THE SOILS OF PALESTINE

A. REIFENBERG

REVISED SECOND EDITION

For fifteen hundred years, because of erosion, the burning of dung and the destruction of ancient irrigation, the land "wherein thou shalt eat bread without scarceness, thou shalt not lack anything in it" has steadily deteriorated. If the new Jewish immigration is to restore the ancient fertility, it is obvious that the investigation of the properties of the soils of the country is a task of primary importance. In the following pages a description is given of soil formation within the framework of the Mediterranean type of weathering and at the same time an attempt is made to give a general survey of the soils of the country. This new edition records the progress made during the last ten years in the exploration of Palestinian soils and includes a short survey on the "Jordan Valley Authority." The chapters on the loess-soil of the Negeb, on peat and on fertilisers have been rewritten. New chapters dealing with the effects of saline irrigation water and with soil erosion have been added.

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THE SOILS OF PALESTINE

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STUDIES IN SOIL FORMATION AND LAND UTILISATION IN THE MEDITERRANEAN

BY

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PREFACE

For the Lord thy God bringeth thee into a good land, a land of brooks of water, of fountains and depths that spring out of valleys and hills; a land of wheat, and barley, and vines, and fig trees, and pomegranates; a land of oil olive, and honey; a land wherein thou shalt eat bread without scarceness, thou shalt not lack any thing in it.—Deut. viii. 7-9.

For fifteen hundred years the land has steadily deteriorated. The abandonment of terrace cultivation and the destruction of the trees have left the soil bare and unprotected from the forces of erosion. The ancient irrigation works have been destroyed, and far and wide the once fertile countryside is covered by sand dunes. For centuries dung has been burned as a fuel, and thus an unmitigated policy of soil impoverishment has been pursued.

Now, if the new Jewish immigration is to restore the land's ancient fertility, it is obvious that the investigation of the properties of the soils of the country is a task of primary importance. On the other hand, the soil investigator must also strive to compare the soils of his country with those of other regions, for it is only by this method of treatment that profitable use can be made of knowledge gained elsewhere. In the following pages a description is given of soil formation in Palestine within the framework of the Mediterranean type of weathering, and at the same time an attempt is made to give a general survey of the soils of the country. The author is fully conscious that many years must still elapse before all the problems are completely solved, but he believes that he has been able to detect some mistakes, and these may serve as cautionary examples for new projects, both in Palestine and elsewhere.

The soil problem of Palestine is closely linked with the colonisation work of the Zionist organisation, and on this account it has been thought desirable to include a short chapter on the progress of colonisation up to the present time.

The author thanks the Hebrew University at Jerusalem for having made it possible for him to work for thirteen years without interruption on the soil problems of the country; at the same time he expresses his sincere gratitude to his

present and former co-workers, particularly Dr. S. Adler, Miss E. K. Ewbanks, M.A., Mrs. Rosowsky and Dr. Maisler, for their co-operation. The author desires to express his gratitude to Dr. C. L. Whittles for translating the book and for his help and criticisms, which were of invaluable assistance.

The author feels extremely indebted to the publishers, Messrs. Thomas Murby and Co., for the kindly way in which they have helped him.

A. REIFENBERG.

JERUSALEM,
December, 1937.

PREFACE TO THE SECOND EDITION

THIS new edition records the progress made in the exploration of Palestinian soils. The chapters on the loess-soil of the Negeb, on peat and on fertilisers have been re-written; new chapters dealing with the effects of saline irrigation water and with soil erosion have been added.

The fate of Palestine and of Jewish colonisation being again in the balance, the author has refrained this time from making any estimates as to the future "absorptive capacity" of the country. Instead, a short survey on the "Jordan Valley Authority" scheme is given. The author is well aware of the fact that administrative boundaries and political difficulties may render the execution of this plan impossible for the near future. But the plan shows what could be done with good will and human understanding.

The author wants to express his gratitude to his assistants, Mrs. R. Rosowsky and Mrs. T. Starkman-Menahem, for their co-operation during the author's service with the Army. A revised soil-map, a plan of the Jordan scheme and many new photographs have likewise been added.

The author is again indebted to his publisher who, notwithstanding the difficult times, has made this new edition at all possible.

A. REIFENBERG.

JERUSALEM,
January, 1947.

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A. Geology and Relief.

It cannot be our task here to give a complete description of the geological conditions of the country; for this the reader is referred to the works of Blanckenhorn (1, 2), Blake (3-5), Picard (7-11, 20), Löwengart (6), Picard and Avnimelech (21), Avnimelech (22), and Range (12). We can only consider those conditions which are of importance in soil formation, such as relief and the nature of the rocks which constitute the parent material of the soils.

Palestine can be divided topographically into seven main districts, of which the most characteristic is the Jordan Rift running from north to south, which separates the mountains of Judæa from the highlands of Trans-Jordania. On the west of the mountains of Judæa stretches the Maritime Plain, and on the north of the mountains of Judæa and of Samaria the Plain of Esdraelon, which, running from west to east, separates the latter from the mountains of Galilee. On the south of the mountains of Judæa is found the so-called "Negeb," a low-lying undulating plain which gradually merges into the deserts of Sinai.

We thus have the following districts:

(1) The Maritime Plain.
(2) The mountainous districts of Judæa and Samaria.
(3) The Rift Valley of the Jordan.
(4) The Negeb.
(5) The Plain of Esdraelon.
(6) The mountains of Galilee.
(7) The Highland of Transjordan.

1. THE MARITIME PLAIN.

The substratum of the coastal plain consists of Tertiary limestones, calcareous sandstone marls, clay and marine diluvium. Wide stretches are covered by partially fossilised dune-sand deposits; these dune sands are often cemented by calcareous and siliceous infiltrations, and so form compact masses. It may be presumed that the calcareous sandstones owe their development to similar processes having taken place in earlier geological periods. At many places on the Maritime Plain are found alluvial deposits which have been formed as a result of the denudation of the mountainous districts. In localities where, as a result of the presence of such deposits, the rain torrents from the mountains have been unable to find an outlet to the sea, swampy areas are developed. The drainage of these swamps has been, and still is, one of the chief tasks of the Zionist colonisation.

Of great importance is the occurrence in the Maritime Plain of a grey, sandy-clay horizon at no great depth, which Löwengart calls the "Saqye" layer. This forms the impermeable substratum on which the ground-water of the coastal plain collects and moves to the sea. The presence of this layer is responsible for the success of citrus cultivation in these districts. At the same time all other crops which can be grown under irrigation flourish here.

2. THE MOUNTAINS OF JUDÆA AND SAMARIA.

The hill country of Judæa and Samaria consists, in the main, of Cenomanian, Turonian and Senonian limestones. Whilst the Cenomanian and Turonian limestones are mostly very hard and resemble marble, the Senonian and Eocene limestones are generally of a soft, chalky nature. As a result of the raging torrents in the valleys during winter, narrow cañon-like valleys are frequently formed in the mountains. These are completely dry in summer. On the whole, however, the landscape in the west and south takes the form of a stepped, gently sloping mountain range, whereas towards the east the slope is decidedly steeper and, in the direction of the Jordan Depression, more irregular.

In consequence of the shortage of water only a limited number of isolated areas in the mountainous districts can carry crops requiring irrigation. Terrace cultivation plays an important part here, and, indeed, has done so since the most ancient times. Only a short time ago this hill country was unmistakably a grain country, though, in addition, olives, figs, vines, etc., were grown. Within recent years other kinds of fruit have been grown by the Jews with success, notably plums, apples and pears, which likewise do not require irrigation.

3. THE JORDAN DEPRESSION AND THE TRANS-JORDANIAN HIGHLAND.

The Jordan Rift Valley, one of the lowest depressions of the earth, has been formed as a result of an "earth fissure," and is, for the most part, covered by diluvial marls which frequently display "bad-land topography." Tertiary limestones also occur in some localities. In the north the River Jordan flows out from a vast swamp, called the Lake of Huleh, of which the drainage and colonisation are now being planned. Farther south, the Jordan is responsible for the formation of the Lake of Galilee, and then, after flowing through the Valley of the Jordan, finally reaches the Dead Sea, a trough without an outlet. The eastern flank of the Jordan Depression, bordering the Trans-Jordanian highlands, consists of limestone, Nubian sandstone and basalt, which, in the south, adjoin Cambrian and Pre-Cambrian rocks. In complete contrast to the hill-country of Judæa, Trans-Jordania consists of a high plateau with an extraordinarily steep fall to the west, and which gradually merges into the desert in the east. Even in the south-west of the plateau the landscape bears the impress of desert formation in that the detritus from the mountains accumulates in the valleys and so tends to neutralise differences in level: the mountains drown in their own débris.

The Trans-Jordanian plateau is exceptionally fertile; at one time it formed one of the granaries of the Roman Empire. In the Jordan Depression the hot climate prevailing there permits the growth of tropical crops, which are especially successful where the diluvial marls are covered by alluvium derived from the hill-country.

4. THE NEGEB.

The Negeb forms the southern boundary of the highlands of Judæa to the Desert of Sinai. The eastern part is a badly eroded, hilly wilderness. In the western part, apart from sand dunes, a typical loess area, frequently affected by dust storms, is found. Characteristic here are the large dry valleys (wadis), which, after the winter rains in the mountains, frequently convey, for short periods, torrential quantities of water. In the Negeb itself the rainfall is sporadic in nature, with the result that in many years no harvest at all is possible. With sufficient rainfall barley forms the principal crop. The possibilities of irrigation have, unfortunately, not yet been sufficiently investigated.

5. THE PLAIN OF ESDRAELON.

The Plain of Esdraelon consists, in the main, of a deep alluvium, which has been derived from the denudation, firstly, of the limestone hills of Samaria and, secondly, of the basalt hills of Galilee. Towards the east, in the neighbourhood of the Jordan Depression, diluvial marls are found. The Plain of Esdraelon has been, in part, one of the granaries of Palestine for hundreds of years; in later times, however, it has been grazing ground for nomadic Bedouins. With the commencement of Jewish colonisation, fodder crops (lucerne, etc.) have been grown, and to-day it displays an intensive dairy industry. At the same time it also appears that, where irrigation is possible and the soil is not too heavy, citrus cultivation (grape-fruit) promises good results.

6. THE HIGHLANDS OF GALILEE AND CARMEL.

The highlands of Galilee consist partly of limestones of various geological ages and partly of recent volcanic basalts which have broken through the limestone cover. The weathering of the two kinds of rock, progressing similarly, proves to be particularly interesting, as will be seen later.

As a result of the similarity in the natural conditions, we find the same type of landscape here as in the highlands of Judæa. The same remarks apply to the Carmel, which is composed of limestone of various ages.

B. Moisture Conditions.

The uneven distribution of the rainfall during the year and its scarcity in various parts of the country make the water question one of the principal problems of agriculture in Palestine. Water supply is primarily the factor limiting plant growth in Palestine. Further, the considerable quantities of water falling in the hills during the wet seasons rapidly soak down into the soil, which carries but a scanty vegetation, or are carried away through the wadis to the valleys and the sea, and are so lost to agriculture. Often in summer it is only the dew falling by night which preserves the miserable vegetation.

Of the perennial rivers, first place must be given to the Jordan (16 cubic metres per second); the Yarmuk (15 cubic metres per second, is of service only for the irrigation of a limited area. On the Maritime Plain the 'Aujah (8½ cubic metres per second) is of agricultural importance. The little Crocodile River which was once responsible for the formation of the Kabbara swamps is now drained and will be used for the irrigation of that region. Elsewhere the agricultural population has to rely for the supply of water for irrigation partly on springs, the majority of which are not very productive, and partly on the ground-water, which is pumped to the surface, often from a considerable depth.

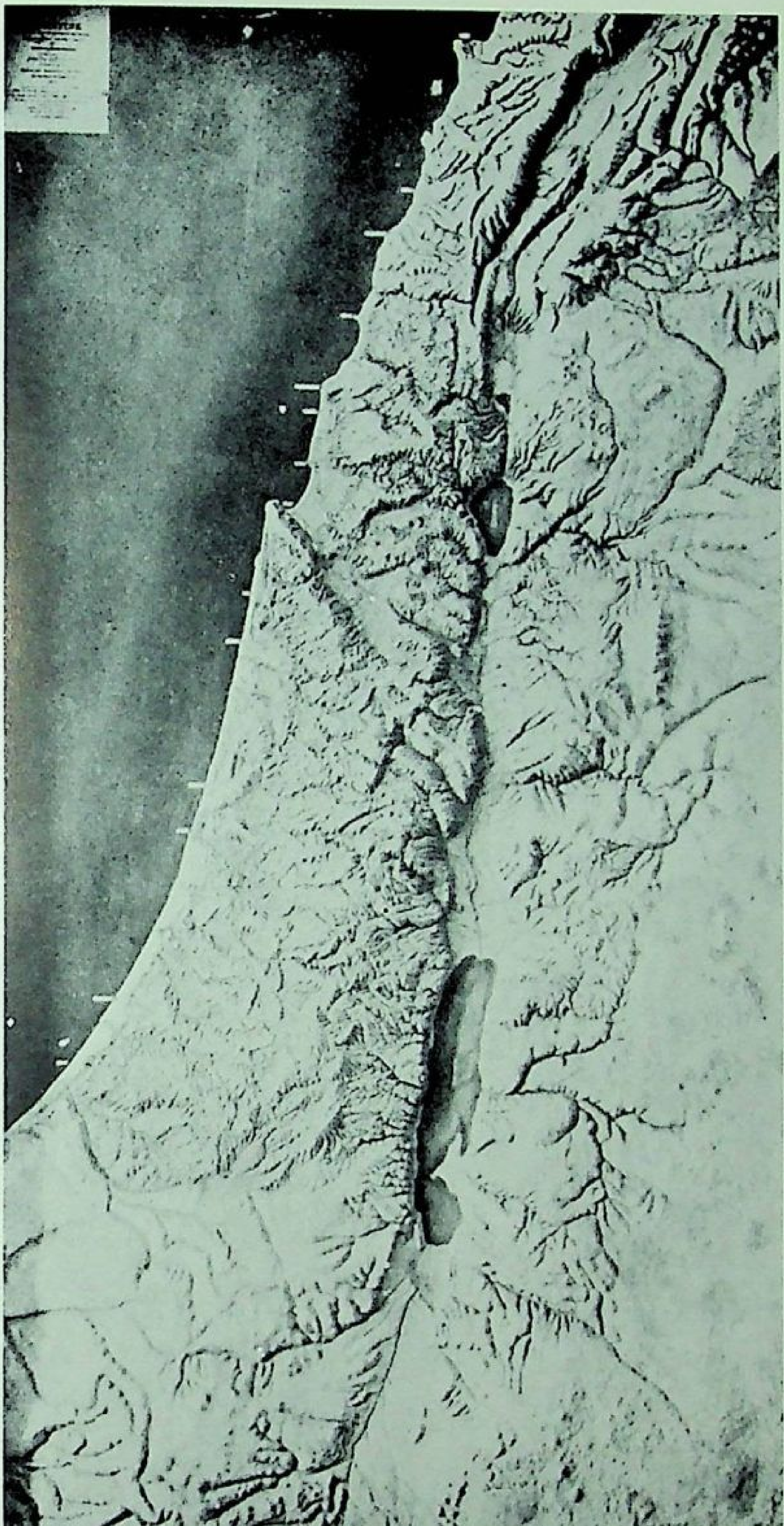
The latter source is of especial importance in the Maritime Plain and in the Plain of Esdraelon (23).

We have already alluded to the importance of the so-called "Saqye" horizon, a stratum of impermeable clay, which, in the Maritime Plain, makes the irrigation of the prospering citrus groves possible. In the highlands only a few springs provide limited possibilities for irrigation as the ground-water is not attainable at an economic depth. Recently sources of water supply are being considered which have not so far been utilised, such as the conservation, by means of dams, of the rain water running to waste in the wadis to the valley. Experiments in this respect are being made in the Negeb. Borings made up to the present have shown that the water is either situated at an uneconomic depth or that it is extremely saline.

Recently, borings made on the Plain of Esdraelon and on the highlands of Galilee have revealed the presence of water in some localities; in the Jordan Valley obviously the river will serve for irrigation; in all other parts the population has to depend on the most meagre supplies. An exception is afforded by the neighbourhood of Beisan and Jericho, where several copious sources serve for an intensive irrigation system.

At this point it is desired to make a few remarks on the quality of the water used for irrigation purposes. In Palestine—and here we have a great contrast with conditions in Europe—not only the rivers but also the spring and well waters contain large quantities of soluble salts, which is in part to be ascribed to the aridity of the climate. The salt content of the water, however, depends in the first place on the chemical composition of the geological stratum from which the water is derived. In many cases waters with high and low salt contents are found close together. The following analyses may afford an insight into the nature of the waters of Palestine:

These figures show that it is not merely hard waters, rich in carbonates, that we have to deal with, but waters



[Photo by Jewish National Fund.

I.—RELIEF MAP OF PALESTINE.

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TABLE 1

ANALYSES OF VARIOUS IRRIGATION WATERS (MG. PER LITRE)

No.	*Locality.*	*Source.*	$-HCO_3$	-Cl	$-SO_4$	$-NO_3$	Na	K	Ca	Mg	Fe	*Total Salts.*	pH
1.	Rehoboth	Well	148	47	9	6	5	3	39	14	11	220	7·5
2.	Ascalon	Well	96	51	9	16	22	2	39	7	Tr.	226	8·6
3.	Gaza	Well	292	221	128	31	122	57	74	40	10	952	7·4
4.	Jordan	River	330	316	6	—	117	10	73	62	—	—	—
5.	Migdal, Southern District	Well	364	369	88	57	187	3	69	62	11	1,204	7·4
6.	Migdal, Northern District	Well	344	1,784	189	28	917	Tr.	265	102	Tr.	3,804	7·3

which, in addition, always contain larger or smaller quantities of chlorides. On the whole, the reaction is weakly alkaline. The alkalinity may, however, increase considerably if the water be exposed to the air, since the bicarbonates are gradually converted to normal carbonates with the loss of carbon dioxide; at the same time calcium carbonate is precipitated, with the result that an undesirable increase in the proportion of sodium to calcium takes place.

The most suitable types of water for irrigation purposes are those such as Nos. 1 and 2, and, fortunately, most of the irrigation water supplies in the citrus districts are of this character.

In the south it is quite different; here frequently the chloride content is considerably higher. The chloride content of No. 6 is abnormally high.

C. Climate.

On the basis of geographical position, Palestine belongs to the Sub-Tropical Zone; but on the coast in particular, and in the highlands, the climate is decidedly of the Mediterranean type, whereas the south and the Jordan Depression display arid conditions. The most striking feature of the Palestine climate is the occurrence of a well-marked season of winter rains. Two entirely different climatic seasons alternate with one another, in that five of the summer months are nearly and three completely devoid of rain.

Lang's method of calculating the "rain factor" (the quotient obtained by dividing the rainfall by the temperature) (16), which has been justly criticised when applied to many climatic regions, has proved of great value in rapidly summarising the climatic and soil-formative conditions for our area (17). Admittedly false conclusions would be arrived at by the usual method of calculation, for the processes of chemical weathering which start in winter are brought almost to a complete standstill in summer by the absolute dryness which permits only such actions to take place as predominate in an extremely arid climate.

This theoretical consideration is also supported by observation. Violent rainstorms of a cloud-burst type scour the loose earth from the slopes down into the gorges, the "wadis," which are dry in summer and frequently in winter become filled with muddy, dark-coloured, roaring torrents, which can cause great devastation. Quite different are the conditions in summer. All weathering by the solvent action of water ceases as a result of the absence of water. The intense insolation destroys most of the organic matter in the soil and causes mean soil temperatures of approximately 40° C. in the summer months in many parts of the country (24). It may be as well at this point to emphasise the fact that in summer the movement of soil moisture is, naturally, upwards from below, so that we have a lower eluvial layer and an upper illuvial layer in the soil, whereby in extreme cases salt efflorescences, etc., may be produced. In many parts of the country the extremely arid conditions during summer are only mitigated by the heavy night dews.

In summer the rain factor naturally has the value 0; no chemical weathering takes place. We can only make use of the data for the winter months in the calculation of the rain factor, since the physical disintegration of the rock is of much smaller pedological importance than weathering by hydrolysis.

Taking the winter season as seven months (October-April), we obtain climatic data for a number of localities as shown in Table 2 and illustrated by the map (Fig. 1).

If we compare the map of the rain factors with that of the soils of Palestine (Fig. 2), we see that, on the whole, the rain factors correspond broadly with quite definite soil types. This correlation is summarised in Table 3.

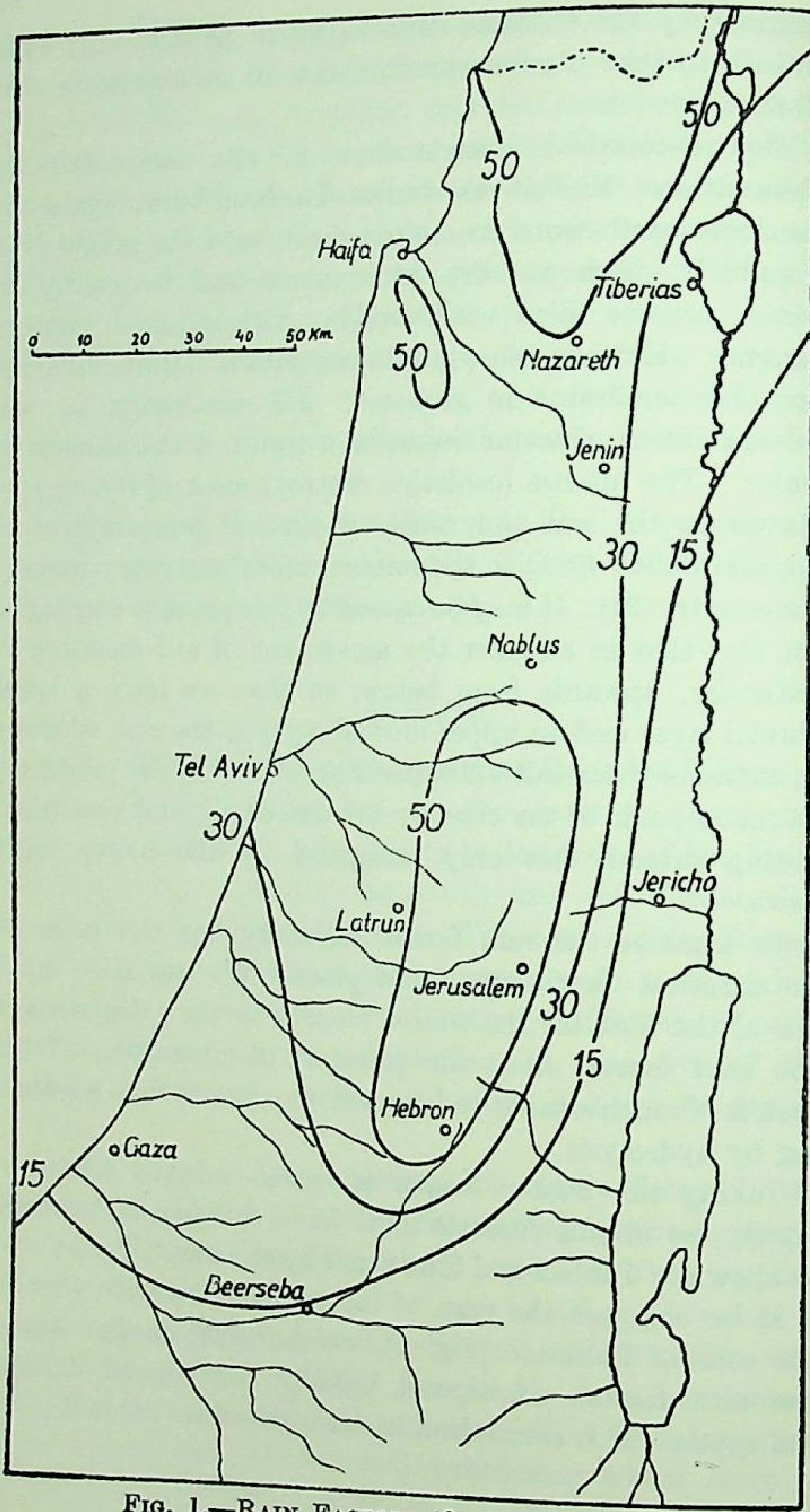

Fig. 1.—Rain Factors (October-April).

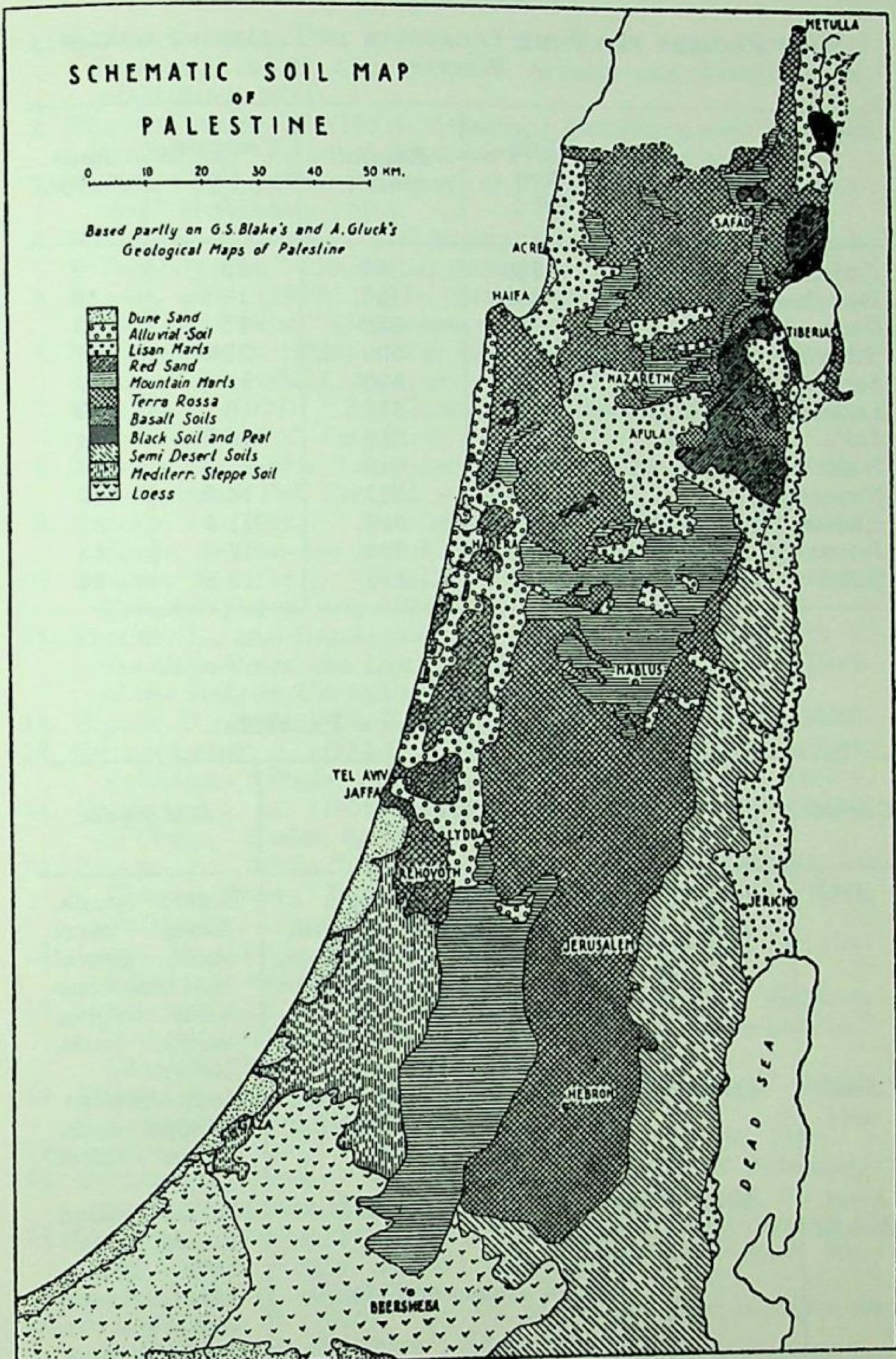
SCHEMATIC SOIL MAP
OF
PALESTINE
0 10 20 30 40 50 KM.
Based partly on G.S. Blake's and A. Gluck's Geological Maps of Palestine
Dune Sand
Alluvial Soil
Lisan Marls
Red Sand
Mountain Marls
Terra Rossa
Basalt Soils
Black Soil and Peat
Semi Desert Soils
Mediterr. Steppe Soil
Loess
METULLA
SAFAD
ACRE
HAIFA
TIBERIAS
NAZARETH
AFULA
NABLUS
TEL AVIV
JAFFA
LYDDA
REHOVOTH
JERICHO
JERUSALEM
HEBRON
DEAD SEA
BEERSHEBA

FIG. 2.

TABLE 2

RAIN FACTORS FOR SOME LOCALITIES IN PALESTINE DURING WINTER

Locality.	*Elevation (M.).*	*Rainfall (mm.).*	*Temperature (° C.).*	*Rain Factor.*
Jericho	− 260	187	20	9
Beersheba ..	300	190	16·3	12
Gaza	20	382	16·3	23
Tiberias	− 185	500	20·0	25
Jenin	187	500	15·4	32
Latrun	190	537	16·7	33
Jaffa	30	545	15·9	34
Haifa	10	646	17·0	38
Nazareth	303	732	14·5	50
Hebron	927	592	11·3	52
Jerusalem ..	*ca.* 780	660	12·0	55
Safed	800	889	13·8	64

TABLE 3

CLIMATES AND SOILS OF PALESTINE

Climate.	*Rain Factor.*	*District.*	*Soil Types.*
Arid	Less than 15	Most southerly districts of Maritime Plain, most southerly outliers of highlands, southern portion of Jordan Depression, southern portion of the eastern slopes of the highlands	Desert sands, Lisan Marl soils, gravel and limestone semi - deserts, saline soils, loess.
Semi-arid	15-30	Maritime Plain near Gaza, northern portion of Jordan Depression	Mediterranean Steppe soils. Lisan Marl soils.
Semi-humid	30-50	Northern portion of the Maritime Plain in Judæa, Plain of Sharon, Carmel, highland of Judæa and Galilee	RedEarths,Red Sands, basalt soils, mountain marl soils (aclimatic Black Earths)
Humid	Greater than 50	Highest portions of the highlands of Judæa and Galilee	Red Earths, basalt soils, Yellow Earths

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II. SOIL FORMATION IN PALESTINE

A. The Weathering Process.

1. general.

Physical weathering prepares the rock for the attack of the agencies of chemical weathering, since, by the disintegration of rocks into small and minute fragments, the necessary surface area is created.

In the desert regions of the country, in particular, these rock fragments are transported to the valleys, undecomposed, by heavy sporadic rain storms. The detritus from the mountain peaks accumulates in the plains, the mountains "drown" in the levelling débris (Plate VIIIa).

In a country such as Palestine, where the mountains mainly consist of limestone, weathering by solution naturally plays a very large part. In the highlands on all sides are seen hollows, clefts and fissures as a result of the solvent action of carbonated water. The irregularities of this process of solution are partly due to chance peculiarities of the rock and partly to the fact that in Nature the solvent liquid is not supplied regularly. In this way irregular structures arise, and the soil frequently appears to be dotted with blocks of rock. The limestone highlands of Palestine are, in fact, typical "Carst" areas. The dissolution of the calcareous rock can be readily recognised where the limestone layers are interbedded with igneous rocks; the almost unattackable quartz is then seen projecting from the limestone in beautiful ribbons.

In the further progress of weathering, it is not only the silicate rocks, but also the ferro- and alumino-silicate compounds occurring in the veins of the limestone, which are hydrated and oxidised. By this process the crystalline jointing of the minerals of the rock is loosened considerably, and hydrolytic decomposition by the percolating water is rendered possible. Weathering by hydrolysis proceeds very rapidly, since the water is highly dissociated as a result of its high carbon dioxide content and the high temperature.

The resultant decomposition products, in the first place colloidal solutions of silicic acid, ferric oxide and alumina, may be again combined by mutual precipitation processes (coagulations), and by this means the particular type of soil formation is decided. As is well known, these allophane clays, in contrast to the felspar residue clays (kaolin, etc.), are found predominantly in warm climates. In the course of thousands of years they can apparently acquire a crystalline character.

2. THE RÔLE OF COLLOIDAL SILICIC ACID.

The natural occurrence of colloidal silicic acid is a fact which has been recognised for a long time, in which connection particular reference must be made to Polynov (14) and to Ramann (1) and Meigen (2), who emphasise the increased solubility of silicic acid in warmer climates. Scofield (3) reports the occurrence of sodium silicate in arid soils under irrigation, and B. von Horvath (4) gives prominence to the high solubility of silicic acid in the presence of alkalies. Already Wi. Ostwald (5) has drawn attention to the probability of silicic acid crystallising out from solution in the soil, which process, according to the investigations of other authors, would be especially favoured by higher temperatures. Transitions from opal to quartzite and quartz have been observed by Storz in the Namib. With Stremme (6) we may regard the occurrence of flints (siliceous concretions), of colloidal hydrated alumina, and of ironstone—whose mobilisation and concentration cannot be brought about by the agency of true solution—as conclusive evidence of the primary occurrence of silicic acid in the colloidal condition.

Colloidal silicic acid, an extraordinarly highly hydrated substance, displays great powers of resistance to flocculation by electrolytes, though divalent hydroxides readily cause coagulation. For this reason colloidal silicic acid is probably the most stable of the soil colloids, and this can result in a complete impoverishment of a soil in silicic acid (laterite). The adsorptive power of colloidal silicic acid is extraordinarily high, especially as regards bases. According to investigations carried out by Fodor in collaboration with the author (7), the maximum base fixation amounted to about 1,000 equivalents of alkali, whereas the maximum acid fixation amounted to only about 25 equivalents of hydrogen. A 0·3 per cent. silicic acid sol dialysed in the usual way had a hydrogen-ion concentration of pH 5·7; this is evidence that it still contains latent (adsorbed) bases, which are only removed by the more drastic process of electro-dialysis, whereby the pH value falls to 3·9.

It could now be shown that a silicic acid sol containing latent alkali not only exerts a protective action on sols of the hydroxides of iron and aluminium, but also has the power of directly peptising the ignited oxides (Fe_2O_3 and Al_2O_3).

The results of an experiment to demonstrate the protective action of silicic acid sol on ferric hydroxide sol are given in Table 4.

TABLE 4.

PROTECTIVE ACTION OF SILICIC ACID SOL ON $Fe(OH)_3$ SOL AGAINST FLOCCULATION BY SODA.

	c.c.	c.c.	c.c.	c.c.
$Fe(OH)_3$ sol	5·0	5·0	5·0	5·0
SiO_2(sol . .	—	—	5·0	5·0
0·1 N NaOH	0·2	0·5	1	6
Water . .	0·8	1·5	0·5	0·5
After 24 hours	No precipitate.	Precipitate.	0·5 Precipitate.	— No precipitate.

Similarly it could be shown that a protective action is also operative against flocculation by neutral salts. The protective action of silicic acid, which is of such importance in soil phenomena, has been confirmed by Mattson (8), Demolon and Batisse (59) and Barbier (60). As will be stated later in greater detail, it alone can explain the translocation of iron sols in the presence of calcium (and in the absence of humus).

It has already been stated that colloidal silicic acid has the power of directly peptising the ignited oxides of iron and aluminium, and of transforming them into stable sols. The resulting ferric oxide - silicic acid sols are brick-red in colour, whereas sols prepared from ferric hydroxide are more brownish in colour, while aluminium oxide-silicic acid sols are milk-white. Ferrous oxide can be peptised successfully if the reaction be kept slightly alkaline. There are then formed sols, a dark grass-green in colour, which oxidise slowly, with the result that the colour becomes a muddy yellow. Table 5 shows the effect of varying the hydrogen-ion concentration on the process of peptisation.

TABLE 5.

INFLUENCE OF pH ON THE PEPTISATION OF FERRIC OXIDE BY SILICIC ACID SOL.

pH of Silicic Acid Sol.	*Fe_2O_3 Dispersed.*
	%.
8·0	0·031
7·3	0·022
5·7	0·008
3·9	0

The optimum reaction for peptisation thus lies on the alkaline side of neutrality, although even with a slightly acid reaction peptisation still proceeds, since such sols contain latent alkali; if the latter be completely removed the power of peptisation is lost.

It must be noted that in the case of peptisation at pH 5·7 the hydrogen-ion concentration of the ferric oxide - silicic acid sol formed is pH 8; there is thus a definite increase in alkalinity during peptisation, and this alkali can only be derived from the latent alkali of the silicic acid sol. The process taking place is that of an exchange between this latent alkali and the ferric oxide which goes into suspension. With electro-dialysed sols the peptising action does not proceed for the obvious reason that the alkali required for exchange is not present in the micelles of the silicic acid. The buffering of soils towards acids is probably to be traced in many cases to such latently combined alkali.

The coagulative properties of these metallic oxide-silicic acid sols resemble those of clay to an extraordinary degree, so that it is probable that similar products are also present in the colloidal solutions which are involved in the formation of clay. The sols display a great sensitivity towards acids, whereas alkaline hydroxides in small quantities tend to produce suspensions. Neutral salts, by the formation of irregular series, tend to produce flocculation. In general, the flocculation phenomena resemble those found with clay; a close, compact precipitate is produced by acids and neutral salts, whereas a voluminous one is formed by alkalies.

According to current views [Wiegner (10)] the formation of clay is to be regarded as the result of negatively charged silicic acid sol coming into contact with positively charged aluminium hydroxide sol, in electrically equivalent amounts, whereby mutual precipitation takes place. We believe that it is very difficult for this process to take place, for it is impossible to imagine, in Nature, that it is always sols with exactly equal charges which come into contact; it appears to us to be far more probable that in Nature mixed sols of silicic acid, alumina and ferric oxide are precipitated by electrolytes and so cause the formation of clay.

Colloidal silicic acid appears to play a great part in Nature, generally as an "omniadsorbens," and possibly many soil processes are explicable by its properties as a protective colloid. In due course we will show in considering the formation of Terra rossa that it alone can explain the translocation of colloidal iron and aluminium in the presence of calcium (*cf.* p. 82) (11).

B. The Evolution and Characteristics of the Soils of Palestine.

1. Arid Region.

(a) *Desert Soils.*

The northern portion of the Sinai Peninsula and the Isthmus Deserts are covered by extensive areas of sand, which are to a great extent responsible for the coastal belt of sand dunes bordering the cultivated land. Microscopic examination shows that this pale yellowish sand consists almost entirely of very fine quartz grains. In individual cases it is naturally difficult to differentiate it from the dune sand, as it displays all the characteristics of the latter (dune formation, ripple marks, etc.). Nevertheless, this desert sand is often hardened by salt efflorescences, which serves as a reminder that even in the desert chemical changes cannot be completely neglected.

In the south-east of the Dead Sea are found Pre-Cambrian conglomerates as well as Nubian sandstones, which weather to a rose-red sand having an iron content of only 0·94 per cent. (12).

TABLE 6.

Analysis (Hydrochloric Acid Extract) of a Red Desert Sand (Wadi Saramuj) (Per Cent.)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	(H_2O)
0·04	1·94	0·94	2·91	0·33	0·08	1·20	0·05	0·16	0·35

The insoluble residue, amounting to about 93 per cent., consists solely of silica. Mechanical analysis shows that over 95 per cent. of the soil consists of sandy constituents. The red colour, despite the low iron content, is surprising. On no account can this soil be included amongst the Red Earths; it is a typical desert sand, whose red colour is to be ascribed to the red-coloured parent rock. Blanckenhorn (13) also states that in extremely arid districts red soils occur only where the parent rock is red in colour. Ramann (1) and Wiegner (10) also come to the same conclusion.

The formation of "sand and gravel" is characteristic of desert weathering, and, accordingly, we find that a gravel and limestone semi-desert is the predominant soil type on the eastern slopes of the mountains of Judæa. Picard (15) describes a "Hamada" steppe of the Plateau of Estuh el Amaz in the following terms: "After traversing the slope, on arriving at the top one sees before one an extensive broad highland plateau. Projecting above the general level are isolated rounded knolls which, presumably, are remnants of a shallow 'peneplain' area; shallow wadis and ravines cross the landscape and the ground is covered with a vast accumulation of brown masses of flint. The soil over which these are scattered is a fine powdery dust." This stony and gravelly "desert carpet" represents the most desolate habitat of the desert.

Frequently, as in other desert areas, the rocks are covered with crusts consisting of iron and silicic acid, together with manganese. Linck (16) was able to show that these crusts must have developed, for the most part, from the underlying rock, on which they are first deposited in the colloidal-amorphous condition, while, later, they become crystalloidal and more resistant to renewed peptisation. Whilst up to the present no satisfactory explanation has been found for the primary peptisation of the iron present in the rock, we believe that the peptisation of the iron can without doubt be explained by the protective action of colloidal silicic acid, which we have already established (p. 26). The colloidal silicic acid peptises the iron present in the rock, and protects the colloidal iron sols, as they rise by capillarity to the surface of the rock, from precipitation by the limestone. At the surface of the rock these sols suffer evaporation and form crust-like coatings, which have been designated "desert-lac" (52).

In general, iron does not take an active part in the actual process of soil formation in desert regions, but remains passive, forming crusts which are extremely resistant. In direct contrast to this, aluminium assists in soil formation as a result of the decomposition of alumino-silicates by hydrolysis, although this displays more of the marks of a physical disintegration of the rock in consequence of the scanty rainfall. Mention must be made of the fact that various investigators have drawn attention to the occurrence of hydrolytic actions even in the desert, and these are aided by the high salt content of the soil. Under these extremely arid conditions silicic acid appears to be hydrated very readily, even though this often involves the immediate gelation of this constituent, as a result of the high salt content.

The following table clearly shows the non-participation of iron in the evolution of the actual soil. This is revealed in Nature by the pale, greyish-brown colour of desert soils on the one hand and by the crust formation described above on the other.

TABLE 7

SILICA-SESQUIOXIDE RATIOS OF PALESTINE DESERT SOILS (CLAY FRACTION)

Locality.	*Parent Rock.*	$\frac{SiO^2}{Al_2O_3}$	$\frac{SiO^2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	*Rain-fall (mm.).*	*Temper-ature (° C.).*
Jauf ed Derwish	Limestone	3·14	14·53	2·58	*ca.* 75	*ca.* 20
Jauf ed Derwish	Basalt	3·69	13·87	2·91	,,	,,
Aquaba ..	Granite	4·02	12·25	2·77	*ca.* 50	,,

As in all desert regions, a high silica-ferric oxide ratio is characteristic of the deserts of Palestine.

It is obvious that in the unmistakable deserts of Palestine, as a result of the lack of rain, agriculture is only possible in those quite isolated places where scanty springs occur.

(*b*) *Lisan Marl Soils.*

In the basin of the Jordan the nature of the soil changes as a result of changes in the geological formation. In the depression area of the Jordan basin we find the deposits of a former vast inland lake. These deposits consist of loose diluvial marls, which, after Lartet, have been called Lisan Marls on account of their particularly typical occurrence in the El Lisan Peninsula. The powerful erosive action of the wind, combined with the chalk-like nature of the rock, is responsible for the many remnants of mountains (monadnocks) (53) in the area of the diluvial marls; the landscape is that of typical bad-land topography. The Lisan Marl soils are generally of a rather light character, their clay content varying from approximately 10 to 20 per cent. The lime content is a very high one, varying between 25 and 50 per cent. A preliminary survey of these soils in the lower Jordan Valley has lately been carried out by Puffeles (61).

It is only in places where water is available for irrigation that agriculture is at all possible in the southern part of the Jordan Valley. Particularly fertile areas are created where the marl strata are covered by alluvium washed down from the hills.

But here, too, is the danger of salinisation, as we showed in an investigation carried out in the neighbourhood of Jericho. The chloride content of the water used for irrigation amounted to 593 mg. Cl per litre, and an orange grove established there displayed all the symptoms of intense chlorosis. The results of an examination of the soil profile are given in Table 8.

TABLE 8

Marl Soil Salinised by Unsuitable Irrigation Water (Plantation Ruined by Chlorosis)

	0-25 *cm.* *Brown Loam with Calcareous Concretions.*	25-50 *cm.* *Whitish-Yellow Calcareous Crust.*	50-75 *cm.* *Whitish-Yellow Calcareous Crust.*	75-95 *cm.* *Yellow Loam.*
	%	%	%	%
pH	7·5	8·0	8·2	8·3
$CaCO_3$ ..	32·1	27·4	32·7	26·6
Water Extract:				
Cl	0·061	0·078	0·159	0·629
SO_4 ..	0·637	0·280	0·782	0·751
HCO_3 ..	0·024	0·024	0·024	0·031

[Photo by Keren Hayesod.

II.—SAND DUNES ENCROACH ON FERTILE LAND (RED SANDY SOIL). TYPICAL LANDSCAPE OF THE CITRUS DISTRICT (NEAR RISHON LE ZION).

[*Photo by Keren Hayesod.*

III.—TERRA ROSSA LANDSCAPE. DEEP FERTILE SOIL IS ONLY FOUND IN THE VALLEYS. THE LIMESTONE HILLS ARE DENUDED. NOTE THE TERRACES AND THE PARTLY AFFORESTED HILLS NEAR THE JEWISH COLONY OF KRYAT ANAVIM.

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In the immediate neighbourhood of Jericho the marls are covered by alluvial loam derived from the mountains. The water used for irrigation has a chloride content of 27 mg. Cl per litre. A four-year-old orange grove situated there has developed quite normally. The results of an examination of the soil are reported in Table 9:

TABLE 9

ALLUVIAL LOAM AT JERICHO IRRIGATED WITH SUITABLE WATER (PLANTATION WELL DEVELOPED)

	0-25 *cm.* *Brown Loam.*	25-60 *cm.* *Brown Loam.*	60-95 *cm.* *Brown Loam.*	95-110 *cm.* *Brown Loam.*
	%	%	%	%
pH	8·0	8·2	8·3	8·4
$CaCO_3$	33·2	36·0	33·9	33·9
Water Extract:				
Cl	0·005	0·011	0·018	0·007
SO_4	Tr.	Tr.	Tr.	Tr.
HCO_3	0·061	0·049	0·037	0·043

These two examples clearly show the danger of the use of unsuitable water for irrigation. The chloride content of the substratum of the ruined plantation has risen to 0·629 per cent. The sulphate content is also very high indeed, but in this instance is in the form of the non-injurious calcium salt.

Where there is no possibility of irrigation the Lisan Marls display only a very sparse growth of halophytic plants. Two soils from this area were examined. Both soils were pale grey in colour.

The analysis shows that the soils are extraordinarily rich in salts; analysis also reveals the reason for the sterility of the one soil, for the chloride content amounts to 7·94 per cent., corresponding to 13·09 per cent. of sodium chloride. The other soil has a Cl content of 0·12 per cent., corresponding to 0·2 per cent. of NaCl.

These two soils correspond very closely to the "white alkali soils" of Hilgard (18), which contain preponderant amounts of sodium sulphate, magnesium sulphate and sodium chloride; according to the Russian terminology they are Solonchak soils.

TABLE 10

ANALYSES OF LISAN MARL SOILS FROM THE JORDAN DEPRESSION

	Saline Soil, with Sparse Plant Covering.		*Sterile Saline Soil: HCl Extract.*
	Fusion	*HCl Extract*	
	%	%	%
SiO_2	26·58	0·44	0·31
Al_2O_3	2·81	2·61	9·93
Fe_2O_3	7·59	7·34	3·51
CaO	31·80	26·33	18·93
MgO	3·86	1·64	0·82
K_2O	0·71	0·66	1·64
Na_2O	0·42	0·40	5·18
P_2O_5	0·05	0·05	0·45
SO_3	4·46	4·46	1·81
Cl	0·12	0·12	(7·94)
CO_2	18·16	(18·16)	(15·10)
H_2O	4·38	(4·38)	(6·18)
N	0·13	—	—
	101·07		

Experiments, however, have shown that by leaching the soil with sweet water one is able to remove any excess of salts, and a settlement has in fact been established on such soils just north of the Dead Sea (84).

The evergreen maquis (macchia or macchie) flora of the shores of the Mediterranean (54) cannot grow here; instead, we find Ephedra and other halophytes. It may be noted that Schwarz and Guggenheim (19) were able to prove, on similar soils, the great dependence of plant growth on the salt content of the soil. At places where the salt content was high Salsola predominated; in places where the content was lower, Suæda; on the other hand, the hydrogen-ion concentration (between pH 7·1 and 8·2) had no influence.

Most desolate of all is the "Sebcha," a saline desert situated south of the Dead Sea, which owes its origin to flooding by sea-water. The ground is completely covered with a salt crust which entirely inhibits growth. In the upper Jordan Valley, owing to higher precipitation and therefore lower salt content, the main plant associations are Zizyphus Spinosa Christi-Zizyphus Lotus and Presopis farcata-Garthamus glaucus (62).

(c) *The Loess.*

(i) *General.*—The southern end of Palestine has the shape of a triangle with the apex at Aqaba and the base represented by a line drawn from Gaza to Beersheba. This desert-like district, the biblical Negeb, has of late frequently been discussed as a territory offering possibilities for Jewish colonisation.

The area of the Negeb is about 12,500 sq. km., almost half the total area of Palestine, and consists of a level or slightly undulating plain in its western part and a hilly, badly eroded wilderness in its eastern part (approximately east of an imaginary line Beersheba-Auja Hafir). Cultivation in this eastern part is possible only in years of ample rainfall, but even in such years it is confined to some wadis and flats where sufficient soil has collected. Generally speaking this eastern area possesses a very shallow layer of soil only, quite unsuitable for any kind of cultivation. Most of the land is stony desert, covered by a gravelly " desert carpet."

In the western part the " Beersheba area " has an extent of 3,200 sq. km., of which 1,600 sq. km. are regarded as cultivable land (63). The Beersheba area is mostly covered by a loessial soil gradually assuming a more loamy character towards the west and north. Most of the area in the south and many stretches towards the west are covered by moving sand dunes.

(ii) *Climate.*—Rainfall is sporadic, and in many years no harvest at all is possible. Table 11 gives the rainfall at various places in this region.

TABLE 11

MEAN ANNUAL RAINFALL IN THE NEGEB (MM.).

Auja Hafir	Khan-Junis	Ras Zu-weira	Kurnub	Asluj	Beersheba
100	270	115	76	90	240

The mean annual temperature exceeds 20° C. everywhere. Winds are sometimes very strong, and the whole area is afflicted by dust storms.

(iii) *Geology.*—The geology of the Gaza-Beersheba district is described by Picard and Salomonica (64). The oldest formations are cretaceous and are found in the neighbourhood of Beersheba. Besides hard Turonian limestone, series of chalk, breccious flint, and phosphatic limestone belonging to the Campanian-Maastrichtian are also found. Then follows the Danian zone and soft Eocene limestone. Oligocene is represented by a quartzitic chalky marl and hard limestone. Sporadically, marl of Miocene Age is also exposed. The main rocks of Pliocene Age are sandstones and marls. The gravel on the mountain slope and all the older dunes of the coastal plain belong to the Pleistocene, the latter being often covered by a dark-brown loamy soil which should be distinguished from the loess. This short survey shows that limestone and sandstone are the soil-forming rocks.

(iv) *Hydrology.*—The enormous amount of rain that falls in the southern part of the Judæan highlands drains mainly into the Negeb. The gorges (wadis), dry in summer, become filled with muddy, roaring torrents in winter, sometimes causing great devastation. The Wadi Shari'a and the Wadi Ghazza should be especially mentioned, the latter forming a bed ¼ km. in breadth south of Gaza. Since much of the rain caught in the mountains probably flows underground to the Negeb, the hope of striking large subterranean reserves of water by boring was considered justified. Borings made by the Government of Palestine showed that such strata exist generally at great depth and are very saline. Only the dune region yielded water of better quality, but of limited amount. Many shallow wells show water of better quality, but the amount of water obtainable from them is everywhere insufficient for agricultural purposes.

The high salt content of the underground water may partly be attributed to salt-bearing rock strata. The Eocene in Palestine is known to contain sometimes salt (82), and a rock near Wadi Sheneq, *e.g.*, showed a content of 1·4 per cent. sodium chloride !

Two complete analyses of water were made by the author, the first being a sample of the abundant supply of a deep water-horizon (at km. 26 of the Beersheba-Gaza road), and the second a sample from a shallower horizon (near Beersheba), which, however, yielded insufficient water for agriculture.

TABLE 12

Analyses of Water (mg. per Litre).

	Na	*K*	*Ca*	*Mg*	*Fe*	HCO_3	*Cl*	SO_4
1. Boring at km. 26, Gaza-Beersheba road ..	1,927	54	353	250	Tr.	164	3,553	944
2. Boring near Beersheba ..	276	6	130	147	Tr.	232	507	323

Analysis shows that the water from well No. 1 contains 7,637 mg. of salts per litre, and is therefore absolutely unfit for agricultural purposes.

(v) *The Loess Soil.*—It is generally assumed that the loess owes its origin mainly to the dust storms of the desert. The æolian movement of these soils can readily be observed. Range (20), the first to describe these soils as loess, found Egyptian potsherds of the second millennium B.C. beneath a layer of loess 3 metres thick. It seems, nevertheless, quite plausible that the " loess " is not only composed by material blown out from the desert, but that it includes to a great extent locally weathered material. The weathered product of he local limestones shows a loessial character and resembles to a great extent the soils found in the Western and Lybian deserts. It may be mentioned that a none-æolian theory of loess formation is held by Berg (65).

Æolic and fluviatile redisposition of the weathered soil is surely taking place and in such cases the thickness of the loess may vary between 3 and 15 metres.

The loess is of a yellowish colour and microscopic examination shows it to consist mainly of grains of fine quartz intermixed with chalky particles, the latter sometimes indicating a fossil origin. Chemical analyses of two typical loess soils, which were absolutely uniform in structure, gave the following results:

TABLE 13

ANALYSES OF LOESS SOILS

SAMPLE NO. 1 TAKEN NEAR BEERSHEBA AND SAMPLE NO. 2* TAKEN AT KM. 26 ON THE GAZA-BEERSHEBA ROAD (PER CENT.)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	CO_2	HCO_3	N
No. 1	59·97	4·30	3·40	12·70	1·58	0·61	0·97	0·11	0·28	10·93	6·24	0·06
No. 2	66·70	0·64	4·33	14·15	1·61	0·21	0·11	0·20	0·05	8·25	2·59	0·07

The pH of these soils was 7·8 and 7·9, respectively.

* On soil No. 2, hard chalky sandstone is struck at a depth of only 7½ Metres.

These analyses show that the loess soils are rich in calcium but poor in iron and alumina. Nevertheless, mechanical analysis shows that the loess contains a high percentage of fine particles, mainly belonging to the " fine sand " fraction. Even ordinary chemical analysis indicates comparative richness in mineral nutrients and deficiency in nitrogen. The mechanical composition of the loess is given by the following typical analysis:

TABLE 14

MECHANICAL ANALYSIS OF A TYPICAL LOESS SOIL (PER CENT.)

Course sand.	*Fine sand.*	*Silt.*	*Clay.*
0·40	61·11	24·62	13·87

These loess soils are easily permeable to water and air and of a texture most suitable for cultivation. The drainage also is excellent, as can be seen from the easy absorption of rain-water. The lime content of these soils averages about 25 per cent. and is most advantageous. The reserve of mineral nutrients was determined on two samples by Neubauer's method and gave the following results:

TABLE 15

NEUBAUER ANALYSIS OF LOESS SOILS

	P_2O_5 (*mg.*).	K_2O (*mg.*).
Sample 1 (Beersheba)	9·3	21·5
Sample 2 (5 km. north of Beersheba	7·8	29·0

These figures show the soils to be sufficiently provided with nutrients for the growth of barley, the main crop of the Negeb. The comparatively high amount of nutrients is easily explained by the fact that, owing to climatic conditions, there is no leaching of salts; during the greater part of the year there is capillary movement from the deeper layers to the surface, where the water carrying the salts evaporates. On the other hand, loess soils are deficient in organic matter and nitrogen, a fact for which climate is responsible. Various analyses showed the nitrogen content to vary between 0·05 and 0·07 per cent. Given sufficient water and nitrogenous fertilisers, these soils are capable of producing excellent yields.

Irrigation experiments with loess soils.—Rainfall being very sporadic, experiments were carried out to determine the salt-resistance of various plants grown on these soils and irrigated with saline water (the only water available) containing varying amounts of salts (66).

In greenhouse experiments, soil No. 2 was used and the water was brought from the well at km. 26, Gaza-Beersheba road, the water being diluted with distilled water to various concentrations.

In the field experiments near Beersheba, water of the Beersheba town supply was used for the lowest concentration (160 mg. Cl per litre) and for the higher concentrations the well-water No. 2 at the experimental field (containing *c.* 500 mg. Cl per litre) was employed. In order to obtain higher concentrations sodium chloride was added in varying amounts, a justifiable procedure because in Palestine salinity is mostly due to the presence of this salt.

The following table records the salt-resistance of various plants in some of our experiments. The harvest obtained when irrigating with water containing only 100-350 mg. Cl per litre is put at 100, and the other figures show the percentage of harvested material when the plants were irrigated with water of higher salinity. All experiments were run in duplicate and sufficient nutrients were added.

TABLE 16

PERCENTAGES OF YIELD OBTAINED AFTER IRRIGATION WITH WATER OF VARYING SALINITY

Mg. Cl per litre :	100–350	500	750	1,000	1,500	1,750	2,000	2,500	3,500
Potatoes*	100	35	14	11	0	—	5	0	0
Berseem	100	72	0	0	0	—	0	0	0
Barley	100	—	75	50	—	31	—	—	6
Onions*	100	71	51	40	16	—	9	3	6
Durra*	100	82	84	73	68	—	25	19	0
Maize I	100	89	92	67	64	—	43	24	0
Maize II	100	—	83	56	54	—	28	28	17
Sugar-beet	100	59	—	60	54	—	37	29	19
Bermuda grass	100	—	103	—	96	84	—	—	29

* Field experiment; all other experiments were carried out in the greenhouse at the Hebrew University.

These figures show that even with a salinity of 1,500 mg. Cl per litre, durra, maize, sugar-beet, and Bermuda grass give yields of over 50 per cent. of those obtained under normal conditions of irrigation. (It should be noted, however, that maize was harvested in the greenhouse as green fodder.) The enormous salt-resistance of Bermuda grass is, of course, well known (67).

Nevertheless we hold that, under the climatic conditions of Palestine, no irrigation with so saline a water can be recommended, except perhaps for date palms and similar plants, since the salts tend to accumulate in the soil, and owing to the scanty rainfall they are not leached in the rainy season. The following figures, which could be amplified by many others, show the salinisation taking place during the vegetation period of 3-4 months:

TABLE 17

SALINISATION OF SOIL AT END OF VEGETATION PERIOD

Irrigation water containing Cl, mg. per litre.	*Potatoes (greenhouse), Cl in soil (per cent.).*	*(Durra (field experiment), Cl in soil (per cent.).*
160	0·04	0·03
500	0·09	0·04
750	0·18	0·07
1,000	0·28	0·10
1,500	0·33	0·23
2,000	0·30	0·33
2,500	0·34	0·45
3,500	0·49	0·73

It may be mentioned that Puffeles (69) found strong alkalinisation in his experiments with saline water and Beersheba soils.

Agricultural Possibilities.—To-day barley is the most important crop, covering about 80 per cent. of the total area sown. Besides wheat, durra, water-melons, and beans are sown by the Bedouins. Agriculture seems to have been much more highly developed in antiquity (68). The remains of ancient settlements and ancient cultivation found at various places should, however, not deceive us into exaggerating its importance. Such settlements were first and foremost caravan stations. For the growing population such caravan centres had naturally to provide storage facilities of water in order to render possible a modest cultivation of vegetables, etc. Although such storage facilities, terracing, and the skilful exploitation of run-off water from the hills may still excite our admiration, we should nevertheless be careful not to be misled. In isolated cases the storage of run-off water may be possible, but an experiment undertaken by the Government of Palestine (7) in recent years proved to be a failure. More experiments of this kind will be carried out near one or two of the new Jewish settlements established in the Negeb.

Unless sweet water is brought into the Negeb (*cf.* pp. 170 *et seq.*) or unless run-off water is stored in sufficient quantities the agricultural future of the Negeb will have to be based on dry farming. This does not mean that the present methods of farming could not be considerably improved. The rain should be conserved and care be taken that every inch of it soaks into the soil. For this reason no run-off of water should be allowed. This aim can partly be achieved by terracing and contour ploughing, but probably the most efficient method of rain-water storage in the Negeb is offered by the basin-listing method developed recently in the U.S.A. This method consists in building dams at intervals across the contoured furrows and so making reservoirs that are capable of holding the rain. Future experiments should be carried out in this direction.

2. SEMI-ARID REGION.

(a) *Mediterranean Steppe Soils*

North of the boundary line Beersheba-Gaza, mentioned in the last section, we come to a district with a higher rainfall; it is the belt which lies between the rain factors 15 and 30. Towards the north the loess merges into a brownish, greyish-brown, or even a bright brown loam. According to Range (20), the origin of this loam is to be ascribed to material having been washed down from protrusions of the marine diluvium and from the calcareous strata of the highlands, and then becoming mixed with loess. Now because, on the one hand, Red Earths are never found in this region, and, on the other hand, the soils are rich in calcareous concretions, we believe that they can best be characterised as "Mediterranean Steppe Soils." The potash and phosphate contents of these soils, owing to climatic conditions, are usually extremely satisfactory, and, consequently, agriculture is well

TABLE 18

DETERIORATED CITRUS GROVE ON LOAM NEAR GAZA

	A. 0-30 *cm.* *Yellowish Sandy Loam with Small Calcareous Concretions.*	*B.* 30-70 *cm.* *Yellowish Loamy Sand with Small Calcareous Concretions.*	*C.* 70-125 *cm.* *Yellowish Loam with Calcareous Concretions.*	*D.* 125-150 *cm.* *Yellowish Loam with Calcareous Concretions.*
	%	%	%	%
H_2O ..	2·33	3·00	4·45	3·97
$CaCO_3$ ..	6·15	6·82	16·39	14·03
pH	8·6	8·1	8·3	8·5
Water Extract:				
HCO_3 ..	0·06	0·04	0·04	0·04
Cl	0·04	0·04	0·02	0·01
SO_4 ..	0·03	0·03	0·04	Tr.
Total salts ..	0·19	0·14	0·08	0·07
Water capacity	25	24	35	33
Water permeability	2·71	2·56	0·66	1·16
Mechanical Analysis (mm. diameter):				
1·00 - 0·25 ..	2·24	1·70	1·05	0·55
0·25 - 0·05	70·52	67·25	58·60	61·95
0·05 - 0·01	16·90	27·20	37·15	35·60
Less than 0·01	10·44	3·85	3·20	1·90

developed. In these soils we found P_2O_5 contents of 0·2 per cent. and over, and a K_2O content of 0·1 per cent.

Irrigated crops flourish exceptionally in this district, provided that care be taken in the choice of soil and of the irrigation water. The latter factor is of particular importance, because salinisation can easily set in as a result of the dryness of the climate. In the vicinity of Gaza, for instance, we found, on a loam soil with a very impermeable sub-stratum, a citrus grove whose development had been severely checked by chlorosis. Although the injurious effects are scarcely recognisable analytically in the case of this young plantation, there is no doubt that energetic steps had to be taken to save it (22).

The water used for irrigation had a high chloride content and was taken from a depth of 33 metres. At a depth of 6 metres there is a less copious water supply, which, in comparison with the water at a greater depth, has a low chloride content. (The fresh water, with a lower specific gravity, floats on the saline denser liquid.) A mixture of the two supplies had been used for irrigation, and an examination of this water yielded the figures shown in Table 19.

TABLE 19

IRRIGATION WATER AT GAZA (MG. PER LITRE)

HCO_3	415
Cl	417
SO_4	120
Total salts	1,140

Obviously water with such a high chloride content (corresponding to 680 mg. NaCl per litre) is quite unsuitable for the irrigation of citrus trees.

The permeability of the soil to water was measured by the following method: Cylinders, as described by Kopecky (55), were filled with sifted soil, and the time required for 1 litre of water to pass through the cylinder was noted. From this observation, the number of litres which would pass in twenty-four hours was calculated. This is the measure of permeability cited in the tables. Referring now to Table 18, we see that in this instance the permeability attains its lowest value in the C stratum, whilst the water capacity here reaches its highest value. These results must be attributed to the fact that the clay and silt fractions attain their maximum value in this layer (over 50 per cent.). The relatively high degree of compactness of this layer appears to obstruct root growth in a downward direction, for, up to the present, roots have not penetrated this layer; but it must be remembered that the high-water capacity prevents adequate aeration, a contributory factor which cannot be ignored.

Both the chloride content and the total salt content diminish from A to D, and this must be attributed to the fact that the irrigation water has a high salt content, and in summer the salts are deposited after the ascent of the water to the surface by capillarity. Slight traces of soda formation were detected in the A layer. Although up to the present sodium chloride has not accumulated to a very great extent in the soil, it is nevertheless to be feared that a gradual salinisation will take place if no preventive measures be taken. Up to the present, chlorosis in this part of the grove (another profile of this grove is described on p. 133) is not to be ascribed so much to the chlorides present in the soil as to the chlorides absorbed by the plant roots directly from the irrigation water.

Any amelioration by drainage seems to be out of the question. Since the upper water horizon, though providing rather a scanty supply, proved to have a low chloride content, the farmer was advised to use this water alone and to dig additional wells for this purpose. The advice was followed and the grove is now in a much better condition.

(b) Dune Sands

Almost the whole of the Palestine coast south of Jaffa is fringed by sand dunes gaining a depth of 5 km. and more at many places. North of Jaffa the dune belt is more often interrupted, and with the exception of the Hadera-Cæsarea region it is much narrower.

This dune sand is not brought to Palestine by the Nile, as is so frequently asserted (62), nor is it a product of local weathering only. Quartz is predominating, but minerals of the Hornblende and Augite group are also abundant (70). It seems obvious that the dune sand originating from the Sinai desert has accumulated along the Palestine coast by coastal sea-drift, the prevailing wave-and-wind direction being S.W. Local material is added by the action of the surf and predominates, *e.g.*, near the Lebanese border, where over 90 per cent. of the dune sand consists of calcium and magnesium carbonate. In Syria, where volcanic rock approaches the shore south of Lattaquie (Banyas), the sand is black and basaltic.

The dune sand has made considerable inroads upon fertile country and its effect can well be observed at places like Gaza, Ashdod and Ascalon, where the ancient harbours are to-day completely sanded up. It is with feelings of wonder that we see the march of the dunes on the town walls of Ascalon (finally destroyed in A.D. 1270), whose southern rampart, 4 metres thick and 8 metres high, is already nearly buried (20). The Forest Department of the Palestine Government is striving to stem the advance of the dunes by means of plantations (*Acacia cyanophylla*, tamarisk, and grasses, such as *Artemisia monosperma* and *Anophylla arenaria*) (*cf.* p. 150).

Where dune sand is overlying alluvial soil in a shallow layer ideal conditions for plantations are created. Plantations, however, also exist on deep dune sand accumulations, and their success depends, of course, on the quality of the irrigation water (22). The following examples may be given to illustrate the point:

A Deteriorated Citrus Grove on Pure Dune Sand, near Gaza.—This grove was planted about forty years ago; Shamouti was grafted, partly on Sweet Lemon and partly on Sour Lemon stocks. In both cases the trees are now highly chlorotic, those on Sweet Lemon being completely crippled at a height of 1 to 1½ metres, whereas those on Sour Lemon are better developed. The grove is said to have suffered from drought during the last war.

The oranges grafted on Sweet Lemon yield a maximum crop of 1 box per tree, whereas those on Sour Lemon yield, in some years up to 3 boxes per tree, and in other years almost no fruit whatsoever. It is said that the crops were better about 25 years ago, and this may be due to the fact that at that time the irrigation water had a much lower chloride content.

TABLE 20

Irrigation Water at Gaza (mg. per Litre)

HCO_3	342
Cl	195
SO_4	250
Total salts	834

Reaction alkaline.

The irrigation water is found at a depth of 38 metres. Owing to the nature of the soil irrigation has to be carried out every eighth or tenth day. The water has a fairly high chloride content and also a high sulphate content, and is thus not suitable for irrigation purposes.

Dune sands, such as these, have an exceedingly low water capacity and a very high water permeability. For these reasons the roots penetrate to great depths. Strong roots were found even at the lowest point of the examination pit at a depth of 1½ metres. It will readily be seen that such sands will never show a high salt content, for their adsorptive capacity is low as a result of their low clay and humus contents. Because of the perfect drainage all the layers show about the same salt content; as water cannot rise to the surface in a sand soil we do not find an accumulation of salts on the surface. Chlorosis is caused, not by the chloride content of the soil, but by the saline irrigation water directly taken up by the roots. Because of the complete absence of any material capable of absorption, such sand dunes are, of course, very poor in nutrient substances. For the same reason the alkalinity is fairly high (pH 8·6), and in the absence of other buffering substances they are directly dependent for buffering on the small amount of bicarbonates present.

The poor growth of the trees is caused by the bad quality of the irrigation water (chlorides and sulphates), the bad physical condition of the soil, which, being a pure dune sand, has a very low water capacity and a very high water permeability, and by the lack of nutrient material caused by the bad physical conditions.

TABLE 21

Deteriorated Citrus Grove Soil (Dune Sand) near Gaza

	A. 0-35 *cm.* *Dune Sand, with Traces of Humus.*	*B.* 35-50 *cm.* *Dune Sand.*	*C.* 50-150 *cm.* *Dune Sand.*
	(%)	(%)	(%)
H_2O	0·27	0·12	0·19
$CaCO_3$	1·68	0·39	0·59
pH	8·6	8·6	8·6
Water Extract:			
HCO_3	0·004	0·002	0·002
Cl	0·003	0·006	0·006
SO_4	—	—	—
Total salts ..	0·05	0·07	0·05
Water capacity ..	9	3	6
Water permeability	72·00	96·00	68·57
Mechanical Analysis (mm. Diameter):			
2·00 - 0·25	1·25	0·75	0·60
0·25 - 0·05	96·00	98·25	97·90
0·05 - 0·01	1·50	—	0·50
Less than 0·01 ..	1·25	1·00	1·00

Plantations develop very differently when they are not situated on a perfectly pure dune sand, and especially when the irrigation water contains only small quantities of salts.

Well-Developed Citrus Grove on Loamy Dune Sand, near Gaza.—This grove was planted at about the same time as the one mentioned above—*i.e.*, about forty years ago.

Photo by Keren Hayesod.

IV.—THE MUCH-DISSECTED JUDÆAN DESERT WITH THE DEAD SEA IN THE BACKGROUND. NOTE THE SOFT EROSION OF THE SENONIAN CHALK.

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[Photo by Keren Hayesod.

V.—THE MEANDERING JORDAN WITH RIVERINE VEGETATION. THE MUCH-DISSECTED "LISAN MARLS" ARE OFTEN CAUSING "BAD LAND TOPOGRAPHY."

In most cases Shamouti was budded on Khushkhash (Sour Orange Stock). The trees are well developed and give fair yields of about 3 boxes per tree.

TABLE 22

IRRIGATION WATER (MG. PER LITRE)

HCO_3	366
Cl	135
SO_4	—
Total salts	408

The main difference between this and the former profile is because, firstly, the irrigation water has a much lower salt content, and, secondly, we have to deal not with pure dune sand, but with a mixture of loam and sand.

TABLE 23

LOAMY DUNE SAND NEAR GAZA

	A. 0-50 *cm.* *Yellowish Loamy Sand.*	*B.* 50-90 *cm.* *Greyish Loam with Large Calcareous Concretions.*	*C.* 90-150 *cm.* *Greyish Loam with Large Calcareous Concretions.*
	%	%	%
H_2O	1·43	2·35	2·22
$CaCO_3$	11·35	8·73	10·58
pH	8·3	9·0	9·2
Water Extract:			
HCO_3	0·04	0·07	0·08
Cl	0·03	0·02	0·01
SO_4	0·03	Tr.	Tr.
Total salts	0·16	0·11	0·15
Water capacity	21	33	34
Water permeability	0·65	0·26	0·14
Mechanical Analysis (mm. diameter):			
1·00 - 0·25	0·26	3·65	5·70
0·25 - 0·05	48·90	42·85	41·90
0·05 - 0·01	10·30	10·45	9·60
Less than 0·01	40·55	43·05	42·80

Here the irrigation water is found at a depth of 35 metres, and as the analysis shows, is suitable for irrigation purposes. The Cl content of 135 mg. per litre is not too high, especially when we take into consideration the fact that we are dealing with a very sandy soil.

As will be seen from the analysis, all three layers contain appreciable amounts of silt and clay. For this reason the water permeability is much lower than in the previous examples, and the water capacity is somewhat high, especially in the C layer. In every other respect the soil is similar to the dune sand described above. The difference in the growth of the tree and in the better yields is explained by the fact that the irrigation water here is much more suitable than in the other instances. It produces no harmful effect whatsoever when absorbed by the plant roots.

Still another example may be cited to illustrate the fact that dune sand is capable of serving as a suitable substratum for citrus plantations, provided that suitable water be used for irrigation purposes.

Well-Developed Citrus Grove on Dune Sand near Ascalon.—The grove was planted in the year 1923, Shamouti being grafted on Sweet Lemon. The yield is about 2½ boxes per tree. The irrigation water has a Cl content of 51 mg. per litre (for complete analysis see p. 17).

TABLE 24

DUNE SAND NEAR ASCALON

	A. 0-20 *cm.*	*B.* 20-70 *cm.*
	%	%
H_2O	1·3	1·6
$CaCO_3$	16·5	6·74
pH	7·7	8·0
Water capacity	15·5	16·4
Water Extract:		
HCO_3	0·067	0·061
Cl	0·004	0·004
SO_4	—	—
Total salts	0·075	0·075

The examination shows that here again we have a slight admixture of loam, for the water capacity is about twice as high as that found in the pure dune-sand profile described on p. 48.

3. SEMI-HUMID REGION.

In the northern portion of the Maritime Plain, the Plain of Sharon, we do not find extensive dune-covered areas of recent formation as in the southern portion of the plain, where the dunes generally attain a height of about 10 metres. In the north, bare dunes of wind-blown sand are only of isolated occurrence. The moister climate of Central Palestine has prevented a great development of sand dunes. The course of weathering is in accordance with the change in the climate. Deeply cut cañon-like valleys, the wadis, which are dry in summer, are found everywhere in the mountains and foothills.

(a) *Kurkar Soils.*

The substratum of the Maritime Plain of Palestine is, almost without exception, composed of Senonian Chalk, which is covered by marine diluvium whose age cannot be determined with certainty.

In the neighbourhood of the coast this layer consists of a friable, calcareous sandstone, which is to be regarded as a coastal formation, the original dune sand having been cemented anew by the upward filtration of telluric waters containing calcium and silica in solution. The primary product of the weathering of this calcareous sandstone is locally called "Kurkar," and consists of calcareous sand concretions which vary in diameter between ½ and 20 cm.

The following table gives the analyses of such a calcareous sandstone, and of the Kurkar soil to which it has given rise, though the latter has more of the characteristics of a rock gravel (11).

TABLE 25

CALCAREOUS SANDSTONE AND RESULTANT KURKAR SOIL

	Calcareous Sandstone.	*Kurkar Soil.*
	%	%
SiO_2	55.30	73.75
Al_2O_3	0.35	1.05
Fe_2O_3	0.53	1.45
CaO	24.76	14.20
MgO	0.44	0.16
K_2O	Tr.	Tr.
Na_2O	Tr.	Tr.
P_2O_5	Tr.	Tr.
CO_2	19.50	10.99
H_2O	0.26	0.85
N	—	—

Wherever this Kurkar soil occurs, and wherever it is to be found at a slight depth below the surface, the soil is quite unsuitable for citrus culture. It is only possible for the trees to grow in such places when the layer of weathered soil is of sufficient depth to afford the necessary root anchorage and to provide the necessary nutrients, with the further proviso that the irrigation water does not drain away too rapidly. The tree roots never enter the Kurkar layer, but terminate at a sharply defined level above it.

(b) *Red Sandy Soils.*

In complete contrast to the Kurkar soils, wherever the calcareous sandstone has weathered to form a deep red sandy soil we have a soil which is almost ideal for plantations of citrus. It is in this very area that we find the chief centre of the citrus culture in Palestine. The formation of this soil is quite strikingly connected with the more humid conditions of the district. Every traveller coming from the south is amazed at the brilliant red colour displayed by the soils alongside the railway-line from, approximately, Rehoboth onwards; the colour appears to be especially intense where the soil has been freshly ploughed.

The evolution of this soil has not so far been explained. Though certainly, in part, connected with fossil soils it appears to us that there is no doubt that these red sandy soils are still being formed at the present time. The chemical composition of an example of these soils is given in Table 26.

TABLE 26

CALCAREOUS SANDSTONE AND RESULTANT RED SANDY SOIL

	Calcareous Sandstone.	*Red Sandy Soil.*
	%	%
SiO_2	22·10	93·24
Al_2O_3	0·70	1·88
Fe_2O_3	0·82	1·80
CaO	48·83	1·25
MgO	0·31	0·08
K_2O	Tr.	Tr.
Na_2O	Tr.	Tr.
P_2O_5	Tr.	Tr.
CO_2	27·53	1·15
H_2O	0·63	1·97
N	—	Tr.

The calcareous sandstone appears to be a hard and massive formation, so that we probably have to deal with a deposit of marine origin and of the Pleistocene to Pliocene Periods. The layer of soil covering this rock consists of a brilliant red sand and is approximately 1 metre in thickness. Microscopic examination has revealed the presence of magnetic compounds of iron in a fine state of division; but it appears to us to be of especial interest that the individual quartz grains of all sizes of which the soil consists are all surrounded by a thin film of compounds of iron, which dissolve readily in dilute hydrochloric acid or even in boiling water. As is seen from the analysis, the dominant change in the evolution of this soil is the removal of calcium carbonate. Nevertheless, the soil cannot well be regarded simply as a "residual soil" in the sense of the residual theory promulgated by W. G. zu Leiningen (23). The latter theory could well explain the enrichment in silica and sesquioxides, but not the brilliant red film of iron compounds which coats the individual grains. These iron compounds cannot be simply a residue, for the iron must have been in solution before it coated the grains. We believe that we are able to explain this primary dissolution of the iron (11) by the aid of colloidal silicic acid as peptising agent, in a manner similar to that described later in the formation of the Red Earths. But even this explanation is not completely satisfactory, for, as we will see later, in the substratum of these soils are often found quite massive layers of clay, whose sesquioxide content can scarcely have come from the calcareous sandstone. Further, it must be clearly understood that in many cases these soils are indubitably of fossil origin, since, for instance, Blake (24) found Red Sands overlaid by calcareous sandstone.

From an agricultural point of view these soils are, as already noted, the ones which are most suitable for citrus culture. The clay content, small in amount but strongly colloidal in character, imparts ideal moisture characteristics to this almost pure sand. Attention may, however, at this point be drawn to the fact that these soils are universally deficient in calcium and require heavy dressings of lime. Analysis and experience show that the red sandy soils are at the same time most deficient in all other nutrients (*cf.* p. 138).

As a result of the calcium deficiency the reaction of the red sandy soils is, for the most part, approximately neutral (pH 7·1 to pH 7·6).

(c) *Nazzaz Soils.*

A compact, impermeable pan-layer, concretionary in character, is often found at a slight depth below the surface in red sandy soils (and also in dune sands). This layer, locally known as "Nazzaz," when well developed can render any attempt at citrus culture abortive. These concretions, red, yellow and black in colour, of silicic acid and oxides of iron and aluminium, frequently occur in such quantities that the layer displays definite clay characteristics. Consequently the soil is sealed, with the result that the tree roots cannot obtain an adequate supply of oxygen, and at the same time the soil becomes impermeable to water. The colloidal fraction is considerable, and a further characteristic is the marked calcium deficiency and, often decidedly, acid reaction. The calcium deficiency is responsible for the clay in this layer being in single-grain structure and consequently closing the soil pores.

Menchikovsky (25) and, later, Ravikovitch (26) suppose that the formation of this Nazzaz layer is a result of the degradation of the red sandy soils, in which the iron and aluminium compounds are gradually washed down to lower levels where they bring about the formation of a pan. The explanation given by these two authors for the evolution of this sesquioxide layer, often attaining the thickness of a metre, appears to be inadequate, for it seems impossible that the trifling amounts of iron and alumina present in the red sandy soils can lead to such an accumulation of sesquioxides. Bergy made the attempt (27) to explain the extraordinary accumulation of sesquioxides by the transport of iron and alumina in the colloidal state from the mountains during the Mousterian Period (Stone Age). Similar views are held by Picard (70), according to whom fluviatile material was poured in from the mountains in the east, especially during the Lower Pleistocene.

A description, in rather greater detail, will now be given of a light Nazzaz soil from Kefar Saba, on which the growth of trees has been affected to a marked extent (22).

The red sandy soil is underlaid at a depth of 76 cm. by a Nazzaz layer, about 30 cm. in thickness, which is very compact, hardens on drying, and contains many black, red and yellow concretions of iron and aluminium (ferrous oxide is not present) (Plate X). Not only is the water permeability at its lowest value, but the water capacity is at its highest, undoubtedly owing to the fact that in this layer the colloidal fraction attains its highest value. In accordance with the highest value for the clay fraction in the D

TABLE 27

"Nazzaz" Profile near Kefar-Saba

	A. 0-26 *cm.* *Yellowish Red Sand.*	*B.* 26-41 *cm.* *Red Sand.*	*C.* 41-76 *cm.* *Red Loamy Sand.*	*D.* 76-105 *cm.* *Nazzaz.*	*E.* 105-135 *cm.* *Red Loamy Sand.*
	%	%	%	%	%
SiO_2	93·68	93·18	91·80	78·67	80·62
Al_2O_3	3·23	2·39	1·68	6·70	7·69
Fe_2O_3	1·36	2·17	2·50	5·12	3·19
CaO	Tr.	Tr.	Tr.	Tr.	Tr.
H_2O	0·89	2·65	3·68	8·50	8·81
Water permeability*	28·80	23·23	9·73	3·03	4·68
Colloidal clay	Tr.	Tr.	9·5	19·6	16·9
pH	7·5	7·0	6·6	6·6	7·0
	mg. Equivalents in 1,000 gm. of Soil.				
Water-Soluble:					
HCO_3	0·3	0·3	0·2	0·2	0·2
Cl	0·9	1·1	0·3	1·4	0·6
Exchangeable:					
H	0·3	0·3	0·6	0·5	0·6
Ca	25·0	24·7	19·1	85·6	75·0
Mg	9·0	11·0	17·5	46·8	40·5
K	2·8	4·6	3·6	3·8	4·9
Na	25·6	26·5	29·5	32·6	52·6

* See p. 44 regarding this value.

horizon, the percentage of iron also attains its maximum in this layer. The whole stratum is apparently cemented by compounds of iron and aluminium in a very fine state of division. Consideration of the absolute values of the physical constants (water permeability, water capacity, colloidal content) shows that these are not sufficiently high to afford a satisfactory explanation for the compactness of the Nazzaz layer.

The almost complete absence of salts and calcium carbonate is, of course, one of the factors contributing to the compactness of the layer. In the presence of salts or lime the primary colloidal particles are for the most part coagulated and in a coarse state of dispersion, whereas here the primary colloidal particles are in a very fine state of dispersion and consequently cause the pores of the soil to be choked. On the other hand, it may be that it is the chemical character of the finely divided iron compounds which is the most important factor concerned in the hardening and cementing of the Nazzaz. Roots penetrate only with great difficulty into such a layer, as Plate X clearly shows. It is easily understood that a root-depth of 76 cm. is quite insufficient for the normal development of a citrus tree. At the same time the pores of the soil are blocked in such a manner by iron concretions that the roots do not receive adequate supplies of oxygen in this layer. Further, the extraordinary deficiency of calcium in the whole profile is very significant, particularly the fact that the Nazzaz layer is distinctly acid (pH 6·6). Such an acid reaction—which has been encountered in a number of other Nazzaz layers—is remarkable when found in an arid country like Palestine, and may give valuable indications, not only as to the origin of Nazzaz, but also as to the agricultural methods to be employed in combating it.

Of particular interest is a study of the sorption complex (28) of these soils. Fortunately, irrigation waters in the principal planting areas usually have a low chloride content; the numerical ratio between their calcium and sodium contents is generally greater than 1.

Because the irrigation water contains a large percentage of calcium it would be expected that the calcium content of the sorption complex would greatly exceed the sodium content. But in the top-soil the conditions are entirely different. A calcium content larger than that of the sodium is to be found only from the Nazzaz layer downwards. This cannot be explained by the larger quantity of clay in the Nazzaz layer, for the sodium content remains unchanged. The most likely explanation appears to be that citrus trees assimilate relatively large quantities of calcium. This calcium supply is naturally extracted from those layers in which the roots develop. Since the roots cannot penetrate into the Nazzaz stratum, they draw their supplies from the upper layers and not from the Nazzaz layer itself. If we assume that every crop extracts from the soil about 100 kg. of lime per hectare (*i.e.*, $\frac{3}{4}$ cwt. per acre) per annum, we can understand why the sorption complex of the topsoil shows such an accumulation of sodium as compared with the calcium content. We therefore conclude that both soil research and plant physiology demand artificial liming as an urgent and indispensable cultural operation. This instance certainly proves that irrigation waters rich in lime do not form an adequate substitute for artificial liming, as has been maintained by one author (29). Lime accumulating in the Nazzaz stratum or percolating to the ground-water does not form such a substitute. Although the proportion of calcium to sodium in the irrigation water may be satisfactory, sodium indirectly accumulates in the sorption complex, bringing about undesirable changes in the soil and a physiological deficiency in lime. [*Cf.* Russell (58).]

(*d*) *Other Soils of the Semi-Humid and Semi-Arid Region—Alluvial Soils and Aclimatic Black Earths.*

Obviously the soils described above are not the only ones found in this climatic region, but merely those which are the most characteristic products of weathering. Wide stretches are covered by alluvial deposits, and these soils must be regarded as such, and not as climatic soil types.

The most extensive and most important area of alluvial soils is found in the Plain of Esdraelon (Emek) and its eastern continuation, the Plain of Jezreel, constituting an aggregate area of approximately 40,000 hectares. In its western part the plain is mainly filled by material brought down from the Samaritan and Galilean limestone mountains, whereas in its eastern part basaltic detritus is also taking part in its composition. The soils thus deposited by water transport are generally of very great depth and of clayey character. They are little adapted to plantations, for they are very liable to injury by the accumulation of salts, and the tree roots are not adequately aerated. It is the grain-growing district *par excellence* of Palestine, the formerly swampy areas being completely drained to-day. At the same time fodder crops are grown and an intensive dairy industry has developed.

Another type of alluvial soil is found in mountain-enclosed basins, some of them typical " poljes," by far the largest of which is the Sahl el Battauf (almost 5,000 hectares). Here drainage is very deficient and the basin floor is partly inundated into late spring. The deep reddish or brownish alluvial soil brought down from the mountains has therefore at many places been leached of its lime content. An analysis of such a soil gave the following result:

TABLE 28

ALLUVIAL SOILS FROM PALESTINE

	1 *Terra-Rossa (Mt. enclosed Basin Soil) (Sahl el Battauf)*	2 *Basalt Soil (Hittin)*	3 *Mixed Alluvium (Plain of Esdraelon)*	4 *Swampy Soil (Kabbara)*
	%	%	%	%
Coarse Sand ..	7·9	0·5	—	0·7
Fine Sand ..	9·2	11·3	11·1	10·2
Silt	8·9	13·5	9·9	14·2
Clay	66·0	61·8	57·3	52·3
H_2O	7·5	9·4	11·6	8·8
$CaCO_3$	—	4·2	10·2	13·2
*p*H	7·0	—	7·9	7·5

At many places alluvial soil was also deposited in the coastal plain. Some of such soils and their peculiarities are described on pp. 108 *et seq.* Wherever sand dunes prevent the natural drainage of the wadis carrying the rainwater from the mountains into the sea swampy areas are formed.

Thus in the basins of the Nahr Sukrer, Nahr Rubin, Nahr el Auja, etc., are found Black Earths, which resemble the Chernosem of Southern Russia. Their origin has already been explained by Blanckenhorn (30), who pointed out that in winter, in particular, the soils are really swamps. In winter the standing water not only prevents decomposition of the organic matter, but rather causes it to increase. In summer, again, the humus is protected by the dryness of the topmost layer of the soil. In Black Earths of this kind we found nitrogen contents of about 1 per cent. In the Kabbara Swamp, Menchikowsky (31) found salt contents of 7 per cent. and over, consisting mostly of the chlorides of sodium and magnesium. This salinisation of the soil is a result of the bad drainage alone, and it must be distinctly understood that it is not an instance of Black Alkali Soils —*i.e.*, soils containing soda. At the same time it must be pointed out that, thanks to the activities of the Palestine Jewish Colonisation Association, the Kabbara Swamp has been completely drained, whereby a marsh, infested with malaria, has been transformed into an excellent soil.

(*e*) *Peat.*

Palestine has, north of Lake Huleh, a considerable peat deposit, which differs in many respects from other known peat accumulations (74). The swampy character of the Huleh District results from an eruption of basalt which impedes the complete drainage of the Jordan into the Sea of Galilee. The resultant swamp covers an area of about 5,200 hectares. The vegetation consists chiefly of papyrus (*Cyperus papyrus*), but it also comprises ferns, reeds, and other aquatic plants (71, 73). In the surroundings of the peat profile described in Table 29 the plant cover was composed mainly of Papyrus, *Phragmites communis*, Polygonum, *Bidens tripartita*, and *Cynanchum acutum*. The profile was dug in June, 1937, about a hundred metres north of the lake near the Jordan River.

(i) *Chemical Characteristics of Palestine Peat.*

The distribution of organic matter and of certain inorganic components and the hydrogen-ion concentration of the peat profile are given in Table 30. This table shows that peat proper is first encountered at the depth of layer E, where the water table occurs. Palestine peat contains a high percentage of mineral matter, a feature common to all lowmoor peats. The overlying layers apparently consist partly of alluvial soil, and although rich in organic matter they nevertheless contain a large quantity of mineral matter. The reaction of these soil layers is fairly alkaline, whereas the peat itself is approximately neutral and in layer F even slightly acid. The pH values correspond roughly to the amounts of calcium carbonate present. The amount of hygroscopic water is, of course, smallest in those layers (C and D) which contain the least organic matter. It will be noted that in the bottom layer (I) a much lower content of organic matter and a correspondingly higher percentage of ash as compared with the immediately overlying layers are again encountered. As pointed out in Table 29, this layer contains many particles of grey clay. Such an accumulation of mineral matter in the lowest layer of a lowmoor-peat profile is common (79, p. 276).

In order to ascertain the composition of the mineral matter in the peat, an average sample of layers E-I was analysed. The results, in percentages, were as follows: H_2O, 13·95; organic matter, 62·91; SiO_2, 4·22; Al_2O_3, 0·15; Fe_2O_3, 5·31; CaO, 6·99; MgO, 0·17; Na_2O, 1·34; K_2O, 0·24; CO_2, 1·37; SO_4, 3·10; P_2O_5, 0·15.

Most of the Huleh-peat layers, like all lowmoor peats, are rich in calcium, which is present partly as carbonate and

TABLE 29

DESCRIPTION OF A PALESTINE PEAT PROFILE

Horizon.	*Depth.*	*Characteristics.*
	cm.	
A	0–10	Brownish-black clay soil with much organic matter (roots, etc.).
B	10–20	Brown clay soil with thin roots and yellowish-red concretions of iron.
C	20–40	
D	40–50	Brown clay soil.
E	50–70	*Water table.* Black peat with many decomposed roots.
F	70–90	Black peat. Abundant brown plant residues.
G	90–110	Black peat as above. Many red mouldered stains. Strong smell of H_2S.
H	110–130	Black peat as above. Fewer red stains. Weak smell of H_2S.
I	130–150	Black peat with many particles of grey clay. Yellowish-brown remains of plants. Few red stains. Faint smell of H_2S.

TABLE 30

WATER, $CaCO_3$, ASH, ORGANIC MATTER, AND HYDROGEN-ION CONCENTRATION IN THE PEAT PROFILE

(On an air-dry basis.)

Horizon.	H_2O.	$CaCO_3$.*	*Ash.*†	*Organic Matter.*‡	*pH.*
	%	%	%	%	
A	13·10	15·23	58·38	21·81	7·7
B	13·86	14·71	63·67	25·99	7·9
C	9·40	22·13	63·81	17·04	7·9
D	8·53	24·70	62·73	17·86	7·8
E	16·78	2·83	29·87	52·10	7·1
F	16·34	0·07	21·09	62·54	6·2
G	20·04	1·23	13·09	66·33	7·3
H	19·58	4·61	17·01	61·38	7·3
I	16·39	9·32	33·86	45·64	7·3

* Calculated from CO_2. † Excluding CO_2.
‡ Nitrogen content 1·53 per cent.

partly as sulphate. The latter is common in phragmites peat. The high content of iron is noteworthy. The peat is relatively rich in phosphoric acid and potash, but it is not so high in nitrogen as the more common lowmoor peats.

Clearly, the most important for our study are the organic constituents. Both the peat profile and the two main peat-forming plants were subjected to a detailed analysis according to the method of Waksman and Stevens (76). The

TABLE 31

COMPOSITION OF PEAT-FORMING PLANTS AND OF PEAT MATERIALS

(Percentages of total dry matter.)

	Ether-Soluble Fraction.	*Alcohol-Soluble Fraction.*	*Water-Soluble Fraction.*	*Hemicelluloses.*	*Cellulose.*	*Lignin.*	*Proteins.*	*Ash.*
Plants:								
Cyperus papyrus	1·43	3·08	14·39	21·35	25·74	12·15	9·49	4·53
Phragmites communis	2·45	2·67	17·59	21·26	23·45	9·59	10·62	10·95
Peat:								
A ..	0·18	0·15	1·45	2·04	0·92	13·23	4·88	74·72
B ..	0·19	0·20	1·05	2·01	1·02	13·23	4·86	69·86
C ..	0·16	0·11	1·34	1·94	1·01	6·24	3·13	81·19
D ..	0·11	0·10	0·91	1·92	0·95	5·36	2·93	80·49
E ..	0·30	0·51	1·18	4·43	1·96	33·68	10·16	37·39
F ..	0·27	0·66	1·49	4·60	2·76	45·14	10·18	25·22
G ..	0·23	0·81	1·48	4·64	3·39	49·11	9·21	17·01
H ..	0·35	0·81	1·49	4·58	2·12	49·73	9·54	23·68
I ..	0·25	0·78	1·52	3·96	1·44	34·23	7·42	45·45

results of this analysis* are given in Table 31. When the plant materials and the peat products are compared, it is readily seen from this table that important changes have taken place. The ether-soluble fraction (ethereal and fatty oils, part of the waxlike and resinlike substances), the

* Such terms as "hemicelluloses" and "cellulose" have been retained for the sake of convenience; it is fully realised, however, that the hydrolysable fractions need not accurately represent these constituents.

alcohol-soluble fraction (phlobaphenes, waxes, resins, alkaloids, chlorophyll, etc.), and the water-soluble fraction (sugars, organic and amino acids, alcohols, soluble proteins, part of the starches, tannins, and pectins, etc.) are greatly decreased in the peat, as are also the hemicellulose and cellulose fractions. Since the uppermost layers contain much alluvial material and since all the layers are very rich

TABLE 32

CHEMICAL COMPOSITION OF PEAT-FORMING PLANTS AND OF PEAT MATERIALS

(Percentages of water-free and ash-free material.)

	Water-Soluble Fraction.	*Hemi-Cellu-loses.*	*Cellulose.*	*Lignin.*	*Proteins.*
Plants:					
Cyperus papyrus ..	16·42	24·37	29·37	18·37	10·83
Phragmites communis	20·11	24·25	26·75	10·93	12·12
Peat:					
A	6·35	8·93	4·03	57·90	21·35
B	4·65	8·91	4·52	58·65	21·54
C	9·62	13·93	7·25	44·79	22·47
D	7·41	15·63	7·74	43·65	23·86
E	2·26	8·48	3·76	64·48	19·46
F	2·29	7·07	4·24	69·34	15·63
G	2·15	6·73	4·29	71·32	13·38
H	2·17	6·67	3·08	72·49	13·90
I	3·07	7·99	2·90	69·01	14·96

in salts, percentage increases in the lignins and proteins, calculated on a water- and ash-free basis, are very pronounced. Results calculated on this basis are shown in Table 32. It will be seen that the decreases of hemicelluloses and cellulose are slightly greater in the real peat layers than in the alluvial layers. The corresponding accumulation of lignins is to be ascribed to their resistance to decomposition. The decrease in water-soluble material is less in the uppermost layers (especially C and D) than in the true peat layers

[Photo by Keren Hayesod.

VI.—LOESS LANDSCAPE IN THE NEGEB. THE LOESS IS OVERLYING EOCENE LIMESTONE IN A SHALLOW LAYER. IT IS ONLY IN WADIS AND FLATS THAT ENOUGH SOIL HAS ACCUMULATED TO ALLOW FOR A PRECARIOUS CULTIVATION.

[Photo by Keren Hayesod.

VII.—THE PLAIN OF JEZREEL, WITH THE JEWISH COLONY OF BETH ALPHA (ALLUVIAL SOIL).

To face page 65

and, correspondingly, the increase in lignin is not quite so great here. The remarkable increase in the protein fraction in all layers may be regarded as due to the synthesis of nitrogenous microbial cell substances, resistant to rapid decomposition, as shown by Waksman and Stevens (77). These nitrogenous cell substances seem, nevertheless, to be subject to decomposition under anaerobic conditions, since

TABLE 33

NITROGEN DISTRIBUTION IN PEAT-FORMING PLANTS AND IN PEAT MATERIALS

(Percentages of total nitrogen.)

	Water-Soluble.	*Hydrolysable by Dilute Acids.*	*Non-hydrolysable by Dilute Acids ("Humin" N).*
Plants:			
Cyperus papyrus	9·9	25·7	64·4
Phragmites communis ..	10·5	25·0	64·5
Peat:			
A	4·7	28·1	67·2
B	4·4	27·6	68·2
C	4·4	22·0	73·6
D	5·3	24·1	70·6
E	3·7	24·8	71·5
F	3·7	34·5	61·8
G	4·2	20·5	75·3
H	4·0	22·6	73·4
I	4·8	14·6	80·6

the percentage of the protein fraction* diminishes gradually from top to bottom.

The distribution of nitrogen both in peat-forming plants and in the peat profile is shown in Table 33. As in all peats (76) the water-soluble nitrogen fraction (ammonia, nitrate, amino acids, soluble proteins) is very low. This is largely true also of the nitrogen hydrolysable by dilute acids (true proteins). Greenhouse experiments on the availability of

* The " protein fraction " does not, of course, necessarily consist of true proteins.

nitrogen in Huleh peat carried out by us have yielded negative results, a finding obviously attributable to the relative insolubility of the greater part of the nitrogen. The amount of insoluble " humin " nitrogen present is rather high, but is normal when compared with other types of lowmoor peat. The percentage of water-soluble nitrogen is much higher in the living plant than in the peat. Similar observations were made by Waksman and Stevens (77), who ascribe the relative decrease of soluble nitrogen in the peat partly to assimilation by growing plants and partly to the action of micro-organisms which decompose the hemi-

TABLE 34

Composition of various Plants which give rise to Peat

Percentages of total dry matter

	Plant.	*Ether-Soluble.*	*Alcohol-Soluble.*	*Water-Soluble.*	*Hemicelluloses.*	*Cellulose.*	*Lignins.*	*Proteins.*	*Ash.*
Typical for lowmoor peats	Cladium*	1·14		6·87	21·45	28·31	29·09	7·19	3·89
	Carex*	2·54		12·56	18·36	28·20	21·08	7·08	3·30
	Cyperus papyrus	1·43	3·08	14·39	21·35	25·74	12·15	9·49	4·53
	Phragmites communis	2·45	2·67	17·59	21·26	23·45	9·59	10·62	10·95
Typical for highmoor peats	Sphagnum*	1·47		3·86	30·82	21·13	6·97	5·88	3·18
	Sphagnum†	1·94	2·97	6·02	21·91	28·57	18·81	4·05	5·10
	Sphagnum†	2·54	2·23	10·11	26·79	28·69	16·20	2·73	3·24

* According to Waksman and Stevens (72).
† According to Kivinen (2) and Waksman (78).

celluloses and cellulose. In fact, all our figures point to the secondary formation of insoluble proteins, as demonstrated by Waksman and others (72, 75).

(ii) *Palestine Peat in comparison with other Peats.*

The chemical and physicochemical properties of a peat are closely linked with the nature of the plant associations from which peat is derived. The nature of these plant associations depends on climatic conditions and on such ecological factors as the chemical composition of the water. If only the two principal peat types are taken into account, it may be said that, in general, waters rich in calcium and other nutrients favour the development of sedges and reeds and ultimately give rise to a lowmoor peat; on the other hand, telluric waters or waters originating from soils poor in soluble minerals favour the development of mosses and bring about the formation of a highmoor peat.

Table 34 shows, however, that the chemical composition of different plant species is not so specific as might theoretically be supposed; such differences as are actually found may, in many cases, be explained by differences in development, age, and ecological conditions (72). The main difference apparent from these figures is in the protein content, which seems to be much lower in mosses than in sedges or reeds. Nevertheless, the corresponding peats show much more marked differences, and these must be ascribed to differences in the ecological conditions of the locality concerned, which in turn are largely determined by climatic factors.

Just as differences in climate may cause the same parent rock to yield essentially different soil types, so differences in climatic and ecological conditions may cause plants of similar composition to yield essentially different peat types. On the other hand, it must be borne in mind that, just as the nature of the parent material has a certain effect on soil formation, so also the nature of the plant exerts a considerable influence on the resulting peat. The nitrogen content of the plant is particularly important in this connection.

A lowmoor peat is characterised mainly by a low content of cellulose and a relatively high content of lignins, proteins, and ash; a highmoor peat, on the other hand, is poorer in the latter constituents and richer in the former. Consequently, lowmoor peats consist of much better decomposed plant residues, their percentage of lignin, the end-product of decomposition, being greatly increased. At the same time, synthesis of proteins by microbic cell activity takes place. Highmoor peats have a much lower percentage of proteins, and because, in turn, greater proportions of hemicelluloses and cellulose are still intact, the physicochemical qualities of these peats are very different from those of lowmoor peats.

Tables 35 and 36 illustrate the differences between peats and indicate the relative position of Palestine peat, a product of the Mediterranean climate. The amount of mineral matter in Palestine peat is extraordinarily high and must be ascribed to the prevailing climatic conditions. As the climate is Mediterranean, a rainy winter season alternates with a completely dry period in summer. Under these conditions the water table is subject to frequent fluctuations. The upper layers of the bog may dry out in summer and thus cause a capillary water movement from the lower layers to the surface. In consequence, salts are not leached out but concentrate in the uppermost layers, which also increase in lime content. Because the salts are not leached out,

TABLE 35

NITROGEN, MINERAL CONTENT, AND pH OF VARIOUS PEATS

On the basis of total dry matter

Type of Peat.	*Plant Formation.*	*Nitrogen.*	*Phosphoric Acid.*	*Potassium.*	*Calcium Oxide.*	*pH.*
		%	%	%	%	
Highmoor*	Sphagnum	0·64–0·74	0·03–0·04	0·02–0·03	0·15–0·65	3·5–4·5
Lowmoor*	Carex	2·47–2·94	0·14–0·20	0·05–0·06	1·80–4·50	5·5–6·5
	Phragmites	2·29–3·32	0·09–0·28	0·09–0·19	1·80–4·50	5·5–6·5
Palestine†	*Cyperus papyrus* and *Phragmites communis*	1·53	0·15	0·24	6·99	7·1

* According to Waksman (79, pp. 264, 276). † Average sample.

Palestine peat is rich in phosphoric acid and potash, nutrients which are important for bacterial activity. Closely associated with the high content of calcium in most layers is the hydrogen-ion concentration, which is near the neutral point and lower than that in lowmoor peats generally. In consequence, organic compounds in Palestine peat are saturated by bases. To this peculiarity, the high degree of decomposition in this peat must be partly ascribed, since a slightly alkaline reaction is most favourable to bacterial activity. The drying up of the top layers favours aerobic processes, and these too cause decomposition processes to proceed much more intensively. The high temperature prevailing throughout the year likewise favours bacterial processes.

Table 36 shows the organic composition of Palestine peat in relation to other types of peat. From this it may be seen that, compared with other lowmoor peats, Palestine peat possesses a relatively low amount of proteins. This circumstance might be ascribed to the presence of calcium, which causes nitrogen to be liberated and thus counteracts the synthesis of proteins by bacteria. The figures for cellulose and hemicelluloses in Palestine peat are very characteristic: because of the prevailing high degree of

TABLE 36

ORGANIC COMPOSITION OF VARIOUS PEATS

Percentages of total dry matter

Type of Peat.	*Plant Formation.*	*Ether-Soluble.*	*Alcohol Soluble.*	*Water Soluble.*	*Hemi-Celluloses.*	*Cellulose.*	*Lignin.*	*Proteins.*	*Ash.*
Highmoor	Sphagnum*	3·96			16·24	19·91	38·26	6·58	1·50
	Sphagnum†	3·53	4·56	7·82	18·15	16·55	38·53	3·81	1·48
Lowmoor	Phragmites and Cyperaceæ*	1·10		1·24	8·95	0	50·3	18·72	10·13
	Cyperaceæ†	4·73	5·10	2·98	12·32	5·44	41·78	14·72	4·95
Palestine	*Cyperus papyrus*‡ and Phragmites	0·28	0·71	1·43	4·44	2·33	42·38	9·30	29·75

* Waksman (78, p. 187). † Kivinen (72, p. 22). ‡ Average of layers E-I.

decomposition they are much lower than the figures for these products in other lowmoor peats. The same is true also of the ether- and alcohol-soluble substances, their great resistance to decomposition notwithstanding. It is only because of the high ash content that the increase in lignin is not pronounced (*cf.* Table 32, where all figures are calculated on an ash-free basis).

It should be remembered, as pointed out before, that the main value of peat in our case consists, not so much in its chemical properties as in its power to improve the physical conditions of irrigated soils. We therefore examined its water capacity and its capacity to absorb nutrients. The maximum water-holding capacity, the volume weight and the pH of various American peats (51) and of Huleh peat are shown in Table 37.

TABLE 37

PHYSICAL DATA OF VARIOUS AMERICAN PEATS AND OF HULEH PEAT

	Weight per Cu. M.	*Maximum Water-Absorbing Capacity.*	*pH.*
	kg.	%	
Moss-peat (partly decomposed)	144	1,485	3·8
Reed-peat (partly decomposed)	416	653	—
Sedge-peat (partly decomposed)	576	309	5·9
Woody peat	896	162	3·7
Sedimentary peat A ..	544	157	3·5
" " B ..	896	262	6·8
Huleh peat	783	246	5·7

These figures show that there is no similarity between the water-holding capacity of moss peat and that of Huleh peat, whereas the latter compares closely with woody and sedimentary peat. It should, however, be borne in mind

TABLE 38

EFFECT OF ADDITIONS OF HULEH PEAT ON MINIMUM WATER-HOLDING CAPACITY OF A SANDY SOIL

Mixture.		*Mixture.*		*Minimum Water-Holding Capacity.*
Sand	*Peat*	*Sand*	*Peat*	
gm.	*gm.*	%	%	%
10	0	100	0	7·3
9·5	0·5	95	5	11·7
9	1	90	10	12·3
8	2	80	20	18·5
7	3	70	30	23·7
6	4	60	40	27·0
5	5	50	50	32·7
0	10	0	100	66·7

that our sample of Huleh peat had been allowed to become too dry, whereby it lost much of its water-holding capacity. When various amounts of this peat were added to a sandy soil, changes were observed to have taken place in the *minimum* water-holding capacity, which are reported in Table 38.

In order to ascertain the amount of nutrients adsorbable by Huleh peat, 5 gm. of peat were shaken for two hours with each of the following solutions: (i) Potassium dihydrogen phosphate, (ii) potassium monohydrogen phosphate, and (iii) ammonium chloride. The results obtained are reported in Table 39.

TABLE 39

ADSORPTION OF NUTRIENTS BY HULEH PEAT

	Present in Original Solution.			*Adsorbed.*			*Adsorbed.*		
	gm.			*gm.*			%		
	K_2O	P_2O_5	N	K_2O	P_2O_5	N	K_2O	P_2O_5	U
(i)	0·217	0·328	—	0·084	0·150	—	38·7	45·7	—
(ii)	0·403	0·308	—	0·162	0·142	—	40·2	46·7	—
(iii)	—	—	0·63	—	—	0·035	—	—	5·56

The adsorption, of course, depends on various factors—as concentration of the solution, chemical combination of the salts, etc.—and no definite conclusions can therefore be drawn from these results. If we nevertheless assume that each year 8·5 kg. of K_2O, 3 kg. of P_2O_3 and 7 kg. of N have to be applied to 1,000 sq. m. of orange land, it may be roughly calculated that one ton of peat per 1,000 sq. m. suffices to absorb all the nitrogen, twice the amount of potash and ten times the amount of phosphoric acid.

Although, therefore, the sample of peat examined by us does not seem to be very suitable for the improvement of the water capacity of the soil, it seems to be well adapted to absorb nutrients and to protect them from leaching by irrigation water. Furthermore, such material makes a much better litter than straw. It should be borne in mind that only one sample of Huleh peat has been examined by us, and that many more examinations are to be carried out in order to ascertain definitely the value of Huleh peat for agricultural purposes. Such examinations are most important because the future of Palestine agriculture will depend on the supply of sufficient quantities of organic manure.

4. HUMID REGION.

In the highlands of Judæa and Galilee, where the annual mean temperatures are considerably lower, we have rain factors which exceed 50. If, for this reason, we designate the climate as *humid*, this naturally applies only to the winter months. If the yearly averages are considered, here again evaporation is in excess of the rainfall, as may be seen from the following summary given by Exner (32):

TABLE 40

EVAPORATION IN JERUSALEM IN MM.

Spring.	*Summer.*	*Autumn.*	*Winter.*	*Total.*
271	392	285	106	1,054

"Comparing the annual rainfall at Jerusalem (630 mm.) with the evaporation of an exposed surface of water, the rainfall shows a deficit of 0·4 metre." If, in the case of a reservoir which derives its supply entirely from the rainfall, we regard the rainfall as positive but the evaporation as negative, the following figures would show (according to Exner) the rise or fall in the level of the water during each month in mm.:

TABLE 41

CHANGES IN LEVEL OF EXPOSED RESERVOIR IN JERUSALEM

Jan.	*Feb.*	*Mar.*	*Apr.*	*May.*	*June.*	*July.*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
130	83	35	–50	–121	–135	–135	–122	–110	–107	6	102

This shows very clearly that this district can only be regarded as *humid* on the basis of our method of calculating the rain factors. Similar values will be found in a paper published by Ashbel (56) which deals extensively with the evaporation power of the atmosphere in various parts of Palestine.

(a) *Terra Rossa.*

(i) *General.*

On limestone, the most typical soil of the mountains is Terra rossa, though at the same time it must be pointed out that all limestones do not necessarily give rise to Terra rossa as a product of weathering. More particularly, the weathering of soft calcareous rocks seldom results in the formation of red-coloured products. These mountain marl soils are described on pp. 91 *et seq.*

Terra rossa is a product of the Mediterranean climate, whose chief characteristic is the alternation of rain in winter with a dry period in summer. This type of soil formation is found in all the Mediterranean countries—Spain, Southern France, Italy, Dalmatia, Syria, Cyprus, Palestine, etc. Where Red Earth formation is in progress the value of the rain factor usually lies between 30 and 60. Typical Terra rossa is developed on limestone, whereby, as a result of the absence of humus, the reaction is generally neutral or moderately alkaline. As a rule, Terra rossa has a high content of soluble salts, since the evaporation during the dry summer of the water rising to the surface by capillarity leaves the salts in the soil. Thus, as a result of the climatic conditions prevailing during the summer, translocation of the soluble products of weathering takes place in an upward direction; in other words, during the greater part of the year we have a denudation (eluvial) horizon below and an accumulation (illuvial) horizon above—the opposite of the conditions found in humid countries. Apart from exceptional cases, Terra rossa is deficient in humus, a result of the calcareous substratum on the one hand and of the arid climate in summer on the other. As a matter of fact, a low humus content is a characteristic feature of the Mediterranean countries. The little humus present is in the adsorptively saturated condition (mild humus), due in the first place to the presence of copious supplies of calcium. Adsorptively saturated humus—and it is desired to emphasise this statement—naturally cannot act as a protective colloid on compounds of iron. In winter, the humid conditions in combination with a comparatively high temperature bring about a vigorous hydrolysis of the sesquioxides and silica which are dispersed throughout the limestone; at the same time the calcium carbonate itself is dissolved and washed out.

We have already defined the properties of Terra rossa in the following terms: "Terra rossa develops on limestone under the conditions of the Mediterranean climate. In comparison wtih its parent material, the limestone, it has been greatly enriched in sesquioxides and in silica. In comparison with the soils of humid climates, it contains large quantities of salts of the alkalies and alkaline earths. The high iron content together with the low humus content are responsible for the red colour, which is often brilliant. They are mostly soils with an alkaline reaction and loamy structure; they may contain calcareous and ferruginous concretions" (11). At the present time this definition is generally accepted. The similarities and dissimilarities in the weathering of volcanic rock into red soil will be described later (pp. 85 *et seq.*).

(ii) *Theories of the Evolution of Terra Rossa.*

Although we are in some measure well informed as to the regional distribution of the development of Terra rossa and as to the climatic conditions prevalent in such regions, as well as to its characteristic properties, yet widely differing theories have been advanced in explanation of the chemical, particularly the physicochemical (colloidal), processes involved in its formation, more especially in connection with the problem of which factors cause the dissolution of the iron.

Vageler (36) was the first to tackle the question from the point of view of colloid chemistry. He laid particular emphasis on the greater degree of dissociation of water at higher temperatures and the effect of this on the weathering of the rock. The Al_2O_3, Fe_2O_3 and SiO_2 sols resulting from the hydrolysis of the sesquioxides, according to Vageler, behave quite differently. Fe_2O_3 and Al_2O_3 sols are, contrary to silica-sol, extraordinarily unstable. These sesquioxide sols are coagulated by an alkaline reaction at the place of their formation, whereas the stable silica sol remains mobile, is leached out and under certain circumstances accumulates in the subsoil.

This theory is controverted when it is applied to calcareous Red Earths, for, as indeed Vageler himself rightly observes, the Fe_2O_3 and Al_2O_3 hydrosols must be coagulated immediately they are formed, and this must take place within the limestone rock. But such is not the case. Instead of finding a deposition of the iron within the limestone, we find a translocation of the peptised iron from the parent rock out into the soil, and it is only there that it is precipitated, frequently enveloping other soil particles and gradually accumulating.

The so-called "Residue Theory," first propounded by Zippe (37), later by Tucan (38), and further developed by W. G. zu Leiningen (23), is certainly valid, but this also fails to explain the primary dissolution of the iron which undoubtedly takes place. According to W. G. zu Leiningen, in Terra rossa we are concerned solely with a residue of difficultly soluble material, whilst the readily soluble calcium carbonate is washed out.

In addition to the foregoing investigators, Blanck has paid particular attention to the problem of the evolution of the Red Earths, and his views have been expressed in a large number of valuable papers (39). Blanck and Alten (40) have sought an explanation of the protection of the ferric hydroxide sols from precipitation by the calcium. Starting from Aarnio's assertion (41) that humus can act as a protective colloid on ferric hydrosols, and from a consideration of the Liesegang type of diffusion, Blanck came to the conclusion that ferric sols can penetrate into limestone when they are protected by humus compounds, where they flocculate out and accumulate. According to Blanck these iron solutions descend only to a trifling extent from the dolomitic limestone of the parent rock. Ehrenberg (42, 43), criticising this view, points out that these ferric hydrosols must have been derived from the underlying rock. Without wishing, at this point, to discuss the question as to the extent to which protective action by humus compounds may be operative in such areas as Northern Italy, for instance, the author is of the opinion that (considering the very small quantities of humus present, and which are adsorptively saturated) this protective action of humus cannot come into the question so far as the true Mediterranean zone is concerned. Blanck's newer view (39, p. 229), that the Red Earths represent the accumulation horizon of a humus layer which is now no longer in existence, is likewise untenable in the case of the true Mediterranean zone, amongst others, because in the whole of this vast area no trace of this hypothetical humus horizon is preserved, whereas the accumulation zone often has a thickness of many metres. Further evidence for the rejection of this view is afforded by the fact that Red Earths are being formed to-day in the absence of humus.

According to Eichinger (44) the evolution of the Red Earths is to be explained by the difference in the behaviour of the positively charged sols of ferric hydroxide and aluminium hydroxide compared with that of the negatively charged sols of silicic acid. He declares that the accumulation of sesquioxides is due to the positively charged sesquioxide sols precipitating on ascent in a capillary medium such as the soil, whereas the negatively charged silicic acid sol remains stable, and so is leached out. Now, although it is true that sesquioxide sols prepared in the laboratory can display migration in the positive direction, this is not so in Nature. Without exception we have only been able to establish a movement in the negative direction in the migration by cataphoresis of all the colloidal constituents of the soil. In this connection it is desirable to find out whether the sesquioxide sols are actually negatively charged or whether they acquire a charge as a result of the peptisation by the silicic acid sol. Further, it is to be noted that, in contrast with laterite formation, the silica accumulates in the Red Earths and is not leached out.

Summarising, it is clear that, with the exception of Blanck, none of the authors cited has gone into the problem of how the primary formation of the sols of ferric hydroxide and aluminium hydroxide on limestone can be explained. It is impossible to imagine the peptisation of the Fe_2O_3 and Al_2O_3 dispersed throughout the limestones in the absence of a protective colloid.

Before giving our views a description of some Terra rossa profiles will be considered.

(iii) *Description of Some Terra Rossa Profiles.*

1. *Terra Rossa Profile near Jenin.*—The parent rock consists of Cenomanian-Turonian limestone. The Red Earth resting on this has a thickness of about 1 metre. The profile of the Red Earth is quite uniform in appearance, and no horizon of decomposition can be distinguished. Humus is present at the surface, but only in traces. From the analytical data it is clear that silica in particular, and to a lesser extent aluminium and iron, have increased at the expense of the calcium. The reaction of the soil was pH 8·4. It is noteworthy that the composition of this Red Earth is extraordinarily similar to that of one from the neighbourhood of Jerusalem analysed by Blanck, Passarge and Rieser (45), with the exception that in this case the leaching process has made greater progress.

2. *Terra Rossa Profile near Nablus.*—Here the manner in which the parent Cenomanian-Turonian limestone is weathered into individual blocks and innumerable fragments is very clearly seen. In places the Red Earth has eaten into the clefts and cracks of the parent rock; everywhere it fills the pores and crevices of the rock fragments and

cements them into a hard mass. Without exception the rock fragments are coated with a moderately hard crust which resembles the Red Earth. The colour of this layer

TABLE 42

TERRA ROSSA PROFILES FROM PALESTINE

	1. *Terra Rossa near Jenin.*		2. *Terra Rossa south of Nablus.*			
	Limestone.	*Superficial Red Earth.*	*Limestone.* *White.*	*Limestone.* *Veined.*	*Subsoil.*	*Surface Red Soil*
	%	%	%	%	%	%
SiO_2 ..	0·29	51·07	0·80	1·40	50·39	48·08
Al_2O_3 ..	0·90	12·29	—	0·03	16·50	14·94
Fe_2O_3 ..	1·50	7·85	Tr.	0·60	9·19	7·81
FeO ..	—	0·14	—	—	0·09	0·38
CaO ..	54·22	6·60	55·44	54·31	3·39	6·35
MgO ..	—	2·27	Tr.	Tr.	0·75	1·38
K_2O ..	—	0·79	—	—	0·81	1·08
Na_2O ..	—	0·47	—	—	2·91	2·16
P_2O_5 ..	—	0·09	—	—	0·08	0·12
SO_3 ..	—	0·32	—	—	0·63	1·88
CO_2 ..	42·60	4·12	43·56	42·67	6·03	3·90
H_2O ..	0·14	13·75	—	0·25	8·61	10·43
N ..	—	0·08	—	—	0·03	0·12
Totals	99·65	99·84	99·80	99·26	99·41	98·63

TABLE 43

MECHANICAL ANALYSES OF TERRA ROSSA SOILS

	Near Jenin.	*South of Nablus.* *Subsoil.*	*South of Nablus.* *Surface.*
	%	%	%
Coarse sand ..	0·24	11·88	28·29
Fine sand ..	41·02	16·85	11·68
Silt	10·54	35·64	33·30
Clay	48·20	35·63	26·73

is bright red, whereas that of the soil at the ground level is more of a reddish-brown shade, due to the presence of small quantities of humus. The thickness of the surface layer of soil is about 8 cm., and this rests on 1 to 2 metres of greasy, red soil with innumerable rock fragments, which gradually merges into the unweathered rock. Magnetic compounds of iron in a fine state of division are found in both layers; in places these concretions are as large as the head of a pin. Calcareous concretions are also common. This profile, too, resembles in its composition one described by Blanck, Rieser and Passarge (45) from the neighbourhood of Jerusalem.

TABLE 44

TERRA ROSSA PROFILE FROM CYPRUS (KERYNIA MOUNTAINS)*

	(A) *Limestone.*	(B) *Decom-position Horizon.*	(C) *Terra Rossa.*
	%	%	%
SiO_2	14·74	23·34	45·81
Al_2O_3	1·81	3·73	13·80
Fe_2O_3	10·86	3·54	11·85
CaO	68·26	63·92	21·35
MgO	4·00	3·67	5·00
K_2O	0·11	1·76	1·51
Na_2O	1·62	2·87	1·77
SiO_2/Al_2O_3 ..	35·19	29·66	9·96
SiO_2/Fe_2O_3 ..	3·6	17·3	10·2
SiO_2/R_2O_3 ..	2·8	6·6	3·6

* Calculated on water- and carbonate-free basis.

In considering the Red Earths of Palestine, it is at first surprising that nothing is to be seen of a real profile formation. A decomposition horizon cannot exist here, for the parent rock consists almost entirely of calcium carbonate, and contains but very small amounts of iron and aluminium.

A Terra rossa profile from Cyprus, examined by us, displayed entirely different features (46). This profile consisted of: (A) a compact impure limestone, greyish-yellow in colour, with greyish-yellow, lilac and red veins; (B) a pale lilac, well-weathered decomposition layer with green, red and white products of weathering, 85 cm. in thickness. The brownish-red Terra rossa (C) overlying the decomposition horizon was 65 cm. in thickness.

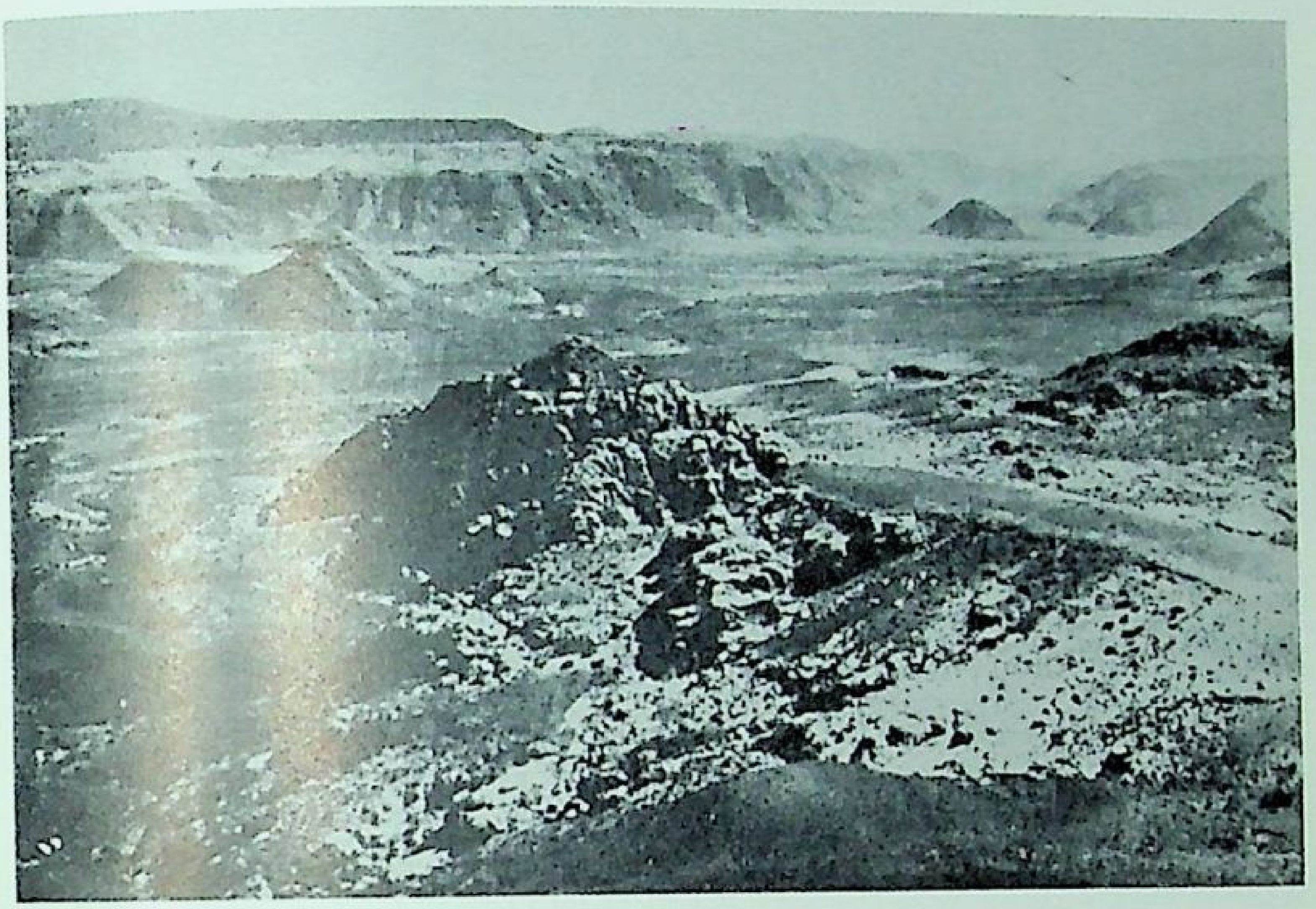
The hydrogen-ion concentration was pH 7·2.

The analytical results show that iron has been removed from the weathering zone (B) and has accumulated in the soil; also that alumina has increased in the soil, although it has not decreased in the decomposition zone. The increase of alumina in the soil is possibly due, not to translocation from the zone of decomposition, but to decomposition of aluminium silicates in the parent rock (A). Whilst the calcium is largely retained in layer (B), it is to a great extent washed from the soil (C), or relatively decreased by the silica and sesquioxides. At any rate we find, as in the other Red Earths examined by us, a marked accumulation of silica and sesquioxides in the soil as compared with the parent rock. This profile is especially interesting because the limestone contains much silica and sesquioxide. The ratios SiO_2/Fe_2O_3 in the three layers show the transport of iron from the zone of decomposition and its accumulation in the soil.

(iv) *The Evolution of Terra Rossa.*

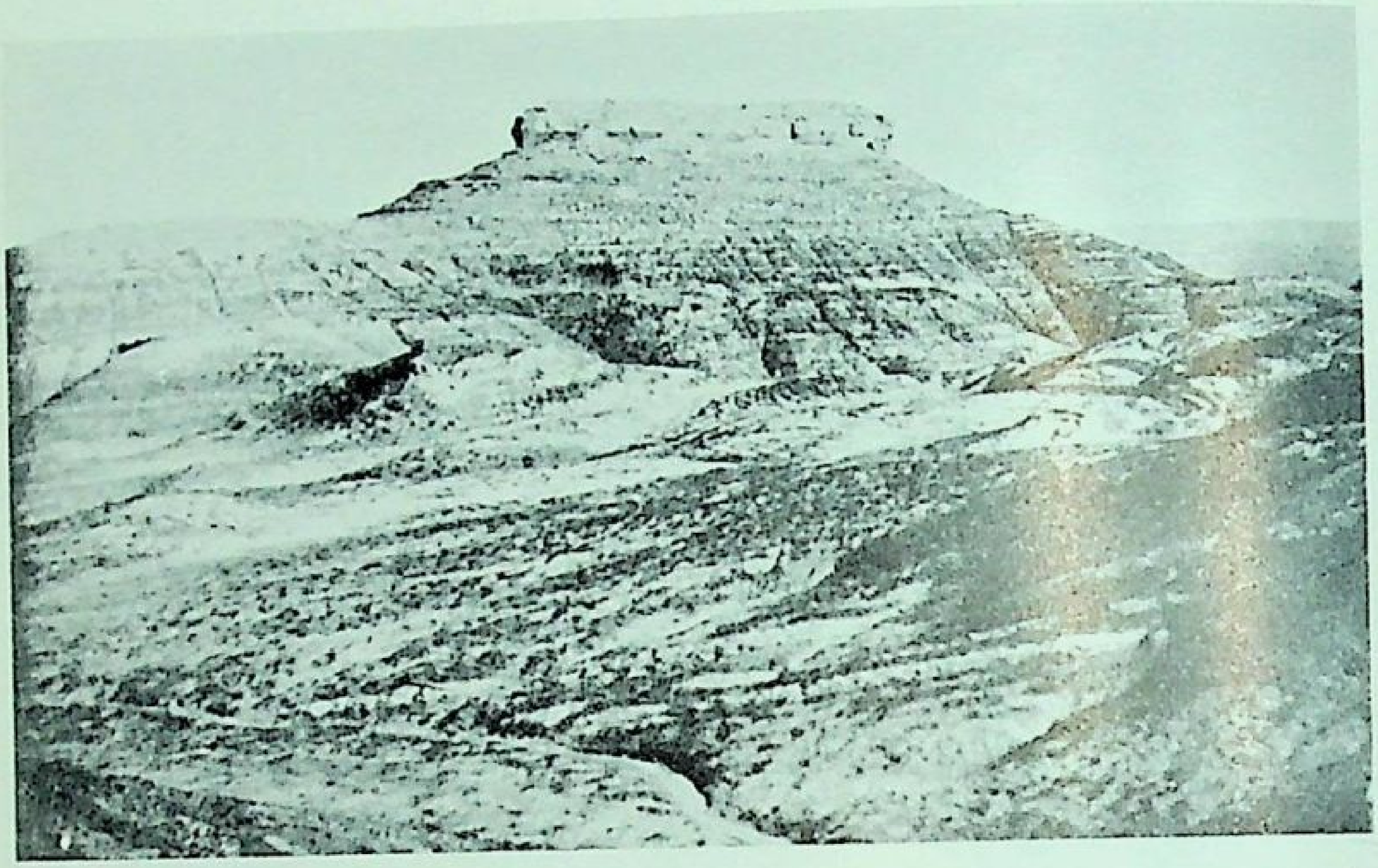
We have as our starting-point the facts that, on the one hand, first of all the iron and aluminium in the parent rock must be dissolved and translocated; on the other hand, however, on account of the flocculating action of the limestone on ferric hydroxide sols, the presence of a protective colloid is indispensable. Because of the small amount of humus, and its adsorptively saturated state, humus cannot function as the protective colloid. From our earlier exposition it is evident that in addition to humus, colloidal silica exercises a powerful protective action on sesquioxide sols.

In this connection experiments may be quoted which demonstrate the coagulation of sols of ferric hydroxide and of ferric hydroxide-silicic acid, prepared in the laboratory and containing the same amounts of Fe_2O_3 (*cf.* p. 27). In



VIIIA.—DESERT WEATHERING BETWEEN AQABA AND MAAN: "THE MOUNTAINS DROWN IN THEIR OWN DEBRIS."

To face page 80



VIIIB.—REMNANT OF MOUNTAIN IN THE LISAN-MARL AREA (MONADNOCK).

both cases finely powdered limestone was used as the flocculating agent.

TABLE 45

FLOCCULATION OF A FERRIC HYDROXIDE SOL (0·009 PER CENT. Fe_2O_3) BY LIMESTONE

	1.	2.	3.	4.	5.	6.
$Fe(OH)_3$ sol (c.c.) ..	5	5	5	5	5	5
$CaCO_3$ (gm.) ..	0·001	0·01	0·05	0·1	0·5	1
H_2O (c.c.)	5	5	5	5	5	5
At once	—	—	—	Complete flocculation	Complete flocculation	Complete flocculation
After 20 minutes ..	—	Complete flocculation	Complete flocculation	"	"	"
After 2 hours ..	Complete flocculation	"	"	"	"	"

TABLE 46

FLOCCULATION OF A FERRIC HYDROSOL, PROTECTED BY SILICIC ACID, BY LIMESTONE

The sol contained: Fe_2O_3 .. .. 0·009 per cent.
SiO_2 .. .. 0·190 "

	1.	2.	3.	4.	5.	6.
Fe_2O_3-SiO_2 sol (c.c.)	5	5	5	5	5	5
$CaCO_3$ (gm.) ..	0·001	0·01	0·05	0·1	0·5	1
H_2O	5	5	5	5	5	5
At once	—	—	—	—	—	—
After 2 hours ..	—	—	—	—	—	—
After 24 hours ..	—	—	—	—	—	Partial flocculation
After 8 days ..	—	—	—	—	—	"

The tables clearly show that ferric hydroxide sol alone is flocculated by calcium carbonate in a very short time, whereas the ferric hydroxide-silicic acid sol is extraordinarily resistant to such flocculation.

On the other hand it was found possible to show that if the reaction of the silicic acid sol is alkaline, the iron present in the crevices of the limestone is particularly easily dispersed by silicic acid sol. 100 c.c. of a silicic acid sol, containing 0·3 per cent. SiO_2, were allowed to act on the parent rock of the Nablus Red Earth described above, sols of different pH being shaken for twelve hours with 1 gm. of the powdered limestone (which contained 0·006 gm. Fe_2O_3). After sedimenting for twenty-four hours the iron and calcium in the decantate were determined. The results obtained are given in the following table:

TABLE 47

ACTION OF SILICIC SOLS ON LIMESTONE

	Dispersed Fe_2O_3.	*Dispersed CaO.*
	gm.	*gm.*
100 c.c. water, 1 gm. limestone	Tr.	Tr.
100 c.c. SiO_2 sol (pH 5·7), 1 gm. limestone	0·0004	0·0195
100 c.c. SiO_2 sol (pH 8·3), 1 gm. limestone	0·0024	0·0272

It will be seen that more than one-third of the iron present in the limestone has been dispersed by the silicic acid sol when the reaction is alkaline. This experiment also shows that silicic acid also exercises a dispersive action on calcium.

If we bear in mind also that in Nature silicic acid and sesquioxides commonly occur together—all clays consist of a mixture of these ingredients—we are now in a position to link up the peptisation of sesquioxides in Nature with the behaviour of artificially prepared metallic oxide-silicic acid sols. In the Mediterranean region silicic acid assumes the rôle of a protective colloid and makes the translocation of iron possible in the presence of calcium. (Generally, silicic acid appears to play a large part in Nature as an "all-adsorbing agent," and possibly other soil phenomena are explicable by its property of functioning as a protective colloid.)

These considerations led us to the following theory of the evolution of Terra rossa:

The Mediterranean climate, with its heavy winter rainfall and dry summer period, permits the presence of only very small quantities of humus. The large amounts of salt and alkaline earths in the soil coagulate the humus and inhibit its protective action on iron compounds. The so-called "Residue Theory" is therefore of greatest significance, in that the chalk, which is the chief ingredient of the rock, is largely washed away during the winter rains, and this itself leads to a relative enrichment in silica and sesquioxides. Owing to lack of humus and the presence of chalk in the rock, the soil is alkaline. Under these conditions the colloidal silica, which is formed by hydrolysis, peptises the sesquioxides from the rock, and protects such oxides as are in solution from precipitation by the limestone. Even silica that only contains latent alkali and has a slightly acid reaction has this peptising effect. There is then an exchange: the sesquioxide takes the place of the alkali attached to the silica micelle, and the soil solution becomes more alkaline. In this way sesquioxides which may be positively charged by electrolytes become negatively charged by the silica. During the dry season the soil solutions ascend. Unlike unprotected sesquioxide sols, which are very easily coagulated, those that are protected by silica are much more stable and are coagulated only by more concentrated electrolytes, which they meet on rising through the soil. The calcium hydroxide that is produced by the dissociation of calcium bicarbonate may play an important part here. Changes in the concentration of the soil solutions and adsorption processes are naturally also operative. On coagulation the sesquioxides often envelop other particles of soil. In comparison with other soil types the marked increase in iron becomes patent in the weathered complex, whereas the increase in alumina is hidden by the presence of equally increased silica. The coagulated particles may in time undergo secondary physical and chemical changes, and form chemically well-defined and even crystalline silicates.

These conclusions, expressed by us in a similar way in 1927, seem to be accepted now in principle by most scientists dealing with soil formation in the Mediterranean (33, 34, 35, 47, 57, 59, 60, 80, 81 and 83).

In conclusion it may be noted that without exception the Red Earths of Palestine have a slightly alkaline reaction (pH 7·2 to 8·4). The high calcium content is also reflected in the composition of adsorption complex; for instance, in the Terra rossa from Nablus, described above, the adsorbed bases were as follows:

TABLE 48

Exchangeable Bases in Terra Rossa from Nablus, Palestine

	Milli-Equivalents per 100 gm. Soil.
Calcium	58·5
Magnesium	1·1
Potassium	1·4
Sodium	4·4

In the mountains Terra rossa is liable to erosion, which is combated by terracing. Though primarily corn land, vines and other fruits grow very well. In all localities where weathering has proceeded to a considerable depth, or where the Red Earth has filled valleys or depressions, it has been established that this soil is extremely well suited to the growth of fruit trees of all sorts (apples, pears, plums, etc.). In the highest parts of the mountains, as, for example, in the districts of Hebron or Hermon, the Terra rossa is more yellowish in colour, probably owing to a further stage in the hydration of the ferric oxide and connected with the more humid conditions.

When transported and deposited in badly drained areas the lime is liable to leaching and the reaction may thus become neutral or slightly acid. In high altitudes or under forest the colour becomes blackish because of the increased humus content.

(b) Red Earths on Volcanic Rocks.

In Upper Galilee recent volcanic basalts and limestones occur side by side. Now, whilst the limestones weather to form a typical Terra rossa, this is not the case with basalt. The decomposition product of the basalt is not a red-coloured soil, but one having a shade which may be called chocolate-brown. The rock underlying the Red Earth consists of Cenomanian-Turonian limestone, which is shattered into innumerable fragments of all sizes. The superficial layer of Red Earth fills the cracks and pores of the rock and cements the whole to a hard mass. The colour of the soil is bright red; humus is absent.

The basalt, too, weathers to innumerable fragments, but these have a more rounded appearance. The soil, again, is of no great depth but covers the rock in a layer of about 20 cm. in height, through which numerous basalt blocks and smaller fragments protrude. The colour of the soil is, as already stated, chocolate brown.

Both limestone and basalt, together with the soils to which they give rise, have been examined, and it has been found that these two rocks, vastly different in composition, have produced soils which are chemically almost identical.

Once more we see the predominant influence of the climate, which, in spite of the greatest difference between the parent rocks, can produce soils having the same chemical composition. This can only be explained by the climatic factors always working in the same direction. (It is of interest to note that Albert (48) showed that a basalt of very similar composition weathers to laterite in a tropical climate.)

Now, before considering the reasons for the difference in colour despite similar chemical composition, it must be noted that the proportion of silica to the other constituents has not decreased but has actually increased. This increase must be ascribed, at least in part, to the removal of calcium. A proportional increase of the sesquioxides has taken place in the same way in the Red Earth as well as in the Basalt Soil.

TABLE 49

COMPARISON OF LIMESTONE SOIL WITH BASALT SOIL (ROSH PINA)

	Limestone Profile.		*Basalt Profile.*	
	Limestone.	*Terra Rossa.*	*Basalt.*	*Basalt Soil.*
	%	%	%	%
SiO_2 ..	0·19	49·93	43·85	49·16
Al_2O_3 ..	0·07	16·67	11·91	13·40
Fe_2O_3 ..	0·24	10·35	6·43	11·34
FeO ..	—	1·05	7·44	3·41
Mn_3O_4 ..	—	Tr.	1·32	0·75
CaO ..	57·35	4·00	10·31	2·07
MgO ..	0·40	1·13	8·86	1·17
K_2O ..	Tr.	0·78	1·76	0·98
Na_2O ..	Tr.	0·68	4·41	1·67
P_2O_5 ..	Tr.	0·06	0·54	0·02
SO_3 ..	—	0·12	Tr.	0·09
CO_2 ..	40·98	0·57	0·60	2·66
H_2O ..	0·15	16·20	1·23	13·31
N ..	—	0·06	—	0·09
Total ..	99·38	101·60	98·66	100·12

The reason for the disparity in the colour of the Basalt Soil, if we ignore the insignificant amount of manganese present, must be sought for in a difference in the iron compounds present in the soils. Actually the Basalt Soil has a larger proportion of ferrous iron (relatively to ferric) than the Red Earth, the ratio ferric/ferrous being about 10 : 4 in the Basalt Soil and 10 : 1 in the Red Earth.

But even in the rock there is a difference in the form in which the iron occurs. In limestone, as we have seen from the analytical data and the colour, we have veins of red ferric oxide which permeate the rock. In basalt it is quite different. Here the ferrous condition is dominant; the iron is present partly as magnetite and partly as ferri- or ferro-silicates.

The discovery, previously described (p. 27), that colloidal silicic acid not only exercises a peptising action on ferric oxide, but is also able to peptise ferrous oxide in the same way, has given us a possible means of undertaking a comparative examination of the properties of peptised ferric and ferrous oxides. A. Fodor, in collaboration with the author (9), found that sols prepared from ferric oxide are brick-red in colour and display the Tyndall effect in a marked degree, whereas sols prepared from ferrous oxide are deep green in colour. Exposed to the air the latter sols undergo a progressive oxidation and acquire a colour resembling that of a muddy white wine, having been more or less transformed to the ferric state. At a higher concentration (after evaporation on the water-bath) these sols assume more of a brownish tint.

In analogy to the difference in the optical behaviour of these sols, we can well imagine that the coagulated sols display a difference in colour in accordance with their primary formation having been from ferric oxide (as in limestone) or from ferrous compounds (as in basalt). In our opinion this, together with the amount of ferrous iron still present in the soil, must take the first place in considering the causes of the difference in colour. Further, in the case of the basalt we are not concerned solely with the residue left after the removal of the calcium and magnesium by leaching. Of particular significance in this connection is the following evidence: On ignition, the powdered basalt rock shows the smaller colour change, the grey colour of the basalt assuming only a light rose tint. The chocolate-brown basalt soil behaves quite differently; after ignition it is found to have undergone a complete colour transformation, the soil having become a bright red. The explanation of this difference in behaviour is, probably, that in the rock we have actual, definite chemical compounds of ferrous (and ferric) silicates, whilst in the soil we have an extremely loose adsorption linkage of iron oxides and silicic acid. The iron compounds responsible for the chocolate colour of the soil are thus not merely a residue which has survived weathering, they must have separated out from some sort of solution of the compounds of iron and oxygen. As to the manner in which this state of solution was brought about, we prefer to make no definite pronouncement at present, although, on the evidence of our experimental work, we are inclined to believe that here again colloidal silicic acid plays a prominent part in the solution (or rather peptisation) of the iron.

Although in Palestine basalt does not usually weather to yield a red-coloured decomposition product, this is not an invariable, general rule. We found in Syria, as well as in Cyprus, volcanic rocks which had weathered to form red-coloured soils. The following description of the profile of a gabbro-norite which had weathered to form a red soil is from Kakopetria, Cyprus (46).

This profile was found about two miles from Kakopetria, on the road from Nicosia to Amiandos. At the bottom lies a dense, quartz-free gabbro-norite, containing about 55 per cent, plagioclase (of which about 20 per cent. is anorthite) and about 45 per cent. pyroxene (of which about 30 per cent. is augite and 15 per cent. hypersthene). The nature of the layers above this can be seen from Table 50.

The analyses and the ratio SiO_2/Al_2O_3 in Zone II show that alumina has been removed and has accumulated in the soil. The apparent increase of silica in II and III is mainly relative, being due to a loss of alkaline earths. This lōss is very great, and in the case of calcium amounts to over 30 per cent. Potassium and sodium, on the other hand, have increased from zone to zone. The final result of weathering is the same here as with serpentine: there is a slight increase of silica and a large increase of sesquioxides as compared with the parent rock.

TABLE 50

RED EARTH ON GABBRO-NORITE, KAKOPETRIA, CYPRUS

	I. *Gabbro-norite.* *Below 470 cm.*	II. *Decomposition Zone (a) Slightly Weathered, containing Some Yellowish Material.* *70-470 cm.*	III. *Decomposition Zone (b) More Weathered, Containing More Yellowish Material.* *30-70 cm.*	IV. *Reddish-Yellow Loam.* *0-30 cm.*
	%	%	%	%
SiO_2	49·73	54·00	53·24	50·97
Al_2O ..	16·78	14·41	18·36	22·41
Fe_2O_3 and FeO	6·19	7·51	8·65	10·53
CaO	14·94	10·53	10·07	5·83
MgO ..	11·15	12·51	7·35	8·20
K_2O and Na_2O	0·54	0·55	0·96	1·10
CO_2	—	—	—	Tr.
pH	—	7·1	7·1	7·1
SiO_2/Al_2O_3 ..	5·0	6·4	4·9	3·9
SiO_2/Fe_2O_3 ..	21·1	19·0	16·2	12·1
SiO_2/R_2O_3 ..	4·0	4·8	3·8	2·9

We were able to establish (46) similar weathering phenomena on diabase, lava and serpentine in Cyprus. Serpentine, in particular, often yielded a decidedly red soil.

We therefore now hold that Red Earths are formed, not only over limestone, but also over other rocks. It is to be emphasised, however, that, despite the similarity of the final products, the process of formation is not identical in the two cases. In the case of limestone, the action of the large amount of calcium hydroxide—formed by the dissociation of calcium bicarbonate—and of other electrolytes coagulates most of the silica. This is retained in the soil, which therefore contains more than did the parent rock. On the other hand, the effect of calcium bicarbonate on the weathering of the igneous rocks is almost imperceptible, and much more silica is removed by leaching,

TABLE 51

SILICA-SESQUIOXIDE RATIOS IN THE CLAY FRACTION OF MEDITERRANEAN SOILS ON LIMESTONE AND ON VOLCANIC ERUPTIVES

	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	$\frac{SiO^2}{Al_2O_3}$	$\frac{SiO^2}{Fe_2O_3}$	$\frac{SiO^2}{R_2O_3}$	*Rain-fall (mm.).*	*Temper-ature (° C.).*
On Limestone :								
1. Jenin (Palestine)	51·84	23·08	10·14	3·81	12·86	2·94	500	19·2
2. Jerusalem (Palestine)	39·57	18·48	9·47	3·36	10·99	2·73	665	15·9
3. Halhul (Palestine)	45·68	23·84	12·44	3·25	9·66	2·43	700	16·0
4. Nablus-Ramallah (Palestine) ..	45.47	26·77	13·19	2·94	9·07	2·19	735	19·2
5. Rosh-Pina (Palestine)	49·74	24·71	16·06	3·40	8·10	2·40	882	18·5
6. Kyrenia Mountains (Cyprus)	47·59	22·84	12·60	3·53	9·92	2·61	401	18·8
7. Famagusta (Cyprus)	50·00	25·81	10·73	3·51	12·25	2·73	395	19·7
8. Kokkini-Trimithia (Cyprus)	47·99	23·03	11·94	3·53	10·57	2·64	365	18·8
9. Limassol (Cyprus)	42·50	20·61	9·71	3·50	11·57	2·67	360	19·9
Mean	—	—	—	3·43	10·56	2·59	—	—
On Volcanic Eruptives:								
10. On basalt at Rosh-Pina (Palestine) ..	48·48	26·35	17·15	3·12	7·44	2·20	882	18·5
11. On diabase at Stavrovouni (Cyprus) ..	40·05	29·08	10·75	2·33	9·79	1·89	635	15·4
12. On diabase at Ayia Varvara (Cyprus)	36·72	19·71	13·36	3·16	7·23	2·20	557	17·8
13. On gabbro-norite at Kakopetria (Cyprus)	45·85	40·05	14·08	1·94	8·57	1·58	522	16·6
Mean	—	—	—	2·64	8·26	1·97	—	—

although in the resulting soil there is no diminution in the ratio of silica to other constituents. Polynov (49) is undoubtedly correct in his statement that limestone increases the "siallitic" character of the red soils of the Mediterranean. A further real difference between the Red Earths produced on limestone and those produced on igneous rocks is that the former usually contain more calcium carbonate and give a more alkaline reaction.

We would therefore restrict the name "Terra rossa" to those red soils that occur widely distributed over limestone in the Mediterranean region, and we would give the name "Red Earth" or "Red Loam" to the red soils formed over igneous rocks. As will be seen from the following table, more silica is lost by leaching in the weathering of the volcanic eruptive rocks with their low calcium content than in the weathering of limestone (Table 51).

Although, in principle, the same dynamic factors are determinative in the weathering of limestone and of eruptive rocks, and therefore similar soils are formed, the absence of calcium is responsible for the composition of the weathering complex of the eruptive rocks being more akin to that of tropical and sub-tropical soils. The red soils of the Transvaal, although having a narrower SiO_2/R_2O_3 ratio, seem to come nearest to the red soils on volcanic rocks of the Mediterranean (*cf.* p. 90).

(*c*) *Mountain Marl Soils.*

Wide stretches of the Judæan and Galilean highlands are covered by chalky marls of Senonian or Eocene age. These soft and friable rocks never weather to terra rossa, but preserve their whitish or greyish colour. This is due to the fact that rocks of this kind do not provide the material for true soil formation; they merely form a rock meal or marl with lime contents of over 50%. True hydrolytic processes characteristic in the evolution of soils do not take place here. The chief action consists in the solution and erosion of the products of disintegration. The soft and dense rock is besides generally impermeable for water and no downward or upward movement of water takes place.

It is emphasised that this behaviour has solely to be attributed to the physical qualities of the rock and not to its geological age. Harder Eocene rocks, *e.g.*, in the Rosh Pina-Safed region, invariably yield true terra rossa.

According to Zohary (62) these marly soils are vegetationally well distinguished from terra rossa and the regeneration of the arboreal Mediterranean association seems to be impeded on these soils. The mountain marls are generally not very fertile because of their bad water-holding capacity and their high lime content. Table 52 gives a description of some of these soils:

TABLE 52

MOUNTAIN MARL SOILS

	1 *Soft Eocene (Near Jenin)*	2 *Albian (Near Rama, N. Galilee)* *Rock*	*Soil*	3 *Senonian (Near Safed)*	4 *Senonian (Near Tarshiha)*
	%	%	%	%	%
H_2O	2·3	0·6	2·9	4·8	3·1
$CaCO_3$ ..	69·5	84·9	67·9	49·2	58·7
Coarse Sand ..	13·2	44·8	19·4	14·3	5·4
Fine Sand ..	23·3	20·1	27·6	23·9	23·1
Silt	25·2	19·9	29·4	24·2	31·6
Clay	35·9	14·6	20·8	32·8	36·2
*p*H	7·7	8·0	7·1	7·4	7·9

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[Photo by Mattson.

IX.—LAND SPOUT IN THE LOESS AREA.

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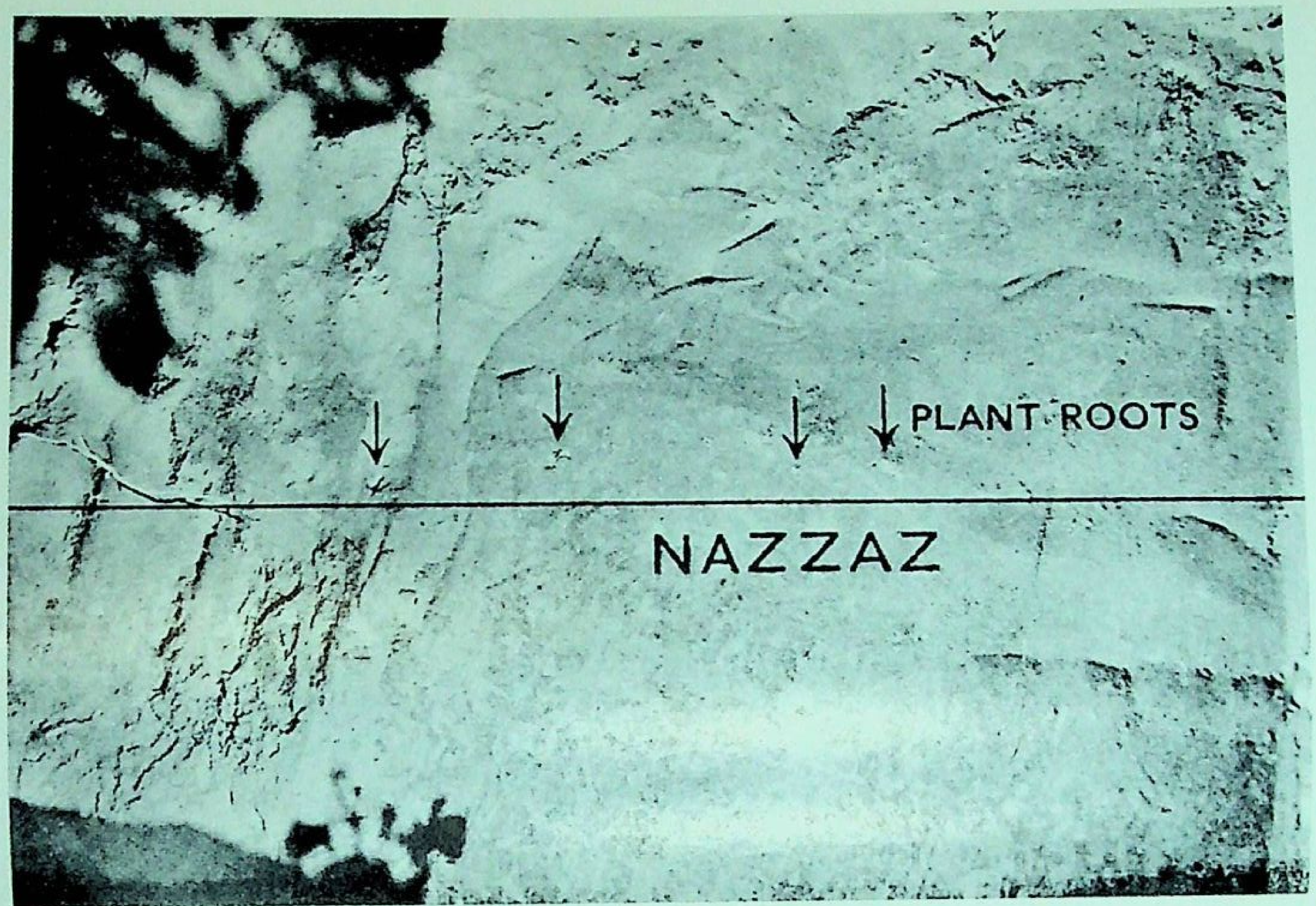

X.—NAZZAZ PROFILE: PLANT ROOTS DO NOT ENTER THE COMPACT NAZZAZ LAYER.

III. SOIL FORMATION UNDER THE MEDITERRANEAN CLIMATE AS COMPARED WITH THAT UNDER OTHER CLIMATES

A. The Influence of the Climate and of the Parent Material.

A comparison of the weathering of various rocks in the Mediterranean and in other climatic regions is extremely instructive.

If limestone weathers to a red soil in the way that we maintain, then the same weathering processes must take place when soil is being formed from other rocks. The following typical analyses show the final stages of the chemical changes that have taken place during the weathering of limestone and of igneous rocks in different climates.

TABLE 53

Weathering of Limestone in Different Climates

	Temperate-Humid (Switzerland) (1).		*Mediterranean (Cyprus)* (2).		*Hot-Humid (Tropics) (Timor)* (3).	
	Rock.	*Soil.*	*Rock.*	*Soil.*	*Rock.*	*Soil.*
	%	%	%	%	%	%
SiO_2 ..	3·26	29·14	9·13	39·05	6·87	27·30
Al_2O_3 ..	0·15	4·73	1·15	12·11	2·55	12·21
Fe_2O_3 ..	0·79	2·91	6·88	10·40	4·64	16·27
CaO ..	52·08	32·60	43·43	18·74	48·14	21·34
MgO ..	0·50	1·15	2·54	4·39	1·15	2·17
K_2O Na_2O	0·93	3·46	1·10	2·88	0·09	2·65
P_2O_5 ..	Tr.	0·13	Tr.	0·14	0·07	0·13
CO_2 ..	42·65	25·48	36·28	11·81	37·78	14·68

It is obvious that the marked increase of sesquioxides in the Cyprus soil is not merely relative, due to the loss of calcium carbonate and silica, for it is this rock, of the examples cited, that has produced the soil richest in silica. This has doubtless been brought about by colloidal solutions of sesquioxides and silica rising during the dry summer months and then coagulating in the soil. In all climates the chief factor in the weathering of limestone is the removal of calcium carbonate by leaching. In the tropics the limestone prevents the complete removal of the silica by leaching, probably for the reason that the calcium hydroxide formed by hydrolysis coagulates the colloidal silica. In this way the development of laterite on limestone is inhibited.

TABLE 54

WEATHERING OF IGNEOUS ROCKS IN DIFFERENT CLIMATES

	Cold-Humid Diabase (Spitzbergen) (4).		*Mediterranean Gabbro-Norite (Cyprus)* (9).		*Hot-humid (Tropics) Diabase (French Guinea)* (5).	
	Rock.	*Soil.*	*Rock.*	*Soil.*	*Rock.*	*Soil.*
	%	%	%	%	%	%
SiO_2 ..	50·64	67·37	49·73	50·97	52·06	16·51
TiO_2 ..	1·38	0·62	—	—	1·56	4·25
Al_2O_3 ..	15·30	13·26	16·78	22·41	13·89	45·49
Fe_2O_3 ..	14·40	8·74	6·19	10·53	9·82	31·51
Mn_3O_4 ..	4·16	1·35	—	—	—	—
CaO ..	8·42	2·69	14·94	5·83	11·25	0·82
MgO ..	2·56	1·82	11·15	8·20	7·87	0·34
K_2O Na_2O	2·97	3·41	0·54	1·10	2·96	0·60
CO_2 ..	0·21	0·28	—	Tr.	—	—
P_2O_5 ..	—	0·22	—	Tr.	—	—

The effect of climate on the weathering of igneous rocks is manifest in Table 54. In a cold, humid climate there is a relative increase in the silica content, due to the loss of other components. In the tropics the absolute loss of silica is very marked. The washing away of sesquioxides in the Spitzbergen soil is due to the action of acid humus. In the Mediterranean soil, on the other hand, we find a marked accumulation of sesquioxides, and in the tropics a still greater accumulation. The Cyprus soil shows a smaller loss of the alkaline earth metals, and this is probably the result of restoration by the solutions that rise during the summer months. For the same reason, the alkali metals also accumulate here.

Whilst recognising the close resemblance between the weathering of igneous rock in the Mediterranean and that of limestone, and appreciating the fact that owing to the identical climate (and similar chemical processes) similar red soils are formed, we wish to emphasise that the processes are not identical, despite the similarity of the final products. There are also the differences in colour, the red soils on igneous rocks showing a more brownish or lilac-red colour, sometimes due to the iron oxides present having been derived from ferrous compounds. Hence our desire to restrict the name " Terra rossa " to the red soils found on limestone, as expressed previously.

B. The Composition of the Clay Fraction in Various Climatic Regions.

In recent years the ratios SiO_2/Al_2O_3 or SiO_2/R_2O_3 have been employed as a measure of the stage of weathering, as well as for the characterisation of a soil type. Some authors believe that a soil can be satisfactorily defined by the SiO_2/Al_2O_3 ratio, whereas Robinson (6), for instance, emphasises that the molecular ratio of the silica to the total sesquioxide content should be employed, and with this view we are in agreement. On the other hand, the molecular ratio SiO_2/Fe_2O_3 gives another viewpoint which is often of value. Now in order to exclude the possibility of unweathered soil particles being involved in investigations of this kind, it has become customary to consider only the colloidal fraction of the soil. As a matter of fact, the colloidal components, the soil gels, constitute the real products of weathering.

A general classification of soils on the basis of the composition of the colloidal fraction is certainly beset with many difficulties. On the one hand, the available material is quite inadequate; on the other, we frequently have to deal with soils whose composition has been influenced by aclimatic factors. Thus, it is often a question of soils which have been transported by wind or water, or of soils with impeded drainage or even having a swampy substratum. Further, in not a few instances, the nature of the parent rock is not cited, and certainly in many cases we have a parent material containing previously formed colloids (clays, marls, etc.). Finally, we have to remember that not only may there be differences of opinion as to the general soil type to which a soil should be assigned, but the climatic conditions of many places are only too often not known with any exactitude. We have tried to exclude, as far as possible, from the comparison given below all those soils in which aclimatic factors are clearly dominant.

The following tentative, experimental classification is based on the " A " horizons alone, although we appreciate that a comparison of soil profiles can yield valuable information. Finally, we have in this first attempt refrained from a mathematical treatment, as was employed by Crowther (8) in such an interesting way in an examination of American soils, because, for instance, in many cases the geological factor was unknown. Although in many soils, in addition to the climate (and age of the soil), the nature of the parent rock is the decisive factor—we were able to demonstrate this with Mediterranean soils in particular—the comparison of the colloidal fraction of about 200 soils from various climates once more confirms the statement that the climate is by far the dominant factor in the evolution of soils. To each climatic soil type there corresponds a characteristic composition of the colloidal fraction, which is fully comprehensible, for the chemical and colloid-chemical reactions taking place in the soil are determined in the first place by the climate. Our tentative values have been corroborated in a study on the various great soil groups of China (10). Notwithstanding differences in detail (11, 13) affecting mainly the prairie and chernozem groups of soil, it seems that the Si/R values of American soils are also mainly controlled by climate (12, pp. 138 *et seq.* and pp. 155 *et seq.*). The relationship between the composition of the clay fraction in various climatic regions (Table 55 and Fig. 3) reveals the characteristic peculiarities of the Mediterranean type of weathering in a very satisfactory manner (7).

TABLE 55

COMPOSITION OF CLAY FRACTION IN VARIOUS CLIMATIC SOIL TYPES

Soil Type.	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3
Desert soils	3·9	17·2	3·6
Mediterranean red soils ..	3·3	9·3	2·4
Subtropical and tropical red soils	2·3	8·2	1·6
Laterites	1·7	8·5	1·3
Brown earths	2·4	9·4	2·0
Podsols	3·4	19·6	2·8

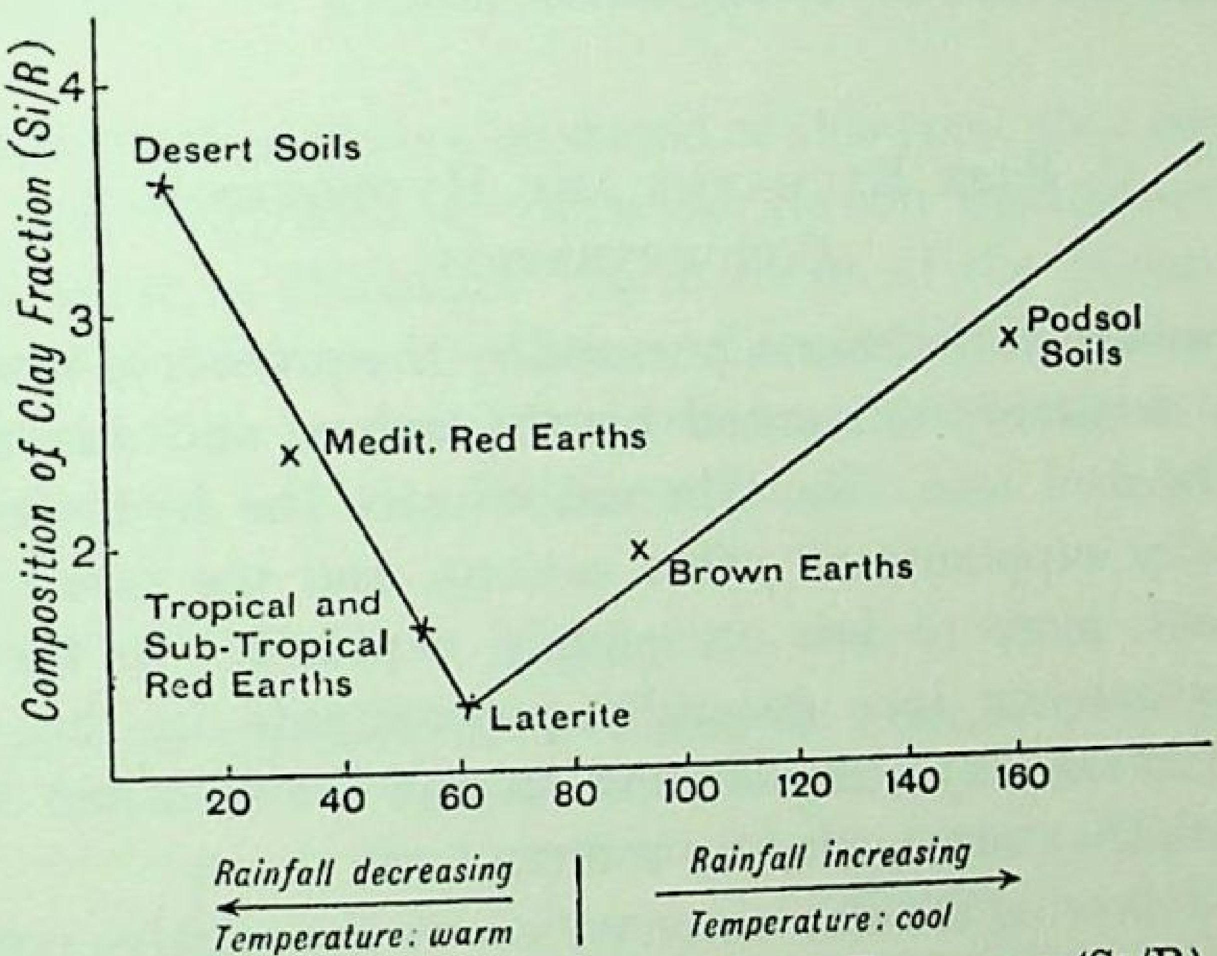

FIG. 3.—COMPOSITION OF THE CLAY FRACTION (SI/R) AS INFLUENCED BY THE RAIN FACTOR (QUOTIENT OF YEARLY RAINFALL AND MEAN TEMPERATURE).

In the Mediterranean Red Soils the accumulation of iron is very marked as compared with that in Desert Soils. According to Piper (14) the Red-Brown earths of South Australia have close affinities with the Mediterranean Red Soils.

Their Silica /Sesquioxide ratio agrees well with our value of 2·43. On comparing the Mediterranean Red Soils with the more humid soils, we find that alumina accumulates to an equally great extent in the latter. Both sesquioxides increase to an equal extent under humid conditions, but the increase here is only relative, and is due to a loss of silica. The fact that iron alone appears to increase in the case of the Mediterranean soils proves that we have to deal, not with a relative, but with an absolute increase. Not only does the loss of calcium carbonate and silica cause an increase in the proportion of the sesquioxide content, but an actual increase from the rock takes place. (There is also an absolute increase in alumina, which is, however, hidden by the increase of silica, whereas the comparatively high increase in iron can be seen clearly.) If we assumed only a relative increase in iron the apparent non-increase of alumina could not be explained.*

C. Base Exchange and Hydrogen-Ion Concentration.

As we know, the course pursued by the process of weathering is decisively influenced by the nature and amount of the adsorbed ions. In a humid climate the hydrogen ion gradually supplants all other cations, and the result is an acid soil, more or less completely peptised. In the arid regions calcium ions generally predominate in the outer swarm of the clay complex, and only in the so-called Alkali Soils are they superseded by sodium ions.

The following tabular summary shows the relative position of the Red Soils of Palestine, in which, as in almost all the soils of that country, the desirable calcium ions predominate. It may be remarked here that the Red Sandy Soils of the Maritime Plain form the only exception (see p. 54).

* It must be pointed out that a recent criticism of this classification has not taken into consideration these restrictions which we ourselves enunciated (9).

TABLE 56

ADSORBED CATIONS IN SOILS OF VARIOUS CLIMATES
(MG. EQUIVALENTS PER 100 GM.)

Climate.	*Country.*	*Soil Type.*	*H.*	*Ca.*	*Mg.*	*K.*	*Na.*
Per-humid	Russia	Podsol	11·4	2·0	4·2	0	0
Semi-humid	Russia	Chernosem	0	45·0	8·3	1·5	0
Mediterranean	Palestine	Terra rossa	0	58·5	1·1	1·4	4·4
Arid	U.S.A.	Alkali soils	0	0	0·8	1·7	6·9

We see the injurious accumulation of H ions in a per-humid climate, in which almost all the other cations are suppressed. Both the Chernosem and the Terra rossa from Palestine exhibit the desirable predominance of calcium. In the American Alkali Soils almost all the cations have been replaced by sodium ions—soda formation has taken place.

In anticipation, it may be stated at this point that genuine Alkali Soils—*i.e.*, soils in which the Na-ion predominates—do not occur in Palestine. As a result of the presence of abundant quantities of calcium, the continued addition of sodium chloride by faulty irrigation cannot produce Alkali Soils; the soils can only become salinised.

TABLE 57

PERCENTAGE DISTRIBUTION OF SOILS OF VARIOUS COUNTRIES ACCORDING TO THEIR REACTION

Climate.	*Country.*	*pH value.*					
		4–4·9 %	5–5·9 %	6–6·9 %	7–7·9 %	8–8·9 %	9 %
Per-humid	Finland	9	61	29	1	0	0
Humid	Denmark	1	15	67	16	0	0
Semi-humid	Italy	4	22	26	44	4	0
Mediterranean	Palestine	0	0	3	63	34	0
Arid	Egypt	0	0	0	62	22	16

The reaction of the soils of Palestine, naturally closely related to the process of base exchange, is primarily determined by the presence of calcium, and we find that it lies between pH 7·5 and 8·5. The Red Sandy Soils of the Coastal Plain form the only exception.

Generally, the Palestine soils contain adequate amounts of calcium in the soil complex to give the desirable crumb-structure, and a hydrogen-ion concentration in the neighbourhood of the neutral point.

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IV. SOILS AND AGRICULTURE

A. Selection of Soils for Citrus Culture.

The economic importance of citrus culture for Palestine—oranges and grapefruit are the principal exports, and their value exceeds the total of all other crops—is responsible for precedence having been given to the problems arising from the utilisation of soils for citrus culture, and in the following pages other crops will be considered only incidentally.

It has already been stated that the main centre of citrus culture is situated in the Maritime Plain. Quite apart from the climate and the generally favourable conditions for irrigation, this is no accident, for the Red Sandy Soils of the Maritime Plain in the absence of a Nazzaz pan provide almost ideal conditions for this crop. The soils, which are deep, contain about 80 to 90 per cent. of sand, whereby a good root growth is ensured, for water movement takes place freely and there is no lack of oxygen. At the same time the soils contain small quantities of a highly disperse clay which renders possible the adsorption of the necessary nutrients and retards the all too rapid downward percolation. These soils suffer from the disadvantage of a low calcium content (rarely exceeding 0·2 per cent. calcium carbonate), which, however, is easily rectified by artificial liming; that such liming is absolutely necessary is clear from the simple statement that each crop removes about 100 kg. calcium carbonate per hectare (about ¾ cwt. per acre).

We have already pointed out that in many cases the Red Sandy Soils are underlaid by a pan which forms an impenetrable barrier to the roots and at the same time restricts the movement of water in the soil. After repeated irrigation the water rises in this "Nazzaz" layer, with the result that the roots of the trees no longer obtain sufficient supplies of oxygen and putrefy. The adsorption complex of these soils is decidedly deficient in calcium, and this is most marked in the layers situated immediately above the Nazzaz stratum, for the roots can only obtain the supplies of calcium necessary for the growth of the tree from these layers (1). The description of these conditions given on page 56 was not based on a single observation, for we have found in a number of instances that the adsorption complex of Nazzaz Soils had a similar composition. A further example is given in illustration.

In the neighbourhood of Rehoboth, grapefruit trees, about ten years old and growing on a Nazzaz soil, are poorly developed. The roots penetrate the soil only to a depth of 50 cm., and there they meet the Nazzaz layer (Table 58).

TABLE 58

NAZZAZ SOILS AT REHOBOTH

	A. 0-25 *Cm.* *Dune Sand, Dressed with Lime and Organic Manure.*	*B.* 25-50 *Cm.* *Orange-Coloured with Some Nazzaz Concretions.*	*C.* 50-90 *Cm.* *Heavy Nazzaz with Many Concretions.*	*D.* 90-110 *Cm.* *Heavy Nazzaz with Many Concretions.*
	%	%	%	%
H_2O	1·4	2·4	4·4	3·3
CO_2	7·20	0·31	0·01	0·03
pH	7·1	6·7	6·6	6·7
Water capacity	2·2	17·9	23·3	23·1
Colloidal clay	2·3	7·4	12·5	6·6
Mg. Equivalents of Water-Soluble and Exchangeable Bases per 100 gm. Soil:				
H	0·01	0·03	0·03	0·03
Ca	4·72	7·12	14·75	10·20
Mg	1·70	1·85	5·85	4·25
K	0·43	0·33	0·36	0·33
Na	4·44	2·74	3·48	4·43

Here again we see clearly that the roots have removed so much calcium from those layers in which they can grow that an undesirable increase of sodium relatively to calcium has been brought about. The few roots which have been able to enter the Nazzaz layer are completely decayed. The addition of lime to the surface of the soil has not so far resulted in any great change in the adsorption complex.

Improvement is possible in all cases where the Nazzaz layer is not too highly developed—*i.e.*, where the layer is neither too thick nor too deep. The soil must be ploughed as deeply as possible and, at the same time if possible, be dressed with quicklime. The object of the deep ploughing is to loosen the Nazzaz layer, and the addition of lime will aid in the production of a crumb-structure in place of the original single-grain, puddled condition.

Our work has already shown that citrus groves require soils with good drainage, so that light soils are generally to be preferred. As a rule, grapefruit appears to be less sensitive than oranges, and with careful irrigation grows well on heavier soils, as, for example, on the alluvial loams of the Plain of Esdraelon.

At many localities on the coastal plain are found heavy black alluvial soils, locally called " Salaga." Here success depends on the depth to which the deposit extends and the form assumed by the alluvium. A very instructive example was found in a grove near Tel-Aviv. At the locality " A " grapefruit was grafted on Khushkhash in 1927 and at " B " in 1926. At " A " the trees have developed normally, the roots now extending to a depth of 80 cm. At " B " all the trees are badly developed, although planted a year earlier than at " A." In an attempt to improve the soil, sand and about 100 kg. of lime per dunam (about 8 cwt. per acre) have been added artificially. The roots grow to a depth of about 70 cm. Commencing at a depth of 320 cm., the soil contains black concretions of iron (2).

TABLE 59

SALAGA ALLUVIAL SOIL NEAR TEL-AVIV: LOCALITY "A," WITH GOOD DRAINAGE

	A. 0-20 *cm.* *Black Loamy Sand.*	*B.* 20-110 *cm.* *Black Loamy Sand.*	*C.* 110 *cm.* *Brownish Loamy Sand.*
	%	%	%
$CaCO_3$	3·31	2·27	1·82
pH	7·8	7·3	7·3
Water Extract:			
HCO_3	0·06	0·04	0·04
Cl	0·002	0·010	0·005
Total salts	0·15	0·17	0·16
Water capacity ..	41	40	20
Water permeability ..	0·94	1·28	16·18
Mechanical Analysis (Diameter, mm.):			
1·00–0·25	0·25	1·15	3·50
0·25–0·05	74·40	78·80	82·10
0·05–0·01	21·50	10·49	5·81
Less than 0·01 .	2·85	9·56	8·59

As the analysis shows, in case "A" the finest particles diminish from the upper to the deeper layers. This progressive diminution of clay and silt results, naturally, in a diminution of the water capacity, and at the same time in a progressive improvement in the soil's permeability to water. Although of a very heavy nature at the surface, this soil is a good substratum for the growth of citrus trees, as any excess water finds a natural drainage in the lower layers, where there is adequate aeration for the roots.

Not so in case "B." Here the alluvial deposit is much heavier and extends to a very considerable depth (bores were made to a depth of 3½ metres). The superficial addition of lime and sand is of no avail because it is precisely the deeper layers, which are not reached, that require such amelioration. At a depth of 1 metre we encounter a heavy loam which is impervious, not only to the roots but even to

TABLE 60

SALAGA ALLUVIAL SOIL NEAR TEL-AVIV: LOCALITY "B," WITH BAD DRAINAGE (IMPERVIOUS SUB-SOIL)

	A. 0-20 *Cm.* *Black Loamy Sand.*	*B.* 20-100 *Cm.* *Black Loamy Sand.*	*C.* 200-320 *Cm.* *Black Heavy Loam.*	*D.* 200-320 *Cm.* *Black Heavy Loam with Concretions of FeO.*	*E.* 320-340 *Cm.* *Black Heavy Loam with Concretions of FeO.*
	%	%	%	%	%
$CaCO_3$	8·01	1·91	2·04	1·50	1·61
pH	7·7	7·7	8·9	8·3	8·2
Water Extract :					
HCO_3	0·06	0·08	0·12	0·11	0·11
Cl	0·003	0·008	0·024	0·03	0·037
Total salts	0·01	0·12	0·18	0·16	0·16
Water capacity	37	41	54	56	67
Water permeability	9·41	0·82	0·05	—	—
Mechanical Analysis (Diameter, mm.) :					
1·00-0·25	3·14	1·52	1·00	—	—
0·25-0·05	65·70	76·10	43·60	—	—
0·05-0·01	7·55	7·03	14·40	—	—
Less than 0·01	23·41	15·35	40·91	—	—

water; no aeration can take place in such a soil, and all the analytical data confirm this. The permeability of the soil to water diminishes with increasing depth and becomes inappreciable at a depth of 1 metre, where it is about 1/1000th of that found in sandy soils. Only in the uppermost layer is the water capacity found to be not very high, which is probably a result of the addition of sand and lime, the latter having flocculated the finer particles of the soil. Owing to the large amount of clay in the deeper layers, the chloride content is much higher here than in the former profile. Through the interaction of calcium carbonate with the sodium present in the soil complex, sodium bicarbonate and even traces of soda are found in the C stratum, which produce very harmful effects. The soil becomes sticky as a result of the presence of bicarbonates with their highly alkaline reaction (pH 8·9 in the C layer), and for this reason, and also on account of its poor drainage and stickiness, appears to be quite unsuitable for citrus cultivation.

These conditions are also reflected in the composition of the adsorption complex (Tables 61 and 62).

TABLE 61

Composition of Adsorption Complex of Salaga Soil (Alluvial Loam from Vicinity of Tel-Aviv), with Good Drainage

(For description of profile see Table 59, page 108.)

	A. 0-20 *cm.*	*B.* 20-110 *cm.*	*C.* 110 *cm.*
pH	7·8	7·3	7·3
Water-Soluble and Exchangeable Bases (mg. Equivalents per 100 gm. Soil)			
Ca	33·0	27·8	7·7
Mg	0·7	1·1	1·6
K	0·4	0·2	0·4
Na	3·6	1·1	2·6

TABLE 62

COMPOSITION OF ADSORPTION COMPLEX OF SALAGA SOIL (ALLUVIAL LOAM FROM VICINITY OF TEL-AVIV), WITH BAD DRAINAGE

(*For description of profile see Table* 60, *page* 109.)

	A. 0-20 *cm.*	*D.* 200-320 *cm.*
pH	7·7	8·3
Water-Soluble and Exchangeable Bases (mg. Equivalents per 100 *gm. Soil):*		
Ca	22·5	12·0
Mg	5·6	10·0
K	0·2	0·2
Na	8·6	5·6

The comparatively large increase in sodium ions is clearly perceptible—that is, the commencement of alkalinisation—which still further aggravates the undesirably compact and impermeable nature of the substratum.

TABLE 63

COMPOSITION OF WATER OF RIVER JORDAN ABOVE AND BELOW LAKE TIBERIAS

	At Entrance to Lake (mg. per litre).	*At Exit from Lake (mg. per Litre).*	*River Jordan at Allenby Bridge (mg. per Litre).*
Cl	9·6	240	315
Na	10·0	133	117
Mg	7·8	28·5	62
Ca	46·0	48·0	73
SO_4	5·6	38·0	6·3
CO_3	60·0	—	165
Br	—	2	3
U	2·0	7	10

The ill-effects due to poor drainage are, naturally, most marked where the irrigation water has a high salt content. This does not apply to the case described above, where the irrigation water had the low salt content of 88 mg. Cl per litre.

The neighbouring settlements of Kinnereth (Kibbuz) and Deganya in the Valley of the Jordan serve as good examples. The River Jordan becomes salty while flowing through Lake Tiberias, the salt being derived from springs. The analyses given in Table 63 by Blake (3) show this clearly.

TABLE 64

SALT ACCUMULATION CAUSED BY DEFICIENT DRAINAGE

	A. 0-30 *cm.* *Black Alluvial Loam with Salt Efflorescences.*	*B.* 30-70 *cm.* *Black Alluvial Loam with Ferruginous Concretions.*	*C.* 70-100 *cm.* *Light Grey Alluvial Loam with Wadi Gravel.*
	%	%	%
pH	7·4	7·5	7·5
$CaCO_3$	18·5	24·1	23·0
HCO_3..	0·05	0·04	0·05
Cl	1·44	0·91	0·64
Water capacity ..	46	49	30
Water permeability	288	5·85	20·57
Silt and clay ..	5·3	33·3	22·8

The irrigation water, derived from the River Jordan and used by both settlements, was found to have a rather higher Cl content—viz., 323 mg. Cl per litre. A high sodium chloride content gives occasion for great anxiety whenever it is a question of the irrigation of heavy soils with impeded drainage. This applies to most of the soils of Kibbuz Kinnereth, consisting mainly of a basaltic alluvium, with which are mixed, to a greater or lesser extent, Pliocene Limestone, Lisan Marl, Wadi Gravel, etc. An additional complication is that the irrigation practice in Kinnereth is extraordinarily intensive. According to statements made

[Photo by Keren Hayesod.

XI.—RICH ALLUVIAL BASALTIC SOIL. NOTE THE ROUNDED EROSION FEATURES OF THE BASALTIC ROCK IN THE BACKGROUND. (THE JEWISH COLONY OF JAVNEEL IN GALILEE.)

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[Photo by Keren Hayesod.

XII.—THE JORDAN WINDING ITS WAY THROUGH THE HULEH SWAMP. IN THE BACKGROUND LAKE HULEH AND THE TRANS-JORDAN PLATEAU.

to the author, each dunam (¼ acre) receives about 3,000 cubic metres annually. Since 1 cubic metre of water contains 323 gm. Cl, each dunam receives 969 kg. Cl, or each square metre about 1 kg. Cl, corresponding to 1·65 kg. sodium chloride. As a result of the permeability to water being low—a condition often found in these soils—and in consequence of the impeded drainage, the initial stages of injury are unmistakable. It is, of course, the low-lying ground which is affected first of all, as will be seen from the analyses given in Table 64.

The ground-water contains over 25 gm. Cl per litre, and a comparison with earlier analyses shows that the salt content has increased tenfold within a period of about four years (4). This salinisation in the Sink, the so-called Old Channel of the Jordan at Chirbeh el Kerak, is thus, at least partially, recent, and is to be ascribed to the intense irrigation practised, which has not only caused an increase in the salt content, but at the same time has brought about a rise in the level of the water-table. In brief, a saline swamp has developed. The vegetation serves as an external indicator. Bananas planted here have, of course, perished; a wood of eucalyptus which formerly flourished has fallen into decay, and its place has been filled by tamarisks, but these also are beginning to succumb. Even on the higher ground, vegetables and bananas suffer from the inadequate drainage, although salinisation has not yet taken place to any great extent.

In complete contrast to the conditions described above, the light Lisan Marl Soils near Deganya do not show any signs of injury as a result of irrigation by the same water from the River Jordan, as will be seen from the analyses given in Tables 65 and 66.

The Deganya soils carry citrus groves (grapefruit) which are in extraordinarily good condition, whereas, on the other hand, the crops (mainly bananas and vegetables) growing on the badly drained, heavy soils of Kinnereth frequently display ill-effects.

TABLE 65

EFFECT OF SALINE IRRIGATION WATER ON POORLY DRAINED HEAVY SOILS (KINNERETH)

	A. 0-30 *cm.* *Greyish-Brown Alluvial Loam with Salt Efflorescence.*	*B.* 30-60 *cm.* *Greyish-Brown Alluvial Loam with Ferruginous Concretions.*	*C.* 60-100 *cm.* *Light Grey Loam with Wadi Gravel.*
	%	%	%
pH	7·4	7·8	7·8
$CaCO_3$	21·9	26·7	24·4
HCO_3	0·05	0·06	0·06
Cl	0·19	0·13	0·08
Water capacity	40	48	35
Water permeability	288	15·5	36
Silt and clay	28·5	29·6	19·8

TABLE 66

EFFECT OF SALINE IRRIGATION WATER ON WELL-DRAINED MARL SOILS (DEGANYA)

	A. 0-30 *cm.* *Yellow-Grey Marly Loam.*	*B.* 30-75 *cm.* *Yellow Marly Loam.*	*C.* 75-115 *cm.* *Lisan Marl.*	*D.* 115-150 *cm.* *Lisan Marl.*
	%	%	%	%
pH	7·7	8·4	8·3	8·3
$CaCO_3$	44·2	44·2	54·5	55·4
HCO_3	0·06	0·05	0·05	0·05
Cl	0·03	0·02	0·03	0·04
Water capacity	34	31	35	30
Water permeability	288	480	360	480
Silt and clay	28·5	36·0	33·8	27·8

At this point attention must be drawn to the fact that, under the conditions prevailing in Palestine, irrigation with water having a high chloride content does not bring about alkalinisation of the soil in the true meaning of the word (*i.e.*, soda formation), but, rather, salinisation of the soil by sodium chloride. On account of the great importance of this problem in Palestine, a special section will be devoted to the dangers of faulty irrigation.

However, it must first of all be pointed out that according, to Ravikovitch and Bidner (5), vines may also suffer as a result of faulty irrigation. The following table is quoted from their paper:

TABLE 67

CHLORIDES AND TOTAL WATER-SOLUBLE SALTS IN THE SOIL

	Vines Healthy.		*Vines Injured.*		*Vines Killed.*	
	Cl.	*Total Salts.*	*Cl.*	*Total Salts.*	*Cl.*	*Total Salts.*
	%	%	%	%	%	%
A. 0-30 cm. ..	0·023	0·185	0·022	0·227	0·049	0·478
B. 30-60 cm. ..	0·011	0·070	0·018	0·109	0·012	0·117
C. 60-90 cm. ..	0·014	0·074	0·031	0·130	0·018	0·091
D. 90-120 cm.	0·024	0·102	0·031	0·130	0·031	0·133

At the same time the injured vines were found to have a higher sodium chloride content than the healthy ones, whereby sugar formation was checked. As a result of drainage the salt content of the soil was reduced considerably.

We recapitulate the results of this work, although it is not clear whether the injury suffered by the vines was due so much to the salt content of the soil as to the unsatisfactory drainage conditions. Experience in Palestine so far seems to indicate that vines are comparatively insensible to the presence of sodium chloride. A marl soil near Jericho, for instance, on which an orange grove had died, displayed a perfectly satisfactory growth of vines. Similar conditions were found at Migdal in the Northern District and also at Beisan. Another interesting paper of the above-mentioned authors deals with the effect of soil-salinity on clover (54).

In conclusion, reference must be made to the fact that there must always be a sufficient depth of soil for the root system, if trees are to grow satisfactorily. In the neighbourhood of Tel-Aviv a dead orange plantation was found where the calcareous sandstone was only 50 cm. below the surface of the soil!

But even where "Kurkar" occurs (pp. 51-52) the roots of the trees cannot penetrate. A satisfactory growth of trees is only possible where a thoroughly weathered layer of actual soil provides sufficient support and nourishment for the roots. In no case will the roots of a citrus tree penetrate typical Kurkar; they always stop short above its surface. This is due to the unfavourable mechanical-physical conditions, which prevent the roots from penetrating such a hard material. It should, of course, be clearly understood that these observations refer only to typical Kurkar and not to the disintegrated sandy soil derived from it. In some cases where shallow Kurkar is underlaid by sand it is, of course, possible to break the Kurkar pan before planting the tree. The following typical example has been selected from a large number of Kurkar profiles (Tables 68 and 69) (2):

"Shamouti" Oranges on Kurkar of Different Depths.— The trees at which the profiles were taken, standing about 60 metres apart, were planted about twenty years ago. Tree A is not well developed, and the fruit is poor in size. The yield of the tree has averaged about 2 boxes annually during the last five years. The roots grow down to a depth of 70 cm., where they meet the Kurkar pan.

Tree B is well developed and its fruit is large and of good size. The yield has averaged about 3 ½ boxes annually during the last five years. The roots grow down to a depth of 125 cm., where they meet the Kurkar pan.

The essential difference between the two profiles is the fact that the Kurkar is much more weathered in case B, where the pan is overlaid by a soil layer, 125 cm. in thickness, and containing about 10 per cent. of silt and clay.

In case A the thickness of the soil is only 70 cm., and it

TABLE 68

LOAMY SAND WITH KURKAR PAN (PROFILE "A")

	A. 0-15 *cm.* *Loamy Sand.*	*B.* 15-70 *cm.* *Sand.*	*C.* 70 *cm.* *Kurkar.*
	(%)	(%)	(%)
$CaCO_3$	11·47	8·31	6·76
pH	7·8	8·4	8·8
Water Extract :			
HCO_3	0·04	0·04	—
Cl	0·008	0·005	—
Total salts	0·1	0·04	—
Water capacity	9·0	9·0	—
Water permeability ..	75·8	75·8	—
Mechanical Analysis (Diameter, mm.) :			
1·00–0·25	1·62	1·44	—
0·25–0·05	91·30	95·76	—
0·05–0·01	4·36	0·00	—
Less than 0·01	1·71	2·80	—

TABLE 69

LOAMY SAND WITH KURKAR PAN (PROFILE "B")

	A. 0-55 *cm.* *Loamy Sand.*	*B.* 55-125 *cm.* *Loamy Sand.*	*C.* 125 *cm.* *Kurkar.*
	%	%	%
$CaCO_3$	7·88	8·42	15·89
pH	7·5	8·6	8·7
Water Extract :			
HCO_3	0·04	0·04	—
Cl	0·007	0·008	—
Total salts	0·07	0·07	—
Water capacity	11	14	—
Water permeability ..	84·7	75·8	—
Mechanical Analysis (Diameter, mm.) :			
1·00–0·25	1·61	3·52	—
0·25–0·05	88·12	87·60	—
0·05–0·01	2·47	0·76	—
Less than 0·01	7·80	8·12	—

consists merely of sand showing no adsorptive capacity. Such a soil is too shallow for a tree to grow satisfactorily; the roots cannot obtain sufficient anchorage and neither nutrition nor water supply is adequate. It may again be pointed out that, not in this instance alone, but in many others, it has been found that the roots never penetrate typical Kurkar. This should be taken into consideration wherever Kurkar is encountered, and on no account should trees be planted where it comes close to the surface—*i.e.*, where the actual soil is too shallow—unless, as mentioned above, it is possible to break through the shallow Kurkar pan which is underlaid by sand.

In this connection it may be remarked that in the hill country orchards (apples, pears, plums, etc.) also require a sufficient depth of soil. The success of some orchards (*e.g.*, Kiryath Anawim) is to be ascribed to the occurrence of a deep red soil in those localities, and this enables the trees to develop a root system extending to a sufficient depth. Whilst in this respect figs and olives are quite insensible, this is not true of stone-fruits. With regard to olives, our experience so far indicates that they grow well only on calcareous soils.

B. Irrigation and its Attendant Perils.

The chemical composition of water used for irrigation is of the greatest importance, because water of bad quality not only affects the vegetation but, in the course of time, will also bring about a deterioration of the soil. A short description of the water resources of Palestine has already been given (p. 17), and their effects on soil and tree will now be discussed.

The quality of irrigation water in Palestine is mostly assessed by the chloride content or by the total salt content. The injurious effects, however, should probably be attributed not only to the high content of sodium chloride but also to the fact that the proportion of sodium to calcium rises with an increase in the chloride content, thus causing a readier absorption of sodium by the plant (6). The following figures, chosen from a large number of analyses, show this clearly:

TABLE 70

CHANGES IN THE MOLECULAR RATIO Ca/Na AND Ca+Mg/Na WITH AN INCREASING AMOUNT OF Cl IN IRRIGATION WATERS

Locality.	*Cl p.p.m.*	*Ca/Na.*	*Ca+Mg/Na.*	*Total Salts p.p.m.*
Rehoboth ..	47	9·1	14·3	220
Ascalon ..	51	2·0	2·6	226
Yarcon	158	1·1	1·9	571
Gaza	221	0·7	1·3	952
Jordan	316	0·7	1·7	812
Migdal S.D. ..	369	0·4	1·1	1,204
Migdal N.D. ..	1,784	0·3	0·5	3,804

Magistad and Christiansen (27) rightly point out that, especially at concentrations less than 2-3 atmospheres, the nature of the salt and ratio of one ion to another may affect plant growth more than does the total concentration.

It will be seen from the above table that when the chloride content is greater than about 200 mg. per litre the number of Na ions present exceeds the number of Ca ions. This fact should also not be overlooked when dealing, for example, with the problem of calcium nutrition (9).

Comparative experiments with sodium chloride and sodium nitrate have shown that much smaller concentrations of sodium chloride are required to produce injury (7). Further, it has been proved that citrus seedlings can withstand much higher concentrations of calcium chloride than of sodium chloride.

We have to deal, therefore, not only with the physiological action of sodium ion or of chloride ion alone, but with the combined effects of both ions, each of which is injurious. Moreover, it has been proved that the injurious action of sodium chloride could be counteracted, to some extent, by the addition of calcium ion (7, 8, 9, 10, 11, 12). Hence, in the presence of chloride ions, the proportion of sodium to calcium is a very important factor in the nutrition of plants, since a large quantity of easily soluble sodium chloride prevents the intake of calcium by the plant to a considerable extent. (In opposition to this, Menchikovsky and Puffeles (13), on the basis of soil and leaf analyses, believe that, on the contrary, a high proportion of monovalent bases to divalent bases is desirable !)

At the same time, according to McGeorge (14), an alkalinity of over pH 8·3 will greatly reduce the absorptive capacity of the plant so far as calcium is concerned. It may also be mentioned that the antagonism between calcium and potassium is well known (15, 28, pp. 164 *et seq.*, 57).

Whereas, therefore, the antagonistic effect of sodium and calcium and potassium and calcium has been well established, this is not the case with the reciprocal effect of sodium and potassium. Available information is furthermore particularly sparse as regards the intake of anions.

It is for this reason that the author and his collaborators have undertaken the investigations to be described below.

1. SALINE IRRIGATION WATER AND ITS EFFECT ON THE INTAKE OF NUTRIENTS.

In order to study this effect barley seedlings were grown in saline natural irrigation water at different dilutions and varying addition of nutrients. The intake of ions from the culture media and the outgo of ions from the plant were measured. For details and technical procedure the reader must be referred to the original paper (29). It may only be mentioned that one hundred seeds of barley were, after germination, transplanted to glass tumblers with a capacity of half a litre and grown in the respective solutions for 18 days. The irrigation water employed was the one described on page 37, and had the following composition:

TABLE 71

Analysis of Irrigation Water Employed

	Na.	*K.*	*Ca.*	*Mg.*	*HPO₄.*	*Cl.*	*SO₃.*	*HCO₃.*
p.p.m. ..	1927	54	353	250	Tr.	3553	944	164
M.E. per litre	83·7	1·3	17·6	20·6	Tr.	100	19·7	2·7

In order to study the influence of concentration the water was diluted with distilled water to obtain: 35, 350, 1,750 and 3,000 p.p.m. of chlorine. As will be seen from the table given above, the amount of monovalent cations present was more than double the amount of bivalent cations. The absence of phosphates and nitrates and the relation of Cl to SO_4 (about 5 : 1) are characteristic for irrigation water of the type employed. In order to study the intake of nutrients under these conditions KNO_3 and KH_2PO_4 were added to dilutions of irrigation water to give the following final concentrations:

TABLE 72

Addition of Nutrients (M.E. 10^{-1} per 500 c.c.)

	K.	*HPO₄.*	*N.*
1. Weak addition of nutrients (NPK I)	31·7	9·2	22·5
2. Medium addition of nutrients (NPK II)	158·5	45·8	112·7
3. Strong addition of nutrients (NPK III)	317·0	91·6	225·4

By these means it has been possible to study the intake of nutrients under a wide range of conditions.

The barley used for our experiments was a local variety of the following composition:

TABLE 73

Amount of Ions Present in Barley Seeds (M.E. in 10 gr.)

Na.	*K.*	*Ca.*	*Mg.*	*HPO₄*	*Cl.*	*SO₄.*	*NO₃.*
0·30	1·11	0·45	1·10	2·31	0·21	0·30	9·71

TABLE 74

AMOUNT OF IONS PRESENT IN THE CULTURE SOLUTION (M.E.: 10^1 IN 500 c.c.)

Culture Solution. Cl p.p.m.	Na	K	Ca	Mg	½HPO_4	Cl	SO_4	NO_3	HCO_3
35	4·2	0·1	0·9	1·0	—	5·0	1·0	—	0·1
35 + NPK I	4·2	31·8	0·9	1·0		5·0	1·0	22·5	0·1
35 + NPK II	4·2	158·5	0·9	1·0	45·8	5·0	1·0	112·6	0·1
35 + NPK III	4·2	316·9	0·9	1·0	91·6	5·0	1·0	225·2	0·1
350	41·9	0·7	8·8	10·3	—	50·0	9·8	—	1·4
350 + NPK I	41·9	32·4	8·8	10·3	9·2	50·0	9·8	22·5	1·4
350 + NPK II	41·9	159·1	8·8	10·3	45·8	50·0	9·8	112·6	1·4
350 + NPK III	41·9	316·9	8·8	10·3	91·6	50·0	9·8	225·2	1·4
1750	209·5	4·0	44·1	51·4	—	250·0	49·2	—	6·8
1750 + NPK I	209·5	35·6	44·1	51·4	9·2	250·0	49·2	22·5	6·8
1750 + NPK II	209·5	162·4	44·1	51·4	45·8	250·0	49·2	112·6	6·8
1750 + NPK III	209·5	320·8	44·1	51·4	91·6	250·0	49·2	225·2	6·8
3000	359·1	6·0	75·6	88·1	—	428·6	84·3	—	11·6
3000 + NPK I	359·1	37·7	75·6	88·1	9·2	428·6	84·3	22·5	11·6
3000 + NPK II	359·1	164·4	75·6	88·1	45·8	428·6	84·3	112·6	11·6
3000 + NPK III	359·1	322·8	75·6	88·1	91·6	428·6	84·3	225·2	11·6

TABLE 74 (*Continued*)

AMOUNT OF IONS ABSORBED BY PLANTS (M.E.: 10^{-1} PER 1 GR. OF DRIED MATERIAL)

Na	*K*	*Ca*	*Mg*	$\frac{1}{2}HPO_4$	*Cl*	SO_4	NO_3	*Total Cations.*	*Total Anions.*
2·3	−0·6	0·6	−0·4	−0·4	1·9	0·2	—	1·9	1·8
0·9	7·0	0·4	0·5	4·1	1·4	—	1·5	8·7	7·0
0·8	12·8	0·8	0·5	6·5	1·7	0·1	9·3	14·9	17·5
0·3	16·9	1·4	−0·3	7·5	1·0	0·1	11·9	18·3	20·5
10·3	−0·7	1·1	—	—	10·6	0·5	—	10·8	11·2
5·6	6·6	2·9	0·5	3·2	8·8	0·5	1·4	15·6	13·9
3·1	15·8	2·5	0·6	6·0	6·2	0·6	9·7	22·0	22·5
3·0	16·8	2·4	0·5	7·7	3·8	0·7	11·5	22·6	23·6
16·2	0·6	3·1	0·7	0·7	18·0	3·1	—	20·7	21·7
10·7	7·5	2·6	1·1	3·7	14·8	1·2	4·0	21·9	23·7
7·1	16·0	3·1	0·7	6·1	10·6	1·3	9·6	26·8	27·5
6·6	18·3	2·6	1·3	6·1	10·5	1·1	13·0	28·9	30·6
20·4	1·8	2·6	1·6	0·1	23·6	2·7	—	26·3	26·4
13·6	6·9	3·2	1·9	3·7	19·9	1·4	2·1	25·7	27·1
13·3	11·3	3·1	2·3	2·9	19·4	1·4	9·8	30·0	33·5
14·1	17·5	2·9	1·8	2·5	22·2	1·4	9·7	36·3	35·7

Before considering the possible physiological effect of salt accumulation in the experiments reported here it may be pointed out that in view of the brief vegetation period (approximately three weeks) damage caused to growth and yield was not very considerable. Nevertheless it is clear that over prolonged vegetation periods the damage due to the sum-total of concentration of salts employed would have been detrimental if not actually lethal.

Table 74 shows the results obtained in our experiments.

It will be seen from these figures that the plants possess a certain power of exclusion, since there is no parallelism between salt concentration in the solution and salt accumulation in the plant. With increased concentration the absorption of ions becomes relatively depressed, a fact which is of course well known (28). Ion absorption by the plant depends, not only on the ion concentration but also on their quality and on the presence and quality of other accompanying ions (27, 28, 30, 48). Because of the incapacity of the plant to exclude even detrimental ions, the concentration in which such ions occur in the vicinity of the roots is of utmost importance. A one-sided predominance of certain ions may impede the intake of vital ions. Apart from the hindrance of nutrient intake, the one-sided predominance and consequent intake of certain ions may also cause considerable disturbance in the colloido-chemical structure of the protoplasm. It is generally assumed that certain ions—*e.g.*, Na, K—augment the swelling properties of the protoplasm and so impede its vital activities. Other ions such as Ca appear to exert an opposite effect and lead to a detoxication of the plasma (15).

The ions present in one-sided predominance in our case are sodium chloride, and, in nutrient-enriched media of low Cl concentration, also potash, phosphoric acid and nitrates.

The undesirable effect of a *sodium* predominance in irrigation water has been stressed by various authors, but probably more because of its effect on the soil than because of its direct effect on the plant. An impeding influence of

Na on the intake of K was found by Lundegard (15, p. 143). Hellriegel (31), on the other hand, states that Na has a promoting influence on the intake of K. Breazale (32) observed but a slight impediment of the K intake by NaCl, whereas Hoagland (33) reports a definite impeding influence. In other experiments carried out by Hoagland (34), however, an impeding influence was only found at NaCl concentrations greater than 3,000 p.p.m. Heinrich (35), and likewise Terlikowsky, Byczkowsky and Sozansky (36), also found an antagonistic influence by Na in respect of K.

A number of recent publications likewise stress the impeding influence of Na on the intake of K (37-40). Van Itallie (41) found an impeding influence with a number of plants, whereas in other cases the K intake was not affected. Gauch and Wadleigh (42, 43) showed that there was practically no influence of sodium chloride on potassium intake with beans.

In our experiments Na and Cl were the ions most readily absorbed. As pointed out before, their intake was, however, not proportional to the amount of NaCl present in the culture solution.

In no case and even at the highest concentration of Na employed was an impeding influence by Na on the intake of K observed. With solutions ranging in NaCl concentration from *ca.* 50 to 4,000 p.p.m. and varying within a wide range in K concentration, the results obtained under the conditions of our experiment fully corroborate those authors who found no impediment of K absorption in the presence of Na.

The intake of sodium is most distinctly impeded, on the other hand, by the presence of *potassium*, the impediment being apparently directly proportional to the amount of K present. The depression effect is much weaker of course at the higher Na concentration. At the lowest Na and highest K concentration the intake of Na is only 10 per cent. of the amount taken up in the absence of K. At a high Na concentration, on the other hand, the impediment is only about 70 per cent. Similar results have been obtained in the case of beets and hay (44) and with six plant species out of eight in the experiments of Van Itallie (41). If this result is corroborated in further experiments it may prove to be of practical significance and application wherever salty irrigation water is used.

Calcium was absorbed to a most marked degree when present in the lowest concentration, but was absorbed only to 25 per cent. at 10 times and to only 4 per cent. at 50 times the amount. Similar figures were recorded for the intake of *magnesium*. Because of the short vegetation period employed the total intake of both these bivalent cations was very small and the figures obtained are subject to experimental error.

With regard to the intake of anions it may be pointed out firstly that relatively and absolutely the strongest absorption occurred in the case of *chlorine*. Nutrients being absent its intake is parallel more or less with that of Na. As in the other cases, intake of Cl becomes relatively weaker as the concentration in the culture solution is increased. In all cases the intake of *sulphates* was much smaller both relatively and absolutely, a finding which has previously been recorded by several authors (15, pp. 76-77, 33, 34, 43).

The intake of *phosphoric acid* was high and only impeded in the presence of the highest chloride amount employed. Relatively less P ion was found to be absorbed at higher concentrations. The finding that no depression of phosphate intake by chlorine occurred, except in the case of the highest Cl concentration, may be compared with the results of Breazale (32), who found no influence of NaCl on the absorption of phosphoric acid by wheat seedlings. Similar results were obtained by Gauch and Wadleigh (42, 43) with beans and by Gauch and Eton (40) with barley.

It is manifest, on the other hand, that the intake of chlorides is very much impeded, except in the case of the highest Cl concentration, by the presence of phosphoric acid. With the highest amount of phosphates the intake of Cl was diminished by about 50 per cent., a result noteworthy for its possible practical significance if the observed phenomenon proves to be generally valid.

The intake of *nitrates* was not influenced at all by the presence of chlorides and sulphates, the difference in NO_3 intake lying within experimental error. The same observation has been made by Breazale (32), by Gauch and Eaton (40), and the same conclusion can be derived, we believe, from the figures given by Hoagland and Martin (34).

It is evident from the difference in the intake of cations and anions recorded that a general tendency for preferential anion intake existed in our experiments. A slight alkalinisation observed in almost all cases where nutrients were added gives further support to this view, since it is known that a preferential absorption of anions is accompanied by an outgo of bicarbonates whereby the electrostatic equilibrium is preserved. The preferential intake of NO_3 has of course long been known (22, 33, 46).

The inundation of the plant by Na and Cl ions harmful to the protoplasma causes the severe damage so often observed in nature such as poor crop, stunted growth and the withering of leaves in the case of citrus trees. In some cases the leaves show only yellow spots (mottled leaves), and in others they become entirely yellow. Such leaves have an abnormally high content of sodium and chlorine (8-11, 16, 51).

In so far as one can generalise from our experiments the effect of sodium chloride can to a certain degree, apart from Ca, also be counteracted by the addition of potassium and phosphates, which tend to impede the intake of Na and Cl. In many cases where farmers are dependent on saline irrigation water, the fear is expressed that strong fertilisation will only harmfully increase the salt content of the soil solution. Since, however, not salt accumulation as such, but one-sided predominance of NaCl, is the main factor for damages observed, this view seems to be ill founded. Our experiments tend to show that under moderate conditions of salinity addition of potassium and phosphoric acid, although slightly augmenting the total intake of ions, has a marked depressing effect on the harmful intake of sodium chloride.

2. THE MAXIMUM CHLORIDE CONTENT TOLERABLE IN IRRIGATION WATER.

It will be easily understood that very great difficulty is experienced in attempting tc give general rules as to the amount of chloride that may be tolerated in irrigation water. Not only is the sodium chloride content of the water of importance, but so, too, is the presence or absence of other salts, as well as their sum total. Furthermore, the nature of the soil, its drainage conditions, and the stock and variety of citrus all have to be taken into consideration. Jordan water, for example, may prove injurious to some plants on the heavy soils of Kinnereth, but not on the light soils of Deganya; on the other hand, *Citrus aurantium* (Khushkhash) appears to be more resistant than other stocks. Nevertheless, when the sodium chloride content is the predominant factor, the following observations may be of some help for practical purposes;

The author has found only two references to the amount of chlorides tolerable in irrigation water under the conditions prevailing in Palestine. Menchikovsky (17) considers water containing more than 100 mg. Cl per litre to be unfit for irrigation purposes, while Picard (18) sets the figure at 200 mg. Cl per litre. Both statements seem to be overcautious.

Table 75 records a number of observations made by the author, supplemented especially from observations made by Mr. G. W. Baker, of the Government Laboratory.

In recording the injury, no distinction has been made between mottled leaves and chlorosis, etc., since both often occur simultaneously. In No. 11 the damage is probably

XIII.—PEAT-SOIL IN THE HULEH SWAMP.

XIV.—SOIL, WHICH HAS BEEN COMPLETELY SALINIZED BY FAULTY IRRIGATION, NEAR KINNERETH.

To face page 129

due not so much to the action of chloride ions as to that of the sulphate ions, which are present to the extent of 128 mg. per litre. The poor quality of the soil is probably a contributory factor.

Nos. 5, 6, 8, 9, and 14-16 are observations made by Mr. G. W. Baker, and Nos. 12 and 23 are observations made by Dr. Menchikovsky (17). It may be pointed out that American authors found that injury was caused by irrigation water containing from 480 to 630 parts Cl per million (22). Recent American publications consider a Cl content of over 245 p.p.m. as unsuitable (46) and a total salt content of 2,000 p.p.m. as injurious to unsatisfactory for most crops (27).

These observations clearly show that injurious effects are only apparent when the chloride content rises to 350 mg. Cl per litre (equivalent to 584 mg. NaCl per litre) or more. It should be emphasised that, although injury is perceptible in the presence of this amount of chloride ion, much higher concentrations are necessary to cause complete infertility or death of the tree. At the same time it must be remembered that the injuries observed are not always due directly to the chloride ions but may be the result of secondary actions. (It is interesting to note that the limit of 350 mg. Cl per litre coincides with the value of the ratio Ca+Mg/Na becoming unity.)

The obvious symptoms of the injurious action of sodium chloride are: a poor crop, a stunted growth of the tree, and especially the withering of the leaves. In some cases the leaves show only yellow spots (mottled leaves), and in others they become entirely yellow. Such leaves have an abnormally high content of sodium, potassium and chlorine, and a low calcium content (8-11, 16).

TABLE 75

CHLORIDE CONTENT OF IRRIGATION WATER AND ITS INFLUENCE ON THE TREE (6)

No.	*Cl p.p.m.*	*Total Salts.*	*Stock.**	*Age of Grove (Years).*	*Soil.*	*Locality.*	*Injurious Effects due to Chlorides.*
1	27		1	8	Calc. loam	Jericho	None.
2	47	220	1	10	Dune sand	Rehoboth	None.
3	51	226	2	12	Sandy loam	Ascalon	None.
4	88	460	1	15	Kurkar	Jaffa	None.
5	120		2	30	Light	Sak. es-Sabil	None.
6	128		1, 2	36	Loam	Salameh	None.
7	141	620	1	5	Dune sand	Natanya	None.
8	200	820	2	40	Loam	Salameh	None.
9	204		2	30	Light	Sak. ed-Darwish	None.
10	214	592	1	30	Loamy sand	Gaza	None.
11	221	952	2, 3	30	Dune sand	Gaza	None ?
12	248					Petah-Tiqvah	Present ?
13	255	710	1	5	Calc. loam	Gesher	None.
14	272	1,064	2	20	Heavy loam	Safrieh	None.
15	292	1,180	1, 2	20	Heavy loam	Safrieh	None.
16	296	1,160	1, 2	80	Light	Jaffa	None.
17	323	893	1		Heavy calc. loam	Kinnereth	None.
18	323	893	1	8	Marly loam	Deganya	None.
19	368	1,130	1	5	Loamy marl	Beisan	Present.
20	369	1,204	1, 2	2	Loam	Migdal, S.D.	Present.
21	378	1,070	1	8	Calc. sandy loam	Ben Shemen	None.
22	439	1,280	1, 2	7	Calc. sandy loam	Gaza	Present.
23	499					Petah-Tiqvah	Present.
24	593		2	3	Calc. loam	Half-way Jericho-Jordan	Present.

* 1 = *Citrus aurantium* (Khushkhash). 2 = *Citrus aurantifolia* (Sweet Lime). 3 = *Citrus limonia* (Rough Lemon).

3. CHANGES IN THE SORPTION COMPLEX AS A RESULT OF FAULTY IRRIGATION.

Soils which are rich in lime, when irrigated with water having a low chloride content, do not raise any special problems (see Gesher soil in Table 76), but when the irrigation water has a high chloride content conditions change.

A continued irrigation with water containing common salt not only enriches the soil solution in sodium chloride (*cf.*, for instance, the Jericho soil described on page 22), but may, under certain conditions, completely change the composition of the sorption complex in the soil. The place of the calcium adsorbed by the clay may be taken, in part, by sodium, which, theoretically, is in a position to displace all the calcium, gradually. The following series of schematic formulæ explain the well-known process:

1. $\boxed{\text{clay}}{=}Ca + 2NaCl \rightleftharpoons \boxed{\text{clay}}\begin{matrix}-Na\\-Na\end{matrix} + CaCl_2$

2. $\boxed{\text{clay}}\begin{matrix}-Na\\-Na\end{matrix} + 2HOH \rightleftharpoons \boxed{\text{clay}}\begin{matrix}-H\\-H\end{matrix} + 2NaOH$

3. $2NaOH + CO_2 \rightleftharpoons Na_2CO_3 + H_2O$

Some scholars have asserted that even under the conditions prevailing in Palestine this process results in strong alkalinisation or, what is tantamount, the formation of sodium carbonate (19, 20). It is true that in a few individual cases there are signs of a commencement of soda formation, for we have to deal here with dynamic equilibria. But we desire to contradict the general statement that, under the conditions here prevailing, we have to deal with the formation of "black alkali"—*i.e.*, the formation of soda, such as is experienced in California, Hungary, etc. Observation in the field and examination in the laboratory furnish no ground for such an assumption.

The main argument against soda formation under our conditions is the abundance of lime in our soils, which in itself is sufficient to impede, for scores of years, the total displacement of calcium. But another theoretical argument likewise contradicts that assumption. The investigations of de Sigmond, Gedroiz, Kelley and others have proved that the sodium-clay formed undergoes a slight hydrolytic dissociation, in the course of which sodium hydroxide is formed. The latter is converted into carbonate in the presence of carbonic acid. However, such hydrolytic dissociation takes place to a considerable extent only when sodium chloride is not present in excess. This is due to the fact that sodium chloride itself is very strongly dissociated, whereby the dissociation of the sodium-clay is greatly impeded. Only after the removal of sodium chloride by leaching will alkalinisation or the formation of soda be possible, with all its injurious consequences (peptisation, stickiness, etc.). Under our conditions irrigation does not cause the removal of sodium chloride from the soil; on the contrary, it causes a constant increase of sodium chloride (1).

We have, therefore, not so much a process of alkali formation, with all its accompanying features, but rather a salinisation of the soil. The following examples will illustrate this (Table 76):

First let us examine an alkali soil in California (9). The pH value is extremely high and the soil contains considerable quantities of sodium carbonate but only trifling quantities of neutral salts (chlorides, sulphates). Calcium and magnesium have been replaced to a large extent by sodium, which constitutes 70 per cent. of the exchangeable bases.

As a contrast, let us now examine some Palestine soils. The Gesher soil shows an absolute preponderance of calcium and magnesium in the sorption complex, whilst the amounts of chlorides and sulphates present indicate that almost half of the small sodium content is to be found, not in the sorption complex, but in the form of soluble salts. The soil at Beisan is very similar, though the chloride content is higher and all varieties of citrus suffer from chlorosis. However, here, too, calcium preponderates and the sodium is to be

TABLE 76

ADSORPTION COMPLEX OF AN AMERICAN AND SEVERAL PALESTINE SOILS (1)

	California.	Gesher.	Beisan. A. 0-30 cm.	Beisan. B. 30-70 cm.	Beisan. C. 70-100 cm.	Kinnereth.	Gaza. A. 0-50 cm.	Gaza. B. 50-90 cm.	Gaza. C. 90-150 cm.
Cl in irrigation water (mg./litre)		255		368		323		439	
pH	9·7	7·4	7·9	8·1	7·9	7·4	8·3	9·0	9·2
$CaCO_3$		37·2	38·0	30·2	28·8	18·6	11·4	8·7	10·6
Water-Soluble (mg. in 100 gm. Soil) :									
CO_3		0	0	0	0	0	0	Tr.	Tr.
HCO_3		49	67	79	43	50	40	70	80
Cl		13	34	42	92	1442	30	20	10
SO_4		29	0	25	115		36	Tr.	Tr.
Total salts		75	95	100	250		160	110	150
Water-Soluble Anions (mg. Equivalents in 100 gm. Soil) :									
CO_3	0·94	0	0	0	0	0	0	Tr.	Tr.
HCO_3	0·80	0·8	1·1	1·3	0·7	0·8	0·7	1·1	1·3
Cl	0·32	0·4	1·0	1·2	2·6	40·6	0·9	0·6	0·3
SO_4	0·20	0·6	0	0·5	2·4		0·8	Tr.	Tr.
Water-Soluble and Exchangeable Cations (mg. Equivalents in 100 gm. Soil):									
Ca .. .. .. }	1·08	58·8	20·3	13·7	27·7	3·2	11·3	18·1	9·3
Mg .. .. .. }		1·2	1·9	1·7	1·0	2·1	5·4	9·1	10·2
K	0·43	2·0	1·5	4·3	2·4	0·3	0·7	0·5	1·3
Na	5·19	4·0	1·7	0·9	6·4	38·2	8·6	4·8	10·1
Per Cent. of Total Amount of Exchangeable Bases :									
Na	78	6	7	4	17	88	33	14	33

found not so much in the form of exchangeable base in the colloid complex as in the form of soluble salts in the soil solution, as is manifest from the figures for chlorides and sulphates. An extreme example is afforded by Kinnereth, where all plants perish, not merely orange trees. The quantity of sodium present is enormous, and yet a large proportion of this occurs, not in the sorption complex, but in the soil solution as sodium chloride, as is proved by the figure for chlorides. The only instance of even a commencement of true soda formation is afforded by the soil from Gaza (6). This soil contains traces of carbonate, while the pH value is higher than in other soils; but even here sodium amounts to only 33 per cent. of the total exchangeable base content.

Whilst only a few examples have been cited, nevertheless the soil at Beisan, and even that of Kinnereth, is evidence that there is no question of soda formation. The investigations carried out up to the present show that, first and foremost, we have to deal with the directly injurious action of the irrigation water, or with the salinisation of the soil by sodium chloride, which, as shown above, actually arrests the formation of soda.

We have stated that the maximum chloride content which is permissible in irrigation water is about 350 mg. Cl per litre. Of course, the limit is fixed only approximately, and this calls for renewed emphasis. It is clear that the value of the limit is liable to extensive variations in accordance with changes in other factors—viz., the variety of citrus, the amount of irrigation water applied, the age of the plantation, the presence of other salts, and, especially, the nature of the soil. In a light, sandy soil sodium chloride will never accumulate to a great extent, and in such cases the sodium chloride content of the irrigation water itself is directly responsible for any damage inflicted on the growing plants. On the other hand, in a loamy or clayey soil, in which sodium chloride can accumulate, the conditions are different; here the possibility of an increasing content of common salt is ever present, in spite of the nature of the irrigation water, which, in itself, may be quite suitable. Unfortunately, the old rule "No irrigation without drainage" has been only too often neglected.

Generally speaking, we have found that, parallel with the use of irrigation water having too high a chloride content, the amount of common salt in the soil also increases, the content ranging from 40 to 620 mg. Cl per 100 gm. soil, and that this was invariably accompanied by injury to the trees. These results resemble those obtained in California, where the use of saline irrigation water brought about an accumulation of chlorides (large quantities) in the soil, amounting to 30-96 mg. Cl per 100 gm. soil; at the same time, here also plantations were injured in all cases (22).

C. Manuring.

The manuring problem in the non-irrigated districts of Palestine, in which "dry farming" is the usual practice, is closely bound up with that of the correct control of the soil moisture (26). As a result of the irregular distribution of the rainfall, the farmer's chief task is the collection and storage of the water underground and the reduction of the loss of moisture by evaporation. An over-abundant supply of nutrients intensifies the transpiration of plants; nitrogen, for instance, increases the leaf-surface and consequently increases the water consumption. On the other hand, it must be remembered that luxuriant growth increases the shade, reduces the evaporation, and consequently conserves the water supply. An inadequate supply of nutrients causes the plant to use water in extravagant quantities. Again, we can hasten blossoming and maturity by applying heavy dressings of phosphatic fertilisers, and so avoid the premature ripening caused by lack of water.

Plants obtain their nutrient salts from the moist upper layer of the soil, which must, for optimum growth, always contain sufficient water to supply the plant with the necessary nutrients. It is possible that the soil may dry out, although there is still sufficient water in the sub-soil. Under these conditions, it is really the lack of nutrient salts and not a lack of water which causes the plant to perish. We have, therefore, to differentiate between two types of drought according to the soil or the sub-soil being short of water. If the soil is too dry, a lack of nutrients results and fertilisers must be applied; here it is advantageous to grow plants which give much shade, such as beets, turnips, potatoes, etc. On the other hand, if the sub-soil is too dry but little manure may be applied, lest a too luxuriant plant-growth will bring about too great an increase in the transpiration current. It is the task of the practical agriculturist to adopt the correct middle course between these two extremes.

In arid regions, such as Palestine, it is necessary that artificial fertilisers be applied at as great a depth as possible, and not on the surface, because the dominant direction in which the movement of water takes place in the soil is upwards from below. If the fertiliser be applied at too slight a depth beneath the surface, there will not be sufficient water to convey the nutrients to the plant. As far as possible artificial fertilisers must always lie in a layer which remains moist.

Organic manures, such as dung, etc., have a rather different effect. In a dry soil, they may seriously affect the movement of water between soil and sub-soil by the creation of pore space, and on this account organic manures should be only lightly covered; the rise of water by capillarity is thus interrupted, and the loss by evaporation is reduced. As a general rule in non-irrigated areas slow-acting, long-lasting fertilisers are to be preferred, because, with the combination of luxuriant growth and a drought, there is a far greater likelihood of the occurrence of crises in the water supply.

(i) *Soils.*—The soils of arid and semi-arid countries are generally assumed to be deficient in nitrogen but rich in soluble salts and lime. The summary given in Table 77 shows the amount of exchangeable bases present in typical Palestinian soils. Apart from the red sandy soils of the coastal plain, they are all rich in lime. Small amounts of potash are present, but the percentage of sodium is a much higher one.

TABLE 77

EXCHANGEABLE BASES IN TYPICAL PALESTINIAN SOILS (MG. EQUIVALENTS PER 100 GM. SOIL)

	Ca.	*Mg.*	*K.*	*Na.*
Red sandy soils	2·5	0·9	0·3	2·6
Terra rossa	58·5	1·1	1·4	4·4
Mediterranean steppe soils	11·3	5·4	0·7	8·6
Lisan marls	58·8	1·2	2·0	4·0
Alluvial soils	33·0	0·7	0·4	3·6

Some experiments tend to show that Palestinian soils do not as a rule respond so much to potash fertilisers as to nitrogenous and phosphatic fertilizers (47). Such practical experience may hold good to a certain extent in some cases, but it would be disastrous if applied to citrus orchards (23, 25, 51, 52), which provide the main cash-crop of the country. The chief centre of citrus culture is situated in the coastal plain, where the soil is mostly formed by a red loamy sand, extremely deficient not only in nitrogen and phosphoric acid but also in potash and lime. The data in Table 78 bear out this contention.

Thus only the terra rossa soils contain a moderate amount of nitrogen, and, apart from the loess, all soils are deficient in phosphoric acid. Most soils contain a fair amount of available potash, exceptions being the alluvial and red sandy soils. The latter soils are also extremely deficient in lime. The lack of nutrients in the red sandy soils was also proved by the results of pot experiments not yet published.

(ii) *Manuring.*—Only the citrus plantations receive artificial fertilisers on a large scale. All other agricultural soils do not as a rule receive any, and are therefore exhausted, which explains the extraordinarily low yields generally obtained on them. The average yield per hectare is about 480 kg. (3·8 cwt. per acre) in the case of wheat and 630 kg. (5 cwt. per acre) in the case of barley. (In many instances, of course, lack of water is the limiting factor.) The value of chemical fertilisers imported into Palestine has increased fourfold since 1931, and was about £130,000 in 1937. Since only citrus plantations (30,000 ha. in 1938) are systematically fertilised, the remainder of the agricultural land (about 800,000 ha.) suffers continuous impoverishment.

TABLE 78

NUTRIENTS IN AND pH VALUES OF TYPICAL PALESTINIAN SOILS (AVERAGE FIGURES OF SEVERAL SAMPLES)

	Available nutrients according to Neubauer		*N*	*$CaCO_3$*	*pH*
	P_2O_5	*K_2O*			
			%	%	
Red sandy soils	0·0	0·0	0·04	Tr.	7·2
Terra rossa ..	5·2	38·3	0·12	9·50	7·6
Mediterranean steppe soils	Tr.	26·9	0·01	23·72	8·1
Lisan marls ..	4·5	14·8	0·07	58·11	7·6
Alluvial soils ..	0·1	6·1	0·07	12·70	7·9
Loess soils ..	8·5	25·2	0·07	26·50	7·9

(iii) *Phosphoric acid.*—Double superphosphate is mostly applied in the plantations at the rate of about 500 gm. per tree. Experiments carried out with finely ground local raw phosphate proved to be a failure because of the neutral or slightly alkaline reaction of the soil. Transjordan raw phosphates, as they contain about 80 per cent. of tricalcium phosphate (49), are now converted locally into superphosphate (approximately 6,000 tons of raw phosphate were imported from Transjordan into Palestine in 1944-45). Palestinian raw phosphates contain only about 50 per cent. of tricalcium phosphate, the remainder being calcium carbonate, so that they cannot profitably be converted into superphosphate. It may, however, be possible to increase the phosphoric-acid content by igniting the material and washing out the quicklime formed. Although it was found that such a treatment raised the content of tricalcium phosphate up to 80-85 per cent., there is no proof as yet of its economic feasibility.

(iv) *Potash.*—Potassium chloride is produced from the Dead Sea; in 1937 over 29,000 tons, and in 1944 some 97,000 tons, were exported. This fertiliser was, however, not used in Palestine before the war, imported potassium sulphate being used instead (at the rate of 300 gm. per citrus tree). This strange state of affairs is due to the fact that the farmer is afraid to increase the chloride content of the soil, a fear, however, which is baseless, especially so far as the light red sandy soils of citrus groves are concerned. By irrigation alone much more chloride is added to the soil than by manuring with potassium chloride. Assuming the irrigation water to contain only 100 mg. of chlorine per litre, and its amount to be 5,000 cu. m. per hectare, about 500 kg. of chlorine are annually added to one hectare by the irrigation water alone. By treating one hectare with 150 kg. of potassium chloride, less than 75 kg. of chlorine are added per hectare. Further, injuries observed from the use of irrigation water containing over 350 mg. of chlorine per litre are not so much to be ascribed to the chlorine content of the water as to the corresponding amount of sodium, because sodium and not chlorine enters the soil adsorption-complex. Moreover, where good drainage is provided, chlorides do not accumulate in the soil. The sums wasted by the unnecessary application of the much more expensive imported potassium sulphate run into thousands of pounds per annum.

(v) *Nitrogen and organic manure.*—Nitrogen is applied in the form of sulphate of ammonia, nitro-chalk, or nitrate of soda, and about 1 kg. of nitrogenous fertiliser is given per tree. All Palestinian soils, including the terra rossa, which contains moderate amounts of nitrogen, respond first and foremost to nitrogen. As the vegetation period is short, a sufficient amount of readily available nitrogen must be present in the soil. A certain economy in the application of nitrogenous fertilisers could be achieved by better preservation of manure, by composting, green-manuring, and the use of town refuse.

Organic manure is often very badly handled in Palestine, the heaps being exposed not only to the intense sun, but also to the torrential winter rains. The dung is very often left for weeks in small heaps on the field instead of being ploughed in as quickly as possible. On almost all farms the very valuable chicken manure is allowed to dry in the sun, thereby losing most of its easily soluble nitrogen. The following analyses confirm this statement:

TABLE 79

ANALYSIS OF CHICKEN MANURE (PERCENTAGES CALCULATED ON A WATER-FREE BASIS)

	Ash.	*Organic matter.*	*N (total).*	*N (easily soluble).*	NH_3-*N.*
Fresh manure	57·8	42·4	4·1	3·1	0·9
Sun-dried manure	49·6	50·4	2·4	0·8	0·1

These figures, as well as other observations, show the necessity for instructing the agricultural population in regard to the preservation and composting of manure.

The problem of providing sufficient quantities of organic manure of good quality is closely linked up with the nitrogen problem. Although nitrogen can of course be supplied by artificial fertilisers, the use of organic manure for the improvement of soil structure, stimulation of bacterial activity, etc., is in many cases imperative. The easily permeable, red sandy soils in the citrus-belt are deficient in a material that can absorb nutrients and water. Because of the scarcity of organic material in the country, great quantities of manure are imported from neighbouring countries, the price being 20s. to 30s. per ton (pre-war). Possibly the low-moor peat found in the north of Palestine (Huleh region) may prove a substitute for organic manure. Our preliminary investigations have shown that an application of 10 tons per hectare of this peat is quite sufficient to absorb all the nutrients added to the soil. The peat contains about 1·0-1·5 per cent. nitrogen, which, although it was without effect in a pot experiment, may become slowly available.

Whereas the author agrees with Keen (55) that the fertiliser-value of organic matter under Mediterranean conditions is more than doubtful, the peasant's custom of using dung for fuel should, nevertheless, be discouraged. The improvement of soil-structure and the stimulation of bacterial activity by organic manure should not be underestimated. Keen rightly stresses the importance of making controlled experiments with town refuse and farmyard compost and manure under Middle East conditions.

(vi) *Lime.*—As mentioned above, most Palestinian soils are rich in lime, the only exception being the red sandy soils of the coastal plain. On these, liming is absolutely necessary,

TABLE 80

NUTRIENTS REMOVED BY THE CHIEF CROPS OF PALESTINE (1935)

Crop.	*Yield.*	*Nitrogen* (*N*).	*Phosphates* (P_2O_5).	*Potash* (K_2O).
	million kg.	M. tons	M. tons	M. tons
Wheat ..	104	3,025	1,297	2,161
Barley ..	68	1,373	687	1,373
Sorghum	46	1,109	512	1,386
Grapes ..	29	232	87	290
Citrus ..	[20,000 ha.]	1,260	380	1,470
Totals ..		6,999	2,963	6,680

ESTIMATED ADDITION OF NUTRIENTS TO PALESTINE SOILS (1935)

	Nitrogen (*N*).	*Phosphates* (P_2O_5.)	*Potash* (K_2O).
	M. tons	M. tons	M. tons
Artificial fertilisers (13,000 tons)	1,666	1,686	585
Organic manures (150,000 tons)	675	300	900
	2,341	1,986	1,485
Deficit	4,658	977	5,195

since every citrus crop removes about 100 kg. CaO per hectare. For example, at the governmental horticultural stations (50), when the pH is under 7, not less than 600 kg. of quicklime (slaked before application) are applied per hectare. A dressing of lime is of course needed not only because of its physiological effect (53), but also for improving the physico-chemical qualities of the soil.

(vii) *Fertiliser Balance.*—By calculating the quantities of nutrients removed annually from the soil and those added to it in fertilisers a fertiliser balance-sheet is attained.

TABLE 81

ARTIFICIAL FERTILISERS (NPK) PER HECTARE OF AGRICULTURAL LAND (KG.)

	N.	P_2O_5.	K_2O.	*Total.*
Palestine (1935)	3·0	2·5	1·9	7·4
Holland (1929)	32·5	54·0	44·1	130·6
Germany (1929)	12·8	17·1	25·0	54·9
Great Britain (1929) ..	2·6	8·1	3·5	14·2
Italy (1929)	4·7	21·5	1·9	28·1
Egypt (1929)	12·0	3·2	0·1	15·3
Algeria (1929)	0·4	0·8	0·7	1·9

From Tables 78 and 80 it will be seen that nitrogen is the element of which Palestine soils are in the greatest need. The situation is aggravated by the fact that, as a result of the arid conditions, the soils are inherently deficient in nitrogen, whereas, as a result of the climatic conditions, they are not so deficient, relatively, in potash and phosphates. In any case, there is no doubt that these soils have suffered for years from continuous impoverishment, and this is confirmed by the excessively low yields (see page 161).

Although the imports of artificial fertilisers have increased fivefold during the last ten years as a result of the activities of the Zionist colonisation, Table 80 shows that the rates at which plant nutrients are applied to the soil in Palestine are still far below those customary in Europe, though in this connection our views regarding soil moisture and manuring must be taken into account.

Although a very big increase is called for in the utilisation of artificial fertilisers, and this can only be brought about by the education of the farming population, the fact remains that the chief problem is the creation of a supply of organic manure.

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XV.—RUINED TERRACES DO NOT PROTECT THE SOIL. EROSION AND GULLY FORMATION IN THE NABLUS VALLEY (NEAR SINJIL, THE ST. GILES OF THE CRUSADERS).

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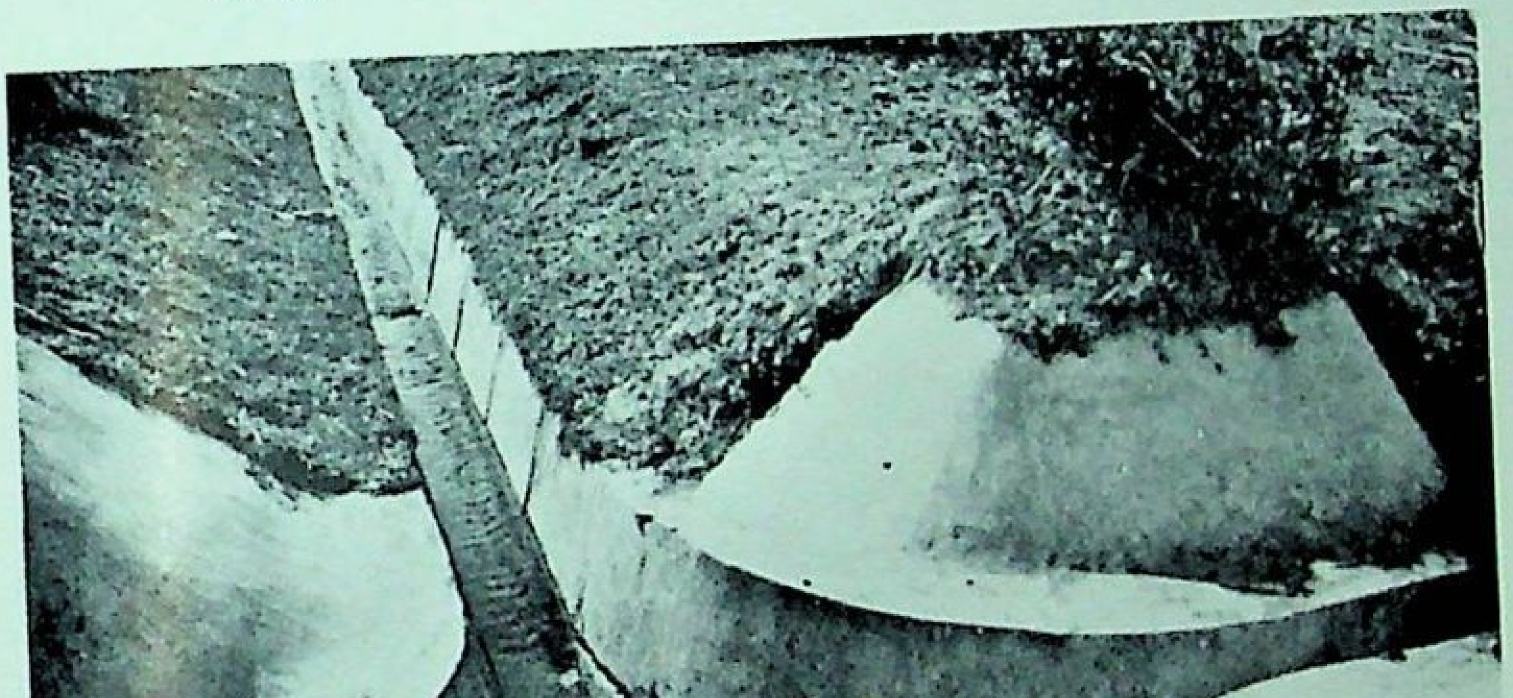
[Photo by Keren Hayesod.

XVI.—TERRACING AND AFFORESTATION OF BASALT HILLS UNDERTAKEN BY THE GOVERNMENT DEPARTMENT OF FORESTS NEAR TIBERIAS.

[Photo by Jewish National Fund.

XVIIA.—SWAMP BLACK EARTH BEFORE DRAINAGE.



[Photo by Jewish National Fund.

XVIIB.—SWAMP BLACK EARTH AFTER DRAINAGE.

Please see overleaf for

XVIII.—THE ENCROACHMENT OF SAND-DUNES AT CÆSAREA.

(By courtesy of the Air Ministry. Crown Copyright Reserved.)

XVIII.—THE ENCROACHMENT OF SAND-DUNES AT CÆSAREA.

(By courtesy of the Air Ministry. Crown Copyright Reserved.)

This aerial photograph reveals the steady progress of dunes at the Palestinian coast. The remains of the ancient city (1) are now fully covered by sand. (The town has been finally destroyed in the 13th century.) The Crusader City (2) and surroundings are still free from sand. Remains of the ancient harbour, constructed by Herod, are clearly visible. The silt carried by the Wadi Mefjir (3) into the sea is moved in a S.-N. direction along the coast. No. 4 shows the remains of the Herodian theatre and No. 5 the ruined hippodrome of the same period. The oval (6) represents a Roman amphitheatre which has only been discovered with the help

of this aerial photograph. The Roman enciente, enclosing presumably the area in which the main public buildings were situated, is clearly discernible; in the south this enciente is partly covered by sand (7). Immediately to the left (south) of the theatre (4) are the houses of a new Jewish village. The ancient aqueducts (8) which once brought water to the city are now destroyed and covered by sand. The coast erosion by wave action is demonstrated by the fact that the upper aqueduct is suddenly breaking off, the connecting part of the land having been destroyed by the sea.

The trees (lower right part of picture) have been planted by the Jewish Colonization Association (PICA), but much more systematic work is needed to stem the advance of the dunes.

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V. SOIL EROSION IN PALESTINE

Whereas in some countries soil erosion often proceeds in sudden upheavals, this is not usually the case in Palestine, where its effect is slower and more gradual; although due to the neglect of centuries, its devastating effect is by no means less serious. The Palestine we see to-day is but the ruin of a once flourishing country (1).

(i) *Destruction of Vegetation.*—In Palestine as everywhere in the world the progress of erosion is linked up with the destruction of vegetation. There is no doubt that Palestine was far better wooded in antiquity than it is to-day. We read, *e.g.*, in the Book of Joshua (xvii. 18): "But the mountain shall be thine; for it is a wood, and thou shalt cut it down."

Whereas in this case the Hebrew word for "wood" may possibly refer rather to shrubs and bushes than to forests in the European sense of the word, there were undoubtedly also groves of oaks, terebinths, carobs, pines, cypresses and sycamores. Concerning the last-mentioned tree we know that it was tended in forests specially planted for timber (1 Chron. xxvii. 28). Remains of oak forests are found even to-day at various places, especially so in Jaulan. But even the Plain of Sharon was covered with bush-wood to such an extent that it derived its name from it in Roman times. Josephus describes the Sharon as the place called "forest," and so does Strabo. Part of this forest must still have been extant in the time of the Crusaders, and notable remnants of it are found even to-day (2, 3). We also know with certainty that wide areas were covered with vines and with fruit trees such as figs and olives.

The destruction of vegetation and forests cannot have been due only to the wars which ravaged the country, although of course much damage was caused in that way, especially during the last war. Far more important is the fact that the type of Palestinian agriculture has changed fundamentally since the downfall of the Byzantine régime. Since then the desert has crept over the country. Whereas it was the ideal of the Jewish farmer that every man should sit peacefully under his own vine and fig tree, the agriculture of the conquering nomads consisted mainly of the rearing of flocks. It is this fundamental change in the type of agriculture which has caused the change we see to-day. In the first centuries of the Christian era there were laws against the rearing of sheep and goats. Rabbi Akiba, for example, said that "Those who rear small cattle and cut down good trees . . . will see no sign of blessing." The fact that the ban on the rearing of flocks is coupled with that of cutting down trees indicates that the inner connection between the two was very well understood. And indeed, not only do the goats eat the young shoots of trees and thereby impede every attempt at reforestation, but they also destroy the last remnants of vegetation by appropriating vast areas for grazing. This pasture gives worse grazing from year to year and therefore extends farther and farther. The cumulative effect of deforestation and grazing is also stressed by Keen (9).

Another reason for the destruction of bushes and shrubs is the use of this vegetation for the manufacture of charcoal and the burning of lime. There is a village, Umm el Fahm ("mother of coal"), which derives its name from charcoal burning. To-day all trace of bushes and shrubs has disappeared completely from the vicinity owing to this lucrative industry. Within the last two years only has Government succeeded in introducing oil burners for lime kilns.

(ii) *The Decay of Terrace Culture.*—Contributing to the loss of vegetation and to soil erosion is the decay of the old terrace-culture in the mountains. Cultivation is possible on sloping land and especially on hillsides only if small plains are artificially created by the construction of terraces. These soil strips protect the soil against erosion and allow for the cultivation of crops and the planting of trees. On unterraced slopes with too steep a gradient the soil is easily washed away and the rain water causes deep rills and gullies. The value of terraces was well known in ancient times, and ancient Jewish writings of the first few centuries of the Christian area give detailed instructions for their construction.

To-day most of the ancient terraces are in ruins, and instead of fertile slopes we meet with nothing but barren rock. It is fantastic to see how age-long custom induces the fellah to plough slopes, which are almost bare of any soil. Such slopes do not of course yield any return to the cultivator. Moreover the plough loosens the sparse soil-cover and makes it still more liable to erosion. But it is far worse if the plough is not drawn in the direction of the smallest gradient, but, as is done quite frequently, in the direction of the slope. In this case the ridges of the furrows afford no protection whatsoever against the descending masses of water, which then rush down through the furrows, carrying away the valuable soil. It cannot be emphasised too strongly that even on moderate slopes all ploughing should be done on the contour—*i.e.*, the furrows should be ploughed at right angles to the direction of the slope at the same level throughout and as far as possible at close intervals. The furrows, together with the ridges produced when they are made, intercept and retain run-off water, thereby preventing erosion and facilitating the distribution, penetration and retention of moisture (4).

A good example in this respect is given by a report on conditions in the Nablus-Tulkarm Valley (5). Here 97 per cent. of the whole area (approximately 140,000 dunams) has steep or precipitous slopes. But only 8 per cent. of the precipitous slopes and 14 per cent. of the steep slopes have any terracing which might be really effective in preventing soil wash-off. No less than approximately 50 per cent. of the steep and precipitous slopes represent areas of neglected terraces; yet 76 per cent. of the former and 44 per cent. of the latter slopes are intensively cultivated. Moreover, 62 per cent. of the steep slopes and 80 per cent. of the precipitous slopes are primarily growing ground crops, thereby requiring ploughing. Small wonder that half the steep slopes and practically all the precipitous slopes "are eroded annually, losing in the aggregate a considerable tonnage of soil, which finds its way on to public highways or road drains, is deposited on and probably damages fertile plains or is lost altogether into the sea." All the slopes show abundant or very abundant rock outcrop.

Well constructed terraces are rarely found nowadays in the hills, a rare exception being, *e.g.*, the village of Bittir, where the possibility of irrigation has induced the peasants to build terraces of the finest type.

(iii) *The Results of Erosion.*—The destruction of vegetation and the decay of terraces have prepared the ruin of the land. Rainfall in Palestine, especially in the mountain region, is comparatively heavy, most of the year's rain falling in the course of a few months. Violent rainstorms of a cloud-burst type scour the loose earth from the barren slopes down into the gorges. The "wadis," which are dry in summer, in winter frequently fill up with muddy, dark-coloured, roaring torrents, which can cause great devastation. No protecting vegetation cover protects the soil and no water can trickle into the barren rock. For this reason the ground-water level is much lower and springs flow much more scantily than in ancient times. To-day it is difficult to understand why the Kidron is described as a torrent. When the slopes were still terraced, the winter rains flowed much more gently and steadily. This is proved, at least to a certain extent, by the many deserted water-mills which we find, for example, in the wadi between Nablus and Tulkarm. The higher the gradient of the slope, the greater the force of the descending water-flow, and this force is increased still further by the silt-masses carried down by the water. Not only is the sparse vegetation carried away, but also stones and boulders, and even large pieces of rock. The roaring water-masses at first form rills on the slopes, which may later be transformed into deep gullies in the plain. As the gullies interfere seriously with the work of the agriculturist, he tries to level them by overploughing, but in this way only loses much more soil in the next year's rain. Once formed, such gullies are extremely liable to additional erosion. The banks of the gully are then damaged still more and many valuable plantations are harmed in this way. At the same time the torrents very often cause damage to highways, bridges, etc., and once even a whole train was derailed. Floods occur at Tiberias almost every year, causing loss of life and property and depositing masses of mud and boulders in the streets. (The township is put to considerable expense for the removal of these obstructions.)

On their way down the hills the torrents deposit the boulders and stones in the wadi, while most of the silt is carried far away into the plains, where it is not needed, and may even do harm to seeds and agricultural lands.

The silt deposited in the plains is also detrimental in another respect, since it chokes up the outlets of the wadis into the sea. This process leads to the formation of swamps, which are not only harmful to agriculture, but also turn the land into malaria-ridden districts. Some of these swamps have now been drained by Jewish institutions (*cf.* p. 155).

The destruction of vegetation, on the other hand, also exposes the soil to wind erosion. In Palestine wind erosion is most pronounced in the Beersheba area, where dust storms are a frequent occurrence. Far greater, however, is the danger to agriculture in the coastal zone, where moving sand dunes threaten fertile stretches and highways in many localities, as for example in the Gaza district and in the vicinity of Cæsarea. The magnitude of the processes involved may be measured at Ascalon, where the city wall, which was 12 metres high in the time of the Crusades, is now almost completely covered over by dune sand. The yearly movement of sand dunes since Roman times has been estimated by Guy (7) to be about 5-6 metres; at other places near the coast it is estimated to be about two metres.

The effect of soil erosion in Palestine can best be gauged from figures prepared by the Government Irrigation Officer.

The run-off of storm-water during an average year is from about 500 to 600 million cubic metres, showing a mean silt content of 1·4 per cent. This means that the quantity of silt carried down the wadis by the flood is from 11 to 14 million tons every year.

If this soil were evenly distributed over the whole area of Palestine, it would have a thickness of about 2 millimetres, which means that a soil layer of about 2 metres in thickness has been eroded during the last 1,000 years. It goes without saying that soil formation through weathering proceeds at a much slower rate.

A comparison between the density of settlement in ancient and modern times likewise reveals a most saddening picture. In the south of Palestine, say approximately the Hebron Sub-District, there were (Joshua xv. 48-57) about 30 towns with their villages, which correspond to about 90 ruined sites in our day. Amongst all these ruins there are to-day only 5 miserable villages—*i.e.*, 5 settlements in an area of about 1,000 square kilometres (6). Similar results were obtained by Colonel P. L. Guy, who examined the catchment area of the Wadi Musrara, which drains the western slopes of Jerusalem to the sea. There are now 32 settlements and only 4 ruined sites in the plain up to a height of 325 feet. At an altitude of 326-975 feet there are, however, only 31 villages apart from 65 ruined sites and on the mountain tops 37 villages apart from 124 ruined sites. The percentages of deserted sites are therefore in the proportion of 11:67:77, a most significant indication of the devastating results of erosion in the hills.

(iv) *Soil Conservation Remedies.*—It is clear from the foregoing that certain measures should and could be taken against this terrible menace. First and foremost, the existing vegetation has to be protected and afforestation in the widest sense of the term undertaken. A tremendous amount of useful work in this respect has been done by Jewish bodies and by the Government. But this is not enough, because on the one hand the area in Jewish hands is restricted, and on the other hand because the funds put hitherto at the disposal of the Government Department of Forests have been quite inadequate. It is here that the artificial restriction of land transfers has an important effect on soil conservation, since a community holding lands in the plain can do nothing to prevent floods caused by the bare condition of the hills.

Obviously no useful work can be undertaken without proper legislative measures. The "Soil Conservation Board," appointed by the Government, is confronted with tremendous difficulties if only because the existing legislation seems in some cases almost to encourage the trespassing and the destruction of existing forests. On the other hand, on the recommendation of this Board an Ordinance was enacted on the strength of which the High Commissioner may declare any land to be a "special area." In such an area the passage and pasture of all domestic animals may be prohibited or regulated. Besides the cultivation of such an area, and the cutting, breaking, burning or removal of any vegetation, whether planted or of natural growth, may be prohibited. One such "special area" is the badly eroded countryside near Tiberias, where the Government Department of Forests has effectively treated the steepest slopes by terracing and tree-planting. Another notable success of this Department is the afforestation of approximately 5,000 dunams of sand dunes near Gaza (8). The activities of various Jewish organisations are described in the chapter dealing with Zionist Colonisation.

It should not be forgotten that many problems, as for example restrictions on the grazing of goats, are closely linked up with economic questions. Much can, however, be done in the meantime in the way of education, and a recently formed "Public Committee for Soil Conservation" has already done much useful work in urging settlers to plough on the contour or to build terraces where necessary.

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VI. THE ZIONIST COLONISATION.

A. The History of Zionist Colonisation.

It cannot be our duty to give an exhaustive account here of the results of the Colonisation Movement, but this book would be incomplete if we omitted to describe the influence on the agricultural colonisation of the country of the natural conditions (climate, soils and possibilities of irrigation) with which we are primarily concerned.

If we disregard the foundation of the Jewish Farm School at Mikveh-Israel near Jaffa with the object of preparing Jews for the adoption of agriculture as a means of livelihood, the first period of Jewish colonisation dates from the foundation of Petah-Tiqva in 1878, which is to-day the largest and most prosperous colony in the orange-growing district. Other colonies, such as Rishon-le-Zion, Zichron-Jacob, Ness Ziona, were founded at about this time, and, at a later date, taken over by Baron Edmond de Rothschild. Because of the early difficulties encountered by these colonies, which to-day are exceptionally prosperous, Baron Rothschild took under his protection the four colonies whose situation was most embarrassing, placed them on a sound economic basis, and "the father of Jewish colonisation" afterwards handed them over to the Jewish Colonisation Association for reorganisation and administration. This association had been founded by Baron Hirsch in 1891 with the object of promoting the settlement of Jews on the land. After the War the association was converted into the Palestine Jewish Colonisation Association (P.J.C.A.), which still carries on its activities to-day, independently of the Zionist Organisation.

The second colonisation period comprises the first ten years of the present century, and is notable for the extensive grain-growing settlements in Lower Galilee, for which the P.J.C.A. was responsible.

The third period starts with the commencement of the colonising activity of the Zionist Organisation, which had been founded in 1897 by Theodor Herzl with the object of "establishing for the Jewish people a home in Palestine secured by public law." A few years later (1902) the Jewish National Fund was formed for the acquisition of land in Palestine to be held as the inalienable property of the Jewish people, and to convey it to the settlers solely on hereditary lease. The expenditure of the J.N.F., derived from the voluntary contributions made by Jews in all parts of the world, amounts up to the present to about £13,000,000, with the aid of which about 75,000 hectares of land have been purchased. Much of this land, situated chiefly in the northern portion of the Jordan Basin, in the Plain of Jezreel, at Akka Bay and in the Wadi Hawareth, had first of all to be reclaimed and drained. In addition, 12,000 hectares of marshland were drained, the necessary facilities provided for irrigation, and approximately 3,500,000 trees planted. Altogether about 48,000 hectares were reclaimed by Jews at an expenditure of £400,000.

The Zionist efforts during this period (roughly from 1908 till 1920) were conducted with the object of replacing the former one-crop holdings (vines or cereals) by smaller holdings under mixed farming. After the end of World War I and the assumption of the Mandate by Great Britain, the Zionist Organisation (later transformed into the Jewish Agency) was recognised as a public body to co-operate with the Government for "the establishment in Palestine of a national home for the Jewish people" (Balfour Declaration of 2nd November, 1917). Of especial importance is Article 6 of the Mandate, which reads as follows: "The Administration of Palestine, while ensuring that the rights and position of other sections of the population are not prejudiced, shall facilitate Jewish immigration under suitable conditions and shall encourage, in co-operation with the Jewish Agency referred to in Article 4, close settlement by Jews on the land, including State lands, and waste lands not required for public purposes." It may be mentioned that, for reasons which cannot be discussed here, practically no State land was allocated, and that the area of the land in Jewish possession, amounting to about 60,000 hectares before World War I, was increased to about 173,000 hectares by further purchases, corresponding to 18 per cent. of the land cultivable under present conditions, or 6·5 per cent. of the total area.

The fourth period begins with the year 1921, when a start was made with the settlement of the land purchased by the Jewish National Fund, as described above. To meet the heavy financial burden of this immense colonisation scheme, the Palestine Foundation Fund (Keren Hayesod) was created. This, like the Jewish National Fund, was based on free-will offerings, and to-day has invested more than £20 million in the land. Of this, about 30 per cent. was spent on agricultural colonisation, the remainder having been applied to education, public health, public works, etc. At the same time the Jewish Agency maintains an agricultural experimental station at Rehoboth, which receives a grant-in-aid from the Government for research in citrus culture. Mention must also be made of investigations in various branches of agriculture which are conducted, quite independently, in the Hebrew University at Jerusalem, and also of the fact that both these institutions have joined in the creation of an agricultural college.

The chief forms of settlement under the Zionist Organisation are the " Kvuzah " and the " Moshav." In " Kvuzah " the revenue and possession of the settlement are the common property of the colonists, and their requirements are met from this common fund. The colonist in " Moshav " obtains the land on hereditary lease, is supported financially at the start if necessary, manages his affairs independently, and only combines with other colonists in a co-operative society for the sale of his produce and for the purchase of his supplies, and also for the provision of implements. An important principle of the "Moshav" is the definition, which has arisen for social reasons, that only under exceptional circumstances can hired labour be employed.

The Zionist colonies have successfully adopted the principles of mixed farming, and are now completely stabilised—*i.e.*, they are mostly self-supporting. At the same time most of the settlements are repaying, in the form of liquidation shares, the capital which had been invested in them. In this connection it may be noted that, on the average, about 40 per cent. of the invested capital was written off on account of the initial difficulties.

From about the year 1930 onwards colonisation by private enterprise has made extraordinary progress and is primarily responsible for the rapid expansion of citrus culture, now providing the principal article of export. It may be taken that since the Balfour Declaration Jewish capital investments amount to £100 million, of which, naturally, most has been placed in industry. Of concerns which are of agricultural interest first place must be given to the Ruthenberg Power Station on the Jordan, the Palestine Potash Company, which recovers potash and bromine from the Dead Sea, and the Shemen Oil Factory. Much non-Jewish, British capital is invested in all these concerns.

The results of the Jewish colonisation policy are to be seen in the 250 or so flourishing farming settlements, whose agricultural and political structure could not be shaken even by so severe a crisis as the 1936 trouble. Since 1920 about 400,000 Jews have immigrated who have found an assured economic existence. The total number of Jews amounts to 600,000, of whom about 24 per cent. are settled on the land. At the same time the Arab population has increased from 630,000 in 1919 to more than double that number in 1945. Of these about 64 per cent. are living on the land.

It is self-evident that all these results have only been achieved because the power of the British Mandate introduced orderly administration in place of Turkish misrule, has built up a network of roads and communications, and has promoted the development of the country. With regard to agriculture, the Government has tried in many ways to help the distressed Arab farmer. The agricultural taxes, formerly the chief source of the State's revenue, have been greatly reduced—indeed, often completely remitted—so that they now form but 2 per cent. of the revenue. Simultaneously cheap credits have been given to the farming population, seeds and plants made available, and a network of practical agricultural experiment stations established. A splendidly organised Department of Agriculture attends to the instruction of the rural populace, the Department of Forests supervises the maintenance of the forests and puts out new plantations. A particularly valuable service rendered by the Government is the successful control of animal disease.

The Government's income of £18 million, for the most part derived from taxes paid by the Jewish community, in the first place benefits the Arab population.

B. The Natural Conditions in Palestine in Relation to Agricultural Colonisation.

As unoccupied land, in the narrow sense, does not exist in Palestine, the success of Jewish agricultural colonisation depends entirely on the possibility of intensifying the present primitive farming practice. The following account will show that not only is this possible, but that successful progress has already been made along these lines.

The distribution of cultivable and uncultivable land is shown in Table 82 (2).

Of the total land area of 2,600,000 hectares, only 937,000 hectares, or 35·6 per cent., are cultivable.* This figure of

* Government estimate: 876,000 Ha. excluding forests and "built-on areas" (1). According to estimates submitted by the Jewish Agency the cultivable area is 1,340,000 Ha. (3).

937,000 hectares agrees closely with the area of land in actual cultivation—viz., 797,000 hectares (according to information kindly supplied by the Director of the Department of Agriculture); thus 15 per cent. of the land is cultivable but not cultivated.

TABLE 82

COMPOSITION OF AREAS IN THOUSANDS OF HECTARES

	Total Area.	*Sand Dunes.*	*Marsh.*	*Forest.**	*Barren Land, Water Unclassified and Undefined Land.*	*Cultivable Land.†*
Coastal Plain	322	34	2	—	19	266
Acre Plain ..	55	3	1	(?)	3	48
Plain of Esdraelon ..	40	—	—	—	3	37
Huleh Plain ..	19	—	4	—	3	13
Plain of the Jordan	107	—	2·5	—	49·5	55
Inhabited hills	612	—	—	17	241	354
Uninhabited hill wilderness	219	—	—	—	219	—
Beersheba area	320	—	—	—	156	164
Southern desert	938	(?)	—	—	938	—
	2,632	37	9·5	17	1,631·5	937

The non-productive area, including the Southern Desert, amounts to almost 65 per cent., which is extraordinarily high, and it appears to us very probable that a large proportion of the "unclassified and undefined land" should be included in the "cultivable" area. Table 83 shows the proportion of productive and non-productive land in a few countries.‡

Of the total cultivable area of 937,000 hectares as much

* Forest Reserve area: 74,500 Ha. (1).

† Excluding marsh and forest.

‡ The figures for the Hill Country were corrected according to Granowsky (3) and those of the Beersheba Region according to the Government Memoranda (1).

as 242,000 hectares are considered irrigable and therefore suitable for intensive cultivation according to the authors of the J.V.A. project (pp. 170 *et seq.*).

TABLE 83

PRODUCTIVE AND NON-PRODUCTIVE AREAS IN VARIOUS COUNTRIES

	Total Area (1,000 Ha.).	*Productive Area.*		*Non-Productive Area.*	
		1,000 *Ha.*	%	1,000 *Ha.*	%
Palestine ..	2,632	937	35·6	1,695	64·4
Great Britain	22,746	19,267	84·7	3,479	15·3
Italy	28,661	26,398	92·1	2,263	7·9
Greece ..	6,321	2,837	44·9	3,485	55·1
Algeria ..	50,578	20,578	40·7	30,000	59·3

TABLE 84

UTILISATION OF AGRICULTURAL LAND IN VARIOUS COUNTRIES

	Arable.	*Meadows and Pasture.*	*Orchards.*	*Forest.*	*Moorland, Heaths and Other Productive Waste-land.*
	1,000 *Ha.*	1,000 *Ha.*	1,000 *Ha.*	1,000 *Ha.*	1,000 *Ha.*
Palestine ..	667	10	120	17	9·5
	%	%	%	%	%
Palestine ..	80·9	1·2	14·6	2·1	1·1
Great Britain	32·2	62·0	0·1	5·7	—
Italy ..	48·7	23·4	5·5	17·7	4·7
Greece ..	33·3	24·3	9·7	29·6	31·3
Algeria ..	22·5	4·1	1·9	13·8	57·7

The irrigable area forms about 25 per cent. of the cultivable land, but actually only about 40,000 hectares are under irrigation—that is, 16 per cent. of the irrigable area—whilst the remainder is under extensive cultivation. The fact that the cultivation of the land is extensive rather than intensive is brought out in Table 84, from which it will be seen that the próportion of arable land is appallingly high for a Mediterranean country like Palestine.

The large proportion of orchard land in Palestine is mainly due to plantations of olives, vines and figs, which are to be regarded as extensive cultures. Citrus plantations do not yet comprise a quarter of this area. Further, it will be seen from the table that the preponderance of arable land is really due to the absence of grassland, for the spring vegetation and the parched stubble residues, which are given up to the herds after harvest, can scarcely be reckoned as such. The growing of green fodder crops has only begun, but is already having a perceptible effect on animal husbandry. Their cultivation under irrigation, so far practised in only a few of the Jewish settlements, could promote the keeping of stock in a great measure and would benefit agriculture generally.

TABLE 85

AVERAGE YIELDS OF CEREAL CROPS IN 100 KG. PER HECTARE

	Wheat.	*Barley.*
Palestine (average)	4·8	6·3
Palestine (Jewish colonies) ..	7·2	11·1
Great Britain (1928-32) ..	21·9	20·5
Italy (1928-32)	13·7	11·0
Greece (1923)	8·4	9·6
Algeria (1926)	4·2	3·5
Syria (1924)	4·9	5·0
Cyprus (1926)	6·4	6·7
Egypt (1926)	16·3	16·3

Now if we are to deplore the disproportionate preponderance of the area under the plough, this plea receives additional emphasis when we consider the low yields obtained.

It must, however, be noted that in some Jewish colonies, particularly on the alluvial loams of the Plain of Jezreel, careful manuring and cultivation have resulted in considerably higher yields, which approach those obtained in Great Britain. As will be seen below, wheat is the principal crop in the extensive type of farming, and it is our belief that it would not be difficult in the course of time to increase the yield obtained by the Arab farmers so as to at least equal the standard of the Jewish settlers.

The extensive type of Palestine farming is rendered still more obvious when we examine the actual values of the agricultural products.

It will be seen that the total value of citrus production of £3,657,000 exceeds the value of all other products (£4,400,000 in 1938, the last normal pre-war year). Actually, the yield of citrus per hectare is higher than that shown, because areas which had not yet come into bearing are included.

The table indicates the manner in which the intensification of agriculture should indubitably be brought about. It is obviously inadvisable that all the potential plantation land should now be planted with oranges—for economic reasons alone that would be a mistake—but it is absolutely necessary that the extensive grain farming should be gradually replaced by intensive, irrigated cropping, in which fodder crops should receive special attention. At the same time the yields of corn should also be increased by more intensive manuring and by selection of varieties.

The "viable lot" (defined hereafter, p. 168) of the Arab farmer depends on all these factors, and, with that, the possibility of the acquisition of land and the further settlement of Jews on the land. It will be seen in the following pages that the intensification of agriculture, here advocated, has made great progress since the beginning of the Zionist colonisation. Citrus growing, in particular, by the creation of a marketable article for export, has revolutionised the whole of Palestine agriculture.

In order to demonstrate this process of intensification we will take two examples—namely, (i) the growth of the citrus industry and (ii) the progressive annual increase in the importation of artificial fertilisers.

TABLE 86

ESTIMATED PRODUCTION OF CROPS, 1935*

	Area in 1,000 Hectares.	*Production in Million Kg.*	*Value in £1,000.*
Wheat	225·1	104	861
Barley[1]	262·7	69	294
Lentils	8·2	3	28
Kersenneh	19·3	9	61
Maize	7·0	0·5 (grain)	—
		8 (fodder	42
Beans	3·3	1·5	11
Peas	0·3	0·2	2
Dura	100·4	46	188
Sesame	27·0	7	107
Tobacco	2·2	1	—
Tomatoes	3·2	17	101
Cucumbers	1·7	8	50
Potatoes	0·6	3	20
Other vegetables ..	6·0	28	(?)
Citrus	29·8	8·3 million cases	3,657
Olives	47·5	45	474
Melons	12·6	69	126
Grapes	14·9	29	156
Almonds	2·6	4	128
Figs	9·8	11	63
Apricots	1·2	3	43
Apples, peaches, pears, plums and pomegranates	1·0	2	(?)
Bananas	0·4	4	(?)
Fodder	10·0	(?)	(?)
	796·8		

C. THE INTENSIFICATION OF AGRICULTURE IN PALESTINE AND THE FUTURE OF THE ZIONIST COLONISATION.

We have already shown that the yields per hectare of the principal field crops are exceptionally low, and, on the other hand, have recorded our experience that the yields obtained in the Jewish settlements are significantly higher, partly owing to better cultivation, seed selection, etc., but partly,

* Low harvest due to drought.

also, to the application of artificial fertilisers. The enormous increase in the importation of artificial fertilisers is, of course, connected with the development of citrus cultivation, which has made it possible to obtain twenty times the monetary return from the land as was possible with wheat.

TABLE 87

IMPORTATION OF ARTIFICIAL FERTILISERS, 1922-39

Year.	*Quantity (Tons).*	*Value (£).*
1922	1,077	12,156
1923	1,544	11,156
1924	2,275	21,346
1925	2,761	28,957
1926	2,617	25,368
1927	2,849	28,606
1928	3,361	28,400
1929	5,986	49,379
1930	7,328	64,073
1931	4,463	38,858
1932	7,498	50,211
1933	10,324	94,170
1934	12,852	104,724
1935	13,000	107,000
1936	9,687	71,815
1937	14,698	128,719
1938	10,243	86,619
1939	10,191	88,515

These figures show that Palestine is gradually effecting a considerable reduction of the deficiency of nitrogen, phosphate and potash (p. 138 *et seq.*).. The reduction in imports in the last few years may partly be explained by the import of more concentrated fertilisers and partly by the greater use of locally produced potash.

The intensification is revealed in a still more striking manner by the growth of the citrus industry, the value of whose products exceeds that of all other crops (Table 86). Both Jews and Arabs have participated in the development of citrus plantations, but statistics show that it was only with the Jewish colonisation that an opportunity was given for the Arabs to change over to this highly intensive form of crop production, whose products to-day form the country's chief export.

It was really the Arabs who first made citrus cultivation possible. They sold superfluous land, often waterlogged, to the Jewish societies; by the sale of this land the Arab community acquired the necessary capital for the intensification of their agriculture. The Government estimates

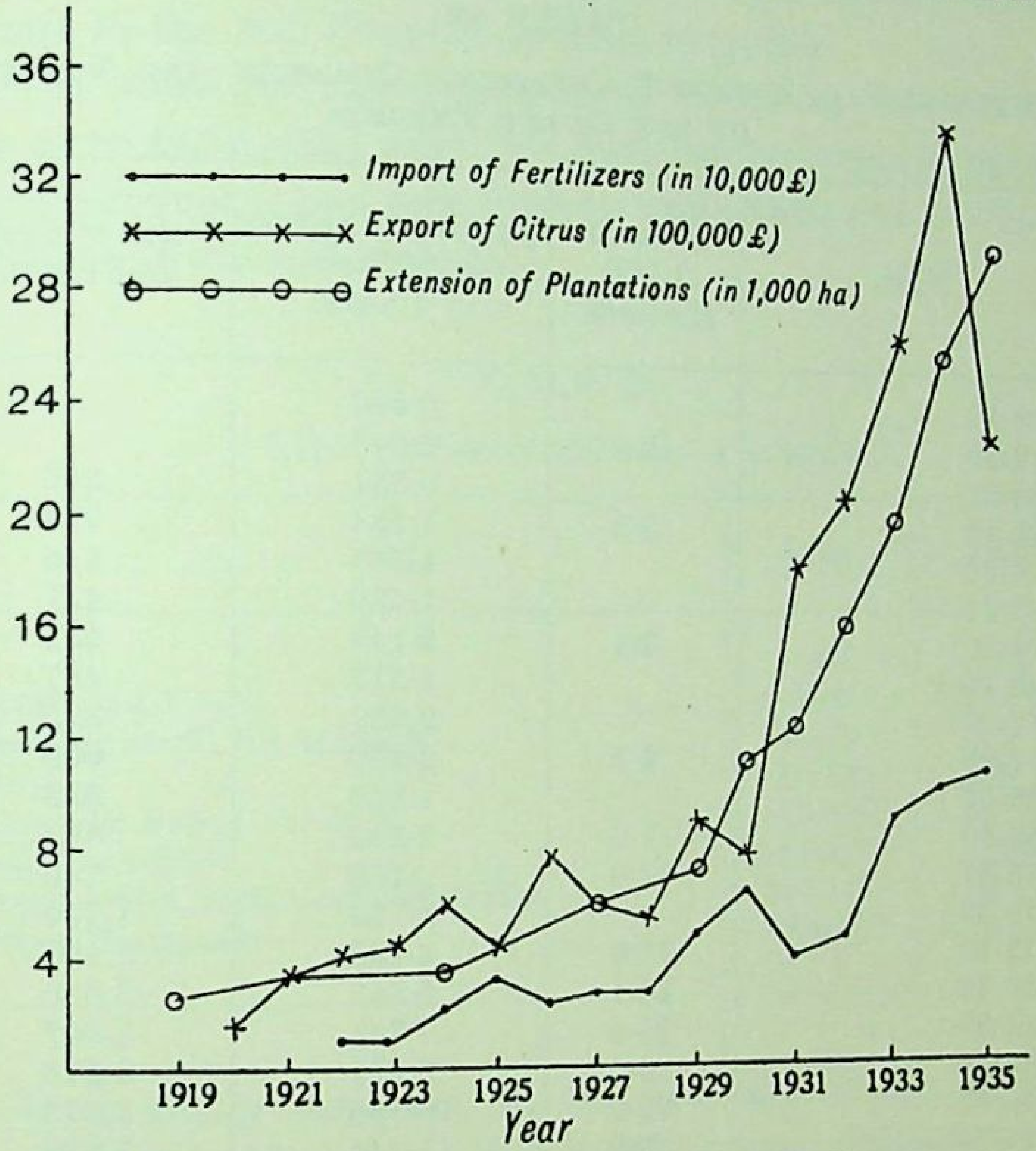

FIG. 4.—IMPORT OF FERTILISERS, EXPORT OF CITRUS AND EXTENSION OF CITRUS.

that since the year 1920 about 68,200 hectares of Arab land has passed into the hands of the Jews at a price of £7,731,000. This fact shows that, even though there is no unoccupied land, there was, nevertheless, a surplus of land which benefited the Jewish colonisation.

In demonstrating the progress made in the intensification of agriculture in Palestine we have confined our attention to the above two aspects. As might be expected, many others might be cited—*e.g.*, egg production has risen in the Jewish coloniesfrom 39 millions in 1937 to 74 millions in 1944, milk production from 33 million litres to 61 million litres, and potatoes from 821 tons in 1926 to 35,000 tons in 1944. In comparison with a milk yield of 500-700 litres (100-150

TABLE 88

EXTENSION OF CITRUS PLANTATIONS: QUANTITY AND VALUE OF THE CITRUS EXPORTS

Year.	*Area in* 1,000 *Hectares.*	*Quantity Exported in Millions of Chests.*	*Value of Export in* £1,000.
1918-19		0·307	
1919-20	2·8	0·647	
1920-21		0·831	206
1921-22	3·2	1·234	334
1922-23		1·365	426
1923-24		1·589	431
1924-25	3·4	2·146	621
1925-26		1·515	467
1926-27		2,659	825
1927-28	6·1	2·220	655
1928-29		1·800	539
1929-30	7·0	2·884	861
1930-31	11·0	2·469	745
1931-32		3·735	1,796
1932-33	16·0	4·499	2,101
1933-34	20·4	5·549	2,650
1934-35	26·5	7·768	3,507
1935-36	29·5	5·897	2,278
1936-37	29·9	10·796	3,873
1937-38	29·9	11·444	3,880
1938-39	29·9	15·265	4,355

gallons) per annum of the native cow, careful crossing with imported stock has resulted in an average yield of 3,475 litres (770 gallons) per cow per annum being attained in the Jewish holdings, though there are many holdings, in which milk recording is conducted, in which the yields equal those of European cows. It may also be mentioned that in the settlements of the Jewish Agency already 64 per cent. of the fodder requirements are supplied from their own holdings, partly by silage made from maize and partly by clover, lucerne, etc., grown under irrigation. Thus a start has been made here in the desired expansion of "meadow and pasture land" (p. 160). Attention must also be directed to the successful trials in growing profitable orchard fruits in the Hill Country without irrigation.

The scope for the expansion of agriculture in Palestine so as to satisfy the country's own requirements in agricultural produce is best seen from an examination of the figures of the agricultural imports.

TABLE 89

IMPORTED AGRICULTURAL PRODUCE

	1938.	1944.
	(£.)	(£.)
Grain and flour	968,857	7,907,043
Feeding stuffs for animals	40,975	397,254
Meat	60,231	66,778
Animals, living, for food	418,857	1,571,901
Dairy produce	487,327	619,254
Fresh fruits, nuts and vegetables	353,101	916,474
Other foodstuffs	779,647	2,357,647

It is highly desirable, in the interests of the farming community of Palestine, that locally grown produce should replace these and similar imports, whose value exceeds £1,500,000.

The great controversy of the last few years has had as its centre the absorptive capacity of the land, which, in turn, depends on the "viable lot" or the smallest area of land which affords a family the means of sustenance. Unfortunately, the compilation of the land register is not yet complete, and, as the last census was taken in 1931, all calculations are beset with great difficulties. The uncertainty of the statistical data resulted in the whole problem becoming a controversial subject with political parties, and this certainly did not assist in the impartial assessment of all the factors. After the unrest of the year 1929, for instance, the number of Arabs rendered landless by the sale of their land to the Jews was alleged to be one of the principal problems of the Government—till it was established on the basis of statistics that 664 Arab families could be designated as having been rendered landless in this way. In the meantime 347 of these families had been settled by the Government, while 317 individually declined to take up land.

In the first edition of this book we tried to arrive at estimates with regard to the number of Jewish immigrants who may in future be settled on the land. So much depends, however, on the coming political settlement of the Zionist question that no such attempt is made this time. The land sale restrictions enacted shortly before the war have put a temporary stoppage on colonisation activities in the greater part of Palestine. Under these land sale restrictions there is a zone of 5,159 square miles to which the restrictions do not apply. In a zone comprising approximately 3,200 square miles all land sales are restricted and in a further zone of approximately 6,600 square miles they are absolutely forbidden. This latter zone comprises all the hilly districts of Palestine, a most regrettable fact, since people living in the plains have to depend on anti-erosion measures to be taken in the highlands. For the time being, therefore, no reclamation of land and intensification of agriculture is possible in the greater part of the country, since all these activities depend practically on Jewish enterprise.

The "viable lot," on the other hand, depends entirely on the creation of irrigation possibilities. Whereas 1·5 hectares of irrigated land may be sufficient for a holding, five or ten times this amount is necessary on non-irrigated land. Of the total cultivable area of 937,000 hectares only 40,000 are at present under irrigation. According to figures released by the Commission of Palestine Surveys, about 242,000 hectares will become irrigable after completion of the "Jordan Valley Authority," a description of which will be given in the next chapter.

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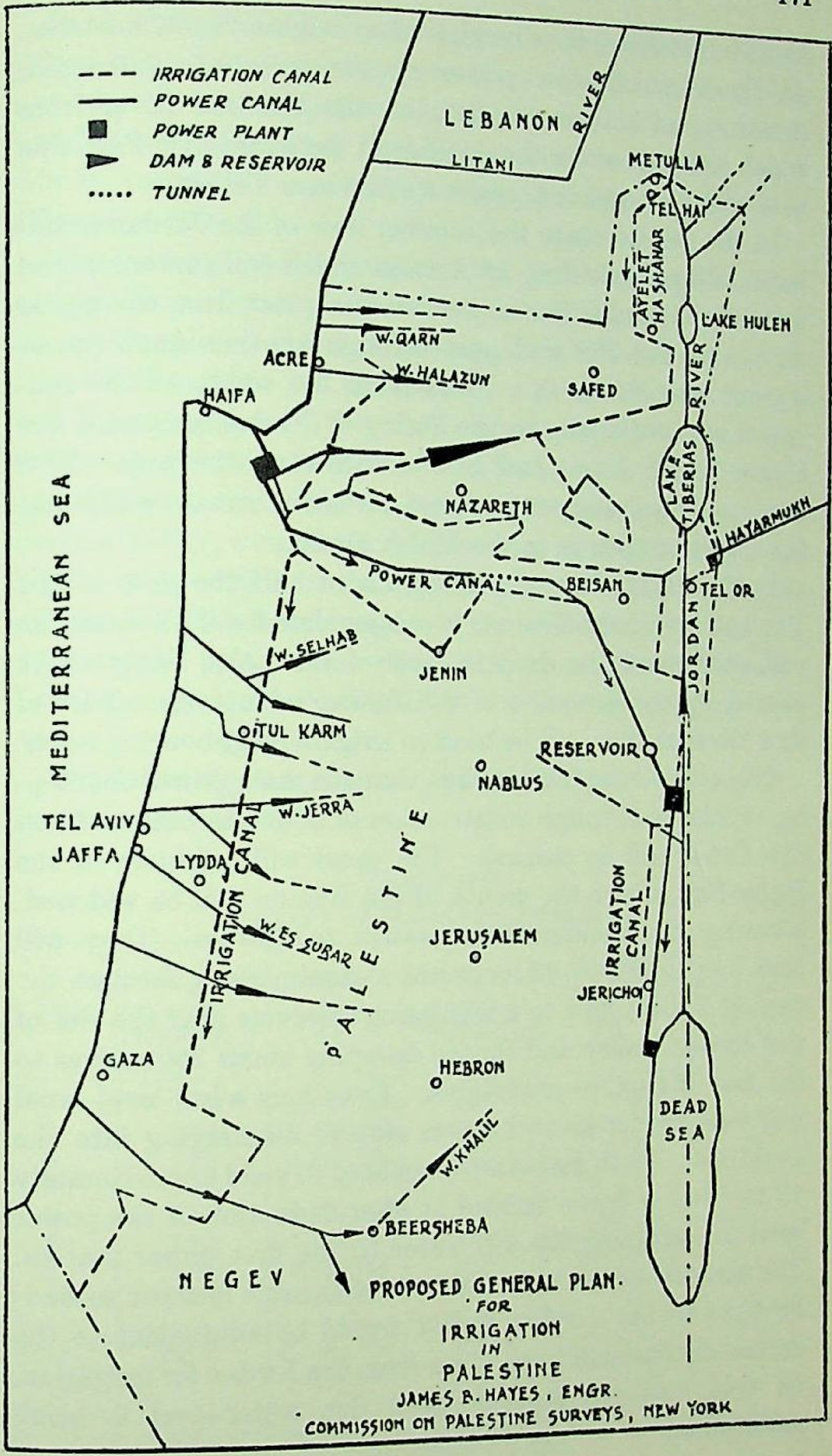
VII. THE JORDAN VALLEY AUTHORITY

In his book " Palestine, Land of Promise " (1) Walter Clay Lowdermilk has put forward a plan for the simultaneous creation of power and irrigation possibilities. In the meantime more technical details have been released and a proposed general plan for the irrigation of Palestine by James B. Hayes, of the Commission on Palestine Surveys (New York), has been published (2, 3, 4).

The main aims of " J.V.A." are the diversion of the sweet waters of the Jordan and its tributaries for the purpose of irrigation and the utilisation of the deep incline of the Jordan Rift Valley for purposes of power development. The annual amount of irrigation water carried through the canals would come to over two million cubic metres, an amount sufficient to irrigate 242,000 hectares of agricultural land as against 40,000 hectares under irrigation at the present time. This estimate does not include irrigable areas at a higher situation than the proposed canal system, nor does it take into account land irrigated by wells or storage possibilities of flood waters. The total length of the proposed main feeder canals are stated to have a length of approximately 450 miles. Three of the largest dams would be from 80 to 300 feet in height and from 1,200 to 8,500 feet in length. The sum-total of power development schemes would amount to roughly 660 million kilowatt-hours per year. This capacity exceeds that of the Noris Dam and will be sufficient to serve the needs of well over a million of additional population.

The co-ordinated programme of power and irrigation development is envisaged in eight stages. In the first stage underground water resources in the coastal plain and elsewhere are to be developed by drilling and it is expected that



IRRIGATION CANAL
POWER CANAL
POWER PLANT
DAM & RESERVOIR
TUNNEL
LEBANON
LITANI RIVER
METULLA
TEL HAI
AYELET HASHAHAR
LAKE HULEH
ACRE
W. QARN
W. HALAZUN
SAFED
HAIFA
RIVER
LAKE TIBERIAS
NAZARETH
HAYARMUKH
MEDITERRANEAN SEA
POWER CANAL
BEISAN
TEL OR
JORDAN
W. SELHAB
JENIN
TUL KARM
RESERVOIR
NABLUS
TEL AVIV
JAFFA
W. JERRA
LYDDA
IRRIGATION CANAL
PALESTINE
W. ES SUBAR
JERUSALEM
IRRIGATION CANAL
JERICHO
GAZA
HEBRON
DEAD SEA
W. KHALIL
BEERSHEBA
NEGEV
PROPOSED GENERAL PLAN FOR IRRIGATION IN PALESTINE
JAMES B. HAYES, ENGR.
COMMISSION ON PALESTINE SURVEYS, NEW YORK

FIG. 5.

enough water will thus be yielded to irrigate 70,000 hectares. At the same time a power system will be constructed, consisting of a 90-metre dam on the Hasbani River from which a tunnel and a canal will lead the water into Palestine near Metullah and to a power station near Tel Hai.

In the second stage the summer flow of the Jordan tributaries will be picked up by a canal which will run north and west of the Huleh Basin, receive the water from the power station at Tel Hai and pass through another small power station near Nazareth. From there the water will be conveyed gravitationally to the Valley of Jezreel, irrigating the Upper Huleh Basin and Lower Galilee on the way. This canal will also receive the stored waters of certain wadis and the water of springs in the Huleh Basin.

In the third stage the diversion of half the flow of the Yarmuk into Lake Tiberias is contemplated. This diversion will counteract the drop in level of the Lake, likely to be caused by the diversion of the Jordan tributaries. Part of this Yarmuk flow will be used to irrigate neighbouring areas.

It is only in the fourth stage that the main power development scheme through construction of a Mediterranean-Dead Sea Canal will be started. The canal will originate in the Haifa Bay, where the mouth of the Kishon will be widened, allowing the Mediterranean waters to flow in. They will then be pumped up 42 metres to a canal passing through the Jezreel Valley, flow to a regulating reservoir near the rim of the Jordan Valley and thence dropping about 300 metres to the first of two power stations. From here a low-level canal will lead to the second power station discharging into the Dead Sea. Both plants are estimated to yield approximately 75,000 kw., a figure arrived at after deduction of the power used for pumping the sea water to the first power station. The amount of sea water (about 1,000 cubic feet per second) brought to the Jordan Valley would be equivalent to the annual diversion of fresh water from the Jordan for irrigation. In this way the present Dead Sea water-level is being maintained.

In the fifth stage the Upper Jordan's winter flows are to be stored in a central reservoir near Nazareth (Sahl el Battauf) and used for the irrigation of additional areas in the Emek and the coastal plain as far south as Rehoboth. The water will be carried by a canal reaching the western watershed through a tunnel.

The drainage and irrigation of the Huleh swamps and the construction of storage reservoirs on wadis in Upper Galilee are contemplated in the sixth stage. At the same time the Kurdaneh springs will be utilised and the Yarkon springs will be pumped into the main canal running south. The next stage provides for a dam to be built on the Jordan about 15 kilometres south of Beisan for the irrigation of the Lower Jordan Valley, a canal taking the water from this dam to the higher-lying section of the Jericho plain. In the final stage all the main wadi discharges on the western watershed will be conveyed by the main canal running south to the Negeb. Local storage in the Negeb will serve to irrigate higher-lying areas.

The following is a summary of the different stages of the irrigation scheme (4):

TABLE 90

SUMMARY OF IRRIGATION SCHEMES

Stage	*Irrigated area* (1,000 *Ha.*)	*Capital Costs £P.*	*Water consumption (Mill.cu.m.)*	*Annual operating costs £P.*	*Power consumption million KWH*
1	70·3	5,645,500	518	871,250	210
2	52·1	9,457,250	343·3	478,000	12
3	11·0	1,989,250	125·5	145,775	23
4	—	—	—	—	—
5	29·2	8,207,500	207·2	469,725	35
6	29·3	5,378,000	229·3	510,950	126
7	16·5	3,838,000	247·5	215,825	10
8	34·2	13,470,500	319·7	720,175	52
Total	242·6	47,986,000	1,990·5	3,411,700	468
Per Ha.		197,800	82 cu.m.	14,000	
Per cu.m.				1·72 mils*	

* Approximately 0·4d.

It may be mentioned that the J.V.A. is not only an agricultural but also an industrial project. The electric power to be created can be used for a fuller utilisation of the Dead Sea chemicals and other schemes. The total cost of the project is estimated at somewhat less than £50 million and is stated to pay out at a 3 per cent. rate of interest in a period not exceeding 50 years. According to the author of J.V.A. (1, p. 227) his plan will in time make possible the absorption of at least four million new immigrants.

Whatever the political future of Palestine, there is no question that the water and soil reserve, if only properly handled, is big enough to accommodate many hundred thousand additional settlers on the land.

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