But this does not affect plant growth in any way. Analytical data are not available.

Table 32. SAR of Sandridge Soils (Lr).

Depth in cm	Site 30	Site 29
0— 10	0.20	0.45
30— 40	0.13	0.58
70— 80	0.13	0.73
110—120	0.15	0.91

Tablo 32. İki kumbendi toprağında (Lr) SAR-değerleri.

Table 33. SAR of Sandplain Soils (Lp).

Depth in cm	Site 31	Site 32
0— 10	0.32	0.33
30— 40	0.30	1.86
70— 80	0.48	3.55
110—120	2.09	3.01

Table 33. İki kumlu ova toprağında (Lp) SAR-değerleri.

Table 34. SAR of Old Sandplain Soils (Lo).

Depth in cm	Site 33	Site 34
0— 10	1.09	0.33
30— 40	0.50	0.28
70— 80	0.48	0.35
110—120		0.74

Tablo 34. İki eski kumlu ova toprağında (Lo) SAR-değerleri.

Table 35. SAR of Marsh Soils (Mf).

Depth in cm	Aslım (Site 36)	Hortu (Site 35)
0— 10	36.7	13.6
30— 40	24.2	8.96
70— 80	18.9	8.93
110—120	22.3	6.81

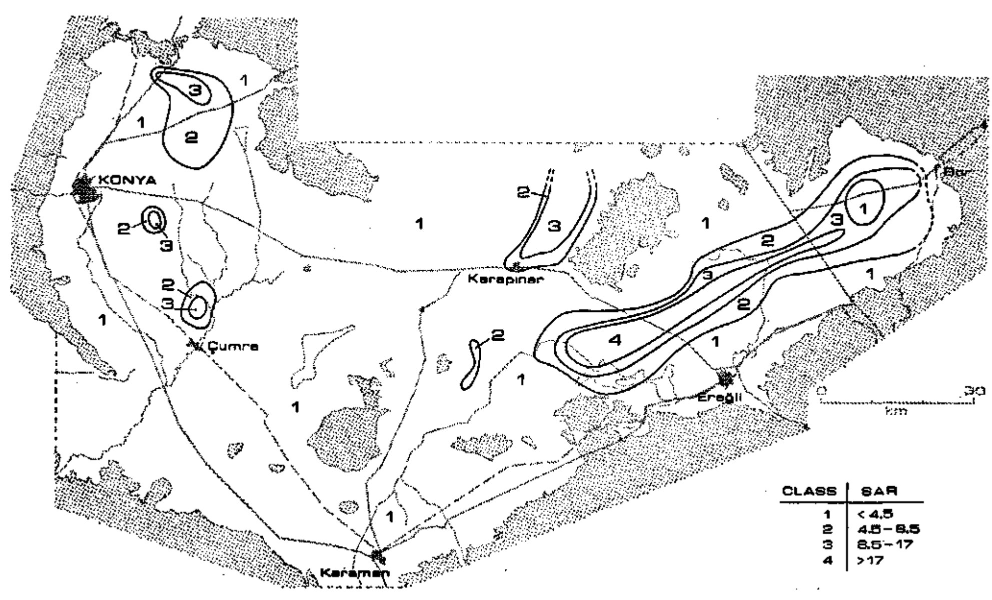
Tablo 35. İki bataklık toprağında (Mf) SAR-değerleri.

3.2.3 Distribution of soil alkalinity

The discussion of the distribution of alkalinity in the various soils in the Basin should have indicated a relation between salinity and alkalinity. Soil salinity is mainly determined by the depth and the composition of the groundwater. An insight into the sodium content of this groundwater is indispensable for a good understanding of alkalization. Therefore the SAR of water samples, collected from all over the Basin, have been estimated and mapped. The map (Fig. 41) shows that the excellent water of the rivers entering in the Basin causes low SAR values along its fringes and in the west of the Basin where Çarşamba water is mainly used for irrigation. Here and there are a few spots with higher SAR, chiefly in depressions. North and east of Karapınar SAR is very high because of evaporation of groundwater and precipitation of calcium as carbonate or sulphate.

To express the danger of alkalization, the terms 'low-sodium water', 'medium-sodium water' and 'high-sodium water' have been introduced: the first for classes 1 and 2 of Table 36 together, the other terms for classes 3 and 4, respectively. Table 36 gives the percentages of the Basin with groundwater for each of these SAR classes. For the higher salt contents, common in the Basin, the SAR limits in this table have to be decreased (Richards, 1954; Wilcox, 1955).

Fig. 41. Sketch map of SAR classes of groundwater in the Great Konya Basin in September 1967.



Şekil 41. Eylül 1967 de Büyük Konya Havzası'nda taban sularının SAR değerlerinin kaba-taslak haritası.

Table 36. Percentages of the Great Konya Basin with groundwater of each of the SAR classes.

Class	SAR	Percentage of the Basin
1	0 —4.5	86.2
2	4.5— 8.5	7.4
3	8.5—17	4.3
4	>17	2.3

Tablo 36. Büyük Konya Havzası'nda taban sularının her bir SAR sınıfı içindeki yüzdeleri.

This classification is in general use for irrigation water, though it does not consider how the water is applied, the infiltration rate of the soil, the evapotranspiration rate, the net downward drainage rate below the root zone, and the salt tolerances of the crops. Hence Bernstein (1967) has proposed new formulae for quantitatively assessing irrigation water quality. But as insufficient data are available, his method could not be used in the Great Konya Basin.

In many parts of the Basin irrigation is by pumping up groundwater, for instance on the sandridges near Çumra and on the Marl soils south-east of Karapınar. This method is economically justified only when special crops are grown as in horticulture.

The quality of the irrigation water has been studied in the data used also for study of salinity and alkalinity as illustrated by Figure 42. Table 37 gives the percentages of the Basin with groundwater belonging to each of the classes.

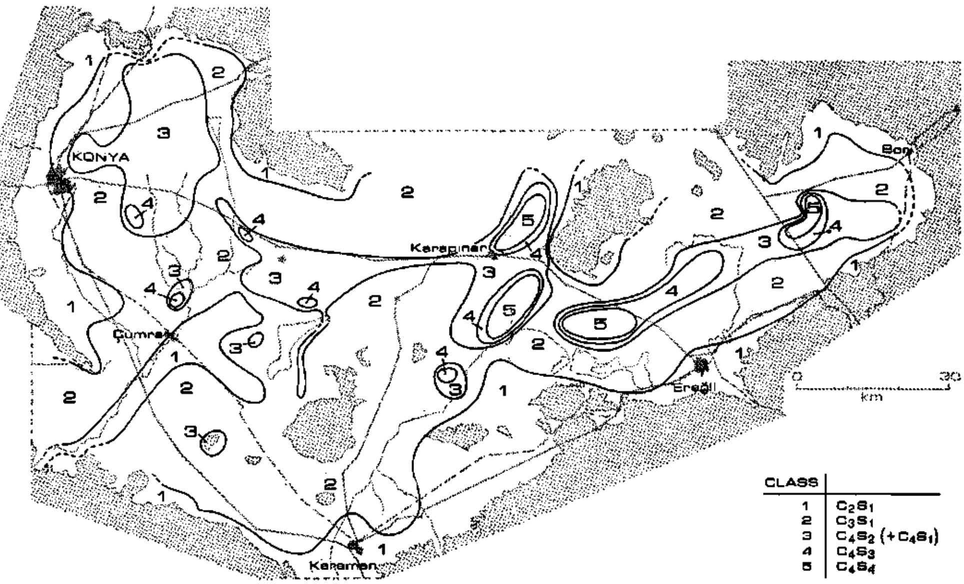
In Map Units 2 and 3 (Fig. 42) the quality of the water seems to be mainly determined by its high salt concentration; danger of alkalization is slight. North and south-east of Karapınar and in the far east of the Basin south of the Village of Zengen, high salt contents and high SAR values go hand in hand (classes 4 and 5).

The quality of the groundwater is greatly influenced by the many volcanoes south and east of Karapınar and, in particular in the centre of the Basin, by the evaporation of shallow groundwater. Near Mekke Dağ, a volcano south of Karapınar, EC exceeds 50 mmho/cm and SAR is very high. In the crater lakes the situation is even worse.

In the western part of the Basin the groundwater deteriorates with local concentrations of salt, in particular east of Konya. However, if watertables are very deep in the dry season, irrigation by pumping is unattractive anyway. Places with shallow, fair quality groundwater that are not yet irrigated will be hard to find.

As with salinity, the study of alkalinity has yielded a sketch map (Fig. 43) for alkalinity. It is based on the SAR of 350 profiles, and allows for hydrological, pedological and geomorphological characteristics of the area. SAR values over 17, roughly

Fig. 42. Classification of the groundwater in the Great Konya Basin for irrigation purposes (sketch map) (for terminology see Richards(1954)).



Şekil 42. Büyük Konya Havzasında tarımsal maksatlar için taban suyunun sınıflandırılması (taslak harita).

Table 37. Percentage distribution of groundwaters of different suitability classes for irrigation in the Great Konya Basin.

Suitability class	Sodium content	Salinity danger	Percentage of the Basin
1	low	medium	30.0
2	low	high	56.8
3	low and medium	very high	9.0
4	high	very high	2.3
5	very high	very high	1.9

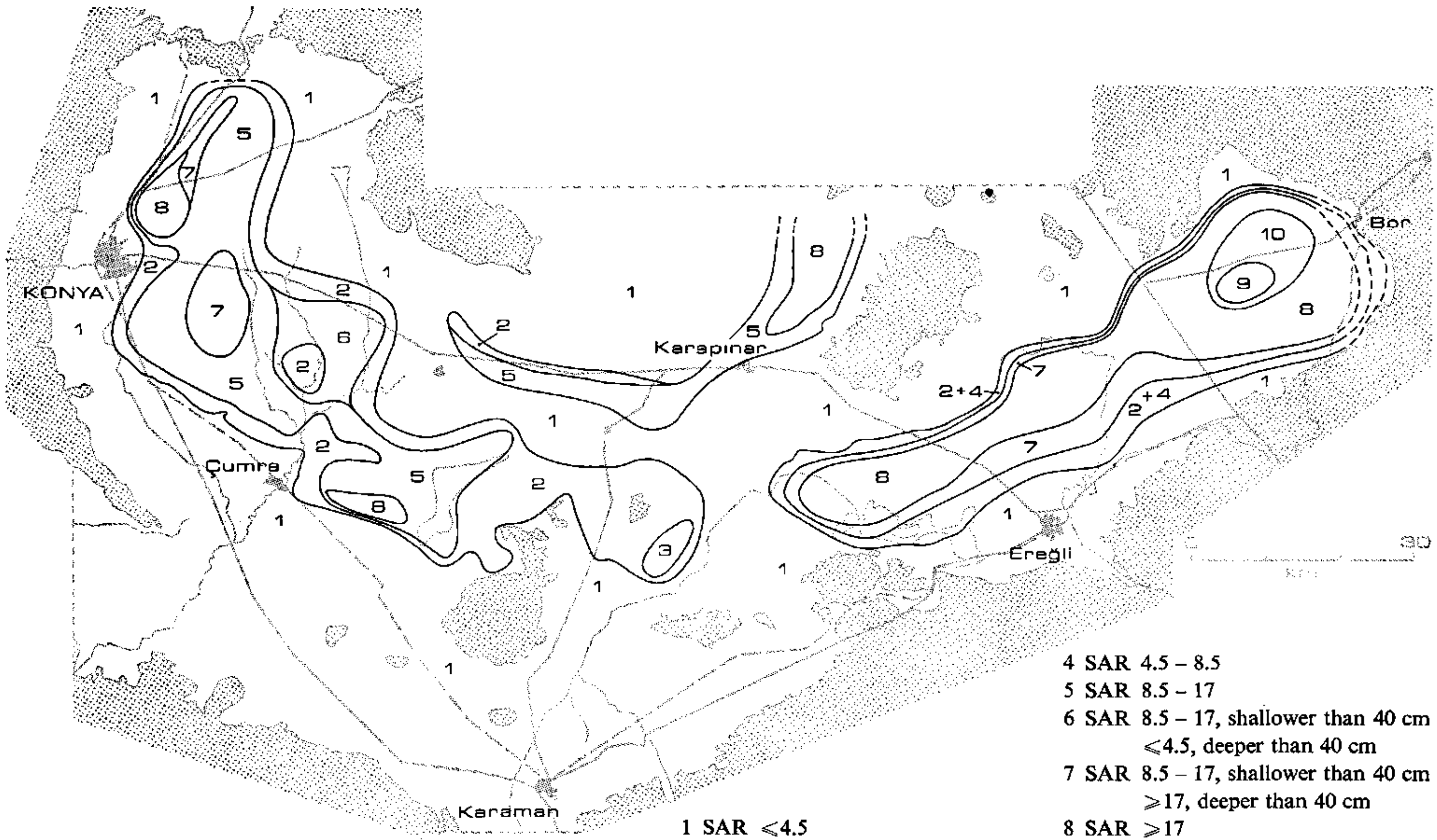
Tablo 37. Büyük Konya Havzası'nda taban sularının sulamaya uygunluk sınıflarının yüzde olarak dağılışları.

corresponding with over 15% exchangeable sodium, occur mainly north and east of Karapınar. Comparatively small areas are found north of Konya (Aslım Swamps) and east of Çumra (near the Village of Ürünlü). Not all possible combinations are present, as the scale of the map does not allow all details to be recorded.

The limit of shallow alkali-affected soils has been defined at 40 cm.

As alkalinity and salinity in the Basin run parallel, shallow alkali soils are found

Fig. 43. Alkalinity sketch map of the Great Konya Basin.



Şekil 43. Büyük Konya Havzası'nın alkalilik kaba-taslak haritası.

1 SAR ≤ 4.5
2 SAR ≤ 4.5, shallower than 40 cm
$4.5 - 8.5$, deeper than 40 cm
3 SAR ≤ 4.5, shallower than 40 cm
$8.5 - 17$, deeper than 40 cm
4 SAR $4.5 - 8.5$
5 SAR $8.5 - 17$
6 SAR $8.5 - 17$, shallower than 40 cm
≤ 4.5, deeper than 40 cm
7 SAR $8.5 - 17$, shallower than 40 cm
≥ 17, deeper than 40 cm
8 SAR ≥ 17
9 SAR ≥ 17, shallower than 40 cm
≤ 4.5, deeper than 40 cm
10 SAR ≥ 17, shallower than 40 cm
$8.5 - 17$, deeper than 40 cm

only in the strongly salt-affected centre. Striking is the alkalinity along the escarpment of the old sandplain, north of the line Demirkent-Hotamış. There leached-out sodium salts cause weak and moderately alkali soils without considerable salt accumulation; ESP never exceeded 15 there, and these soils tend to become (non-saline) alkali. They are, in this respect, unique in the area.

The well drained southern, northern and western parts of the Basin are not at all alkali-affected; the western part east of Konya has an intricate pattern of alkalinity, which is considerably influenced by the irrigation practised north of Çumra.

Except for the volcanic deposits, the deep subsoil of the Basin has not been studied. Here any indirect effect on plant growth would be exerted by the formation of bad structures, causing stagnation of water.

Table 38. Percentages of the Great Konya Basin occupied by the alkalinity classes.

Class	SAR		Percentage of the Basin
	depth (cm)	value	
1	0—120	4.5	69.7
2	< 40	< 4.5	5.7
	> 40	4.5— 8.5	
3	< 40	< 4.5	
	> 40	8.5—17	0.3
4	0—120	4.5— 8.5	2.7
5	0—120	8.5—17	8.4
6	< 40	8.5—17	1.3
	> 40	< 4.5	
7	< 40	8.5—17	3.5
8	0—120	>17	
9	< 40	>17	7.1
	> 40	< 4.5	
10	< 40	>17	1.0
	> 40	8.5—17	
total			100.0

Tablo 38. Büyük Konya Havzası'nda tesbit edilen alkalilik sınıfların kapladığı sahaların yüzdeleri.

Table 38 gives the percentages of the Basin occupied by each of the alkalinity classes. About 22% (classes 4 to 10) is severely affected in the upper 120 cm. As most of these soils contain sufficient gypsum, reclamation by leaching the excess salt will also solve the alkalinity problem, provided gypsum is also present in the surface soil. But it is doubtful whether reclamation is economic for these predominantly very calcareous soils with a low suitability for cultivation.

3.3 Formation of alkali-affected soils

In the Great Konya Basin, both salinity and alkalinity are mainly caused by sodium salts (to a lesser extent by magnesium salts). This explains the striking parallel between the phenomena. But only sodium ions are involved in alkalinity. Sodium is adsorbed onto the soil's exchange complex, in percentages depending on concentration of itself and of other ions in the soil moisture.

In the Basin almost all soils are rich in calcium. As calcium is adsorbed preferentially over sodium, soils containing calcium salts but low in sodium have low ESP. Where sodium is abundant, as in the strongly salt-affected centre of the Basin with dominant sodium sulphate and sodium chloride, high SAR and ESP can be expected. Most of the calcium compounds, like calcium carbonate, calcium phosphate and gypsum, have only low solubility products, which strongly reduce their effectiveness in repelling adsorbed sodium from the exchange complex: the only way in which alkali-affected soils can be cured. Even where originally the soil may have had a low ESP, the calcium salts have not been able to prevent alkalization promoted by waterlogging and poor irrigation management. The nature of the salts supplying Na^+ influences the speed and degree of alkalization, and therefore the Na^+ sources involved need more detailed discussion.

In much of the Basin, in particular its centre, alkalization is almost entirely governed by the sodium compounds dissolved in the groundwater. This contrasts with many other parts of the world, where attention has been paid to the formation of Na_2CO_3 (soda), where this salt is considered the most important and for plant growth fatal source of Na^+. Over its formation, many theories have been presented; the most important will be briefly discussed, as far as they are applicable to the Great Konya Basin.

Formation of soda from sodium bicarbonate is, in principle, possible in the Basin: bicarbonates originating from the limestone formations surrounding the Basin may turn into carbonates if subsurface seepage water is exposed to the open air with a CO_2 tension lower than that in the aquifers through which the water flows. But since many calcium ions are present as well, it is to be expected that exposure to the air will cause calcium carbonate to form rather than soda. The Basin supplies many examples of this phenomenon.

Another way in which soda can be formed is the reaction of neutral sodium salts with $CaCO_3$ (the Hilgard reaction). But Janitzky (1957), quoting Gedroiz (1912), states that in the presence of NaCl no soda will be formed from $CaCO_3$ and, if sodium sulphate occurs, only very small quantities of soda will result.

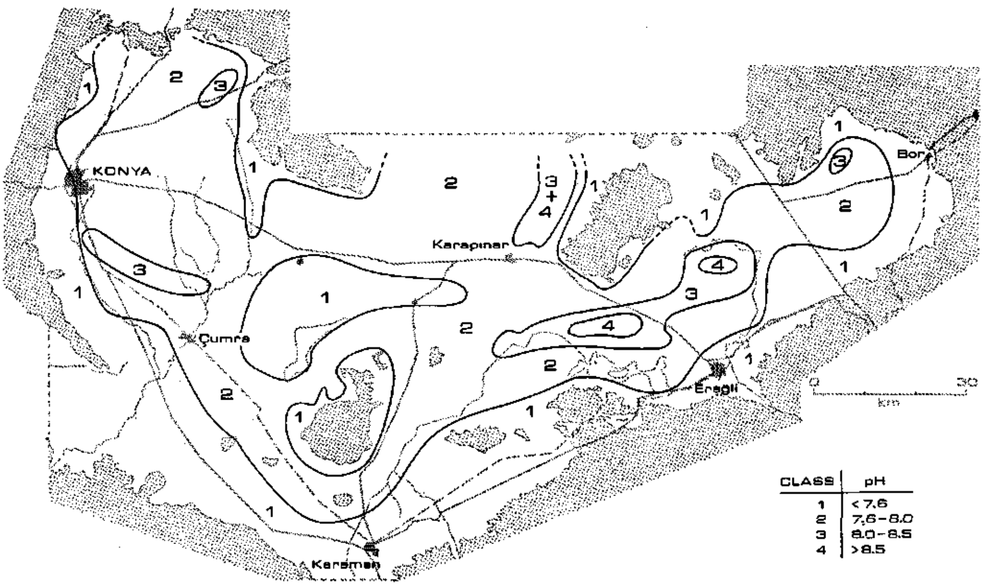
Most probable is the biological formation of soda from sodium sulphate in the reaction $Na_2SO_4 \rightarrow Na_2S \rightarrow Na_2CO_3 + H_2S\uparrow$

This reaction requires the presence of Na_2SO_4 and organic matter under anaerobic conditions (Janitzky & Whittig, 1964). Locally these conditions are fulfilled in the depressions where organic matter and salts accumulate together and where, for part of the year, anaerobic layers occur in the surface soil. Indeed at such places in the

Basin, the soil shows solonetzic properties and smells of H_2S.

A significant soda formation increases pH. When it reaches about 8.5, mobilization and eluviation of clay are favoured. So the determination of pH of all soils in the Basin (Fig. 44) tells us more about the alkali soils. Soda could occur only in Class 4, where pH exceeds 8.5, as rarely happens (Table 39). This means that alkali soils, entirely or to a considerable extent caused by the presence of sodium carbonate in the soil, can only exist in a small part of the Basin and can be expected only in its eastern central parts and north of Karapınar. As shown before, these parts are also strongly saline, which implies that pure soda soils are absent.

Fig. 44. pH sketch map of the Great Konya Basin.



Şekil 44. Büyük Konya Havzası'nın kaba-taslak pH haritası.

Table 39. Percentages of the Great Konya Basin occupied by the pH classes.

pH class	of the Basin Percentage
1 < 7.6	45.2
2 7.6—8.0	47.6
3 8.0—8.5	5.5
4 >8.5	0.8
5 complex of classes 3 and 4	0.9

Tablo 39. Büyük Konya Havzası'nda tesbit edilen pH sınıflarının kapladığı sahaların yüzdeleri.

While measuring pH in the saturated soil pastes it turned out that values in the Uplands and Colluvial Slopes did not exceed 7.6, while in the Basin, except for the centre south of Demirkent, pH was never below 7.6.

Table 40. Analytical data for water from the major rivers entering the Great Konya Basin.

	EC in mmho/cm	Na^+ in meq/litre	$Ca^{2+} + Mg^{2+}$ in meq/litre	SAR
River Çarşamba	0.40	0.60	3.59	0.95
River Selereki	0.40	0.25	4.23	0.17
River Zanopa	0.30	0.21	3.00	0.17
River Sille	0.45	0.38	4.40	0.25
River Ayrancı	0.30	0.17	3.23	0.13
River Çamurluk	0.50	0.43	4.70	0.29

Tablo 40. Büyük Konya Havzası'na ulaşan önemli nehirlerin sularına ait analitik bilgiler.

Table 41. Analytical data of some springs along the fringes of the Great Konya Basin.

	Na^+ in meq/litre	$Ca^{2+} + Mg^{2+}$ in meq/litre	SAR
Aslım Swamps (Site 36)	4.75	19.33	1.53
10 km north of Karapınar	3.65	6.37	2.09
Acıpınar (Site 39)	2.05	9.83	0.92
Narazan (Site 40)	4.35	21.93	1.32
Karapınar	2.90	7.11	1.54
Pınarbası (Site 41)	1.20	7.58	0.62

Tablo 41. Büyük Konya Havzası boyunca bazı su kaynaklarına ait analitik bilgiler.

Table 42. Analytical data of run-off in the west of the Great Konya Basin.

	EC in mmho/cm	Na^+ in meq/litre	$Ca^{2+} + Mg^{2+}$ in meq/litre	SAR
Dedemoğlu (Site 4)	1.80	5.60	13.07	2.20
Kaşınhanı (Site 3)	1.41	4.50	10.63	1.96
Çarıklar (Site 55)	1.02	2.85	9.33	1.32

Tablo 42. Büyük Konya Havzası'nın batı kesiminde yüzey akışlarına ait analitik bilgiler.

Much sodium dissolves in the soil water by weathering of minerals (Akalan, 1962), especially in volcanic areas. There SAR is very high, e.g. north of Karapınar, where values over 60 are common. Obviously the sources of the salt causing salinization also supply the Na^+ causing alkalization.

In Section 2.4, three important sources of salt have been indicated: the rivers, subsurface seepage and surface run-off. As briefly mentioned, the quality of the river water entering the Basin is in general excellent, with SAR values as indicated in Table 40.

Subsurface flow from the catchment area of the Basin is an important source of salts and therefore presumably of sodium. Chemical analysis of some springs, mainly along the fringes of the Basin, confirm this (Table 41).

The contribution of run-off is uncertain, as few exact data are available. They were higher in SAR than the rivers (Table 42), perhaps by dissolving salt accumulated in the surface soil during the previous dry season. In principle all data in Table 42 are for the same run-off. Çanklar is nearest to the mountains and Dedemoğlu is in the central depression, so that both EC and SAR increased from the fringes towards the centre of the Basin; hence sodium compounds from the surface soil must be going into solution. The same occurs with the subsurface flow, though no data are available to trace subsurface seepage of one origin. The sketch maps discussed in Section 3.2 show three areas in which SAR is high; Figure 23 indicates that these depressions are also the places where salt eventually accumulates: the eastern centre, north of Karapınar and east of Konya.

Magnesium salts are peculiar in the formation of alkali soils. Although they lower SAR, soils rich in magnesium usually show the poor physical properties of a solonetz. In the 7th Approximation, the amount of Mg is regarded as important for the formation of a Natric horizon. This is based on the consideration 'that as the sodium is being removed, magnesium seems to follow in the leaching sequence'. To fulfil the requirements for a natric horizon, more than half of the soil's exchange complex must be occupied by sodium and magnesium. Soils rich in magnesium are found near Konya. Pronounced solonetz characteristics have indeed been observed there in the transition between the River Meram deposits and the Marl Soils. As these soils are rich in sodium too, the effect of the magnesium is blurred (Table 43).

If magnesium does contribute to the solonetz properties, the unsuitability of the soils for plant growth because of poor soil structure, water stagnation and other indirect consequences of a high ESP will not be limited to the areas indicated in Figure 43, but will also occur in areas rich in magnesium. In fact, soil analysis has shown considerable quantities of magnesium compounds in most salt-affected areas of the Basin. As a rule SAR and ESP are also high in these areas, so that their harmful effect is emphasized.

The process of alkalization is determined not only by the chemical composition of the water in equilibrium with the exchange complex, but also by the movements of water and the soil's moisture status. In the low wet soils of the centre of the Basin, external salinity occurs and therefore SAR is highest in the upper layers of the profile.

Table 43. Analytical data for a magnesium-rich fan deposit near Konya.

Depth in cm	ECe in mmho/cm	Na^+ in meq/litre	Ca^{2+} in meq/litre	Mg^{2+} in meq/litre	SAR
0—10	15.4	101	28.7	84.3	13.5
20—30	20.8	168	26.7	125.0	19.3
40—60	21.0	156	25.1	148.1	16.8
139, groundwater	21.3[1]	152	12.4	159.9	16.3

1. EC: not ECe.

Tablo 43. Konya yakınlarında mağnezyumca zengin yelpaze yığıntılarına ait analitik bilgiler.

Table 44. SAR of soils of different watertable in the Great Konya Basin.

Depth in cm	Shallow watertable (<< 1 m)		Deep watertable (> 5 m)	
	Tc lime (Site 15)	Tc lime (Site 16)	volcanic fan (Site 45)	Terrace (Site 17)
0— 10	36.5	318	0.38	0.56
10— 20	38.5	120	0.54	0.54
20— 30	24.9	55.2	0.44	
80— 90	5.60	30.5	?	8.54
140—150	0.98	17.7	33.4	10.2

Tablo 44. Büyük Konya Havzası'nda çeşitli derinliklerdeki taban sularına ait analitik bilgiler.

Where movement is predominantly downwards, the reverse alkalinity pattern will be found: SAR low at the surface, alkalinity in the subsoil (Table 44). In such cases clay particles and organic matter are illuviated. In the swampy areas near Ereğli, and east of Konya, organic matter has been considerably illuviated and humus has accumulated at depths varying from 50 to 100 cm (Profile 1; this profile and its description are given on pp. 90-91).

Where the downward movement of water does not predominate, differences in mobility of the salts may cause macrochromatographic separation of the salts. The few data available indicate that this process goes on in the deep dry soils along the Basin's fringes and locally in the centre. The physical properties of alkali-affected soils are in general poor; clay is illuviated into dense illuviation horizons in the subsoil, causing stagnation of water and further decline in the structure. But in the Basin these features are not pronounced: where strongly saline soils are alkali-affected, peptization of the clay is hampered by the high salt content. Many of the alkali-affected soils are so calcareous that they contain only some 10% clay, so that clay illuviation is not pronounced. The heavy clayey soils have, in general, vertic characteristics such as self-mulching and churning, which disturb the formation of textural B-horizons.

4 Consequences of soil salinity and alkalinity for plant growth

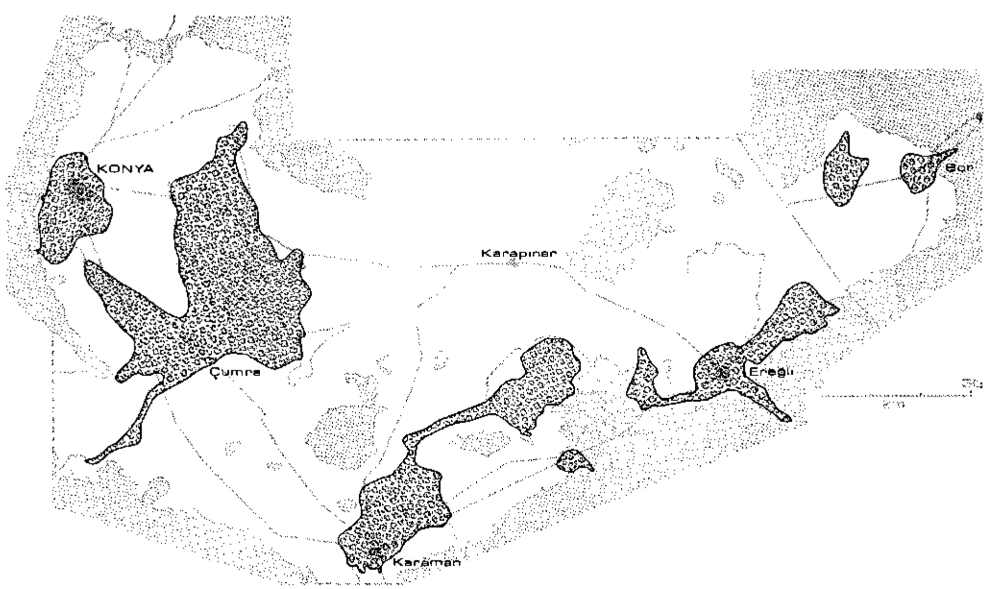
4.1 Present agricultural situation

Origin, composition and dynamics of salts in the Great Konya Basin have been discussed and some sketch maps have illustrated the distribution of salinity and alkalinity. This distribution of salts has consequences for agriculture, but as salinity and alkalinity are both correlated with topography and water status, these consequences are not always distinguishable.

The topography of the Basin favours horizontal drainage from the higher areas along the fringes towards the centre, particularly near irrigated areas (Fig. 45).

Irrigation without adequate drainage has caused salts to accumulate. In the west of the Basin, pronounced salinity has developed after the construction of the Çarşamba irrigation system (1912), causing a gradual decrease after the initial surge in crop yields. Now the situation is worse than ever, especially just outside the area actually irrigated. There lateral flow from the irrigated parts causes shallow and saline ground-

Fig. 45. Irrigated areas in the Great Konya Basin.



Şekil 45. Büyük Konya Havzası'nda sulanan sahalar.

water, and accumulation of salts in the soils. Thus agriculture has become uneconomic in large parts of the central marl plain, where it was formerly already marginal, because of poor soil conditions and aridity.

As already discussed, salt may be concentrated in deeper layers or may occur throughout the profile. Where the upper non-saline layer is sufficiently deep, crops grow without difficulty; where it is only shallow, the crop may be hampered at a later stage of development; where salt reaches the surface, the soil may be unsuitable for arable.

A high salt content of the root layer influences growth in three ways:

a. Uptake of the normal ions necessary for plant growth is hampered
b. Salt is directly toxic
c. Salt causes 'physiological drought', induced by the high osmotic pressure of the soil moisture.

In much of the Basin, the high percentage sodium ions in the soil solution upsets uptake of essential ions. High percentages of a specific ion adsorbed on the soil's exchange complex may disturb uptake of other ions. Such antagonism is known, for instance between sodium and potassium, between sodium and calcium, and between magnesium and potassium. But these antagonisms are difficult to trace, as they depend on such factors as growing conditions and growth stage.

Direct toxic effects have been observed at many places in the Basin as damage to leaf tissues. But not all crops are equally sensitive.

The main effect of high salt concentration on growth is exerted by osmotic pressure (van den Berg, 1952). In many wet and very saline soils in the Basin, physiological drought reduces growth and yield, as the plant cannot compensate for the combined hydrostatic, absorptive and osmotic tensions. In the Basin physiological drought is intensified by climatic conditions favouring evapotranspiration and thus countering sufficient water supply to the crops.

Another indirect effect of salt accumulation may be a diminished microbial population in the soil: at a salt content of 3% bacteria are almost absent (Janitzky, 1957).

The various soluble salts occurring in the Basin are not equally harmful. Soda (Na_2CO_3) starts to affect growth at 0.3 g per litre, whereas the same amount of gypsum is harmless. Very harmful are all sodium salts, chlorides, and $MgSO_4$. They predominate in the salts of the Basin, over the almost harmless calcium and magnesium carbonates, and gypsum. Chapman (1968) indicates differences in the effect of SO_4^{2-} and Cl^-, and states that excess chlorides disturb normal nitrogen metabolism.

The distribution of salinity and alkalinity in the Basin governs land-use. Agriculture is concentrated on the higher Terrace soils, the Bajada soils and the Alluvial soils. The lower parts are mainly used for cattle ranging.

To what extent crop yields suffer from salinity or alkalinity alone is hard to establish. Some isolated data, and discussions with farmers, suggest that salinity may drastically reduce yields in a few years. Details are difficult to obtain because effects of salinity can hardly be distinguished from direct effects of aridity. Salinity in the Basin

Fig. 46. Salt excretion by leaves of *Statice limonium.*

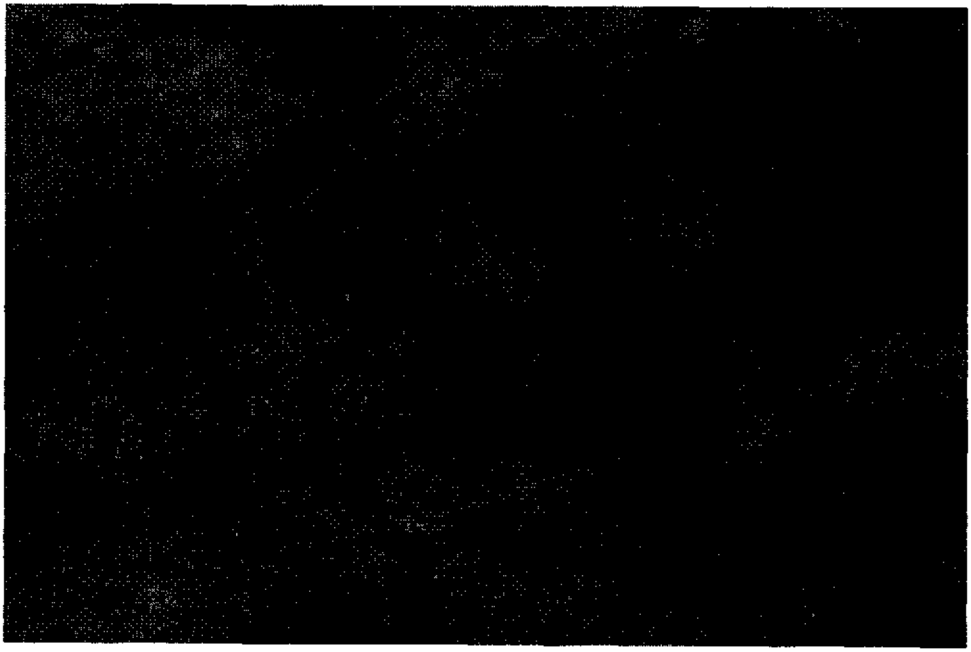
Şekil 46. '*Statice limonium*' yaprakları tarafından ifraz edilen tuz.

is a direct consequence of the aridity. The aridity may lead directly to drought or in salt-affected areas which have been irrigated, the drought is replaced by physiological drought.

In the Basin this stands out along canals and watercourses, where much salt accumulates. Many of the canals have since been lined with concrete by DSI to reduce seepage and salt accumulation in adjacent soils considerably. The same problem arises from the often incorrect way fields are irrigated which, according to a report of 1965 from the International Institute for Land Reclamation and Improvement, is true in 80% of the Çumra Area. To stop the continuously advancing salinization, thorough instruction of the farmers in irrigation is essential. This instruction is already given by DSI, by the Ministry of Agriculture, and by the sugar factories. But for much of the central depression, these measures have come too late: there farming has already disappeared and the vegetation consists entirely of halophytes, including grasses, the latter tolerating up to 2% salt. Where there is more than 3% salt only typical halophytes, such as *Salicornia maritima, Suaeda sp.* and *Statice limonium*, can grow (Fig. 46).

Alkalinity affects plant growth in much the same way as salinity, and in the Great Konya Basin the damage is chiefly due to excess salts.

Fig. 47. Compact horizon with clay illuviation in magnesium-rich Meram Fan Soil near Konya. The crumb surface soil has been removed with a brush.



Şekil 47. Konya yakınlarında Meram çayı yelpazesi toprağında, mağnezyumca zengin ve kil birikmelerine sahip sıklaşmış (pekleşmiş) horizon.

The investigations indicate that, if the soil is kept in a good physical condition, the effect of high ESP on growth is much more pronounced at low than at higher salt concentrations in the root zone. In the Basin, physical conditions are never markedly unfavourable, except for some small areas mainly at the base of the alluvial fans of the rivers Meram and Çarşamba. As many of the saline-alkali soils are low in clay, their structure has not deteriorated, clay has hardly illuviated, dense horizons impeding drainage have not formed, and real natric horizons are almost absent.

An exception is the base of the Meram Fan, where dense horizons are common (Fig. 47). These clayey soils contain much Mg^{2+} as well as Na^{+}. The influence on soil structure of excess Mg^{2+}, adsorbed at the exchange complex, is not exactly known, though high percentages of Mg^{2+} seem to go with deterioration. Moreover Mg^{2+} may cause nutritional imbalance in the plant by depressing uptake of other ions, such as potassium and calcium.

4.2 Some notes on natural vegetation

Apart from such factors as precipitation and general soil conditions, the vegetation in the centre of the Basin is determined by the quantity and type of salts in the soil and by the depth at which they have accumulated. Though the relation with the composition of the salts has been investigated only superficially, it can hardly be close. More obvious is the relation between the depth where the salts are found and the composition of the vegetation.

On external solonchaks, deep-rooting plants predominate (e.g. *Frankenia hirsuta*). Their roots grow through the salty surface soil and branch in the subsoil where salt concentration is lower. On internal solonchaks the roots (mainly of grasses and other grass-like plants) are concentrated in the surface soil, though parts of their rooting system may penetrate deeper.

The relation between salt distribution in the profile and composition of the vegetation can be explained in two ways, as can be illustrated by an area near the Village of Dedemoğlu. Here puffed solonchaks are scattered among internally saline soils, but the profiles differ solely in the upper 10 to 20 cm (Profile 1). On the puffed soil, the vegetation has reacted by eliminating all shallow-rooting plants in favour of *Halocnenum strobilaceum* and some other species.

Such a reaction postulates a distinct difference in the soils on the puffed and unpuffed places before this differentiation started. As no evidence has been found in the field, there may be another explanation. Vegetation and soil interact: where a certain plant species has developed by chance, it may influence conditions especially in the upper layer of the soil in such a way, that other species can no longer develop, or at least are greatly hampered in their growth. Similar processes probably occur in many places where different vegetation types adjoin. In the present case this means that, where shallow-rooting grasses have obtained a foothold, the originally internally saline soil dries out by high evapotranspiration, followed by drying of the grass vegetation. This gradually intensifying process leads to horizontal and vertical cracking of the surface soil, cutting off capillary transport to the soil surface prohibiting further accumulation of salts there and restoration of shallow-rooting vegetation.

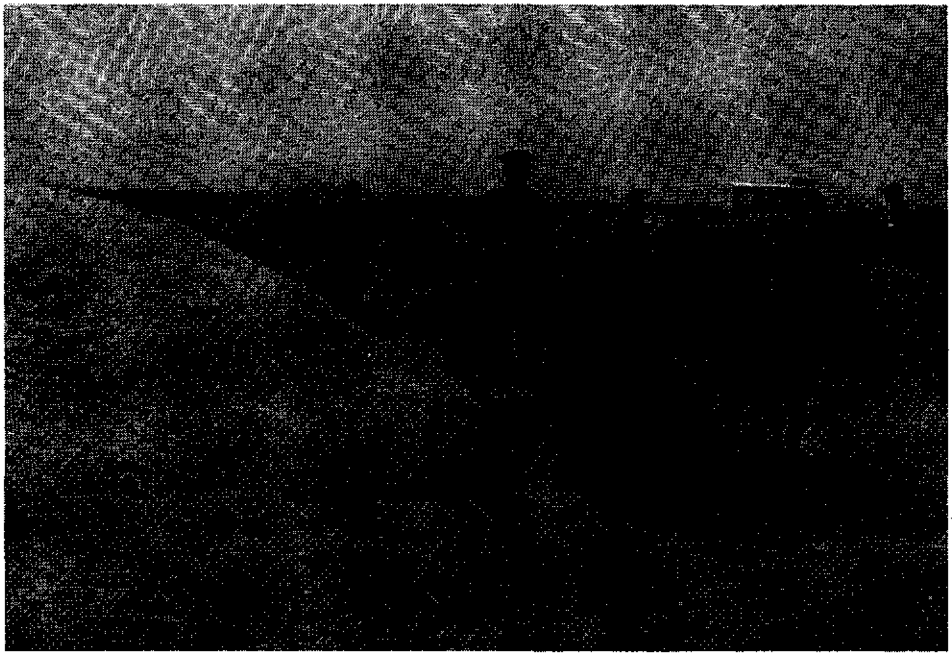
Probably both processes occur in the Great Konya Basin. As their outcome is the same, the part played by each of these processes can no longer be traced.

4.3 Agricultural development

Agricultural methods in the Great Konya Basin are still often primitive (Fig. 48). However it is of little use to improve methods unless yields can be improved similtaneously by combating salinity and alkalinity.

Improvement of the lowest soils seems impossible; it would require an uneconomic drainage system to a region outside the Basin, such as a canal or a tunnel through the surrounding uplands to Tuz Gölu in the north.

Fig. 48. Threshing wheat in Central Anatolia.



Şekil 48. Orta Anadolu'da buğday harmanı.

Therefore improvement should concentrate on the higher soils, where salinity can be cured by draining them towards the lower areas. Although practical schemes did not form part of this study, large parts of the terraces and bajadas could be irrigated with the available water, if irrigation of poor quality soils were restricted, especially in the Çarşamba irrigation system. The present design of this system ignores all soils south of the Konya-Karaman railway, presumably because the company that constructed the railway was also involved in the construction of the irrigation system and wanted to avoid irrigation of soils uphill from the railway.

Expansion of the area irrigated by pumping seems unfeasible, because the available groundwater (Fig. 42) is too poor for irrigation without increasing the danger of further salinization and alkalization of the soils.

Hence storage of winter precipitation seems the only prospect for extension of irrigation and even that has limitations. Many rivers are dry when irrigation becomes necessary. Locally dams have already been constructed to store the winter precipitation (e.g. near Ayrancı Köy, Apa Köy and Altın Apa), though sometimes ineffectually because of karst phenomena in the Basin's floor. Improvement of existing systems or construction of new facilities is desirable.

Available irrigation water should be more economically used, as losses are 80%. Lining of canals and tributaries has still to be completed and alongside these technical improvements, farmers must be better instructed and controls must be more rigorous. An increase of 10% in the effective use of the water should allow better irrigation or extension of the irrigated area by 50%. As well as reducing waste of irrigation water, lining of watercourses should decrease salinization of low areas caused by accumulation of seepage water.

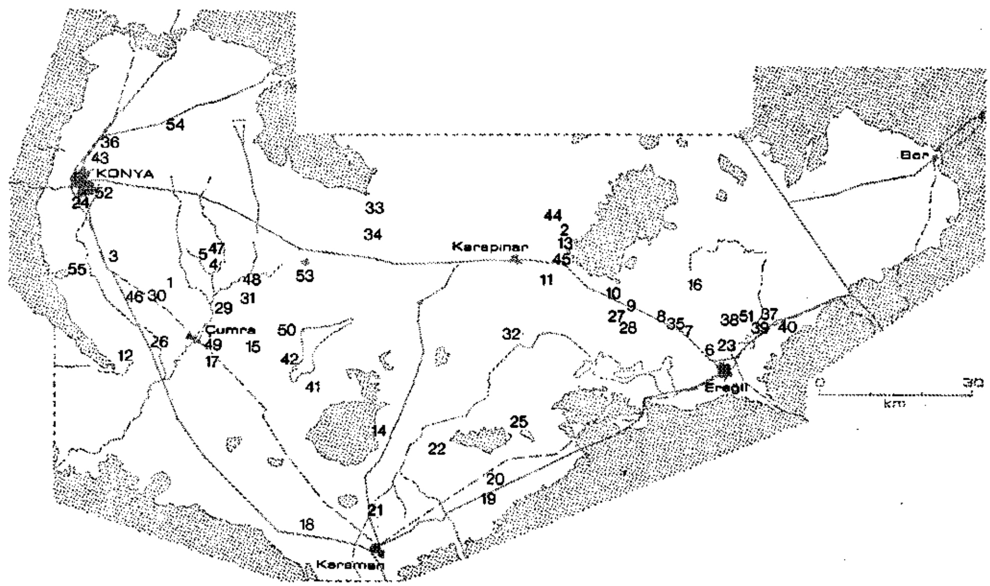
Irrigation of Terrace and Bajada soils should be extended to eliminate the fallow. These soils are ideally suited for irrigation (Driessen & de Meester, 1969). Production can be expected to increase by 100 to 200%, as illustrated by some small irrigated areas on Bajada soils south of Çumra, where sugarbeet yields of 35 tons per hectar are common.

Improvement of salt-affected soils by leaching is technically and economically justified only on the best agricultural land, such as found in parts of the Alluvial deposits.

Table 1 showed that for most crops the consumption of water is between 500 and 800 mm. Rainfall during growth supplies only up to 240 mm, of which perhaps 100 mm could be utilized by the plants, so that roughly 450 to 700 mm has to come from irrigation. If 20% of the water is effective irrigation, this requires 2250 to 3500 mm. Table 17 and the corresponding text have shown that the main rivers could at the most supply some 760×10^6 m^3, which is sufficient for adequate irrigation of some 22 000 to 34 000 ha (the surface irrigated by pumping can be neglected in this context). Actually the area irrigated intermittently is about six times as large, and though part of the water may be used more than once, it is obvious that the amount of irrigation is almost always suboptimum. This again stresses the necessity of restricting irrigation to the best soils.

All excess irrigation water is directed towards the central part of the Basin, where it evaporates and causes extensive salt-affection. By diverting this salty drainage water to a few selected depressions that are already completely saline, such as the playa north of Karapınar, Ak Göl or Lake Hotamış, further encroachment of salt-affected areas might be prevented.

Fig. 49. Location of the described profiles.



Şekil 49. İzahları yapılan profillerin yerleri.

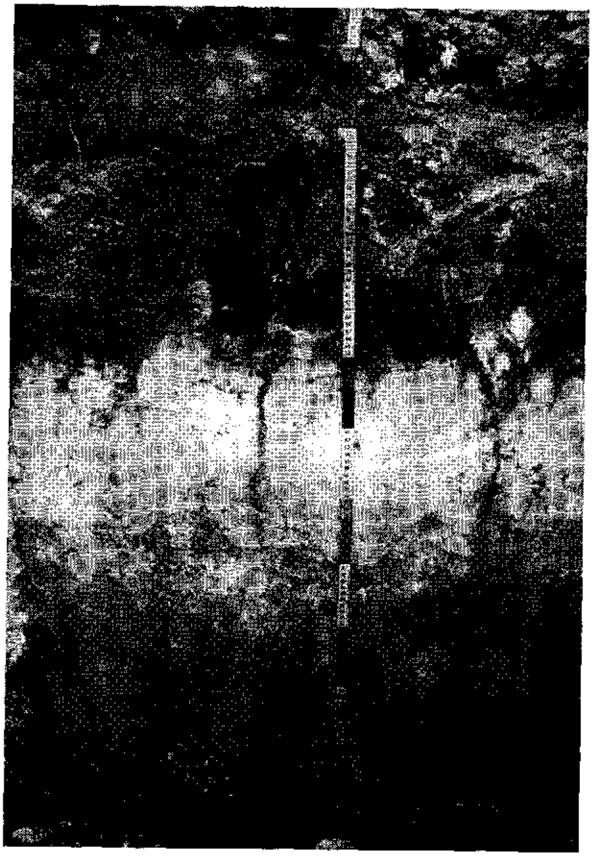


Fig. 50. Organic matter illuviation in a saline-alkali soil near the Village of Dedemoğlu (Site 4, Fig. 49).

Şekil 50. Dedemoğlu köyü yakınlarında tuzlu-alkali bir toprakta organik madde birikmesi.

Profile 1 (Site 4, Fig. 49).

Lm: hydromorphic locally gypsiferous and cemented clayey marl soil, Serpil series. Çumra Area, 74.0° N, 73.2° E, alt. about 1000 m, August 1966 (Driessen & van Vuure).

Geology: lacustrine marl plain
Parent material: gypsiferous highly calcareous clay-loam covered by alluvial heavy clay
Relief and slope: flat, level
Stoniness: class 0
Hydrology: imperfectly drained, watertable at 120 cm
Moistness: moist
Salinity: strongly saline, partly puffed solonchak
Biological activity: restricted to upper 35 cm
Vegetation: *Halocnemum strobilaceum* and *Aeluropus littoralis*
Classification: Thapto Calciorthidic Salorthid

Soil description of Profile 1, (Site 4, Figure 49).

Puffed spot

A11sa 0— 8 cm light gray (10YR 6/1) clay; moderate angular-blocky structure; very hard when dry, slightly sticky and very plastic when wet; common fine and medium roots; few mesopores and macropores; surface crust of prominent white partly detiorated sodium sulphate crystals; clear smooth boundary.

A12sa 8—20 cm light brownish-gray (10YR 6/2) clay; fine crumb and single-grain structure; loose when dry, slightly sticky and plastic when wet; common fine and medium roots, few big roots; many mesopores and macropores; abundant white needle-shaped $Na_2SO_4 \cdot 10H_2O$ crystals, clear smooth boundary.

Csa 20—35 cm light brownisch gray to grayish-brown (10YR 5.5/2) clay; massive and structureless; slightly hard when dry, slightly sticky and plastic when wet; common fine and medium roots, many mesopores; very few shell fragments; gradual tongued boundary.

Non-puffed spot

A1 0— 3 cm light gray (10YR 6/1) clay; strong fine and medium angular-blocky structure; hard when dry, slightly sticky and very plastic when wet; few fine roots; few mesopores and macropores; clear smooth boundary.

A2sa 3—20 cm grayish brown (10YR 5/2) clay; strong coarse prismatic structure; very hard when dry, slightly sticky and slightly plastic when wet; few fine roots; common mesopores and macropores; at a depth of 12 to 13 cm many prominent white sodium sulphate crystals; few shell fragments; clear smooth boundary.

Csa 20—35 cm grayish brown (10YR 5/2) clay, massive and structureless; hard when dry, slightly sticky and slightly plastic when wet; few fine and medium roots; common mesopores and macropores; gradual tongued boundary.

IIA1 35—52 cm very dark grayish brown (10YR 3/2) clay; massive and structureless; some illuviated organic matter; hard when dry, slightly sticky and plastic when wet; common fine and medium roots; many mesopores and macropores; common distinct medium white pockets filled with sodium sulphate crystals; gradual tongued boundary.

IIC1 52—74 cm white (2.5Y 8/2) very carbonatic clay; massive and structureless; hard when dry, very sticky and slightly plastic when wet; common macropores; few faint fine white gypsum crystals; few distinct fine white pure carbonate mottles; clear smooth boundary.

IIC2cs 74—95 cm light gray (2.5Y 7/2) very caıbonatic clay; massive and structureless; hard when dry, slightly sticky and slightly plastic when wet; very few fine roots; common macropores; patches of distinct fine to medium gypsum mottles; common medium distinct white lime pockets; gradual smooth boundary.

IIC3cssa >95 cm light brownish gray to light gray (2.5Y 6.5/2) very carbonatic clay; massive and structureless; very hard when dry, slightly sticky and slightly plastic when wet; few mesopores, common macropores; abundant fine old root channels; abundant distinct medium gypsum clusters.

Summary

In the summers of 1964 to 1968 a study was made of soil salinity and alkalinity in the Great Konya Basin, under the auspices of the Konya Project, a research and training programme of the Department of Tropical Soil Science of the Agricultural University, Wageningen.

The Great Konya Basin, some 300 km south of Ankara, at an altitude of about 1010 m, covers about 10 000 sq. km. For centuries it has been an important agricultural area.

The Basin is surrounded by mountains, draining into it by rivers, surface run-off and subsurface seepage. Some of the riverwater is used for irrigation. Since the Basin has no outlet, the remaining water collects in the central depression, whence it evaporates.

The climate is semi-arid with a dry warm summer and a cool rather wet winter. As annual evaporation considerably exceeds precipitation, salts collect in many places in the soil or on the surface. This causes increasing salinity harmful for agriculture, especially since Na^+ is the major cation so that most saline soils are alkali-effected as well. The distribution of the salts has been related to hydrology and topography.

During the summer of 1964, 1965 and 1966, numerous salt-affected soils have been studied and analysed as basis for a survey of salinity and alkalinity during one week of September 1967. In the survey about 800 samples were taken from over 250 soil profiles and 500 wells at representative sites throughout the Basin were sampled, after analyses of 500 groundwater samples in May 1967 to check variations in depth and electrical conductivity of the groundwater during the dry season. Taking into account the physiography and distribution of the soil types, the collected information has been presented in sketch maps of salinity and alkalinity of the soils, and depth, chemical composition and properties of groundwater throughout the Basin.

To study salinity, some new techniques were introduced: the sum of the cations in the saturation extract has been related to its electrical conductivity. This relation shows geographic variation.

Salinity in the Great Konya Basin occurs mainly in three areas: the western central part of the Basin, a depression north of the Town of Karapınar, and the central eastern part of the Basin. The north and south are not salt-affected. Generally salinity increases with decreasing altitude, except for the central western part, where this trend is disturbed by irrigation. The low parts also have the highest watertable, with very high electrical conductivity. There salinity is caused mainly by supply of salts from subsurface flow from the higher soils towards the central depression.

The salts accumulating in the soil chiefly consist of sulphates and chlorides; sulphates predominate in the west, chlorides in the east.

The alkalinity map, based on sodium adsorption ratio (SAR), shows a similar pattern to salinity.

Dynamics of the salts in the soil have been examined. Efflorescence has been studied by chemical and X-ray analysis, and by electron-microscopy. It had an influence on evaporation from the surface. A salt crust considerably decreases further salinization because of decreased evaporation. Three types of salt crusts, differing in morphology and structure, were distinguished.

Consequences of salinity and alkalinity for agriculture in the Great Konya Basin are discussed. Recommendations for increasing yields and for preventing or decreasing salinity in irrigated soils are given.

Özet

Büyük Konya Havzasında, Wageningen Ziraat Üniversitesi Tropikal Toprak İlmi Bölümünün bir araştırma ve eğitim programı olan Konya projesinin amacı içersinde uygulunan, toprakların tuzlulaşma ve alkalileşmesi üzerinde 1964-1968 yaz aylarında bir çalışma yapılmıştır.

Ankara’nın takriben 300 km güneyinde ve denizden 1010 metre yükseklikte bulunan Büyük Konya Havzası, kabaca 10 000 km^2’ lik bir saha kaplamaktadır. Asırlar boyunca burası önemli bir ziraat merkezi olmuştur.

Çaylar, fazla sularını, yüzeyden akıs ve yüzey altı sızması şeklinde, dağlar tarafından çevrelenen havzaya doğru drene etmektedirter. Havzaya ulaşan çay suları kısmen sulama suyu olarak kullanılmaktadır. Havzanın kapalı oluşu dolayısiyle sulamadan arta kalan su, alçak merkezde toplanmakta ve burada buharlaşmaktadır.

İklim, yazları sıcak ve kuru, kışları serin ve yağışlı şeklinde yarı arid’dir, senelık buharlaşmanın yağıştan fazla olması pek çok yerlerde, toprak içersinde veya yüzeyinde tuz toplanmasına sebep olmaktadır. Bu sebeple, tuz miktarının artması ziraat için çok zararlı olabilir. Katyonların önemli bir kısmının Na^+ olması sebebiyle, pek çok tuzlu topraklar aynı zamanda alkalidirler. Tuzların yersel dağılışları, hidroloji ve topoğrafya ile ilgili olarak araştırılmıştır.

1964, 65 ve 66 yaz aylarında çok sayıda tuzlu topraklar üzerinde çalışmalar ve analizler yapılmıştır. Bu çalısma kısmen 1967 Eylül ayının bir kaftası içersinde o andaki tuzluluk ve alkalilik envanteri esas alınarak yapılmıştır. Bu envanter, mayıs 1967 de taban suyunun kuru mevsimde derinliği ve elektriki geçirgenlik’teki değişiklerini izlemek için 500 taban suyu örneğinin analiz edilmesinden sonra, bütün havzada daha önce sahayı temsil eden seçilmiş 500 kuyu ve 250 den fazla toprak profiline (takriben 800 toprak örneği) dayanmaktadır. Bütün havza içersinde, fizyografi ve toprak tiplerinin dağılımı göz önüne alınarak, toplanan bilgiler, tuzluluk ve alkaliliğin yersel dağılışlarını, derinliğini, kimyasal bileşimini ve taban suyunun tarımsal özelliklerini gösteren, bir çok kaba-taslak haritalar halinde takdim edilmiştir.

Tuz etkisinde kalma üzerinde çalışmalarla ilgili olarak bazı yeni teknikler takdim edilmiştir. Doygunluk çamurunun suyundaki katyonların toplamı ile elektriksel geçirgenliği arasında bir ilgi bulunmuştur. Bu ilgi tuzluluktaki değişikliklerin yersel dağılışlarını göstermektedir.

Bunlardan başka tuz tezahürlerinin kimyasal ve X-ray analizleri yapılmıştır.

Yapılan bu çalışmadan, Büyük Konya Havzası’nda tuzluluğun genellikle üç sahada toplandığı görülmektedir: havzanın orta-batı kısmı, Karapınar’ın kuzeyindeki çukur saha ve havzanın orta-doğu kısmı. Kuzey ve güney kısımlar tuz etkisinde

kalmamışlardır. Genellikle toprak tuzluluğu, sulamanın sebep olduğu orta-batı kısım hariç, denizden yüksekliğin azalmasiyle artmaktadır. Bahis konusu diğer alçak sahalar, yüksek elektriki geçirgenlik değerleri ile en yüksek taban sularına sahiptirler. Buralarda toprakların tuzlulaşması, genel olarak yüksek olan yerlerden tuzların havzanın alçak merkezine doğru, yüzey altı akışıyla meydana gelmektedir.

Topraklarda biriken tuzlar başlıca sülfat ve klörürlerden meydana gelmektedir. Batı yarım-kesiminde sülfatlar, doğuda klörürler hakimdir.

SAR değerlerine dayanan alkalilik haritası tuzluluk haritalarına benzer dağılımlar göstermektedir.

Toprakta tuzların dinamiğine'de ayrıca dikkatedilmiştir. Daha sonra toprak yüzeyinde tuz tezahürlerinin buharlaşma üzerine olan etkileri ve tuzlulaşma hızı üzerinde çalışmalar yapılmış, tuz etkisinde kalmış toprakların ıslahı ile ilgili bazı imkânlar münakaşa edilmiştir. Yüzeyde biriken tuz kabuklarının hissedilir miktarlarda daha sonraki vaki tuzlulaşmayı, buharlaşmanın azalmasiyle, azalttiği görülmektedir. Morfoloji ve strukturları değişik üç çeşit tuz kabuğu tesbit edilmiştir.

Nihayet, Büyük Konya Havzası'ında tuzluluk ve alkaliliğin ziraat üzerinde olan etkisinin sonuçlarına dikkat edilmiştir. Sulanan sahalarda tuzların azaltılması veya tuzluluğa karşı korunması ve verimin artırılması için bazı tavsiyeler yapılmıştır.

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