FAO SOILS BULLETIN 25

sandy soils

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

F O R E W O R D

This report contains the papers and proceedings of the FAO/UNDP Seminar on the Reclamation and Management of Sandy Soils in the Near East and North Africa. It was the fourth seminar in the series suggested by the Regional Commission on Land and Water Use in the Near East to be organized under the Near East Applied Research Programme on Land and Water Use. On this occasion, owing to the technical subject, FAO invited other countries in North Africa along the Meditteranean coast with sandy soils to participate and share their knowledge and experience on ways to utilize them.

Although in many cases sandy soils are regarded as a menace and unproductive, yet from the proceedings of the seminar it became clear that their productivity could be considerably enhanced provided that the right soil and water management practices are followed. It was also realized that in irrigated as well as rainfed conditions there is a need to expedite research on reclamation and management of sandy soils with special reference to water utilization and fertilization.

The present shortage of land resources and food supplies on a global scale means that soils previously regarded as unproductive, such as sandy ones, and covering very large areas, will have to be brought into use.

The implementation of the recommendations made at the seminar and contained in this publication will be a valuable basis to make sandy soils produce more successfully and to promote effective land use in areas previously considered as less suitable.

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I. INTRODUCTION, SUMMARY OF RECOMMENDATIONS AND ACKNOWLEDGEMENTS

1. Introduction

The FAO/UNDP Seminar on Reclamation and Management of Sandy Soils in the Near East and North Africa was held in Nicosia, Cyprus from 3 to 8 December 1973, by courtesy of the Government of the Republic of Cyprus.

This Seminar was the fourth in a series held in the Near East region as part of the FAO/UNDP Regional Project MID/25 "Applied Research on Land and Water Development in the Near East", in compliance with recommendation No. 2 made by the Regional Commission on Land and Water Use in the Near East at its second session in 1969. Its purpose was to bring together senior government officials and high level experts to review and discuss scientific and technical activities in the reclamation and management of sandy soils.

The Seminar was attended by 42 government participants from 17 countries of the Near East and North Africa, by 19 observers and special participants, 8 FAO/UNDP project staff and 5 technical officers from FAO.

The subjects presented for discussion were along the following lines:

- classification, distribution and agricultural potentialities;
- fertility and fertilization;
- soil management and conservation;
- water management;
- applied research.

It provided a good opportunity for the presentation and discussion of 9 technical papers, 3 supplementary papers and 17 country reports dealing mainly with sandy soils. The excursion gave the participants the chance to see and observe the profile characteristics of sandy soils, stabilized sand dunes and the experimental activities of the Agricultural Research Institute in fertility and water management studies. From the proceedings of the Seminar it became clear that although sandy soils are frequently described as droughty, erodible, infertile and uneconomical to develop, they can be as productive as any other type of soil provided that the right soil and water management practices are followed. There is a need in the Region under irrigated as well as rainfed conditions to expedite research on reclamation and management of sandy soils with special consideration to water utilization and fertilization and to strengthen the technical training and the extension services.

2. Summary of Recommendations

The Seminar adopted several recommendations which could be summarized under the following points:

i. The Seminar recognized the extensive occurrence of sandy soils in the Near East and North Africa and recommended the compilation and dissemination of the available information on their effective use under the auspices of FAO.

ii. From the discussions it was felt that sandy loam soils could behave similarly to sandy soils and it was recommended that they be considered for practical purposes as sandy soils. In the classification of sandy soils their mineralogical composition and the characteristics of hard pans should be considered. Furthermore, sound land and water utilization should be based on land and water resources evaluation surveys of suitable scale.

iii. The Seminar realized that certain questions on methods of characterization and practices for utilization of problematic soils in the region remain to be solved and requested that panels of experts be held under the auspices of FAO to discuss these problems and set guidelines and establish priorities.

iv. Training and extension services in soil and water management and agronomic practices are critical issues in most of the region and the Seminar recommended intensifying these aspects among extension workers as well as farmers.

v. The Seminar, being aware of the potential pollution hazards from heavy fertilization of sandy soils, use of sewage water and intensive grazing on these soils, recommended that factors involved, and practices to avoid pollution, be studied.

vi. The Seminar recognized the progress achieved in the techniques of sandy soils improvement and utilization and the limited experience in the region, and recommended the carrying out of basic and applied research on:

a) Soil and water conservation and management:

- i) sand dune stabilization (materials, economics)
- ii) erosion control (methods including minimum tillage)
- iii) mulching (methods and techniques)
- iv) placement of barriers in the soil (materials, techniques and economics)

b) Fertility and fertilization:

- i) movement and transfer of nutrients
- ii) forms and techniques of fertilizer application
- iii) interaction between fertilization and irrigation
- iv) soil fertility evaluation

c) Irrigation and drainage:

- i) water quality (use of saline, sewage and desalinized waters and their critical limits)
- ii) irrigation efficiency (application and conveyance)
- iii) integrated experimentation (soil, water, plants and environment
- iv) drainage testing (materials and methods of installation)
- v) lining of canals (use of local, low cost available materials and their economics)
- vi) control of algae and microflora in irrigation and drainage systems (use of chemicals)

vii. The Seminar realized that under rainfed agriculture, special soil and water conservation measures should be followed and therefore recommended carrying out experiments on breeding plant varieties most adapted to sandy soils and especially drought resistant ones, on fertilization practices and on moisture conservation and agronomic practices.

viii. The Seminar, recognizing the vital importance of the Regional Applied Research Programme for Land and Water Use on Sandy Soils for the promotion of improved land and water use on sandy soils in the countries of the region and noting that a decision has not been taken so far in support of this regional programme by the UNDP, the Seminar urges that immediate action be taken by the UNDP in expediting the early implementation of the regional programme's objectives.

It is further requested that coordination should be made between this programme and other Regional Centres dealing with applied soil and water research.

3. Acknowledgements

The Food and Agriculture Organization of the United Nations wishes to express its gratitude to the Government of the Republic of Cyprus for hosting the Seminar, to the Ministry of Agriculture and Natural Resources for their excellent organization of working and social events and to the Ministry of Labour for placing at the disposal of the Seminar the facilities of the recently established Hotel and Catering Institute with its new and up-to-date equipment.

FAO would particularly like to mention the warm and cordial atmosphere which pervaded the Seminar and to thank the countries of the Near East and North Africa who participated in the Seminar and the special participants who contributed technical material to the proceedings.

It would also like to thank the United Nations Development Programme for its material support which made possible the holding of the Seminar.

Special thanks are extended to the Mr. R. C. Michaelides, Director General, Ministry of Agriculture and Natural Resources, Cyprus, for his active support and interest from the very instigation of the Seminar and to his colleagues in Cyprus who gave such a warm welcome to all the participants, and to Dr. V. D. Krentos of the Agricultural Research Institute in Nicosia who so ably carried out the duties of Director and Chairman of the Seminar, also to Monsieur Hacène Kharchi of Algeria who acted as Vice-Chairman.

II OPENING SPEECHES

1. Mr. R. C. Michaelides, Director-General, Ministry of Agriculture and Natural Resources

Excellencies, Distinguished Delegates, Ladies and Gentlemen,

It gives me great pleasure to extend to you all a very warm welcome on behalf of the Ministry of Agriculture and Natural Resources and to say how grateful we are to FAO and the UNDP who have accepted our invitation to convene this Regional Seminar on the Reclamation and Management of Sandy Soils, here in Nicosia.

It is an opportune time to renew contacts and discuss problems of mutual interest with delegates from member countries of the Region.

It is gratifying to note that the agenda of the Seminar covers a wide range of very interesting items relating to the physical and chemical properties of sandy soils and especially those directly related to aspects of water and fertility management.

Although the extent of sandy soils in Cyprus is limited, and by no means comparable in importance to that in most member countries of the Region, yet where they are cropped, they may present special problems in the management of irrigation and fertilization.

Under unsaturated moisture conditions, the unimpeded movement of water and nutrient ions imposes the necessity for effective and proper methods of irrigation in order to regulate moisture and ion movement, thus ensuring an efficient use of water and fertilizers, yet preventing through ease of leaching the build up of salinity from irrigation waters of marginal quality.

Generally under our soil conditions sandy soil horizons overlay finer texture layers or intermingle in sequence of layers of varying textural classes. It is in this latter connection that their physical properties, such as hydraulic conductivity modify the properties of the whole profile.

Naturally, a thorough knowledge of the behaviour of sandy soils and their internal drainage characteristics are of fundamental importance both in the process of reclamation and also in the prevention of salinity and secondary salinization.

We are aware of the tremendous effort made, and the large investment in funds and scientific effort by a number of member countries in reclaiming large areas of sandy soil and in "making the desert bloom". We wish them every success in their noble endeavours to develop their land and water resources and increase agricultural production. We are only too anxious to hear our distinguished colleagues report on their recent research developments in the field of land reclamation and management.

It has become commonplace to say, and repeat saying, that scarcity of water resources is the most severe constraint to the impetus of agricultural development. Yet this fact pervades omnipotently in our minds. The increasingly serious situation relating to the world-wide decline of water resources has been amply focused by the important document, "Water Problems affecting Agriculture Development" presented to the recent Seventeenth Session of the FAO Conference. Indeed, this could provide the guidelines for a collective approach for efficient water use, water conservation and salinity control in sandy soils and for that matter, to other soil types.

No matter how much we can do by ourselves on the national level, whether it be research or development, it is never enough. In a spirit of true cooperation, we in this region of the world, proud of nurturing all past and present civilizations and cultures, must join in an action-oriented effort to attack and solve the problems that beset land and water development.

If on the national level we can, and must, pursue agricultural development as a multi-dimensional concept, encompassing the economic, social, institutional and physical elements of development, in a wider sense, it would be relatively easy to effect the necessary adjustments for a truly effective cooperation on the regional basis. This is fully consonant with our official position taken and the full support of the concept of international agricultural adjustment at the recent Seventeenth FAO Conference.

In concluding, I wish you every success in your deliberations and a very pleasant stay in Cyprus.

2. Dr. M. H. Abbas, on behalf of the Director-General of FAO

Mr. Chairman, Honourable Delegates, Ladies and Gentlemen,

It is my privilege to address you, on behalf of the Director-General of the Food and Agricultural Organization of the United Nations, Dr. A. H. Boerma, and welcome the participants to this Seminar on the Reclamation and Management of Sandy Soils in the Near East and North Africa Regions.

The Director-General requested me to express, on his behalf, our thanks and gratitude to the Government of the Republic of Cyprus for hosting this Seminar and for all the facilities which will undoubtedly highly contribute to the success of this Seminar. This magnificent meeting room with all modern interpretation equipment is but one example of these facilities.

I wish to take this opportunity to welcome the participants from Algeria, Morocco and Tunisia and the representative of the Arab League; these participants have joined this series of technical seminars for the first time.

I also wish to welcome Mr. Pavicic, the Resident Representative of the UNDP in Cyprus, and wish to thank this Programme for financing the Seminar. Mr. Pavicic will address you soon, on behalf of the United Nations Development Programme.

Mr. Chairman, Honourable Delegates, it should be pointed out that this Seminar was held in accordance with the recommendation of the Regional Commission on Land and Water Use in the Near East. In fact, this is the fourth seminar held under the auspices of FAO. The first seminar dealt with improvement of saline and waterlogged soils and was held in Baghdad in December 1970. The second seminar dealt with efficient use of water at the farm level and was held in December 1971. The third was held in Cairo in December 1972 and dealt with reclamation and management of calcareous soils.

Mr. Chairman, in view of the large areas in this region which are covered by sandy soils and sand dunes, and in view of the limited available cultivable areas, it becomes necessary to expand agricultural lands into some of the sandy soils. Therefore, it becomes essential to find out the ways and means of utilizing and maintaining this natural resource; of course, this is the purpose of this Seminar. I may add that there is a prevailing idea which indicates the high cost of the reclamation and management of sandy soils. With modern agricultural practices, it may, however, be economic to use some of these sandy soils.

There is another important consideration and that is the population growth which might necessitate the utilization of some of these sandy soils even though the cost of their reclamation and management may reach non-economic limits.

On this occasion I should like to advise that the latest figures available to FAO indicate that about 40% of the total area of the Near East is covered by sandy soils. Thus from the total area of about 13 million m^2, sandy soils cover an area of about 5 million m^2.

Mr. Chairman, improvement and reclamation of sandy soils are not difficult to achieve in view of the advanced techniques in land reclamation and use of fertilizers and other inputs. We will have the opportunity to listen to experts at this Seminar on this matter. I am confident that the discussions held during the Seminar will lead us at the end to important technical conclusions on the subject of reclamation and management of sandy soils.

In conclusion, I should like to wish you, on behalf of the Director-General of FAO, every success in your work.

3. Mr. V. Pavicic, Resident Representative of the UNDP in Cyprus

On behalf of the Administrator of UNDP, it is my pleasure and privilege to welcome to Cyprus all the distinguished participants to this UNDP/FAO Seminar.

We know that, basically, the main purpose of the Seminar is to exchange ideas. And participating in this exchange will be, on the one hand, senior Government officials and, on the other, high level experts of international repute. The result, it is hoped, will be to the benefit of those countries represented here, which are involved in the reclamation and management of sandy soils.

Frankly, as a layman I do not know very much about sandy soils, but I know one good example how sandy soil has become good and fertile land. A great majority of you will remember an eminent colleague, Dr. Abdel Razzak Sidky, ex Minister of Agriculture in Egypt and retired Assistant Director-General of FAO for the Middle East Region.

Dr. Sidky, whom I had the pleasure to meet in 1965 in Egypt, had a piece of land behind the Pyramids. I cannot recollect the exact year, but I think it was in 1963/64, when Dr. Sidky sent samples of his land for analysis, and the reply was: "Pure sand". Despite the disappointing news, Dr. Sidky continued to investigate all possibilities for the improvement of his land. At first, he brought water and then fertilizers. He planted tangerines, lemon trees and orange trees; later he planted mangoes. The whole operation from the very beginning was approached in a full scientific manner and today, after ten years, Dr. Sidky has an economic and sound project of his own on ex-sandy soil, with good profit and excellent prospects.

This example shows, I think, what can be achieved when perseverance and a scientific approach are joined in marriage. Perhaps, it may also be a headline for other people - private entrepreneurs, co-operatives, and others.

But let me return to the work of the Seminar. Personally, I feel one absorbs information best when the surroundings are congenial. Here, on the island of Aphrodite, you have the most pleasant framework possible. As hosts, you have an obliging and hospitable Government, on an island renowned for its beauty. As if this were not enough, at your disposal are new conference room facilities, of which you are the first international clients.

You carry with you the best wishes of UNDP for a productive and successful Seminar, and a pleasant stay amongst us.

III. WORKING PAPERS

III. 1. CLASSIFICATION AND DISTRIBUTION OF SANDY SOILS IN THE NEAR EAST REGION AND THEIR AGRICULTURAL POTENTIALITIES

by

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SUMMARY

Sandy soils are of widespread occurrence in the Near East region. Their classification has been established by the recent comprehensive USDA soil classification system as well as by the FAO Key to Soil Units for the Soil Map of the World. In this paper, a review is made of the classification, distribution and agricultural potentialities of the sandy soils in the region.

The aridity of the climate is responsible for their slow chemical weathering and soil formation. The sparse vegetational cover coupled with high soil temperature is the cause of the low organic matter content and biologic activity in the soil. Carbonates, gypsum and salts may be present at some level depending on the penetration depth and intensity of rainfall. Generally, all sandy soils are weakly developed. Calcification and gypsification are the main soil forming processes. Under strong winds which promote sand and dust storms, the upper layer is either blown off or buried under aeolian deposits depending on the topography.

According to the USDA system of soil classification, sandy soils of the arid and semi-arid regions are included in the Order Aridosols. In the Suborder Orthids, one can distinguish the following great groups:- Camborthids, Calciorthids, Paleorthids, Salorthids and Durorthids. The paper presents a key to Orders, Suborders and Great Groups of the sandy soils components of taxonomic units under arid and semi-arid regions and shows both systems of classification: the 7th approximation and the FAO soil units for the Soil Maps of the World.

The distribution and origin of sandy soils are given for the countries in the region. In Egypt, the western desert plateau is predominantly sandy while in the Nile Valley and delta only two distinct soil areas exist as a result of the torrential depositions in the Pleistocene period. In Pakistan, sandy soils occur extensively in the north west, the centre and the Thar desert. The regions in the Sudan where sandy soils prevail predominantly are Kordofan and Darfur Provinces, the central west, north west and north of the country. The sandy soils of southern Jordan and the Rift valley regions are of Nubian sandstone origin. In Somalia, of the total of 55 soil mapping units, 28 are sandy soils and of the 20 million ha total land resources, 3 million ha of sandy soils are classified with a class B suitability for cultivation.

The main physiographic units where sandy soils and sand dunes occur in Iraq are the northern and southern deserts, the Jezireh, north-western steppe plains, the river terraces, floodplain and delta, foothills and alluvial fans. In Iran, sandstones and igneous rocks constitute the lithologic origin of the sand fraction of sandy soils which occur in almost all physiographic units. By virtue of the heterogeneity in the physical nature of the terrain and the climatic conditions of the country, a wide variety of sand dunes and sandy soils is found. In Kuwait

the sandy soils are predominant; 10 soil mapping units, mainly sandy textured, have been identified. Sandy soils occur extensively in Libya and they are being developed in a number of projects e.g. Kufra in the central Libyan desert and the Tawurgha project near Benghazi. Similarly, major parts of the soils of Saudi Arabia and other countries in the Arabian Peninsula are sandy.

The paper discusses the agricultural potentialities of the sandy soils in the region. Their susceptibility to wind erosion and sand dune encroachment seriously impair their utilization. Sand dune fixation by vegetative covers and crude oils has been successfully achieved in Iran, Iraq, Egypt, Lebanon and Saudi Arabia. The low water holding capacity organic matter content, biologic activity and fertility of sandy soils and their association with salic, calcic and gypsic or duric physico-chemical conditions hamper their productivity. Problems such as those of high evaporative demand and occurrence of compacted layers that impede the natural drainage are not uncommon. Experience gained in Egypt and the countries in the Arabian Peninsula are mentioned in the paper.

A scheme is outlined for developing the agricultural potentialities of sandy soils in the region based on (i) surveys of their resources and needs for conservation, reclamation and improvement and (ii) programme formulation and implementation for their utilization according to land mapping units and development of projects based on applied research on land and water use.

1.1. INTRODUCTION

Sandy soils whose textural classes include the sands, loamy sands, sandy loams and their respective fractional subdivisions are of widespread occurrence in the predominantly arid and semi-arid subtropical continental climatic zones of the Near East region. They also occur to a lesser extent in the subhumid, humid subtropical and tropical climatic zones of this region.

The arid and semi-arid zones in the Near East are characterized by their sparse shrubby vegetation and their very dry to semi-dry and variable climate dominated by windstorms and torrential winter rainfall of short duration. The sandy soils in these zones possess a combination of typically characteristic properties: slow pedogenic evolution as reflected by their shallowness; highly decomposed and scanty organic matter as a rule distributed in the soil profile; almost structureless; slightly weathered sand grains reflecting the predominance of physical over chemical weathering; stable clay mineral fraction; and occurrence of soluble deposits near the surface in the form of soluble crystals, calcic, gypsic or soluble nodules or crusts. In the alluvial areas of the semi-arid zone, sandy soils are associated with stratified and hydromorphic soil conditions. The classification of sandy soils has been recognized by the recent comprehensive USDA soil classification system (7th approximation 1967) as well as by the FAO Key Chart of Soil Units for the Soil Map of the World. In this paper, a review is made of the classification, distribution and agricultural potentialities of sandy soils in a number of the countries in the Near East region (Kadry, 1972).

1.2. SOIL FORMATION

The soil climate is extreme. Soils are very dry and hot, sometimes reaching 70°C or even more in the surface soil horizon. Wind erosion is dominant. Chemical weathering and soil formation are extremely slow and physical weathering predominates in response to the extreme variations in temperature. This is attributed to the long periods of dryness, since in winter, rain falls in short heavy showers, but it does not percolate through the soils only the upper layer becomes moist for short periods in the desert zone and in the dry steppe zone for a few weeks or months. The lower part of the sandy soil is, therefore, always dry and is called the "dead" horizon. In the arid zones, the dead horizon is just below the surface, but in the semi-arid zones, it is deeper. In wetter years, some sandy soils in the semi-arid zones may become moist to a depth of 1.5 to 2 metres.

Absence of vegetational cover results in an extremely low production of organic matter. As the sparse vegetation has a wide and deep root system, the low organic matter content is well distributed throughout the soil and decreases slowly with depth. Then soils are therefore called isohumic in the French classification. Organic matter content in the sandy soils of deserts is often less than 0.2 percent, increasing with the transition to dry steppe to about 1 percent. The extreme climate, sparse vegetation and low chemical and biological activity cause very slow soil formation processes to occur. With increasing rainfall and little percolation of water through the upper part of the sandy soil, carbonates, gypsum and salts may become soluble and accumulate at some depth. Redistribution of carbonates and gypsum are the main processes in most sandy soils. In the less dry sandy soils of semi-arid regions, some transport of fine clay causes a weak argillic horizon.

The amount of water from showers percolating through the upper part of the soil activates biological reactions. The water in the surface layer evaporates rapidly. The remaining soil moisture therefore determines the rate and duration of the chemical reactions, the production of organic matter and the biological activity.

The morphology of sandy soil reflects the weak processes of soil formation, acting only for a short duration in winter. All sandy soils are weakly developed. Only some old soils may exhibit profile horizon formations. The A horizon is weakly developed and can hardly be seen in a desert sandy soil, but becomes more distinct in the semi-arid sandy soils. The organic matter is almost lacking. Soil structure is weak and very unstable.

The B horizon is almost absent in desert soils except where they are very old and have formed in a pluvial period of the Pleistocene with a wetter climate than the present. In sandy soils of the semi-arid region, a cambic or argillic B horizon, often weakly developed, can be recognized, because there is some weak structuring, some colouring, some recent formation of clay mineral or the transport and accumulation of fine clay. Redistribution of carbonates and gypsum is common and most sandy soils in arid and semi-arid regions are calcareous and gypsiferous.

The processes of calcification and gypsification are, therefore, the main ones. A, Bca and a Bcs horizon at some greater depths are common. These horizons become more pronounced in regions where some water percolates through the profile, eventually leading to the formation of calcic and gypsic horizons. In desert soils, the Ca horizon is near the surface. In the dry steppe soils, the Ca horizon is deeper.

Especially in the desert, many sandy soils have a thin (1 to 2 mm) and brittle surface crust, formed by rain showers. This crusty surface restricts and delays infiltration of water, causing much runoff during the incidence of rainfall thus promoting sheet, rill and finally gully erosion.

In some sandy soils, lime or gypsum crusts occur. These are hardened layers of carbonate or gypsum accumulation.

The strong winds promote sand and dust storms. Depending on the topography, the upper layer is therefore either blown off or is covered with aeolian deposits. Sand dunes and loess occur locally and regionally. Sandy soils containing gravel have a surface gravel layer (desert pavement), that is left behind when the finer soil particles have been blown off.

Rocks and rock fragments have a desert varnish on their surface often consisting of brightly polished dark oxides of iron and manganese.

1.3 CLASSIFICATION OF SANDY SOILS

In the former American system of soil classification, the soils of arid and semi-arid regions were grouped in the order "zonal soils" and in the suborder "light coloured soils of arid regions". The great soil groups are: desert soils; grey desert soils; red desert soils; sierozem; reddish brown soils and brown soils. Some other great soil groups in the orders azonal and intrazonal soils are: regosols, lithosols, alluvial soils; solonchaks, solonetz.

In the USDA comprehensive system of soil classification (7th approximation) arid and semi-arid soils, including sandy soils showing horizon development are classified in the order aridisols. Soils in this order are characterized by the presence of an ochric epipedon and the absence of an oxic or spedic horizon. In additional they are usually dry and have features characteristic of arid and semi-arid regions such as calcic, petrocalcic or gypsic horizons, or a duripan. Usually "dry" indicates that more than half the time, the soil is dry. In the semi-arid regions, the better developed soils often have an argillic horizon (the suborder argids) or they have a cambic horizon (with redistribution of carbonates) often with a calcic, petrocalcic or gypsic horizon or a duripan (the suborder orthids). Some also may have a salic horizon. In the suborder orthids the following great groups are distinguished:-

Camborthids: orthids characterized by a cambic horizon, often with redistribution of lime and gypsum, but not forming a calcic or gypsic horizon.

Calciorthids: orthids with a calcic or gypsic horizon, that has its upper boundary within one metre of the soil surface.

Paleorthids: orthids with a petrocalcic horizon, that has its upper boundary within one metre of the soil surface.

Salorthids: orthids with a salic horizon within 75 cm of the soil surface.

Durorthids: orthids with a duripan, that has its upper boundary within one metre of the soil surface.

SOILS OF ARID LANDS 1/
(Sandy Soil Components of Soil Taxonomic Units Only)

Key to Orders, Suborders and Great Groups of
Soils of Arid and Semi-arid Regions

	ORDER SUBORDER GREAT GROUP
Soils with no diagnostic horizons except an ochric horizon	ENTISOLS
Entisols with a texture of loamy fine sand or coarser between 24 cm and 100 cm depth	Psamments (FAO regosols)
Psamments that are usually dry	Torripsamments
Entisols in which organic matter decreases irregularly with depth or is less than 0.35% at 125 cm depth	Fluvents (FAO fluvisols)
Fluvents that are usually dry	Torrifluvents
Other entisols	Orthents (FAO regosols)
Orthents that are usually dry	Torriorthents
Soils having an ochric epipedon that is not hard and massive, and with one or more of the following: a. usually dry and with an argillic, or natric, cambic, calcic, petrocalcic, duripan horizon, or b. electrical conductivity /2 millimhos to 125 cm if sandy, to 90 cm if loamy, to 75 cm if clayey, and a cambic, calcic, petrocalcic, gypsic, or duripan horizon, or c. saturated with water for 1 month or more and a salic horizon	ARIDISOLS (FAO xerosols, yermosols or arenosols, where texture is coarse < 18% clay and > 65% sand)
Aridisols with no argillic or natric horizon	Orthids
Orthids having a duripan	Durorthids (FAO haplic xerosols, yermosols, cambic arenosols - duric phase)
Other orthids saturated with water for 1 month or more that have a salic horizon above any calcic or gypsic horizon	Salorthids (FAO orthic solonchak)
Other orthids with a petrocalcic horizon	Paleorthids (FAO calcic xerosols and yermosols, cambic arenosols - petrocalcic phase)
Other orthids that are calcareous throughout and have either a calcic or a gypsic horizon	Calciorthids (FAO calcic and gypsic xerosols and yermosols and cambic arenosols)
Other orthids	Camborthids (FAO haplic xerosols and yermosols or cambic arenosols)

1/ Flack and Smith (1969), FAO/Unesco (1968) and FAO/Unesco (1970).

1.4 DISTRIBUTION OF SANDY SOILS IN THE COUNTRIES OF THE REGION

1.4.1 Arab Republic of Egypt

The two main landforms are the desert plateaux and the Nile river valley and delta. In the late Tertiary period the Nile valley was covered by a sea gulf filled gradually with marine and terrestrial deposits during Pleistocene and recent times. The desert plateaux range in age from Cretaceous to Pliocene with formations of sandstones (Nubian), shales and limestones interspersed with gravel, rubble and sand deposits in various stages of consolidation. The Western Desert plateau region is predominantly sandy and the eastern plateau predominantly calcareous. Geomorphologically the following seven landform/soil groupings were classified (Veenenbos, 1966):- (i) rubble terraces; (ii) river terraces - five characterized; (iii) deltaic stages of river terraces; (iv) alluvial fans and outwash plains; (v) wadis; (vi) plain lands; (vii) wind-blown. In the delta, the main landforms were the fluvio-marine marshlands; the lagoon lakes with swamps; the sandy coastal barrier plain and the shifting sand dunes.

The soils of the rubble terraces were subdivided into five soil associations corresponding to five terrace levels. Gravel and sandy loam predominate. In the delta soils sands predominate and gravel content is low. The differentiation of two soil associations was in the presence or absence of loamy sand topsoils. The soils of the alluvial fans and outwash plains, which contain high sand fractions, are differentiated by the gravel and sand textural components. The textural groupings of gravel, cobble and sand differentiated the soil associations of the wadi. Wind-blown soils, marine lacustrine and residual soils were the sub-division of the plain soils.

In the cultivated zone of the Nile valley and delta two distinct sandy soil areas exist as a result of the torrential depositions in the Pleistocene period; these areas are the Eastern Province and Arab El Raml (Menoufieh Sakkarah).

1.4.2 Iran

Sandstones and igneous rocks, phyllites, quartzites, gneiss, granite, etc. constitute the lithologic origin of the sand fraction of sandy soils. The geologic structural units include the Khuzistan plain; folded and thrust-folded zones of the Zagros system; central plateau; Elburz range; Turkanan - Khurasan range and the Caspian littoral sand dunes. Sandy soils in the form of aeolian, colluvial and alluvial sediments occur in almost all the physiographic units of the country - plains and valleys, plateaux, Caspian piedmont, dissected slopes and mountains - as regosols, desert soils, sierozems and in association with the main zonal soils, (Dewan and Famouri, 1964). By virtue of this heterogeneity in the physical nature of the terrain and climatic conditions, a wide variety of sand dunes and sandy soils is formed. According to Bhimaya (1973) sand dune fixation activities exist in each of the following areas:- Khuzistan, Khorasan, Kalatamirali, Barabad, Yahiyabad, Namen, Chubia, Fadisheh, Ahmedabad, Gonabad, Umrani, Tabas, Firdous, Bandar, Abbasm Kerman, Zerund, Sistan Bahishistan, Semnan, Dhamgan, Yazd and the Central Province.

1.4.3 Iraq

The lithologic origin of the sand fraction in the sandy soils may be traced to the Triassic, Jurassic and Cretaceous periods when the Nubian sandstone was sedimented in the western desert region of the country. During the Tertiary period and particularly during the Miocene age, the Fars formation consisting mainly of gravel, gypsum, marl and sand was sedimented in the inland sea and the lowermost foothill areas of the Zagros mountain region associated with erosion activities. During the Pliocene and the Pleistocene ages, older river sediments took place associated with erosional and depositional cycles thus forming the terraces and fans in northern and central Iraq and the terrace zone of the northern region of the Lower Mesopotamian Plain. Gravel conglomerates, sand and mudstone constituted the depositional material in these terrains. During the quaternary period, Holocene age, younger river sediments associated with aeolian deposits occurred where the river flow was turbulent and the windstorms intensive. Coarse to fine sand was the main transported material which, when there were river floods, was deposited to form levees adjacent to the river course and when windstorms subside aeolian deposits were formed, (Buringh, 1960).

The main physiographic units where sandy soils and sand dunes occur are the northern and southern desert; the Jezireh north-western steppe plain; the river terraces, floodplain and delta, particularly in the levee areas of their soil mapping units; and the foothills and alluvial fans.

Coarse-textured soils developed in the residual desert soils from sandstones are the calciorthids (USDA), developed either from calcareous sandstones or gravelly sands (al-Taie, 1968). Quartzipsamments (USDA) developed from gravelly sands have also been noted. In the Ga'ara area of the northern desert unit, sandy soils weathered from calcareous sandstone are the lithic calciorthids (USDA). The cambic horizon which overlies the parent rock in these soils consists of a matrix cemented with carbonates and iron oxides. The weight percentage of heavy minerals in the sand fraction is very low and consists of augite, zircon and opaque minerals. The quartz which is the dominant mineral of the light fraction, is rounded and sub-rounded.

In the Zubari area of the southern desert quartzipsamments occur on a nearby level landscape. The parent material consists of 95 percent quartz and other resistant minerals. Heavy minerals are very low (0.2 percent). Lime content ranges from 11 to 13 percent; it occurs in the clay fraction (Al-Taie, 1968).

Typic torripsamments (USDA) in the form of sand dunes have been noted to occur in the southern desert unit, north of Zubair. In these soils, the quartz component predominates.

Sandy soils prevail in the desert physiographic unit as petrocalcic, paleargids, typic calciorthids and lithic calciorthids. In the alluvial fans unit, sandy soils are associated with the typic torrifluvents and typic salorthids, in the high terrace unit they are in association with gypsic calciorthids and typic salorthids and in the low terraces with thetypic torrifluvents, particularly in the Euphrates levee areas. Sand dunes invariably exist in association with the typic torripsamments.

1.4.4 Jordan

Nubian sandstones, which represent the grouping of sandstone formations ranging in geologic history from the Cambrian to the Paleazoic, to Triassic to Jurassic and Lower Cretaceous, are the lithologic origin of the predominantly sandy soil region of Southern Jordan and the Rift Valley. Adjacent to the Nubian sandstone region is the Granite Hill (Southern Jordan) region, north of which are the flint strewn desert, the lava field and the steppe regions. The sandy soil material formed from the latter geomorphologic regions is medium to fine-grained ranging in colour from yellowish to reddish to charkish grey according to the colour of the parent rock.

Soils whose sandy textural fraction predominates are the alluvial soils, the regosols; the lithosols (sandstone); the grey desert soils (sierozem); and sand dunes of Wadi Araba (Moorman, 1959).

1.4.5 Kuwait

The State of Kuwait is located in the north-east corner of the Arabian Peninsula on a desert plateau. The geologic formations from which originate the predominantly sand soils of the country consist of recent marine deposits, outcrops of Miocene rocks, feldspathic sands and shelly limestones.

Four great groups of soils have been characterized: desert; desert-regosol intergrade, lithosols and alluvial, (Ergan, 1966). The soil mapping units which are mainly sandy textured are: (i) sandy desert hardpan; (ii) gypsiferous desert; (iii) gravelly saline desert; (iv) gravelly gypsiferous saline desert; (v) saline gypsiferous desert; (vi) sandy desert; (vii) desert dune; (viii) escarpment; (ix) hydromorphic saline alluvial; and (x) recent alluvium.

1.4.6 Libyan Arab Republic

Sandy soils occur extensively in Libya. In spite of the physical limitations of the sandy soils, a number of project areas are being utilized for vegetable and crop production, e.g. Kufra project area in the South-West Libyan Desert (Karah,1973) and the Tawurgha project area near Tripoli.

1.4.7. Pakistan

The physiographic landforms of Pakistan from which the soil forming sandy materials originate in the north, south and west include the mountains; piedmont plains and terrace remnants, the dissected old loess and alluvial terraces (Potwar uplands); rolling sand plains; old river terraces; sub-recent river plains; and the Indus delta and recent river plains, (FAO, 1971).

Throughout the geologic periods erosion sedimentation and weathering were active in modifying the features of the landscape. The physical factors from which the origin of the sandy soil parent materials and their formation were derived were the continental sedimentation of sandy beds; peneplanation and dissection of Potwar uplands; permafrost and its melting, deposition by rivers and wind reworking of Cholistan and Thal sediments; down-cutting of eastern rivers into the old river terrace material near Multan.

Sandstone calcareous material coming from the mountains in the north and west during the Mesozoic and early Tertiary was a major lithologic source of the sand soils. The sandy piedmont plains derived from the calcareous sandstones were frequently reworked into sand dune fields i.e. rolling sandy plains.

Sandy soils occur extensively in the following locations:-

i.	North-West:	Multan, Muzaffergard, Dera Ghazi, Khan, Mianwali, part of Sargodha and Dera Ismail Khan District.
ii.	Centre:	Bahawlpur, Rahmiyar Khan and Khairpur
iii.	Thar Desert:	South-eastern districts of Sind and part of Baluchistan.

1.4.8 Saudi Arabia

A major part of the soils in Saudi Arabia are sandy. Sandy soils in association with yermosols and gleysols occur in the El Hassa (Hofuf) irrigation project area, El Qatif experimental area and several land settlement schemes.

1.4.9 Somalia

The Precambrian basement complex and sandy limestone Cretaceous and Jurassic deposits in the Jesouma sandstone formation constitute the main lithologic sources of the widely occurring sandy soils.

Four sandy soil mapping units have been developed on residual parent materials and/or locally derived erosion products and twenty-six sandy soil mapping units are derived from transported materials:- older river alluviae; recent river alluviae; eluviated material; marine deposits and sandy aeolian deposits. Thus of the total number of fifty-five soil mapping units, twenty-eight are sandy soils. Of the 20 000 846 ha total land resources 3 066 000 ha of sandy soils have been classified with a class B suitability for cultivation (De Vries, 1968). From the pedogenic standpoint the sandy soils have been characterized as solonetz, solonchak; brown semi-arid; terra rossa; grey grumosol; reddish brown calcic; reddish brown ferruginous; regosol and lithosol.

1.4.10 Sudan

The origin of the sandy soil material is a mixture of metamorphic, igneous and sedimentary rocks. As a result of volcanic activities, tectonic movements, erosion, deposition, foliation, bedding and weathering, the mineralogic constitution of the sandy grains was formed. The lithologic source of the sand is mainly Nubian sandstone contributed to by the igneous rocks whose main source is the basement complex which forms over two-thirds of the rock exposures of the Sudan. The regions where sandy soils predominantly prevail are the central west, the north-west and the north of Kordofan and Darfur Provinces. In these two provinces, the Nubian sandstone formation, consisting of sandstones and mudstones, evolved in the Mesozoic followed by "Continental Intercalaire" consisting of sandstone; in the Tertiary the Hudi formation consisting of cherts followed by the Urnun Ruwaba formation of alluvial clays and sands; in the Quaternary the Gezira formation of alluvial sands and clays evolved, followed by the Kordofan sands of aeolian origin which were deposited. Four distinct terraces of the Nile River were identified, representing four sequential regimes of its formation.

The main sandy soils which were characterized in Central Sudan by Buursinck (1971) based on the USDA system of soil classification were the following:- the typic kaplustalf, aquic ustifluvent; typic calciorthids; typic paleargid and aquic ustifluvent.

Buursinck (1971) investigated the mineralogic constituents of the sand fraction (500 to 50 micron) and concluded that there is an increasing degree of weathering of soils from Terrace I to IV.

1.4.11 United Arab Emirates, Bahrain, Qatar, Oman, Yemen Arab Republic and Peoples Democratic Republic of Yemen

Sandy soils are widely distributed throughout these States.

1.5 AGRICULTURAL POTENTIALS OF SANDY SOILS IN THE REGION

The susceptibility of sandy soils to the erosive power of the frequently occurring windstorms in the arid and semi-arid zones of the Near East region constitutes a primary hazard which needs to be checked by establishing windbreaks combined with soundly planned cropping systems.

Invariably, aeolian sediments from wind blown sand pile up to form sand dunes which seriously impair the crop growing areas and reduce the efficiency of the irrigation and drainage networks. Measures to fix sand dunes with vegetative cover have been successfully applied, sometimes in combination with crude oil, in Iran (Bhimaya, 1971), Iraq (Greater Mussayib and Babil project areas), Arab Republic of Egypt (South Tahrir and Isna project areas), Lebanon (coast zone near the site of the International Airport in Beirut), Saudi Arabia (El Hassa and Hofuf project areas).

The more acute form of sand dune migration is "desert encroachment" which is a commonly occurring problem in arid lands. To check and control this natural phenomenon a wide range of physical and socio-economic ameliorative measures generally need to be taken concurrently.

The agricultural potentials of sandy soils in the arid environment of the Near East region are hampered by their low water-holding capacity, weak structure and low organic matter content, low inherent fertility and micro-biologic activity and their association with salic, calcic or gypsic or duric physico-chemical conditions. By virtue of their common occurrence in desert terrains not only is the evaporative demand high, but they also have to depend mostly on groundwater of variable quantity and quality for irrigation. The occurrence of compacted layers, e.g. calcic, gypsic, durargid, duric, etc., of varying thicknesses and depths impedes their natural drainage.

In the South Tahrir project area in the Arab Republic of Egypt sandy soils are utilized on a large scale, with irrigation by sprinkler and surface methods. The winter cultivated area in 1968/69 was 46 100 feddans (1 feddan = 4 200 m^2) and the 1969 summer cultivated area was 47 600 feddans. Vegetables, fruit, field and pasture crops were grown. To improve the water-holding capacity and conserve moisture irrigation sediments were mixed with the sandy surface soil. A quantity of 75 m^3/feddan was found to be optimum from the production economic standpoint. In 1972 this rate of irrigation sediments was spread on a 1 000 feddan crop production area. Experiments were also carried out with varying application rates and mixtures of organic manure with irrigation sediment. A mixture of 10 tons organic manure with 40 m^3/feddan of irrigation sediments was the optimum. It was also noted that 20 tons of organic manure was equivalent in its effect of improving the water-holding capacity of sandy soils to 150 m^3 of irrigation sediment application (Naghmoush, 1973). Use of bentonite and agrofix (mixture of bentonite and organic matter) applied in the form of a subsoil layer at depths ranging between 40 and 70 cms was also noted to be effective in improving soil moisture holding conditions and increasing crop production on sandy soils (Makled, 1971). Application of crop residue and organic manure mulching material on sandy soils to redeem surface evaporation, thus conserving the moisture for root absorption (Balba, 1973), was noted to be effective. Application of mixtures of organic fertilizers with low to medium levels of solubility rates to lengthen the effective period of nitrogen utilization on sandy soils such as urea formaldehyde, urea sulphide, hexamin urea was observed to be effective (Balba,1973).

Application of compound fertilizer Folifertil (British product), Bayfolard (Bayer product) and Mutonin (Egyptian product) separately and in combination with berseem clover green or organic manure at a rate of 10 m^3/feddan on grapes on sandy loam soils gave very favourable results (Naghmoush, 1973). The Desert Institute has been carrying out soil surveys and applied research work on sandy soils since 1952, particularly in the field of reclamation and fertility-salinity interaction.

In recent times, the entire sub-region covering Kuwait, Qatar, Saudi Arabia, Bahrain, United Arab Emirates, Oman, Yemen Arab Republic and the Peoples Democratic Republic of Yemen, where sandy soils occur on an extensive scale, has increased production of vegetable and fruit crops, especially cantaloups and melons. It is in these sandy soil areas specifically that the current soil and water management practices should be subjected to investigation under the local conditions.

1.6 DEVELOPING THE AGRICULTURAL POTENTIAL OF SANDY SOILS

To formulate a sound land and water utilization programme for sandy soils and to define the extent of their crop growth inhibiting and inducing effects a sequence of land and water resource evaluation surveys should be carried out on a suitable scale.

Listed below is the sequence of land and water resource evaluation surveys, utilization and development operations which would need to be implemented to produce a land evaluation map and report where an assessment is to be made of the land suitability potentials of the different land mapping units for alternative land and water use and development systems.

i. <u>Surveys</u>

a. Climate and agrometeorology; soils; hydrology and drainage; soil salinity; quantity and quality of water source; present land use.

b. Soil and water conservation and management needs of the land mapping units.

c. Soil reclamation, improvement and management needs of the land mapping units.

d. Production economic and market analysis.

e. Preparation and publication of the land evaluation map and report.

ii. <u>Utilization</u>

Land and water use programme formulation and implementation for soil and water conservation and management in the different land mapping units, based on the background information detailed in the land evaluation map and report.

iii. <u>Applied Research and Development</u>

Applied research and development programme formulation and implementation on land and water use in representative areas of the different land mapping units of sandy soils in the agricultural development projects should comprise three sets of field activities:-

a. Applied research and field experimentation on the factors of agricultural production in pilot experimental areas. These factors cover variants on:-

- windbreak culture practices;

- cropping pattern;

- irrigation practices (Sprinkler, drip, surface systems);

- the use of canal lining and improvement of the water holding capacity of sandy soils through the addition of organic manure, artificial organic material Hygromull BASF product, Agroseal ICI product, Agrofix (mixture of bentonite and organic manure) and others; subsoil layering, surface mudding etc.

- use of fertilisers : NPK and minor elements, placement, quantity, quality and timing of their application;

- land preparation and cultural practices.

b. Test/Demonstration field operations on the basic soil and water conservation and management improvement practices of sandy soils both at the farm and state farm levels, whereby combinations of effective measures are applied on as large a number of farms as is feasible. Close cooperative and coordinative links should be maintained between this activity and that of the applied research field experimentation and pilot development activities through organizing regular field meetings and discussion sessions between the technicians and the farmers, and definition of the roles of the participants in the cooperative action programme.

c. Alternative land and water use and development systems in pilot agricultural development areas. The focus of attention in this respect is the comparative assessment of the cost/benefit and input/output factors based on agricultural production economic criteria. In this respect also, close cooperative and coordinative links must be maintained between this form of activity and that of test/demonstration and applied research and field experimentation through holding regular field tours, meetings and discussions to be attended by all those concerned with these activities.

iv. <u>Training</u>

The major problem of land and water development in the Near East Region is the acute shortage of technically skilled manpower. It is, therefore, imperative that concurrently with the three forementioned activities on developing the agricultural potential of sandy soils in-service training of technical manpower at the medium and advanced level is initiated. The training programme must be focused on providing a background of practical experience on the relevant facets of soil and water conservation management and utilization field practices on sandy soils.

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ORGANIC AND INORGANIC FERTILIZATION OF SANDY SOILS

by

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SUMMARY

Sandy soils are generally poor in plant nutrients and the nutrients applied to these soils are subject to loss by the irrigation water. Fertilization of these soils is therefore a necessary practice. Response to organic or inorganic fertilizers is usually obtained.

To decrease the loss of applied nutrients, especially N by leaching, several practices have been suggested, such as:

i. mixing fine materials, organic matter or farm manure with the soil surface;

ii. forming layers from different materials at different depths of the soil;

iii. foliar spraying of nutrients;

iv. using capsuled, coated or pelleted fertilizers;

v. controlling the nitrification of applied N fertilizers;

vi. utilizing slow N releasing materials.

Experience with these practices has shown the following:

a. When phosphorus was distributed along a sandy soil column 15 cm long, 12.4% of applied P was recovered in the filtrate. In pure sand columns 98% of applied P was recovered in the filtrate. The yield from clover and horse beans increased with P fertilization and the increase was doubled when the seeds were inoculated with specific rhizobia strains.

b. The nitrogen leached from sandy loam soil columns fertilized with NH_4^+, urea or NO_3^- was in all cases in the form of NO_3^-.

c. Pelleting $(NH_4)_2SO_4$ decreased its leachability from sand columns.

d. Leaching of ureaform was lower than $(NH_4)_2SO_4$.

e. In sand pots planted with maize, pelleting $(NH_4)_2SO_4$ or dividing its application into 3 portions increased the dry weight of plants and the amount of absorbed N.

f. Use of ureaform in the above-mentioned pot experiment showed that the conditions of growth were not suitable for the plants.

g. Incubation studies showed that in the case of UF-sand and urea-sand systems, the pH increased from 7.3 to 8.1, NO_2^- accumulated and 20-50% of N was lost in gaseous forms. Application of gypsum precipitated the $CO_3^=$ thus pH did not increase and NO_2^- did not accumulate.

h. Response of wheat to urea on sandy soils was lower than to other N carriers.

The economics of organic fertilization and layer formation should be taken into consideration.

Rates of fertilizer application for different crops and soils should be experimentally determined.

A programme of field investigations is suggested.

2.1 INTRODUCTION

Sandy soils cover vast areas in the Middle East and North Africa regions. Previous experience with these soils has shown that their production is low and expensive. This is attributed mainly to their low fertility level as well as to the loss of water and applied nutrients by leaching.

Attempts to improve their production and decrease expenses were made by:

i. selecting varieties of cropsmost suitable for these soils;

ii. conserving water by minimizing its loss;

iii. improving their fertility status and minimizing losses of applied fertilizers;

iv. growing high priced kinds of crops.

Farming practices in sandy soils have made considerable progress in the last few years, particularly in the above four fields. In this report are presented the problems related to soil fertility and methods of organic and inorganic fertilization of these soils.

2.2 FERTILITY PROBLEMS OF SANDY SOILS

The fine fraction of soils is the natural source of nutrients to the plants. Soils containing high percentages of this fraction are generally rich in nutrient elements and retain them when they are applied. The main constituent of sandy soils is the sand fraction and this does not supply any nutrient to the growing plants. Accordingly the fertility level of sandy soils is controlled by their clay and organic matter content. Nutrients applied to raise their low fertility level remain in solution, subject to loss by leaching. The portion of nutrients which might be retained by the soil is controlled by the amount of the soil fine fraction.

Also, because sand is the major constituent of these soils, their water retention is low. The applied water moves downward easily and the soil needs frequent irrigation at short intervals. Such conditions aggravate the loss of nutrients via the water.

2.2.1 <u>Phosphorus</u>

Uncultivated sandy soils are generally poor in P, having 300-500 ppm total P and 3-5 ppm P extracted by the $NaHCO_3$ method. In the Nile alluvial soils these values are about 1 000 and 12-15 ppm respectively. Good soil management which leads to an increase in the fine fraction and the application of organic manures would tend to increase the phosphorus content and, consequently, the soil fertility.

The loss of fertilizer P by leaching is not a problem in most soils. Phosphorus is usually immobilized upon incorporation in the soil, but because of the low content of clay and organic fractions in the sandy soils, a limited movement takes place of applied phosphate fertilizers by convection with irrigation water. Early work by the writer (Balba, 1951) showed that phosphorus applied to a column 15 cm long of El Khanka sandy soil was distributed along the soil column and the filtrate contained 3.16 mg P, constituting 12.4% of the added amount. The filtrates of columns of a clay loam soil fertilized with P did not contain any significant amount of P above the content of filtrates of unfertilized columns. Actually, all added P was recovered in the first 2.5 cm of the latter columns.

Obviously, the immobilization of P at the soil column surface increases with the increase in the fine soil fraction. Thus one expects the P to move with water when this fraction diminishes, as in the case of some sandy soils. In columns of pure sand, the recovered P in the filtrates reached 98% of the added amount (Balba, 1951).

Under field conditions applied phosphatic fertilizers are better distributed in the root zone and the plants have a greater chance to absorb their need of this element. Experiments carried out on P fertilization in sandy soils showed crop response to increments of P. Hamdi et al. (1966) showed that a significant increase in the weight of clover cuttings and in horse beans occurred with P application (500 kg superphosphate/ha) in South Tahreer area. They also showed that this increase was doubled when the seeds of clover and beans were inoculated with specific strains of rhizobia. Further work on this point is still needed to evaluate relationships between P and micronutrients as well as the most economical rate of P application to each crop in different locations.

2.2.2 Potassium

The situation of potassium in sandy soils is similar to that of phosphorus. These soils contain about 5.0 meq/100 g of total K and about 0.25 meq/100 g exchangeable potassium. The Nile alluvial soils contain about 10-15 and 1-2.5 meq/100 g of the two forms of K, respectively.

The problem of losing applied potassium fertilizers by leaching with irrigation water is not serious in sandy soils. Added K is usually held in an exchangeable form on the surface of the fine soil fraction. Although the cation exchange capacity of the sandy soils is usually of the order of 5-10 meq/100 g, yet applied potassium constitutes a very small fraction of this capacity and can be retained by the soil. However, as stated above, in the case of soils very poor in the fine fraction, leaching of applied K may take place.

Application of potassium to sandy soils is recommended especially for vegetable crops and orchards.

2.2.3 Nitrogen

The prevailing climate of the Middle East region is characterized by a long, warm summer and low precipitation. Soils under such climatic conditions contain a low organic fraction. The uncultivated sandy soils contain as little as 0.008-0.015% organic matter; therefore, their total N content is also low, 0.0015-0.002%. In addition to their low content of N, the leachability of N fertilizers in these soils constitutes a major nutritional problem.

Nitrogen fertilizers are mostly in the forms of NH_4^+, NO_3^- or urea. The nitrates are not retained by the soil colloids. The ammonium is transformed to NO_3^-. Urea is hydrolized to NH_4^+ and consequently nitrified.

i. Bizzell (1926), Benson and Barnette (1939) and Balba et al. (1969) reported that NO_3^- - N is the form which moves most readily with water. In the latter work the leached N from soil columns fertilized with NH_4^+ or urea was in the form of NO_3^-.

ii. Broadbent and Tayler (1958) showed that urea moved less rapidly than nitrate. The results of Balba et al showed that 14, 7.5 or 67% of applied N as $(NH_4)_2SO_4$, urea or $Ca(NO_3)_2$, respectively, was accounted for in the filtrates.

iii. Cooke and Cunningham (1957) and Balba et al. (1969) reported that migration of soluble substances with water depends also on the water-holding capacity of the soil.

2.2.4 Micronutrients

Sandy soils are poor in the micronutrients. Iron, manganese and zinc deficiencies are noticeable on citrus trees grown on such soils. Foliar spraying with these elements and othersis recommended.

2.3. IMPROVED FERTILIZATION PRACTICES

Farmers of sandy soils are aware of their problems on the whole and they try to improve the soil fertility as well as the ability to retain applied nutrients. Their efforts were mainly fertilization by organic manures and application of clay but recently, several other means have been suggested.

2.3.1 Organic Fertilization

The loss of nutrients in organic manures by leaching is slow because of their insoluble nature. Hence they remain in the soil within the reach of the plant root systems for a longer period than the inorganic fertilizers.

In a pot experiment using the sandy soil of South Tahreer, Ahmad (1967) showed that the dry weight of maize and barley increased by application of 130 g manure/pot (37 tons/ha). The former increased from 88.7 to 132.3 g/pot and the latter from 38.5 to 62.4 g/pot. He also showed that the nitrogen absorbed by maize plants increased from 1.23 to 3.15 g/pot. In a field experiment, Makled (1967) showed that fertilization with farmyard manure on the soil surface increased the yield of alfalfa 163% above the control.

In lysimeters and field studies, Mahmoud et al. (1968) obtained results showing that addition of winter or summer green manures or compost to the sandy soil of South Tahreer in equal quantities, had increased the soil organic matter, total nitrogen and soil microbial flora. They also showed that in addition to chemical fertilizers, application of clover or groundnut green manure or an equal amount of compost had significantly increased sesame and maize yields above the control treatment with chemical fertilizers alone.

2.3.2 Application of Amendments

Fine particles, such as Nile mud, are directly or indirectly applied to the soil with irrigation water, organic manures and composts or in a dry form. This practice is widely known and applied by Egyptian farmers in sandy soil regions.

Although application of organic matter to the sandy soils has the same effect as application of Nile mud, usually organic matter is decomposed and has to be added frequently. Ahmad (1967) showed that mixing 1 300 g/pot of Nile silt or 130 g/pot of wheat straw with the surface 15 cm of the sandy soil in a pot experiment increased the dry weight of maize plants from 88.7 to 150.6 g/pot and of barley plants from 38.5 to 62.3 g/pot respectively.

These practices are mainly for improving the physical properties of sandy soils. They are related to fertilization because they decrease the loss of applied nutrients. Their costs are too high to be considered as fertilization cost. Mahmoud <u>et al</u>. (1968) reported that the cost of one month old clover green manure was Egyptian pounds (E£) 35/ha, 50 tons of Nile mud/ha was E£15, 25 tons of mud + 25 tons of compost was E£32 and 35 tons/ha of compost was E£35.

Organic matter is applied below the soil surface at different depths; this layer is not easily decomposed and remains forming a relatively less permeable layer for about 10 years as reported by Egerszegi (1964). The layer decreases the water movement downwards. Other materials were also suggested for forming layers under the soil surface at a depth of 50-100 cm. Egerszegi (1964) placed one or more layers in the soil at least 1 cm thick, at depths from 38 to 75 cm, consisting of manure or compost.

Makled (1967) working on South Tahreer soil experimented with:

i. barriers of clay layers at 50, 60 and 70 cm deep;

ii. farmyard manure layers at 50, 60 and 70 cm deep;

iii. a perforated 3 mm thick asphalt layer at a depth of 60 cm + farmyard manure mixed with the soil just above that layer;

iv. a 3 mm thick asphalt layer over a layer of cement bag paper at a depth of 60 cm + farmyard manure mixed with the soil just above that layer;

v. a perforated 3 mm thick asphalt layer and linen at a depth of 60 cm + farmyard manure mixed with the soil just above that layer;

vi. a perforated nylon layer at a depth of 60 cm + farmyard manure mixed with the soil just above that layer.

He reported an increase in the yield from all treatments when compared with the control varying from 116 to 290%.

Also, Zein El Abdine <u>et al</u>. (1967) showed that the highest yields were obtained when an impervious layer was made of melted asphalt sprayed over canvas and then, in descending order, from asphalt alone, asphalt sprayed over plastic sheet and asphalt sprayed over parchment paper. They stated that the cost of the materials, their resistance to decomposition and cost of application are factors to be considered. Parks <u>et al</u>. (1970) used a plastic barrier under the nitrate band; they found that the N uptake indicated that placing the plastic barrier under the fertilizer band did not increase the plant recovery of N.

2.3.3 Soil Moisture Control

Fertilizer efficiency can be improved when an adequate moisture supply is assured. Sandy soils, being susceptible to high evaporation, need special practices to preserve their moisture supply and to make full use of fertilizers applied, for example, by mulching, covering the soil surface with organic matter, paper, polyethylene and asphalt. In this regard, Black and Greb (1962) stated that a partial or complete plastic cover reduced evaporation of soil moisture and increased plant water-use efficiencies when compared with bare soil. Also a significant increase took place of nitrate accumulation in the soil covered with the plastic mulch. Similar conclusions were drawn by Clarkson and Frazier (1957) and Bennet et al. (1966).

2.4 CONTROL OF NUTRIENT LOSSES

2.4.1 Foliar Sprays

To avoid the loss of nutrients added to sandy soils by leaching, they can be sprayed on plant leaves. Several investigators have shown that nutrients sprayed on the leaves have the same efficiency as those added to the soil in heavy soils. In sandy soils spraying fertilizers has given better results.

Witters et al. (1963) reported that foliar feeding was most successful on crops when soil fertilization had not provided the necessary control of N uptake, or on crops that were regularly sprayed with micronutrients, insecticides or fungicides. Urea sprays are used on many vegetable crops. The amount of N applied is often in the range of only 10 to 20 kg/ha per application. Foliar feeding of field crops like wheat and maize is also possible. Frank and Viets (1965) reported that urea was most effective because of its rapid penetration into leaves, half of an application penetrating the leaf in 1 to 6 hours.

2.4.2 Slow Release Forms

Attempts to decrease the loss of nitrogen fertilizers in the water were directed toward methods to decrease the contact between the fertilizer material and the water by coating with resins or wax or producing the fertilizers in packets or capsules. Skogley and King (1968) compared prilled urea 25% nitrogen, process tankage 7% nitrogen and urea formaldehyde 38% nitrogen in the fertilization of turfgrass over a 2-year period with prilled urea with a petroleum-based coating (material 14275 supplied by Nitrogen Division, Allied Chemical Corporation, 39% N) and two products supplied by the Sun Oil Company, one product named "Standard" X-419-47 containing 27% N, the second product named "High Melt" X-419-68 containing 27% N. They found that significant differences occurred among materials in general, at all rates. The best quality turf resulted from the application of "High Melt" X-419-68 paraffin wax product. The coated urea 14275 and the "Standard" X-419-47 paraffin wax urea were generally slightly poorer in performance.

Oertli and Lunt (1962) studied the factors influencing the rate of release from controlled-release fertilizers by incapsulating membranes. They found that the release rate was largely independent of the pH of the element or the soil pH. An increase in temperature from 10°C to 20°C almost doubled the initial release rate. The release could be regulated very efficiently through the coating thickness. There was an effect of ionic species, nitrate and ammonia being given off more rapidly than potassium or phosphate. Their experiments demonstrated that inorganic fertilizers, which in aqueous solutions would be rapidly soluble, are released slowly after coating. Gradual microbiological breakdown of the coating material can almost certainly be eliminated as a mechanism for the release of the nutrients. A working hypothesis of diffusion as a possible mechanism has been further supported. As a first step, water would diffuse through the coating into the granules and dissolve some of the salts, a concentration gradient would then be established between the internal and external solutions and more water would tend to enter the granules while salts would tend to move outward. During a three-month growing period, an efficiency of recovery ranging from about 25 to 45% by maize was obtained from a single application incorporated in the sand of coated ammonium nitrate.

Attoe et al. (1970) studied the fertilizer release from packets and its effect on tree growth. He found that the length of time required to release the fertilizer was directly related to the size of the packet and inversely related to the number of pin holes. The more soluble fertilizer constituents were released faster than the less soluble ones.

Capsuling provided a positive method for controlling the rate of release of the fertilizer constituents for both maize and grass.

Ahmad and Whiteman (1969) used two slow release pelleted N fertilizers manufactured by Esso Engineering and Research Ltd., known as EAB 3032 (17.7% N, 21 days to release 75% of its N) and EAB 3033 (18.0% N, 63 days to release 75% of its N) compared with $(NH_4)_2SO_4$ as a source of nitrogen for the rice variety Bluebelle in Trinidad. The slow release materials were buried 5 cm in the soil after transplanting, while the $(NH_4)_2SO_4$ was applied and worked into the soil just before transplanting. EAB 3033 resulted in a yield of 2 920 kg/ha, EAB 3032 produced 2 060 kg/ha and $(NH_4)_2SO_4$ 1 195 kg/ha. Plants treated with $(NH_4)_2SO_4$ had absorbed all their N when they had reached only 50% of their final dry weight. At the same stage, plants treated with slow release materials had absorbed only half of their final N content and they continued to absorb N until a much later stage in growth.

Balba and Sheta (1973) formed pellets of $(NH_4)_2SO_4$-gypsum heated at 70°C for 24 hours. They compared the leachability of these pellets with $(NH_4)_2SO_4$ and $(NH_4)_2SO_4$+gypsum in sand columns. The columns were watered 9 times and each time an amount equal to the maximum water-holding capacity was added. Each filtrate was collected separately. They showed (Fig.1) that the pellets dissolved gradually, while almost all the N of the added NH_4^+ was collected in the fourth filtrate and the pellets yielded about 25% of their N. After 9 waterings, the sand column still retained about 25% of the added N as pellets.

In sand pots they compared the leachability and N uptake by maize of $(NH_4)_2SO_4$ (AS) added as in the following treatments:

a. AS in single application after thinning;

b. AS divided into 3 portions: ¼ after thinning, ½ 10 days after the first portion and the rest 10 days after the second application;

c. AS + equal weight of gypsum;

d. Pellets of AS + equal amount of gypsum formed as above;

e. The same as 'd' but ground and used as powder;

f. Control.

They stated that differences in leachability of AS treatments greatly affected plant growth and N absorption (Figs. 2 and 3). The maize plants utilized more N from AS-gypsum pellets and AS applied in 3 portions (treatment b.) than from other AS treatments. The superiority of treatment d. was mainly due to pelleting and not due to the presence of gypsum since treatments c. and e. gave lower plant weights and N absorption. Pelleting decreased the contact between the

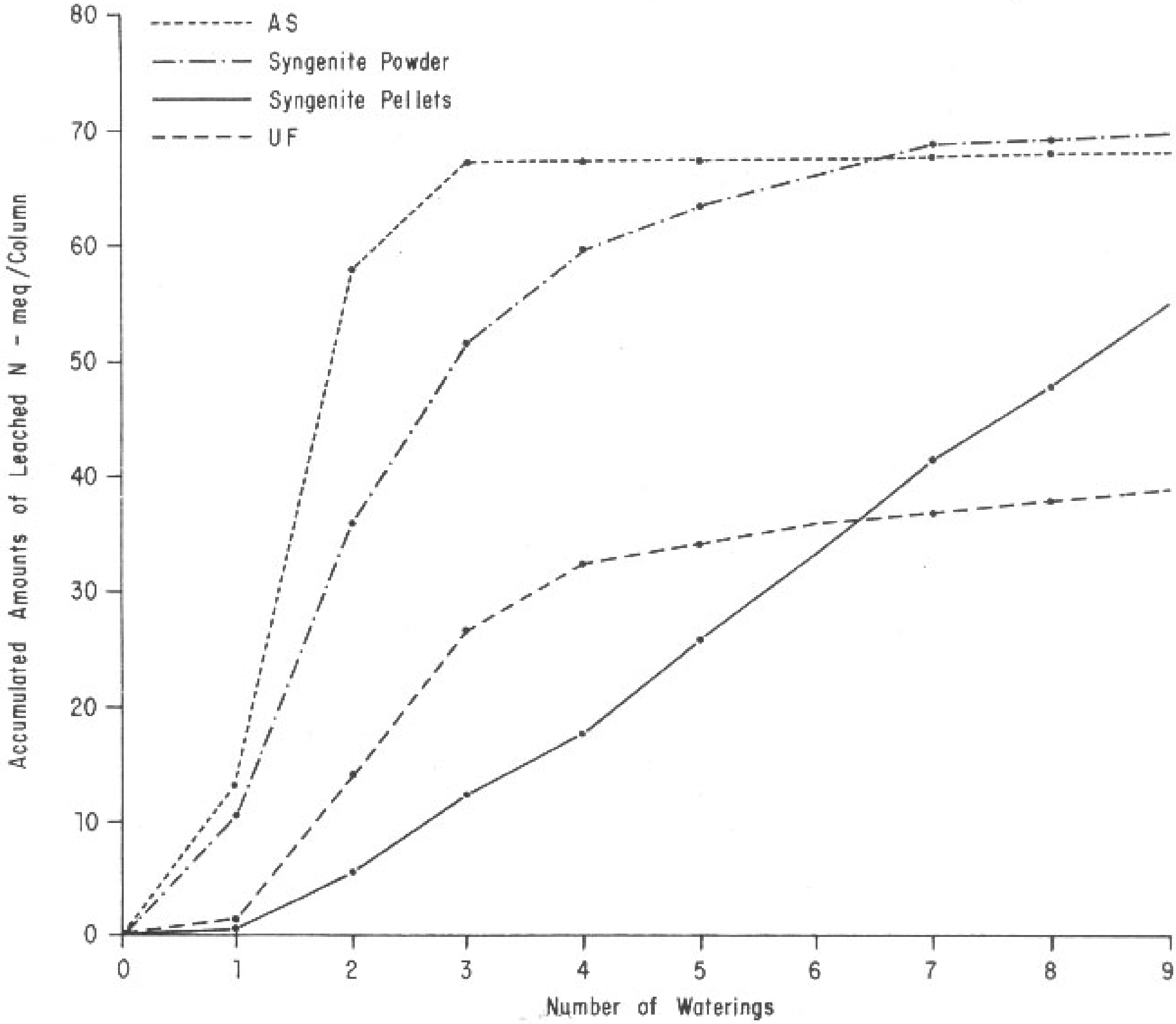

Fig. 1 AMOUNT OF N LEACHED FROM DIFFERENT FERTILIZERS AS AFFECTED BY NUMBER OF WATER APPLICATIONS

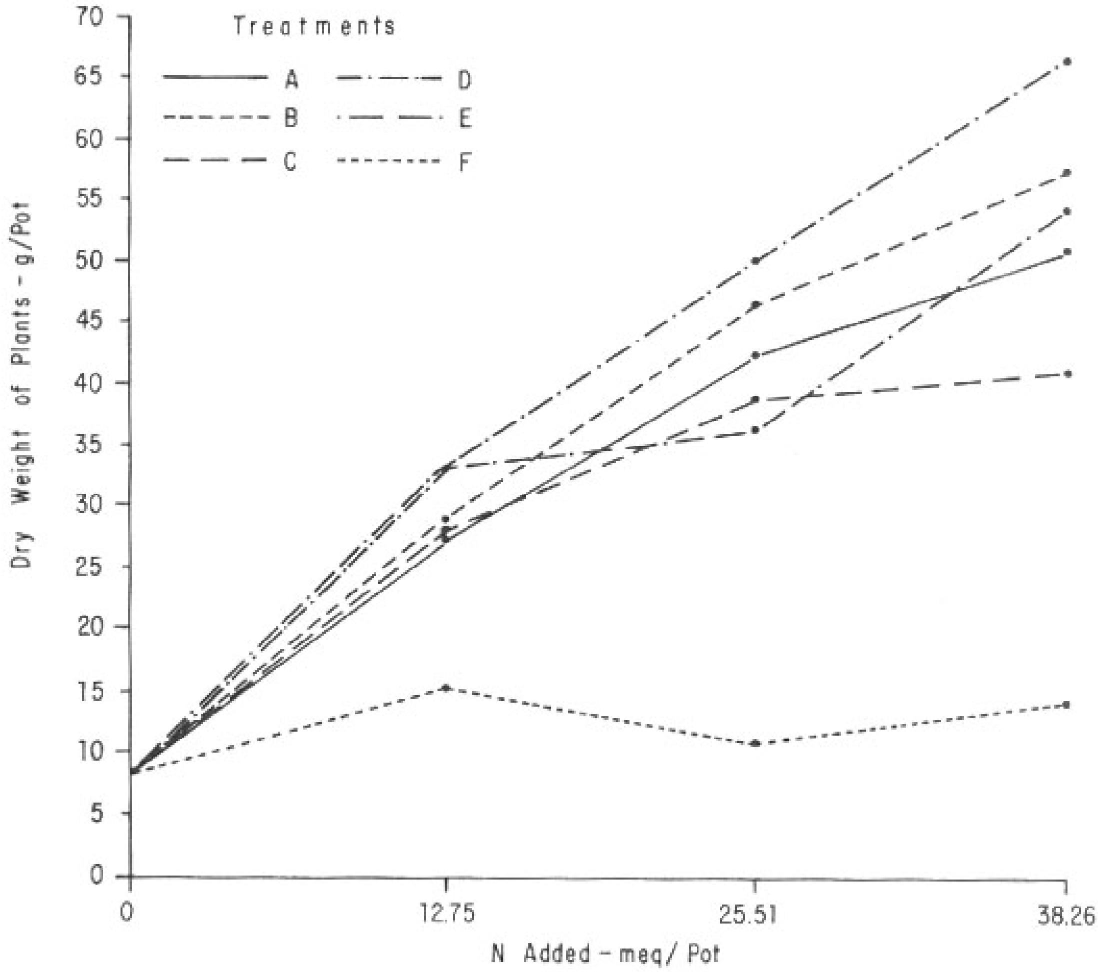

Fig. 2 EFFECT OF INCREMENTS OF N IN DIFFERENT FERTILIZERS ON DRY WEIGHT OF PLANTS

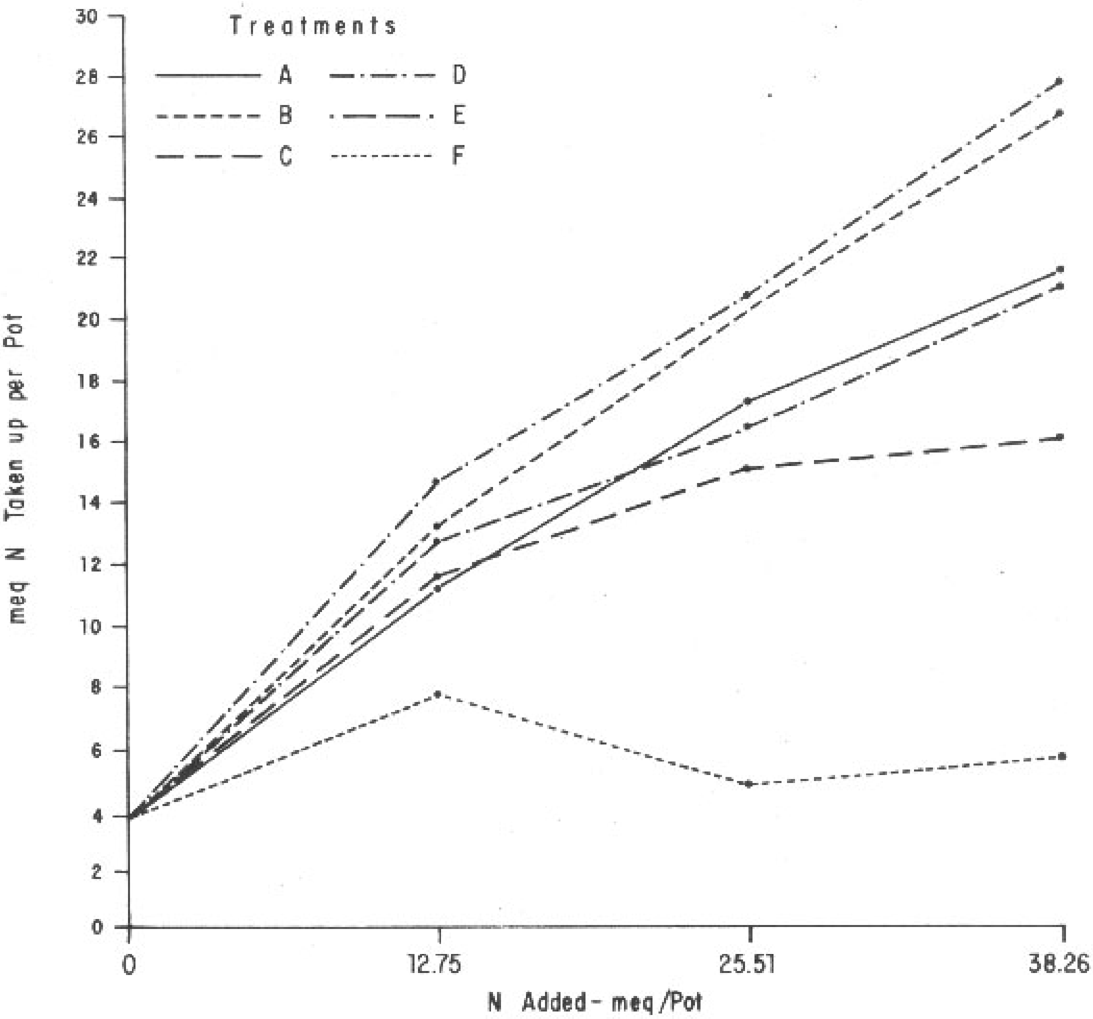

Fig. 3 EFFECT OF N INCREMENTS IN DIFFERFNT FERTILIZERS ON THE AMOUNT OF N TAKEN UP BY THE PLANTS

fertilizer and water. Thus N release slowed down and consequently was less leached, giving the plants a better chance to absorb their requirement of N.

2.4.3 Control of Nitrification

Controlling the nitrification of fertilizers results in a decrease of the nitrate nitrogen which constitutes the major part of the leached N compounds.

Swezey and Turner (1962) used 2-chloro-6-(tri chloromethyl)pyridine for the control of nitrification of ammonium and urea. They reported that higher growth and yield increases were obtained for cotton, maize and sugarbeets with the treated fertilizers than from equal rates of untreated fertilizers. Formulation of 2-chloro-6-(trichloromethyl)pyridine with commercial grade ammonium sulphate and urea was prepared by dissolving the chemical in a volatile solvent and spraying this solution on to the fertilizer while it was being stirred. It was then tumbled until all the solvent had evaporated. The fertilizer was added in bands half an inch wide and 5 to 7 inches deep close to the plant bed. With anhydrous ammonia as a solution 2-chloro-6-(trichloromethyl)pyridine was also used.

Goring (1962) studied the basic biological activity of 2-chloro-6-(trichloromethyl)pyridine in soils. The results showed that it is highly toxic to the organisms converting ammonium to nitrate, and has a low order of toxicity to:

i. organisms or enzymes converting urea to ammonium;

ii. organisms converting nitrite to nitrate;

iii. general fungus and bacterial populations;

iv. seedlings of many plants.

The minimum concentration in soil required to delay the conversion of ammonium to nitrite for at least 6 weeks ranged from as low as 0.05 ppm to as high as 20 ppm. Increasing concentrations delayed conversion for longer periods of time. Goring also reported that similar controlled nitrification of $(NH_4)_2SO_4$, NH_4NO_3, $(NH_4)_2HPO_4$ and urea was obtained in broadcast and band applications, except when leaching conditions occurred immediately after fertilizer application.

2.4.4 Control of Availability of Nitrogen Fertilizers

Considerable attention has been given to the development of nitrogen fertilizers with controlled availability, because they should supply nitrogen continuously over an extended period, thus avoiding the need for repeated applications of conventional water-soluble fertilizers. They also promise to minimize over-consumption of N and upset of nutrient balance, as well as to reduce N losses by leaching, to decrease gaseous losses of N and to reduce the hazard of injury from over-application, particularly to seedlings.

In the late 1930s a fertilizer ammoniating solution was developed which was capable of producing a slowly available or water-insoluble urea formaldehyde type of nitrogen product. The value of this slowly available nitrogen as a useful source of nitrogen was demonstrated in the early 1940s (Sauchelli, 1960). Yee and Love (1947) reported that a solid, water-insoluble nitrogen product having a well defined, controlled availability could be made from the reaction of urea with formaldehyde. Additional information on the urea formaldehyde reaction was reported by the U.S. Department of Agriculture in 1948. At that time, the generic name "Ureaform" (UF) was proposed for this type of urea formaldehyde product. The Association of American Fertilizer Control Officials adopted the following as a definition of the ureaform fertilizer: "urea formaldehyde fertilizer materials are reaction products of urea and formaldehyde containing at least 35% nitrogen, largely in insoluble but slowly available form. The water-insoluble nitrogen in these products shall not test less than 40% active by the nitrogen activity index for urea formaldehyde compounds as determined by the appropriate AOAC method".

In 1955 ureaform became commercially available to the speciality fertilizer market. Since that time it has found growing use in the turf and ornamental markets (Sauchelli, 1960).

Armiger et al. (1951) compared ureaform with standard sources of N in greenhouse experiments using established perennial ryegrass on Evesbaro loamy sand soil as an indicator crop over a growth period of 299 days. They reported that the overall efficiency of properly formulated ureaform materials equals or exceeds that of conventional nitrogen fertilizers in respect to long season crops such as turf. They also demonstrated that a single application of ureaform may be made at higher N levels than would be feasible with more soluble N sources. Brown and Volk (1966) evaluated ureaform using ^{15}N-labelled materials in sandy soils. They reported that a greater proportion of labelled ammonium nitrate -N was recovered in the plants than labelled ureaform-N. However, more labelled N was found in the soil after one year when ureaform was the source.

Several other N-carriers are produced to serve as slowly available N sources to plants. Among these are: coated urea 36.0% N, thiourea (NH_2CSNH_2) 36.0% N, hexamine ($C_6H_{12}N_4$) 40.6% N, oxamide ($H_2NCOCONH_2$) 31.8% N, glycoluril ($C_4H_6N_4O_2$) 39.4% N and oxidized N-enriched coal 20.1% N.

Beaton et al. (1967) showed that apparent recovery of N from various sources decreased in the following order: coated urea (75%) = ammonium nitrate (74%) > thiourea (69%) > oxamide-fine (65%) > urea plus thiourea (63%) > hexamine (59%) > glycoluril (49%) > urea formaldehyde (41%) > ammonium salt of oxidized nitrogen-enriched coal (39%). More N was recovered from ammonium nitrate in the first harvest than from any other fertilizer. However, apparent recovery of N from urea plus thiourea was as high as for ammonium nitrate. The lowest apparent recoveries were obtained with glycoluril and urea formaldehyde. The only sources from which N was recovered in the fourth harvest were urea formaldehyde, thiourea, coated urea, glycoluril and fine oxamide. With the fifth harvest only three sources, ureaform, thiourea and coated urea, were still supplying nitrogen to a crop of orchard grass. This number was reduced to only two, ureaform and coated urea, in the sixth harvest. A small amount of nitrogen was recovered from thiourea in the seventh harvest.

Ureaform "UF" is manufactured in Egypt for industrial purposes. The material used by Balba and Sheta (1973) was obtained from the Nile Company for Matches at Alexandria. It contained 35.5% total nitrogen, 14.6% cold water insoluble nitrogen, 8.4% hot water insoluble nitrogen. Its activity index was 42.4 (Sauchelli, 1960).

Balba and Sheta included UF in the leachability studies described above and showed that only about half of the added N was recovered in 9 filtrates (Fig.1). Increments of N as UF were applied to sand pots planted to maize in a single addition after thinning. The results showed that the absorbed N by the maize plants significantly increased with the first application, but tended to decrease with further application. In the course of the experiment, the plants showed an unhealthy yellow colour. The percent utilization of UF-N was 32.9 and decreased with further application to about 5. The N in the leachates accounted for about 15% of the applied amounts, (Fig. 4).

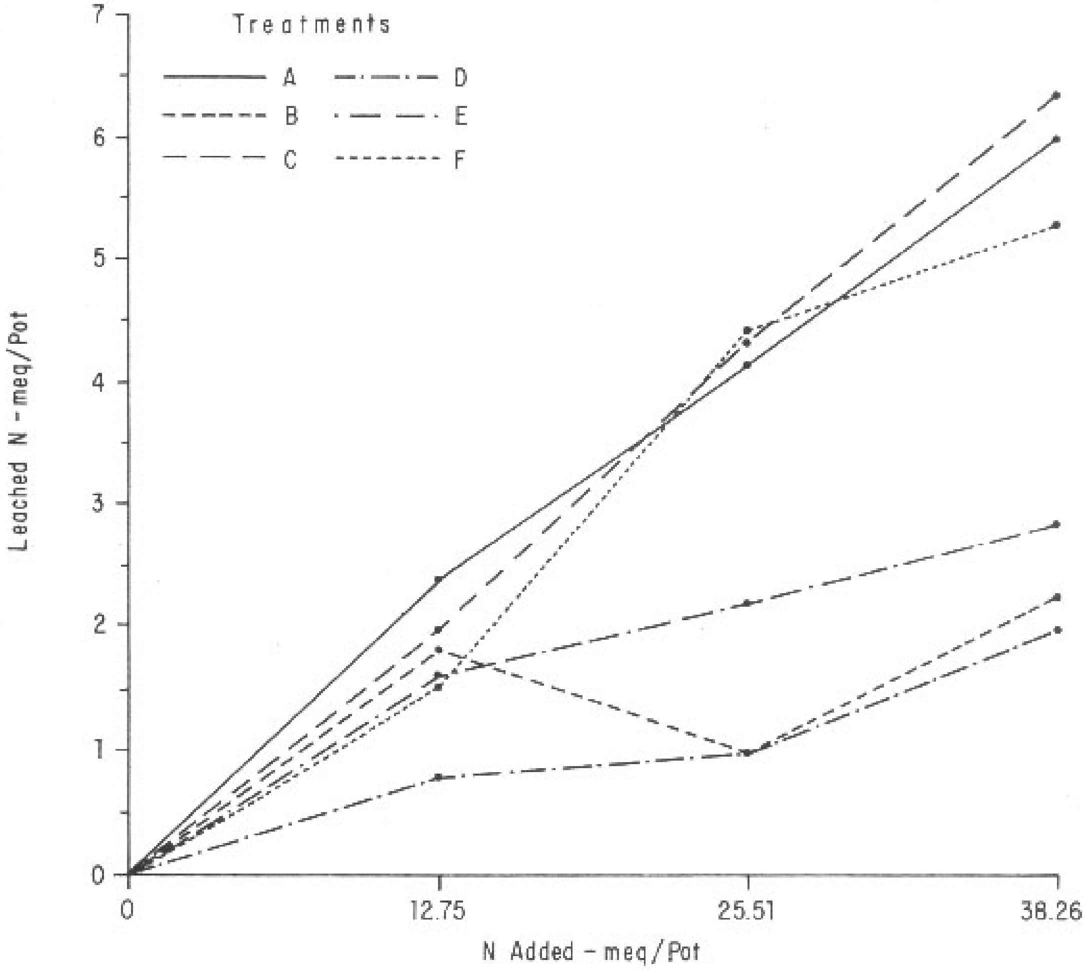

Fig. 4 AMOUNT OF N IN THE LEACHATES AS AFFECTED BY N INCREMENTS IN DIFFERENT FERTILIZERS

The amount of N which remained in the sand after cropping was about 50% of the added N, (Fig. 5). Calculation of the N balance sheet indicated that about 9% of added N was lost in gaseous form at the first rate of application and this increased to 30% with further application.

These results indicated that growth conditions in the presence of UF were not suitable for maize. To understand better these conditions, UF, urea (U) and AS were incubated with sand or with soil. The results of the incubation were as follows:

i. The pH of the sand-UF and sand-U mixtures tended to increase, while that of AS-sand tended to decrease, (Fig. 6)

ii. The NO_2^- - N in the case of UF- and U-sand systems accounted for about 10% of the added N, while only traces of NO_2^- were present in the case of AS, (Fig. 7).

   On the other hand, less than 10% of N added as UF or U was present as NO_3^-. The corresponding value of NO_3^- - N in the case of AS was about 20%.

iii. The N lost in gaseous forms, when calculated as percent of the mineralized portion of N in the case of UF or U, was much greater than the corresponding value in the case of AS, (Fig. 8).

Balba and Sheta (1973) related the accumulation of toxic NO_2^- and consequently the gaseous loss of N due to its presence, as due to the rise of pH as a result of $(NH_4)_2CO_3$ formed during the hydrolysis of UF or U. To test this assumption, gypsum was added to a set of incubation flasks. The hypothesis was that gypsum will react with $(NH_4)_2CO_3$ forming $(NH_4)_2SO_4$ and $CaCO_3$. The results showed that accumulation of NO_2^- and loss of N decreased with increments of gypsum, which is an indication of the validity of the assumption.

Incubation of UF, U or AS with soil was carried out. The loamy soil used contained soluble and exchangeable Ca. The presence of Ca^{++} had resulted in lower pH values, less NO_2^- accumulation and lower loss of N in gaseous forms. Balba and Sheta concluded that on fertilization sandy soils, poor in Ca, with UF or U, might respond adversely, and gypsum application might be recommendable instead.

In a pot experiment, the writer (1973) found that at maturity the weight of wheat plants grown on clay loam soil and fertilized with Ca $(NO_3)_2$, AS or U was not significantly different. On the other hand, the weight of plants grown on sandy soil fertilized with urea was less than for those fertilized with $Ca(NO_3)_2$ or AS. Again the same trend was manifested in a field experiment at South Tahreer (Fig. 9). Fertilization with U resulted in significantly lower yields than those obtained by application of the same amounts of N as AS, NH_4NO_3 or $Ca(NO_3)_2$, (Balba, 1973).

2.5 RATES OF FERTILIZER APPLICATION

Fertilizers are applied at the rates which give the highest return per unit area, or, under certain conditions, per monetary unit (pound, dinar, etc.) spent on fertilizers. Several agronomic and economic factors are involved in determining this rate. Balba and Abd El Gawad (1973) showed that the rate of nitrogen application to wheat which gave maximum return per feddan (4 200 m^2) at South Tahreer was 50 kg N (not as urea). Experiments with N, P and K fertilizers are needed to calculate the rates of application of the 3 nutrients together.

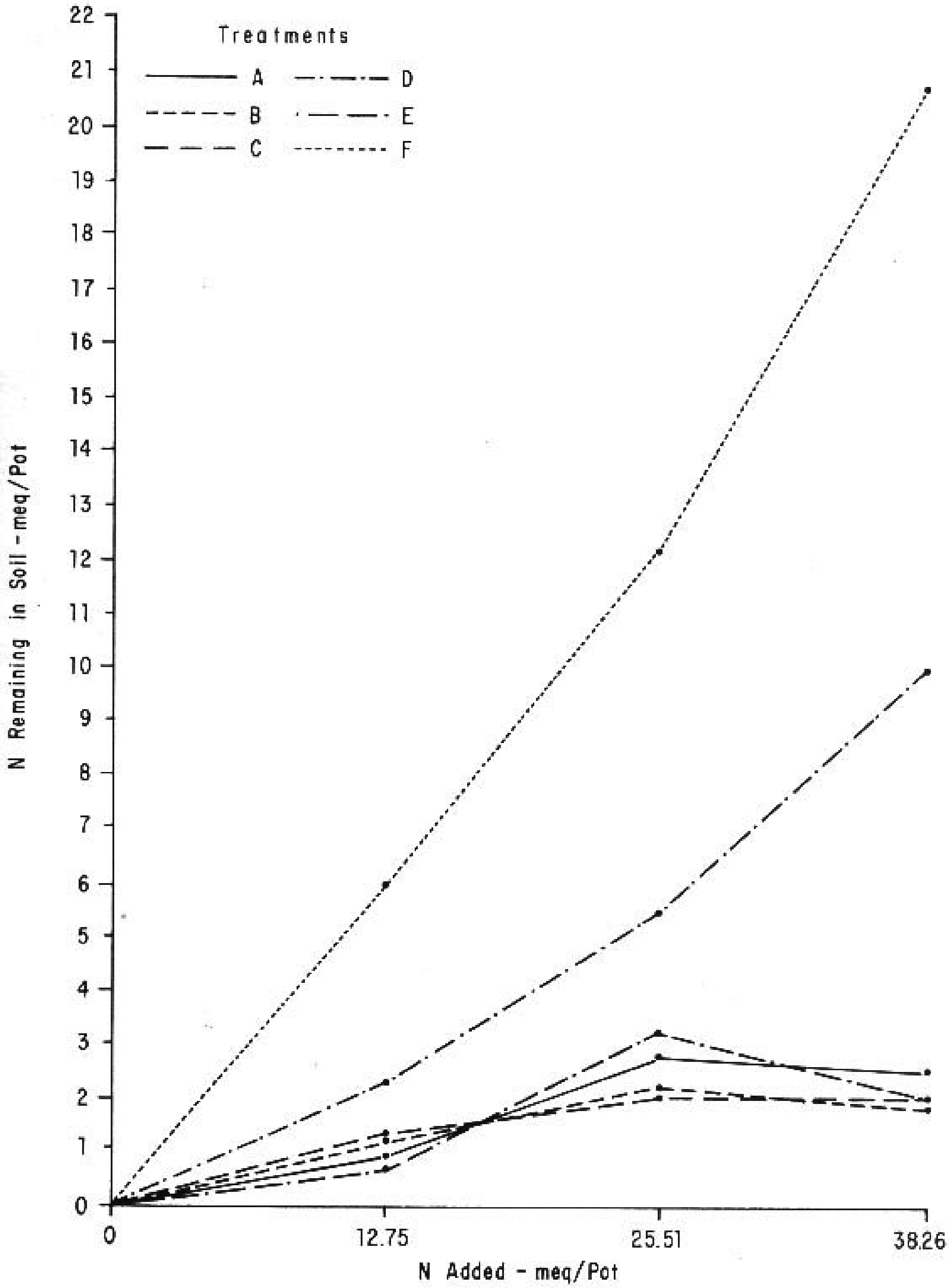

Fig. 5 AMOUNT OF N REMAINING IN SOIL AFTER CROPPING AS AFFECTED BY N INCREMENTS IN DIFFERENT FERTILIZERS

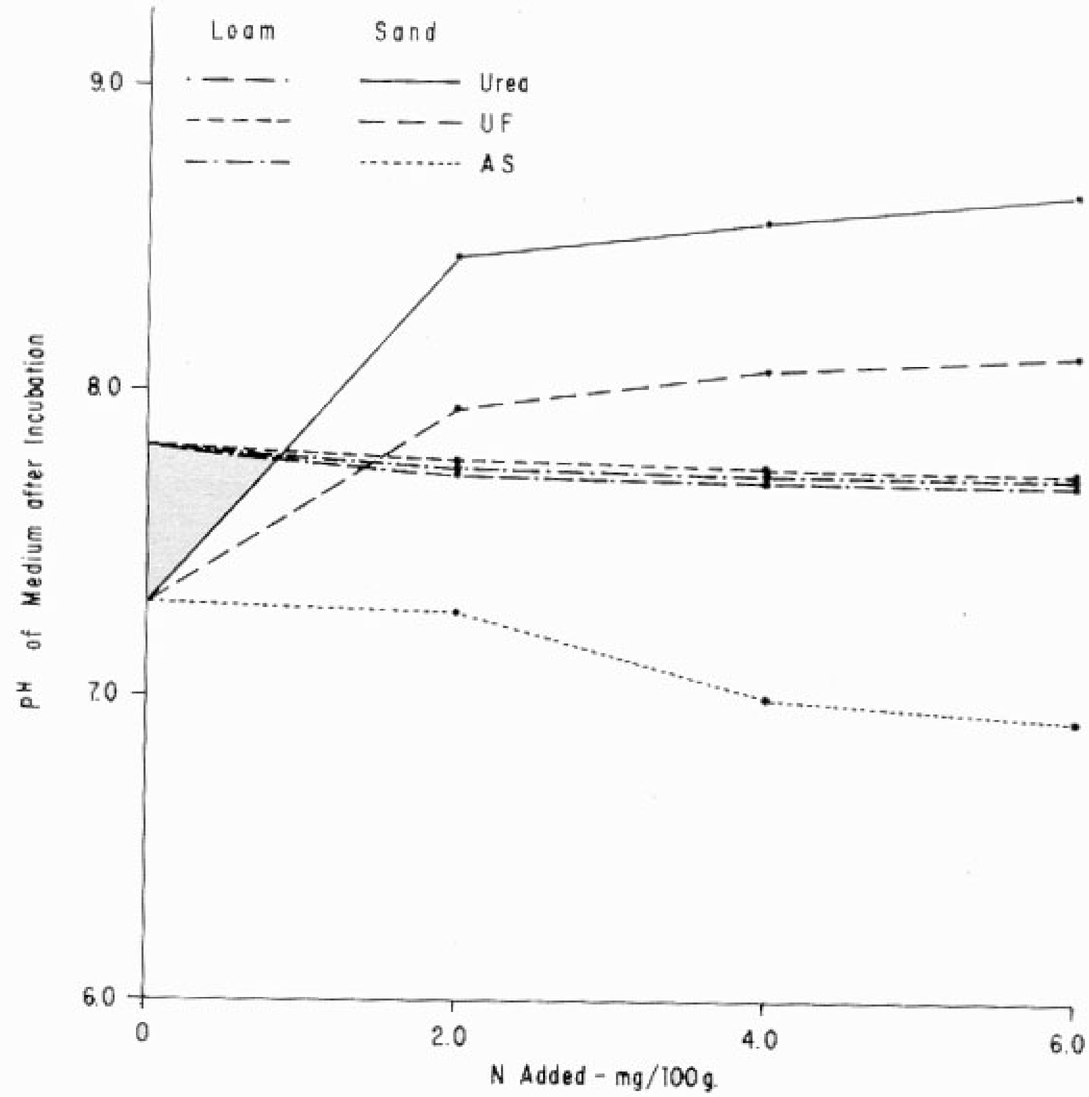

Fig. 6 EFFECT OF INCUBATING INCREMENTS OF DIFFERENT N FORMS WITH SAND OR SOIL ON THE pH

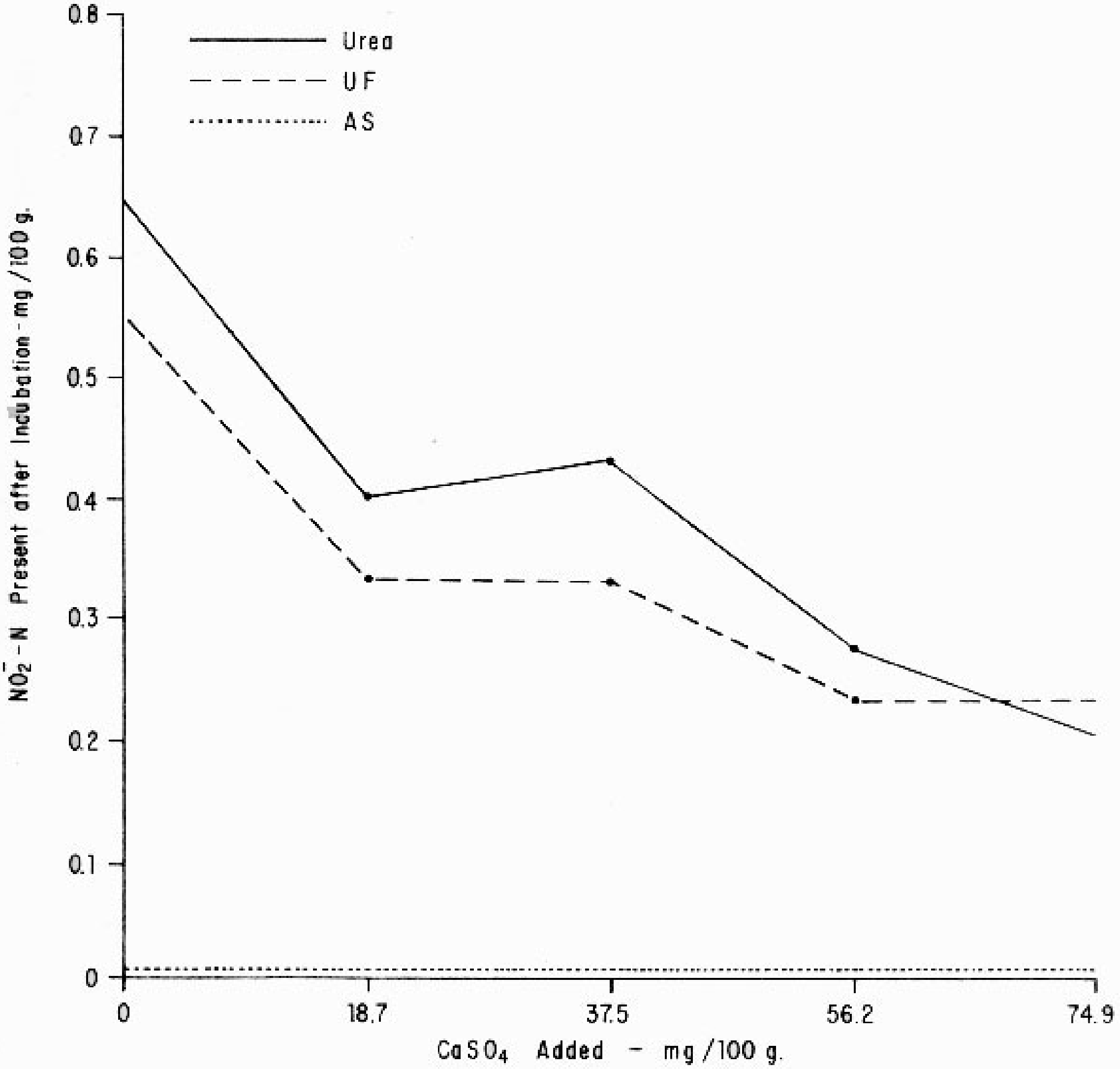

Fig. 7 FORMATION OF NO_2^- UPON INCUBATION OF SAND - N MIXTURE AS AFFECTED BY $CaSO_4$ INCREMENTS

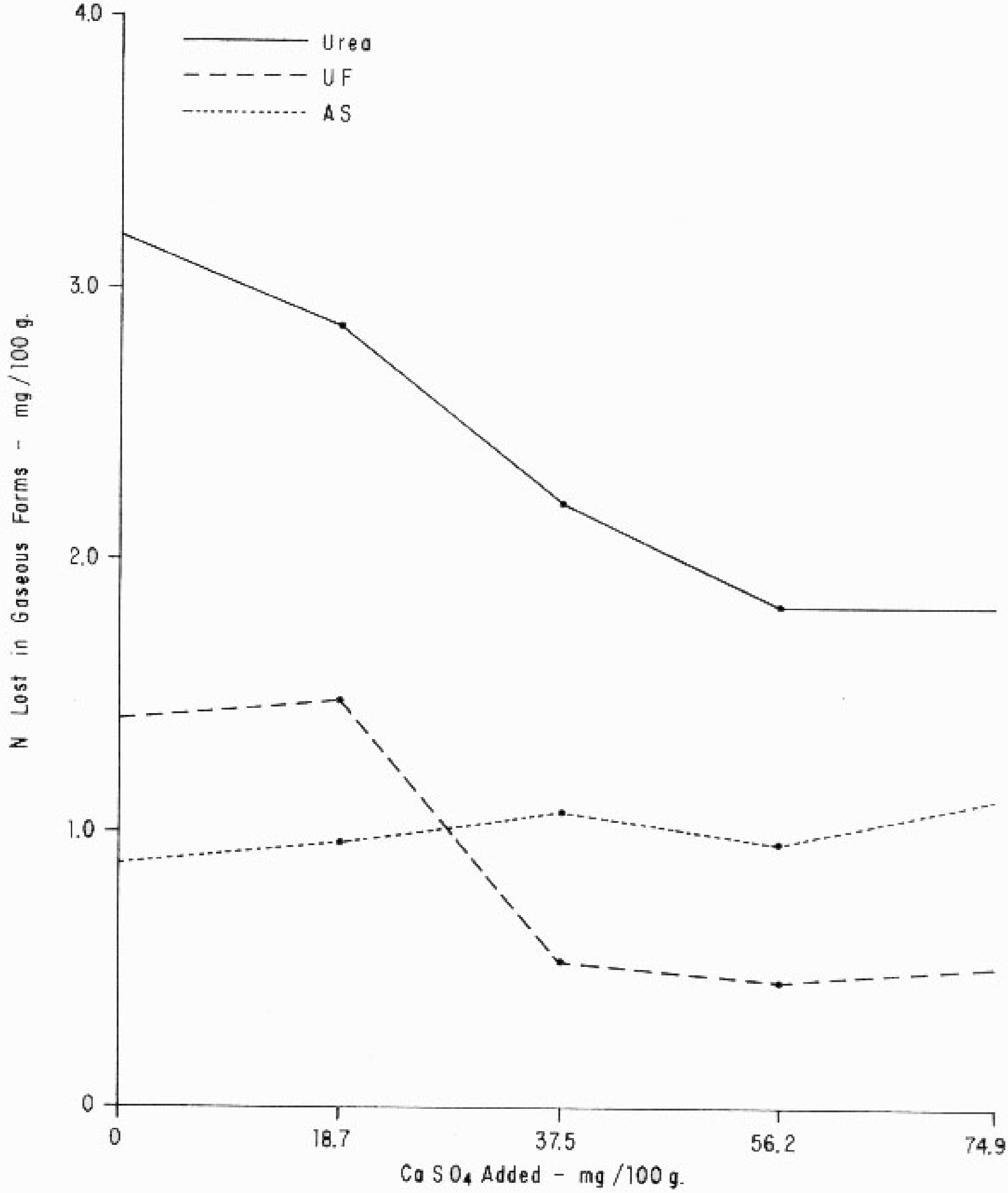

Fig. 8 EFFECT OF $CaSO_4$ INCREMENTS ON THE N LOST IN GASEOUS FORMS UPON INCUBATION OF SAND - N MIXTURES

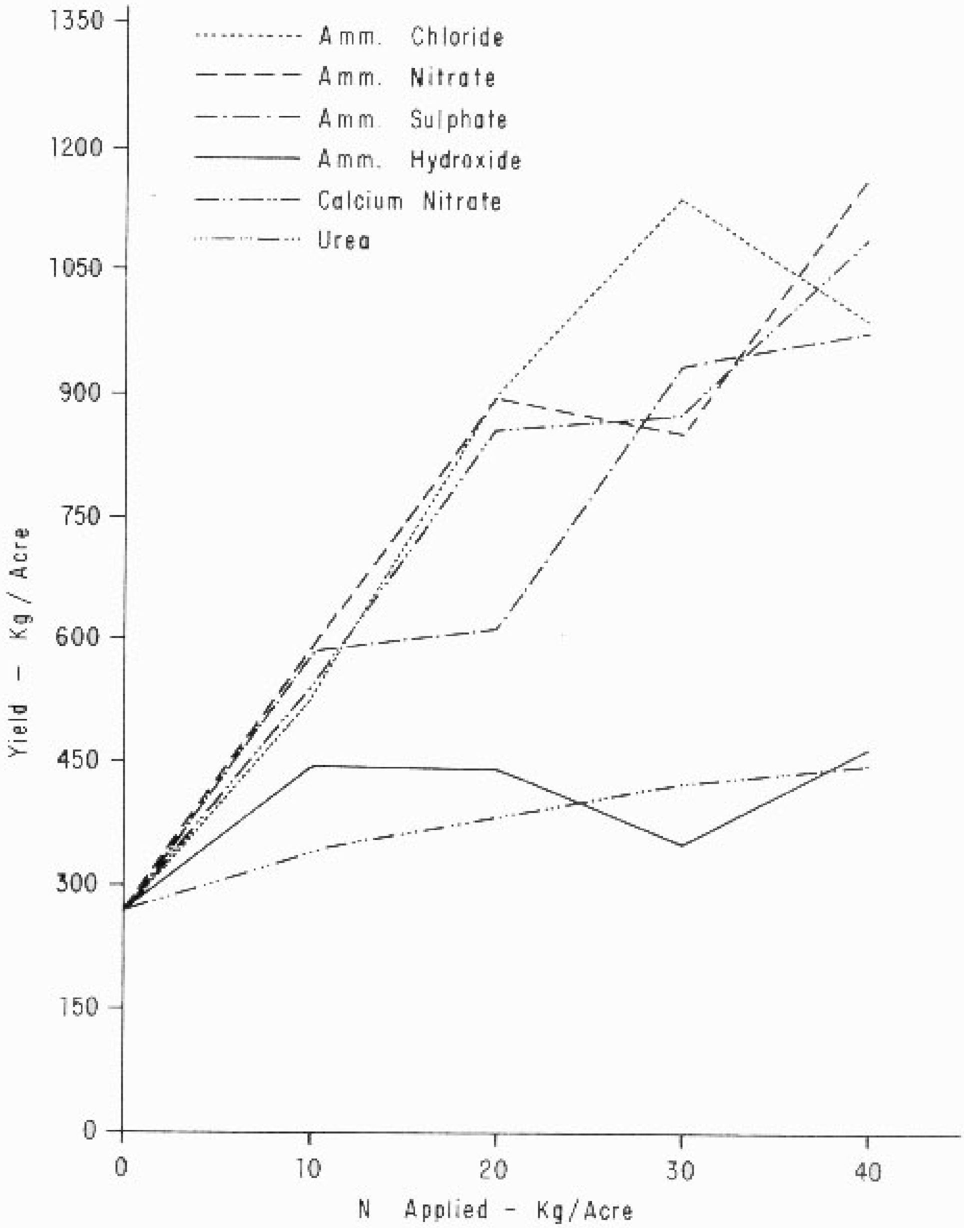

Fig. 9 RESPONSE OF WHEAT TO N INCREMENTS FROM DIFFERENT N - CARRIERS AT EL-TA[illegible]EEP

2.6 CONCLUSIONS

The main fertility problem of sandy soils is that they are poor in nutrients. Also, any applied nutrients are subject to loss with the irrigation water.

Fertilization of these soils is an essential practice for economical farming. Application of organic manures can supply them with all the necessary nutrients in slowly available forms. However, this practice is better suited to farmers with small holdings. In large projects organic fertilization might not be feasible or suitable, unless a nearby farm is specialized in animal production and could provide the organic matter. Mahmoud et al. stated that green manuring was not economical in South Tahreer Province.

Inorganic fertilization is the main practice by which the correct amount of nutrients required by plants to give high yields can be supplied. Soluble fertilizers should be applied in a manner which would decrease their loss in irrigation water. Foliar spraying might be a promising method. Also, capsuled, pelleted or coated fertilizers proved successful. When the practice of layering with organic matter, asphalt, clay, etc. is adopted, the economics of the process should be examined. Studies of each slowly soluble nitrogen material are necessary to understand their transformations under the specific conditions of the soil to be fertilized. The same might be required for materials used for controlling nitrification.

Rates of fertilizer application depend on several factors such as soil fertility, kind and variety of plant and method of application.

Micronutrients are not available in sufficient quantity for satisfactory production and have to be applied. Foliar spraying is a common practice for their application.

2.7 SUGGESTED RESEARCH PROGRAMME

The fertility problems of sandy soils in the Middle East are gaining importance because the soils of several land reclamation and development projects are sandy. It therefore seems a most apposite time to recommend that a research programme be carried out.

2.7.1 Basic Research

A part of this programme might be directed toward a better understanding of the theoretical bases of the problems. In this regard the following points deserve further investigation:

i. Movement of nutrients

a. The movement of nutrients in the soil by diffusion or by convection and the factors which affect the two processes.

b. The mathematical relationships which express the movement of soluble and exchangeable forms of nutrients by each process.

c. The role of each process, diffusion or convection, in supplying the plants with nutrients.

ii. <u>Studies of reactions and transformations of different fertilizers applied to different soils</u>

a. Soluble N fertilizers: capsuled, pelleted, coated or with nitrification inhibitors.

b. Different slow N releasing materials.

c. P and K fertilizers and micronutrients.

2.7.2 Applied Research

The other part of the research programme should be directed to selecting the most suitable and economical practices for the fertility management of these soils. The following phases need further investigation under the local conditions in each area:

i. Reclamation practices and their impact on fertilization

The technology of improving chemical and physical properties of the soil has made significant progress. Materials to slow the water movement and machines to use in establishing layers of different kinds and at different depths have been introduced. However, comparison between the materials, the machines and the effectiveness of the practices under field conditions is needed. The economics of these practices must also be taken into consideration.

ii. Foliar spraying of fertilizers and micronutrients

This practice is gaining much popularity among farmers. Aeroplanes are used in the process for the vaster areas. Studies concerning several points of interest are needed, for example:

a. Suitable concentrations of the nutrients; the lower the concentration the larger is the volume of the solution to be sprayed and the higher are the costs of the process, especially when carried out by aeroplane. On the other hand, high concentrations might injure the plants.

b. The number of sprays.

c. The stage of plant growth most suitable for spraying.

d. The efficiency of machines involved in the process.

e. The feasibility of mixing the fertilizers and various pesticides.

f. Response of different plants to different fertilization treatments.

g. The feasibility of spraying nutrients incorporated in sprinkling irrigation systems.

h. The economics of the process compared with application of fertilizers to the soil.

iii. Comparison of different methods of inorganic fertilization

a. Foliar spraying

b. Broadcasting

c. In Hills

d. In irrigation water

e. Spraying solutions on the soil surface

f. Injection under the soil surface

The response of different crops as well as the economics of each method should be considered. Time and rate of application most suitable for each method must also be investigated.

iv. Mixed and compound fertilizers versus simple fertilizers

Comparison between the response of plants and the economics of the two methods.

v. Developing a suitable system for soil testing and fertilization recommendations

vi. Interaction between fertilization and different irrigation regimes

Multivariant experiments containing factors selected from the above-mentioned problems could be carried out. To achieve these objectives, it is recommended that representative pilot experimental areas be established on reclamation and development projects. A master plan for the field experimental programme could be formulated and applied throughout the region, thus ensuring comparability.

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III.3 PHYSICAL PROPERTIES OF SANDY SOILS IN RELATION TO CROPPING AND SOIL CONSERVATION PRACTICES

by

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SUMMARY

The purpose of this paper is to outline the basic physical properties of sandy soils and to present some of the recent techniques which could be applied to improve or be adapted to suit these properties for better cropping and utilization.

Sandy soils with sand and loamy sand texture deserve special considerations since they have a larger percentage of sand fractions that adversely affect their agricultural potentialities. Sands being noncoherent and structureless are erodible. Although they have a high specific gravity and low total porosity, their pores are large and contribute to good aeration, rapid drainage and low water holding capacity. The low specific surface area of sands is a main factor affecting their low surface activity and explains dissimilarities from clays in their physical behaviour. Sandy soils are often described as droughty. Their low available water range, high infiltration rate and rapid redistribution affect their irrigation practices and agricultural potentialities. The water transmitting properties of sands encourage upward water movement when they are wet and discourage it when they are dry.

For efficient utilization and better cropping of sandy soils one has to overcome their physical disadvantage and to retain their advantage. Of the techniques which could be applied to increase water and nutrient storage placing of asphalt or organic manure barriers and surface mulching are considered. Theoretical aspects, experimental procedures and results have been given to show the effectiveness of these techniques.

With an asphalt barrier, a sandy soil could provide 200% more water to plants than a barrierless one. Increased yields and water savings have been reported for a wide variety of crops including rice. Asphalt barriers permit an increase in the efficiency of furrow and flood irrigations on sandy soils and as to their economy, they are economically feasible.

Surface application of organic manures to sandy soils has a short duration effect, incorporation deeper in the soil has a better effect and placing a carpet-like layer of not less than one centimetre thick has proved to be superior. Improvement of water storage, biological activity, nutrient status and an increase in yields, especially when more than one layer is placed in the soil, are cited.

Improvemant of water storage by reducing evaporation losses can be achieved through the use of surface mulch. Tillage, placement of a gravel layer and surface application of crop residue have been discussed. For tillage to be really effective, it has to be done at the earliest possible time after irrigation or rainfall when the evaporation rate is still high. Gravel layers on the soil surface or at 5 cm below are more effective in reducing cumulative water losses by evaporation than those at deeper depths. This technique is more suited to areas cultivated with trees and where minimum disturbance of the soil is necessary. Crop residues maintained or spread over the surface not only reduce evaporation losses and decrease the range between maximum and minimum soil temperature but also reduce

wind erosion. The roughness of the crop residue and the area it covers of the soil surface are important factors in this technique.

The susceptibility of sands to erosion is related to their large size fraction, cohesionless nature and instability of the clods. Adaptation of certain cropping management practices can reduce the hazards of erosion from agricultural sandy soils. Minimum tillage, maintenance of a cover crop, strip cropping, crop rotations, control of grazing and establishment of shelter belts and windbreaks are discussed as protective measures. Control of sand dune encroachments by stabilization with the conventional dry vegetation method and the recent techniques of spraying asphalt and synthetic materials are also presented.

3.1 INTRODUCTION

Sandy soils are of widespread occurrence in the Near East and North Africa regions (Kadry, 1973) as well as in other arid and semi-arid regions of the world. Considering that one seventh of the earth's surface is covered by deserts distributed among all the continents and that sandy soils and sand dunes make up the bulk of this area, one realizes the extent of the natural soil resources that can hardly be utilized. It is only the part, roughly estimated as 95 million ha, straddling or adjacent to the interface between desert and arable land, that is of immediate concern to agricultural development. At this interface there is a struggle between nature and man where the latter is trying to check desert encroachment by stabilization and afforestation of sand dunes and to reclaim and manage sandy soils for better utilization.

The nature and properties of sandy soils are known in general but there is a need for more knowledge of the techniques which could be applied to improve or be adapted to suit these properties. It is the purpose of this paper to outline the basic physical properties of sandy soils and to present some of the recent work carried out to improve and adapt the physical properties of these soils to obtain better cropping and more effective conservation practices.

3.2 BASIC PHYSICAL PROPERTIES OF SANDY SOILS

3.2.1 Texture and Structure

Sandy soils are referred to in general terms as coarse textured soils. Their basic soil textural class names are sands and loamy sands which can be modified according to the size group of the sand fraction. The definition of these basic soil texture class names as given in the publications by the Canada Department of Agriculture (1972), the Soil Science Society of America (1971) and USDA (1960) is:

Sand: Soil material containing 85% or more sand; the percentage of silt plus 1.5 times the percentage of clay not exceeding 15.

Loamy sand: Soil material containing at the upper limit 85 to 90% sand, and the percentage of silt plus 1.5 rimes the percentage of clay not less than 15; at the lower limit containing not less than 70 to 85% sand, and the percentage of silt plus twice the percentage of clay not exceeding 30.

Apart from these two basic textural classes, the word 'sandy' may be applied to any one of the soil classes that contain a large percentage of sand, i.e. sandy clay $\geq$ 45, sandy clay loam $\geq$ 45 and sandy loam $\geq$ (43-52). It should be made clear that throughout this paper more attention is given to those soils with sand and loamy sand textures since they have a larger percentage of sand fractions that adversely affect their agricultural potentialities.

Most of the soil separates of the sands and loamy sands are noncoherent and remain as single grains, especially in the absence of organic matter or other binding compounds. The grade of their structure is thus termed "structureless". The sandy soils are non sticky, non plastic when wet and have loose consistency when dry.

3.2.2 Apparent Specific Gravity and Porosity

The high apparent specific gravity of these soils (1.55-1.80) is reflected in their low total porosity (32-42%) which is less than that of finer textured soils, (Israelson and Hansen, 1962). The relative distribution of the pore sizes, which is more important than the total porosity, shows that sands have a large number of large pores which are responsible for good aeration, rapid drainage and a low moisture-holding capacity. The deposition of sand grains affects their pore size distribution; those deposited in a loose state have a higher proportion of large pores than those deposited in a dense state.

Upon deformation, loose sand decreases in volume due to sliding or rolling down into a dense state while dense sand increases its volume. These changes in volume accompanying deformation have a marked effect upon the stability of cohesionless materials. Fine sand in a loose state and saturated is a very unstable material, especially in embankments. Static loads on sandy soils produce very littl compaction, e.g. the soil load over a tile drain, but they could be compacted by vibration.

3.2.3. Specific Surface Area

Sandy soils are characterized by their very low specific surface area. Knowing that the ratio between a given weight or volume of very fine sand (100μ), silt (20μ), clay(2μ) and colloidal clay (100mμ) is 1 : 5 : 50 : 1000, respectively, one realizes how the low specific surface of the coarse separates, especially if the are quartz or unweathered primary minerals, affects the surface activity of the sandy soils. The large differences between the specific surface area in clay and sandy soils should permit a clearer understanding of the recognized dissimilarities in their physical behaviour.

3.2.4 Moisture Characteristics

One of the striking features of sandy soils is their low ability to retain moisture, not only at high tensions but also at low ones, and quite often they are described as droughty. Since sandy soils are low in clay content and most of the pores are relatively large, a great portion of the retained moisture is lost at tensions below one bar. Their available water range (FC-PWP) is rather narrow (4-6%) compared to that of clay soils (16-29%) and this has effects on amount, frequency and methods of irrigation.

A good estimation of the field capacity of sandy soils is important in evaluating their suitability for irrigation. According to the standards of the U.S. Bureau of Reclamation, the available water capacity for irrigable soils is 3/48 in (7.5/120cm). An underestimation of 1.5% moisture content results in a difference of more than 2.5 cm of available water capacity in a 120 cm soil profile having an apparent specific gravity of 1.50. This must be realized especially when the field capacity is taken as the moisture content retained in the soil at a given tension which may be 0.1 bar or lower. Rivers and Shipp (1971) found that the field capacity of sandy soils as determined in five foot square plots was 5.6, 7.3 and 7.9% for coarse sand, sand and fine sand respectively, while the corresponding 0.1 bar values were 3.9, 5.8 and 6.4%. In this particular case, the 0.1 bar tension values appreciably underestimated the field capacity of sands.

3.2.5 Infiltration Rate

The infiltration rate of sandy soils (2.5-25 cm/hr) could be 250 times more than that of clay soils (0.01-0.1 cm/hr), thanks to their large pore spaces and the high saturated hydraulic conductivity. Under unsaturated flow conditions, water moves more slowly in sandy soils than in clays as a result of the lower moisture content and lower unsaturated hydraulic conductivity of the former as shown in Fig.1, (Bouma and Denning, 1972). The understanding of these relations is important for proper irrigation and drainage practices, especially in stratified soils. In a coarse soil overlying a fine one, the infiltration rate at first will be that of the coarse soil alone since the fine soil has not yet been reached; when the wetting front arrives at the boundary between layers, the infiltration rate begins to fall off and eventually approaches that of the fine soil alone. The infiltration rate for the fine over coarse sequence may not differ from that of the uniform fine material, since the flow is dominated by the lower conductivity of the layer of fine soil. Also, a discontinuity in moisture content at the layer boundaries may be observed where moisture content is higher in the fine than in the coarse soil.

3.2.6 Redistribution of Moisture

Redistribution of moisture after cessation of infiltration usually proceeds at a faster rate and even to a greater depth in coarse textured soil than in a finer one, as shown in Fig. 2 (Soliman, 1968). This has to be considered in determining the field capacity in situ since gravitational water movement in sandy soils will cease materially in less than two days. A series of moisture redistribution determinations, which must be made under field conditions, would help in determining not only field capacity of the soil but also its moisture storage capacity.

3.2.7 Upward Water Movement

Upward water movement in sandy soils does not proceed at a fast rate, as is the case for finer ones. However, even though coarse textured soils have a rapid initial rate of capillary movement, the finer textured ones eventually have the highest rise, Fig. 3. Thus the water transmitting properties of sandy soils make then suitable for subsurface irrigation - provided that good quality water is available at a shallow depth, (Massoud, 1964). Since wet, sandy soils have a relatively higher hydraulic conductivity than finer ones, their ability to deliver water to the evaporative zone at the soil surface is greater and is mainly determined by the meteorological conditions. As a result, under arid and semi-arid environments the hazards of salinization could exist, Fig. 4. On the other hand, a dry sandy soil is a poor transmitting medium for capillary water and consequently upward water movement and evaporation losses are materially reduced. Water movement could proceed, however, by vapour diffusion

3.2.8 Aeration

It is an accepted fact that most sandy soils have too much aeration at the expense of an adequate water holding capacity. Air permeability was found to decrease with decreasing particle size and increasing bulk density, (Elgabaly and Elghamry, 1970). For a system having a particle diameter of 771μ and a bulk density

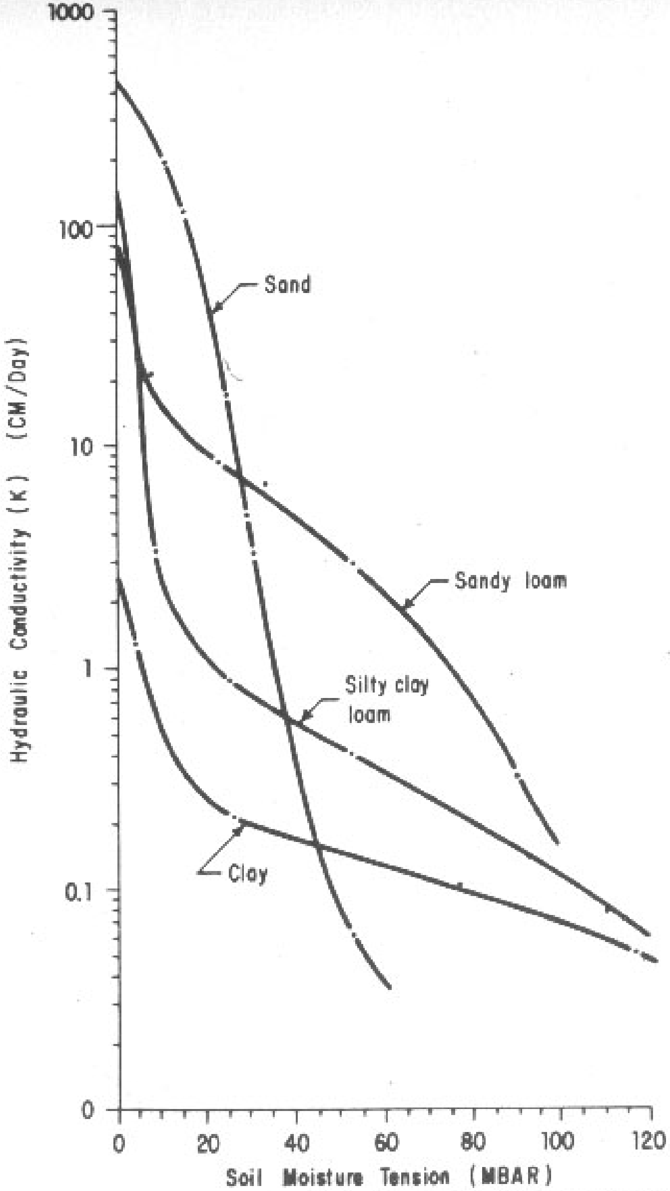

Fig. 1 HYDRAULIC CONDUCTIVITY (K) AS A FUNCTION OF SOIL MOISTURE TENIONS, MEASURED IN SITU WITH THE CRUST TEST FOR A SAND (C of Plainfield Loamy Sand), A SANDY LOAM (IIC of Batavia Silt Loam), AND A CLAY (B2 of Hibbing loam). (After Bouma and Denning, 1972,)

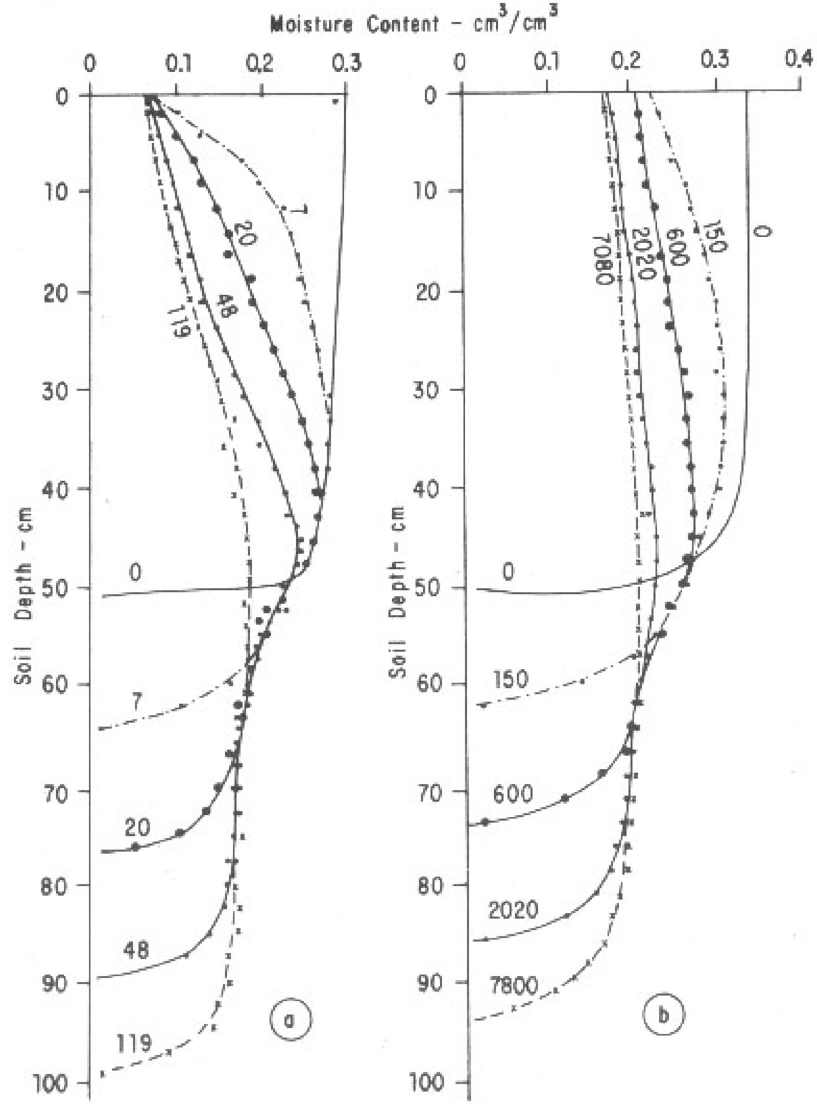

Fig. 2 MOISTURE PROFILES DURING THE REDISTRIBUTION OF MOISTURE AFTER INFILTRATION IN (a) SAND AND (b) CALCAREOUS SOILS (numbers near profiles refer to time in minutes after cessation of infiltration) (After Soliman, 1968)

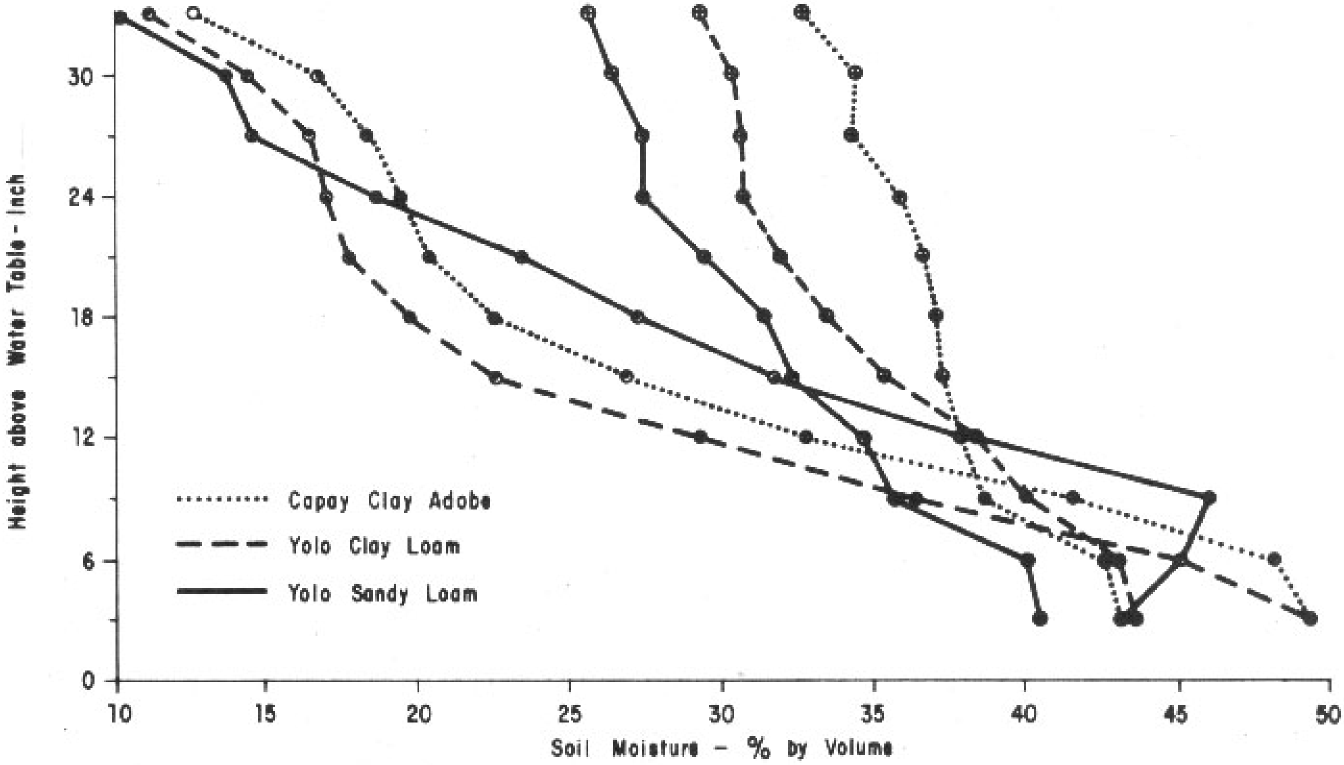

Fig. 3 MOISTURE DISTRIBUTION 2-4 DAYS FROM IRRIGATION ⊕ AND AFTER 10 WEEKS IN CONTACT WITH A CONSTANT WATERTABLE ⊙ UNDER SIMILAR EVAPOTRANSPIRATION CONDITIONS. (After Massoud, 1964)

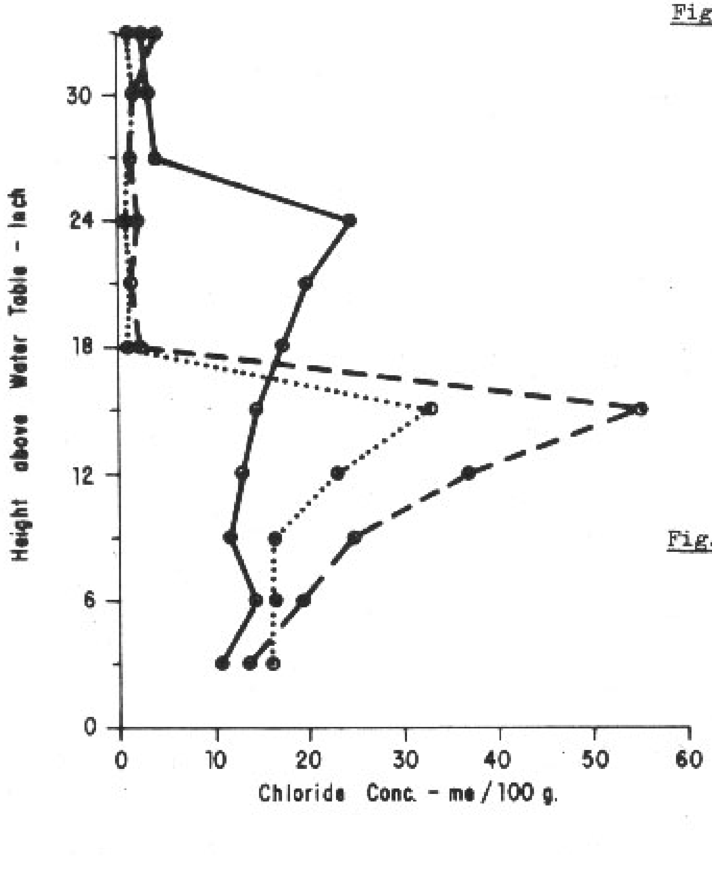

Fig. 4 CHLORIDE DISTRIBUTION AFTER 10 WEEKS IN CONTACT WITH A CONSTANT WATERTABLE HAVING 5 me/l OF $CaCl_2$ UNDER SIMILAR EVAPOTRANSPIRATION FLOW CONDITIONS. (After Massoud, 1964)

of 1.49 g/cm^3 decreasing the size to 88μ reduced the air permeability from 634 to 7μ^2 and increasing bulk density to 1.76 g/cm^3 reduced it to 265μ^2. This indicates that the presence of finer stratified or compacted layers effectively reduces the air permeability of sandy soils.

3.3 IMPROVEMENT AND ADAPTATION OF PHYSICAL CHARACTERISTICS OF SANDY SOILS FOR BETTER CROPPING

The preceding presentation of the physical properties of sandy soils shows that they have favourable as well as unfavourable characteristics affecting their productivity. The high infiltration rate, good aeration and self-mulching are examples of the favourable characteristics while low water retention capacity, low specific surface area and loose consistency are among the unfavourable ones. For efficient utilization and better cropping of the sandy soils the following techniques could be applied to overcome their physical disadvantages while retaining their advantages.

3.3.1 Placement of an Asphalt Barrier in the Soil

The rapid percolation of water through sandy soils when coupled with a low water retention capacity is often a limiting factor to the profitable use of these soils. Not only do special methods of irrigation have to be followed but also irrigation water and plant nutrients could quite possibly be wasted. Placement of relatively impermeable barriers within the soil is one approach to reducing the adverse effects of rapid percolation as well as of the upward movement of poor quality groundwater.

When bentonite clay and plastic films were first tried, there was difficulty in joining the individual barriers into a continuous one but this was later surmounted when asphalt was used, (Erickson et al. 1968). A continuous asphalt barrier of overlapping 225 cm wide strips and 2-3 mm thick can be formed by spraying hot asphalt emulsion at a rate of 14 000 litres/ha, (Palta et al. 1972). Details of the techniques and machinery are given by Hansen and Erickson (1969).

In barriered sand soils, excess water from irrigation or heavy rainfall percolates down to the barrier and then runs across to its edges. As a result of the high conductivity of the saturated sand and the higher gravitational potential at the edge of the barrier, excess water drains rapidly. When the source of free water is removed, the hydraulic conductivity and potential gradient descrease causing low tension water to be detained over the barrier surface. With further capillary discontinuity at the edge of the barrier the drainage of this low tension water is materially reduced.

Erickson et al. (1972) illustrated in a series of capillary rise and drainage experiments made on Ottawa fine sand that the amount of water which can be perched above the moisture barrier after two days of drainage amounted to 10% by volume above the 70 cm height and about 35% at the 35 cm height, Fig. 5. The results of their field investigations on moisture suction after irrigation or rainfall in the same soil with and without an asphalt barrier are given in Table 1 and shown in Fig. 6.

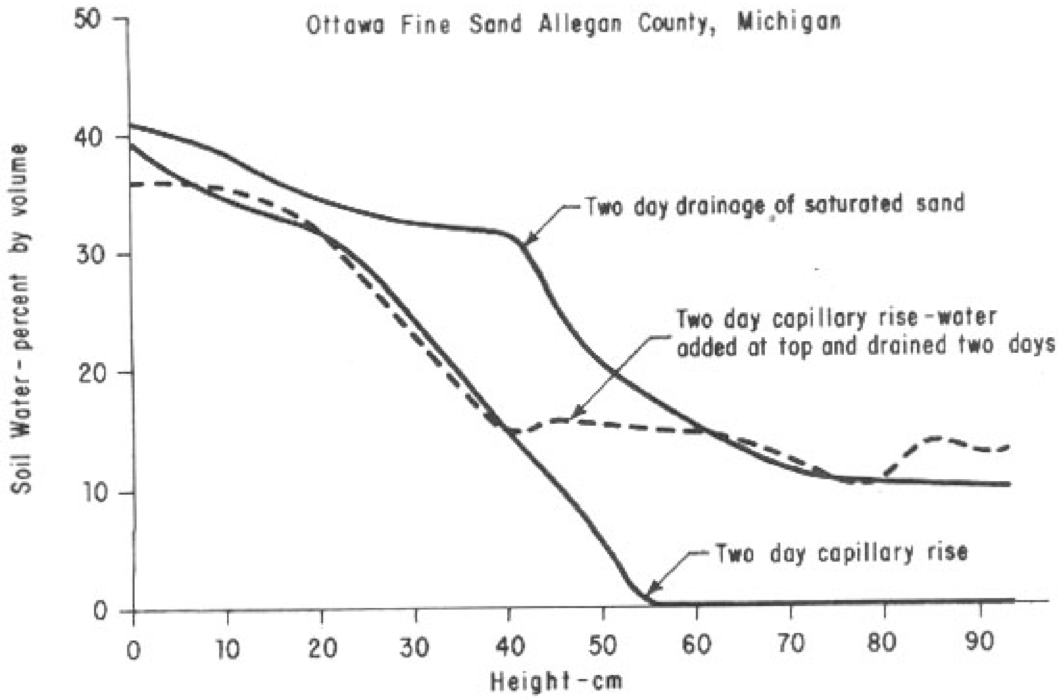

Fig. 5 WATER CONTENT VS HEIGHT OF CAPILLARY RISE, UNSATURATED DRAINAGE CURVES OF AN OTTAWA FINE SAND (After Erickson et al, 1972)

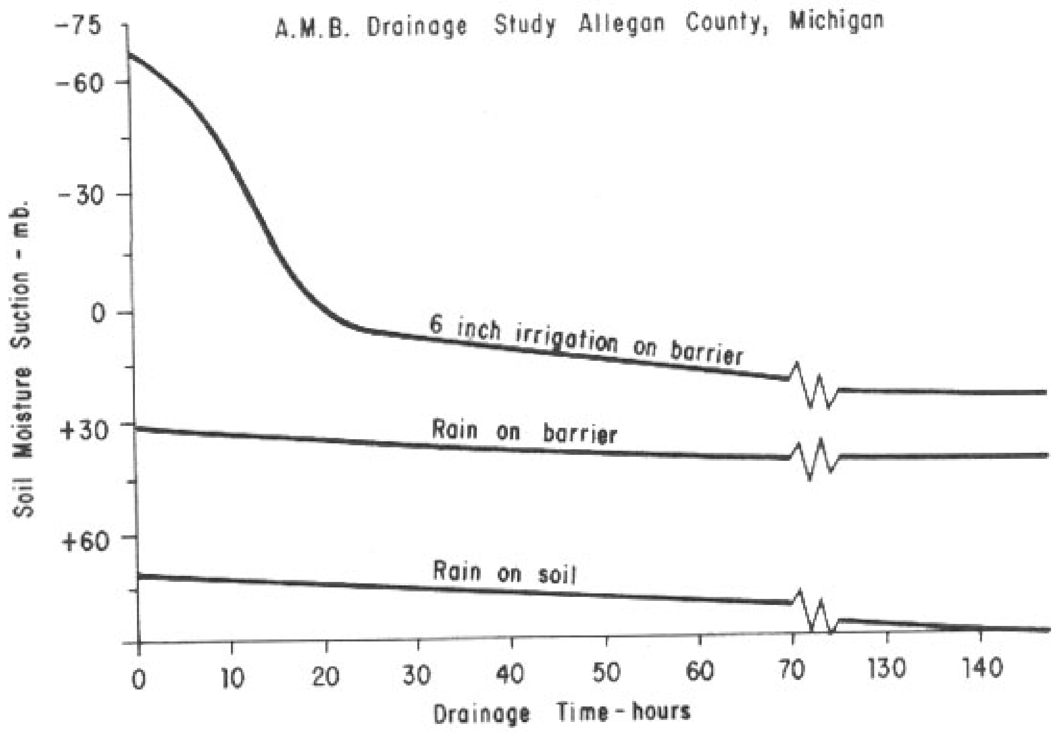

Fig. 6 FIELD DRAINAGE CURVES OF RAIN AND IRRIGATION WATER FROM AN OTTAWA FINE SAND WITH AND WITHOUT ASPHALT MOISTURE BARRIERS (After Erickson et al, 1972)

Table 1 SOIL MOISTURE SUCTION AFTER IRRIGATION OR RAINFALL ON OTTAWA FINE SAND WITH AND WITHOUT AN ASPHALT BARRIER

Drainage time	Suction - millibars		
Days	Rain on soil	Rain on barrier	6 in irrigation on barrier
1	74	34	6
2	82	35	15
6	90	40	25

Adapted from Erickson et al. 1972

Analysis of these results indicated that the 20 cm of soil immediately above the barrier would thus contain over 30% by volume in contrast to the 10 to 12% it would contain without the barrier. Assuming that 50% of the water held by sand is not readily available, the barriered profile could provide 200% more water to plants than a profile of sand without a barrier. Even if an increase of 50% is achieved, the barriered sand soil will thus have a capacity to hold water equal to that of loam soils.

A marked increase in yield of various vegetable crops grown on barriered soils has also been reported (Erickson et al. 1968a, Hansen and Erickson 1969, Saxena et al. 1968 and 1971). The results obtained by Erickson et al. 1968 are given in Table 2.

Table 2 VEGETABLE CROP YIELDS (T/HA) FROM ASPHALT BARRIER EXPERIMENTS

Crop	Cucumber	Cabbage	Potatoes	Beans
Control	18.7	23.0	24.3	13.8
Irrigated control	19.5	18.5	37.3	25.1
Asphalt	24.9	32.7	25.6	14.1
Irrigated asphalt	25.5	23.8	36.8	25.3
L.S.D. 0.01	3.9	4.4	4.2	7.0

The significant increase in crop yields for cucumber and cabbage, being 30-40% due to the presence of the barrier, was hardly noticeable in the case of potatoes and beans because of less favourable rainfall distribution or irrigation frequency, although a 38 mm (18%) saving of irrigation water was achieved by using an asphalt barrier.

The asphalt barrier was also tried for rice cropping on sandy soils in Taiwan (Erickson et al. 1968a). The barrier not only reduced the water needed for flooding the paddies to 1/7 but also increased the yields from 0.40 t/ha for the control to 4.32 t/ha when placed at a depth of 20 cm. Increasing the depth of the barrier to 60 cm raised the yield to 5.38 t/ha.

The experiments of Erickson et al. (1968b) on the use of asphalt barrier for sugar cane production on sand soils, indicated that after a heavy irrigation the free water over the barrier had left within two days and after one month the tension had only reached 41 cm, Fig. 7. Not only the moisture control of the barriered plots during the rainy season was nearly twice that of the control, but also the cane yield was doubled, Table 3.

Table 3 THE EFFECT OF ASPHALT BARRIERS AT DIFFERENT DEPTHS ON SUGARCANE YIELDS AND OTHER DATA TAKEN AT HARVEST TIME 23 FEBRUARY 1968

	Control	Disturbed Control	50 cm	75 cm	100 cm	LSD
Cane yield-m.tons/ha	54.2	48.9	83.2	104.1	97.1	13.0
Available sugar - %	13.22	12.82	12.48	11.55	11.37	0.52
Millable stalks/ha x 10^{-3}	71.8	63.9	86.7	90.5	80.9	9.1
Dead stalks/ha x 10^{-3}	4.4	4.5	7.0	7.3	6.0	1.5
Average stalk length - cm	210	220	266	296	287	15.5

As to the economy of the asphalt barriers, Erickson et al. (1968a, b and 1972) believe that they pay for themselves in one year and that in many cases they are economically feasible because they are a long term investment. Not only do barriered soils save irrigation water and provide higher yields, but they also provide the possibility of more efficient furrow irrigation and even of flooding methods.

3.3.2 Placement of Organic Manure Layers in the Soil

The application of organic manures to sandy soils is a customary practice which helps to increase their fertility and improve their physical characteristics. Under arid and semi-arid climates and where such application is subjected to disturbance by frequent cultivation of the surface layer, the beneficial effect of organic manure becomes rather short lived. Surface application of organic manures encourages lateral growth and horizontal distribution of plant roots in the top soil rather than their extension deeper into the soil, thus limiting the root zone to that depth which is subjected to drying faster than the layers below.

Placement of organic manures or composts rich in colloidal substances deeper into the soil increases the depth of the utilizable soil profile, ensures better exploitation possibilities and permits more water and nutrients to be at the disposal of the plant roots. The best substance recommended by Egerzegi (1958) for improving layers is mature farmyard manure enriched with mineral colloids (clay) or compost abounding in organic and inorganic colloids. A carpet-like layer at a depth of 60 cm can be formed by spreading at least 65 t/ha of farmyard manure, which will

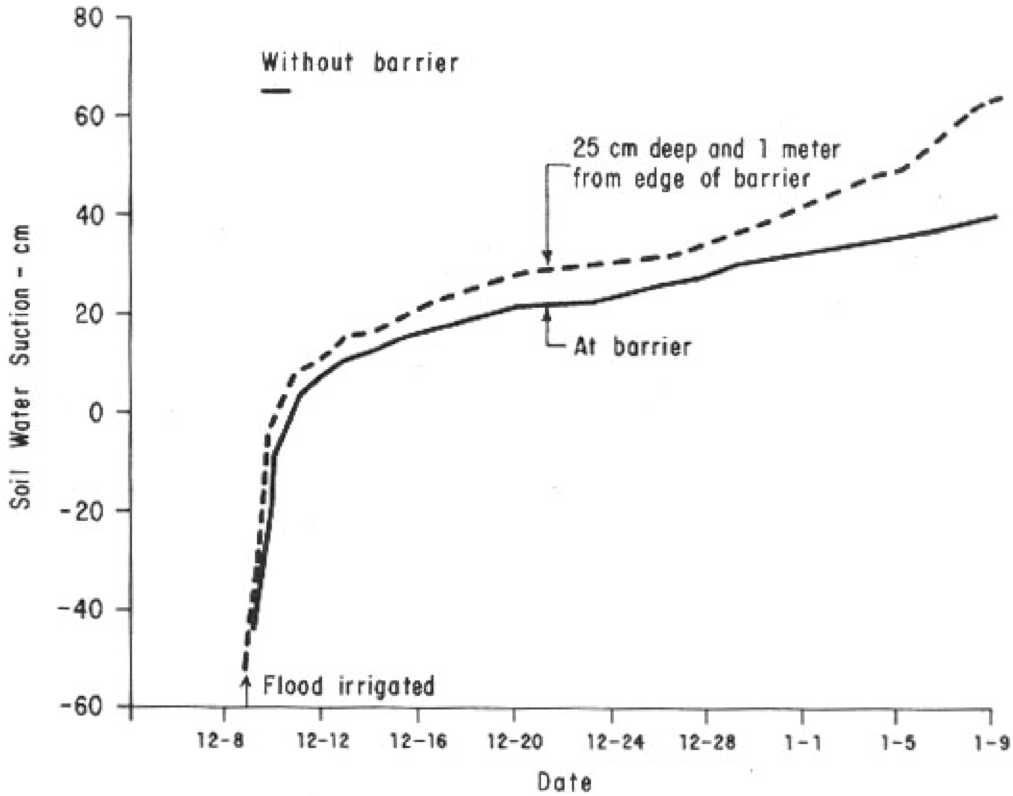

Fig. 7 CHANGES IN SOIL MOISTURE TENSION WITH TIME AFTER AN EXCESSIVE FLOOD IRRIGATION. THE READINGS AT THE BARRIER ARE FOR TENSIOMETERS PLACED ON THE 50 cm DEEP BARRIER. THE DASHED LINE IS FOR TENSIOMETERS PLACED 1 m FROM EDGE OF THE BARRIER AND MIDWAY BETWEEN THE BARRIER AND THE SURFACE OF THE SOIL BUT CORRECTED FOR ITS HEIGHT ABOVE THE BARRIER. THIS SHOWS THE EDGE EFFECT. THE SHORT LINE IS THE READINGS OF TENSIOMETERS PLACED OUTSIDE THE BARRIER.
(After Erickson et al, 1968b)

ensure a thickness of one centimetre at least, in order to improve the biological, chemical and physical properties of the sand profile, Egerzegi (1959). In order to ensure good crops, another ameliorative layer must be placed some 15 cm above the first, and after 2 or 3 years even a third layer may be required. The improving layer is formed by spreading the manures on the 55-60 cm wide bottom of an open furrow to the desired depth.

The ability of the improving layers to retain moisture is clearly demonstrated from the results reported by Egerzegi (1958) and given in Table 4.

Table 4 IMPROVED MOISTURE STORAGE FROM SPOT PLACED LAYERS WITH AND WITHOUT VEGETATION

Depth of layer cm	With vegetation			Without vegetation		
	Soil Moisture - % by weight					
	12/5	28/7	18/8	12/5	28/7	18/8
0 - 20	7.4	2.7	1.1	7.9	4.0	3.7
20 - 40	8.9	2.6	1.6	7.7	7.1	6.5
40 - 60	8.3	2.9	1.5			
In the 2nd layer (48 cm)				145.4	125.1	120.2
Between the layers				8.8	7.2	6.9
Above the 1st layer	8.6	3.1	2.4			
In the 1st layer (65 cm)	84.4	62.7	50.8	131.2	128.0	122.1
70 - 80	4.1	2.7	1.2	4.6	4.4	4.3

Adapted from Egerzegi 1958

Furthermore, a better crop (broom-corn) was obtained from the plots improved with compost layers and stratified stable manure, 20 t/ha, compared with 8.2 t/ha from the plots manured in the ordinary way and with 5.4 t/ha from the loose sand.

The application of this improving layer technique on a large scale in Hungary has proved its effectiveness and the lasting utilization of the organic matter as indicated by crop yields shown in Table 5, Egerzegi (1958).

Table 5 EFFECT OF FARMYARD MANURE PLACEMENT AND ITS DURATION ON SORGHUM AND POTATO YIELDS

Treatment \ Crop	Sugar sorghum (t/ha)				Potato (t/ha)		
	Green		Grain	Stalk			
	1953	1954	1955		1953	1954	1955
Untreated sand	8.9	9.4	0.5	5.6	3.5	7.1	4.9
Manured in the top soil	15.5	13.7	1.1	19.5	6.1	7.8	7.5
Single layer improvement	32.4	44.7	2.5	33.4	13.0	16.7	21.9

Adapted from Egerzegi 1958

Reclamation from dense sandy soils by the improving layer technique creates favourable conditions for the root system not only by loosening the soil but also by providing adequate moisture and nutrients because within the substance of the layer and in its environment the nutrient supplying capacity of the soil increases. This effect is also promoted by the biological activity of the densely populated manure layers. In a comparative study on the effect of ploughing and of improving layers on wheat yield and nutrient content of grain, Egerzegi (1964) found that the highest yield and nutrient content of grain were obtained from plots reclaimed with placed layers, Table 6.

Table 6 EFFECT OF PLOUGHING AND IMPROVING LAYERS ON WHEAT YIELD AND NUTRIENT CONTENT OF GRAIN

Treatment	Grain	Straw	N	P	K	Ca
	t/ha		g/m^2			
Ploughed 25 cm	1.29	2.64	2.12	0.88	0.65	1.18
Deep turning	1.35	2.76	2.17	0.96	0.68	1.18
Shallow incorporation of manure	1.75	3.04	2.85	1.20	0.87	1.53
Sand reclaimed with placed layers	2.71	4.29	4.65	1.97	1.33	2.38
L.S.D. 5%	0.24	0.93	0.34	0.22	0.14	0.28

Experiments have been carried out in Egypt by Makled 1/ on reclamation of sandy soils using improving layer techniques. The effects on crop yields as a

1/ Personal communication - F. M. Makled, College of Agriculture, Al-Azher University, Cairo, Arab Republic of Egypt.

result of deep ploughing, surface manuring and improving layers were investigated in Tahrir Province. These results of the study, shown in Table 7, are taken as percentages of those in the nearby Boheira Province which has normal loam to clay loam soils.

Table 7 AVERAGE YIELDS OF WINTER AND SUMMER CROPS EXPRESSED AS A PERCENTAGE OF BOHEIRA PROVINCE YIELDS AS AFFECTED BY IMPROVING TECHNIQUES

Treatments	Winter crops 1962	Summer crops 1962	Winter crops 1963	Relative effects
Control	24	18	22	1.0
Ploughing to 60 cm deep	30	33	34	1.6
Surface manuring (72 m^3/ha)	45	58	54	2.5
Nile sediments layer (1 cm thick) at 50-60-70 cm deep	59	63	67	3.0
Manure layer (72 m^3/ha) at 50-60-70 cm deep	76	80	82	3.9
Impervious layers (asphalt-plastic-canvas-parchment paper) at 60 cm deep + 72 m^3/ha surface manuring	96	95	96	4.7

1/ Winter crops - tomato, lupin, barley, Chiline vetch, horse beans and wheat
Summer crops - cowpea, sesame, groundnuts and green maize.

The data as presented in the above table are self-explanatory and emphasise the effectiveness of the improving layers and the superiority of the impervious layers when coupled with manure application.

Similar studies were also carried out by Sabet et al. (1971) on amelioration of Wadi-El-Natrun sandy soils in Egypt. These results showed significantly the superiority of deep manuring and the carpet-like placement of clay-organic manure.

3.3.3 Surface Mulch

The low water storage capacity of sandy soils entails certain measures to decrease their water losses. Where deep percolation accounts for most of the losses the previously mentioned techniques could be followed depending on the availability and cost of the improving materials. Increasing the storage capacity of dense sandy soils or those with a characteristic hard pan layer can be achieved by vertical mulch (Fairbourn and Gardner, 1972), since water infiltration into the soil can readily proceed at a greater depth than by wetting downward from the soil surface. Water storage can also be improved by reducing evaporation losses through the use of surface mulch.

Of the various techniques which can be applied to decrease soil water evaporation tillage, placement of gravel layers and surface application of crop residue are worth mentioning.

i. Tillage

Disruption of capillary continuity by tillage is the main mechanism which hinders upward movement to the soil surface and its loss by evaporation. The effectiveness of this practice for a given evaporative demand depends on the stage of evaporation (Lemon, 1956) and on the time after wetting at which tillage is performed (Willis and Bond 1971). Tillage is quite often carried out after there has been considerable surface drying by evaporation which reduces the beneficial effects of mulching.

From a laboratory study by Willis and Bond (1971) on evaporation losses from Parshall fine sandy loam soil as affected by depth of simulated tillage (2.5 and 7.5 cm) and time 1, 4, 7 and 18 days) at which tillage was done, certain practical water conservation measures could be deduced. Tillage was found to cause an immediate decrease in soil water evaporation when compared to undisturbed soil, irrespective of time or depth of ploughing. (Fig. 8). However, for tillage to be really effective, it has to be done at an early stage while the evaporation rate is high. In this way, tillage at the earliest possible time would not only reduce evaporation losses by more than 50% but also be effective for more than just three weeks (Fig.9). Since tillage does not eliminate capillary water movement to the soil mulch, increasing the tillage depth to a certain extent would help reduce evaporation losses.

ii. Gravel Layers

Placement of gravel layers on the surface or within the top soil decreases evaporative soil water losses by disrupting the capillary flow. They not only reduce water losses from the soil beneath, but also help the soil above retain more water than uniform soil when water is initially applied to the soil because water does not move through gravel till the soil above has reached saturation.

The effect of gravel layers on water storage, distribution and evaporation was studied by Unger (1971) under laboratory and field conditions where a layer 2.5 cm thick of gravel (3-8mm) was placed on the soil surface or at 5, 15 or 25 cm beneath it. The results for the Amarillo fine sandy loam soil confirmed the beneficial effects of subsurface gravel layers on water storage in the surface soil but at the expense of deeper moisture penetration as shown in Fig. 10. Placing gravel on the surface or at 5 cm below it was more effective in reducing cumulative water losses by evaporation than by placing it at deeper depths, (Fig. 11). It would seem that the fast drying of the top 5 cm of soil created a self-mulch which decreased further water losses.

Since a gravel layer on or below the soil surface creates a problem when cultivating the soil, this method is best suited for trees where minimum soil disturbance is necessary. The gravel should be placed in a circle around the tree trunk and the use of herbicides will eliminate the need for ploughing the area mulched with gravel.

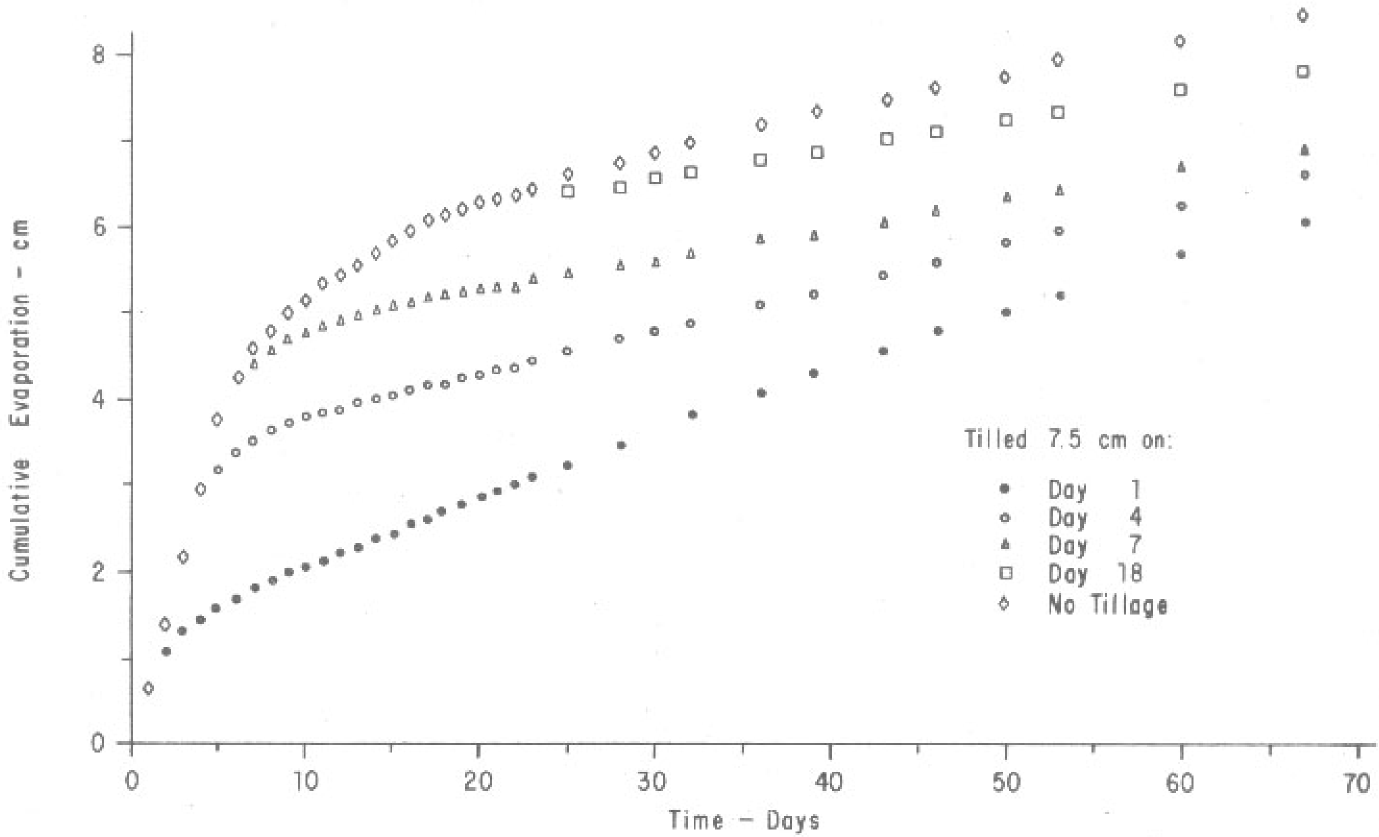

Fig. 8 CUMULATIVE SOIL WATER EVAPORATION WITH TIME AS AFFECTED BY 7.5 cm DEPTH TILLAGE ON VARIOUS DAYS FROM INITIAL WETTING (After Willis and Bond, 1971)

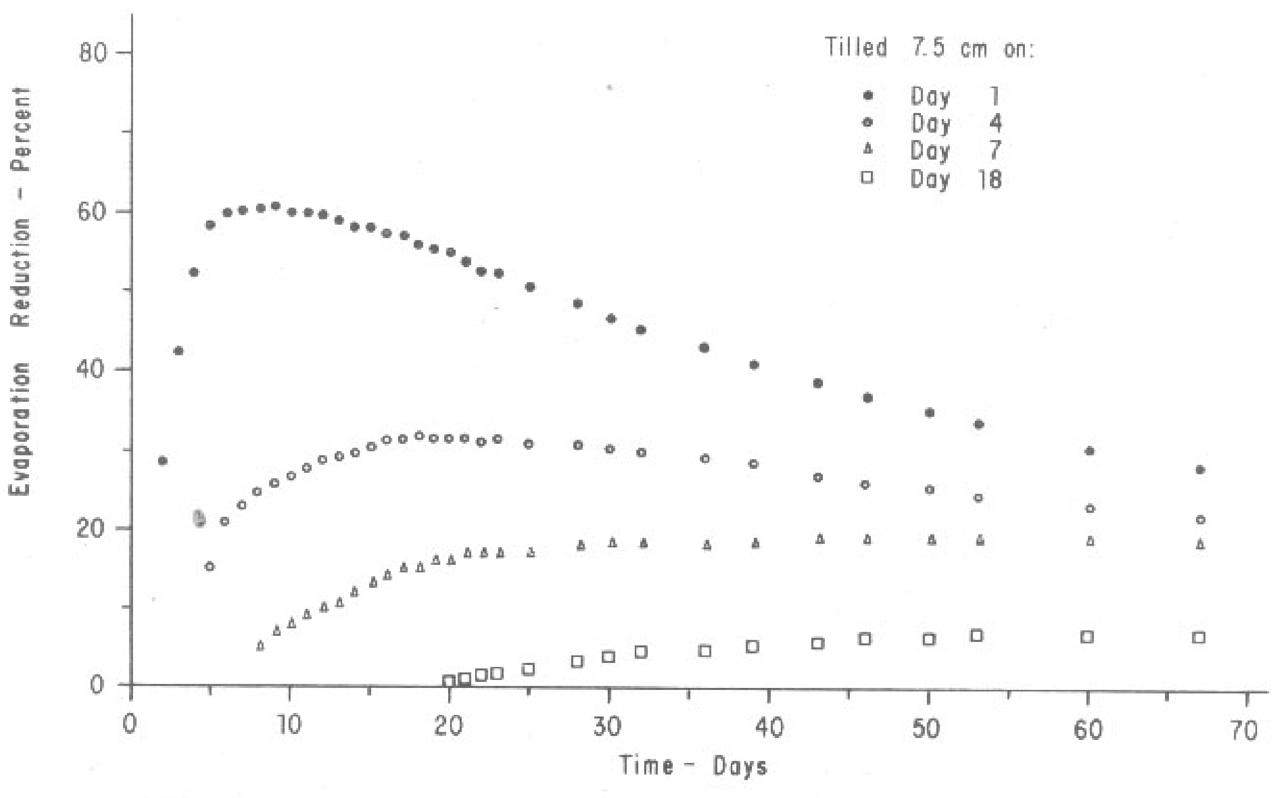

Fig. 9 REDUCTION IN SOIL WATER EVAPORATION WITH TIME AS INFLUENCED BY 7.5 cm DEPTH TILLAGE ON VARIOUS DAYS FROM INITIAL WETTING. (After Willis and Bond, 1971)

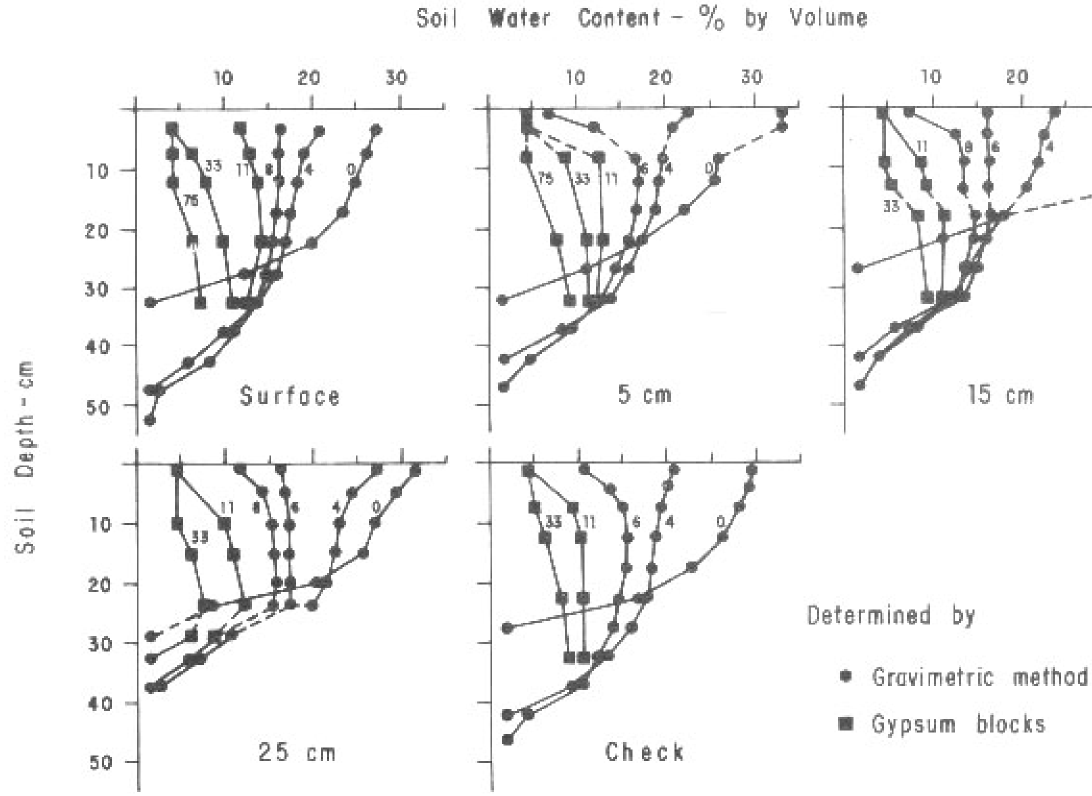

Fig. 10 DISTRIBUTION OF WATER IN LABORATORY COLUMNS OF AMARILLO FINE SANDY LOAM AS INFLUENCED BY DEPTH OF GRAVEL LAYER PLACEMENT AND TIME. NUMBERS AT CURVES INDICATE TIME IN DAYS AFTER ADDING WATER TO THE SOIL. DASHED LINES INDICATE LOCATION OF GRAVEL LAYERS. EVAPORATION WAS PREVENTED UNTIL DAY 4. (After Unger, 1971)

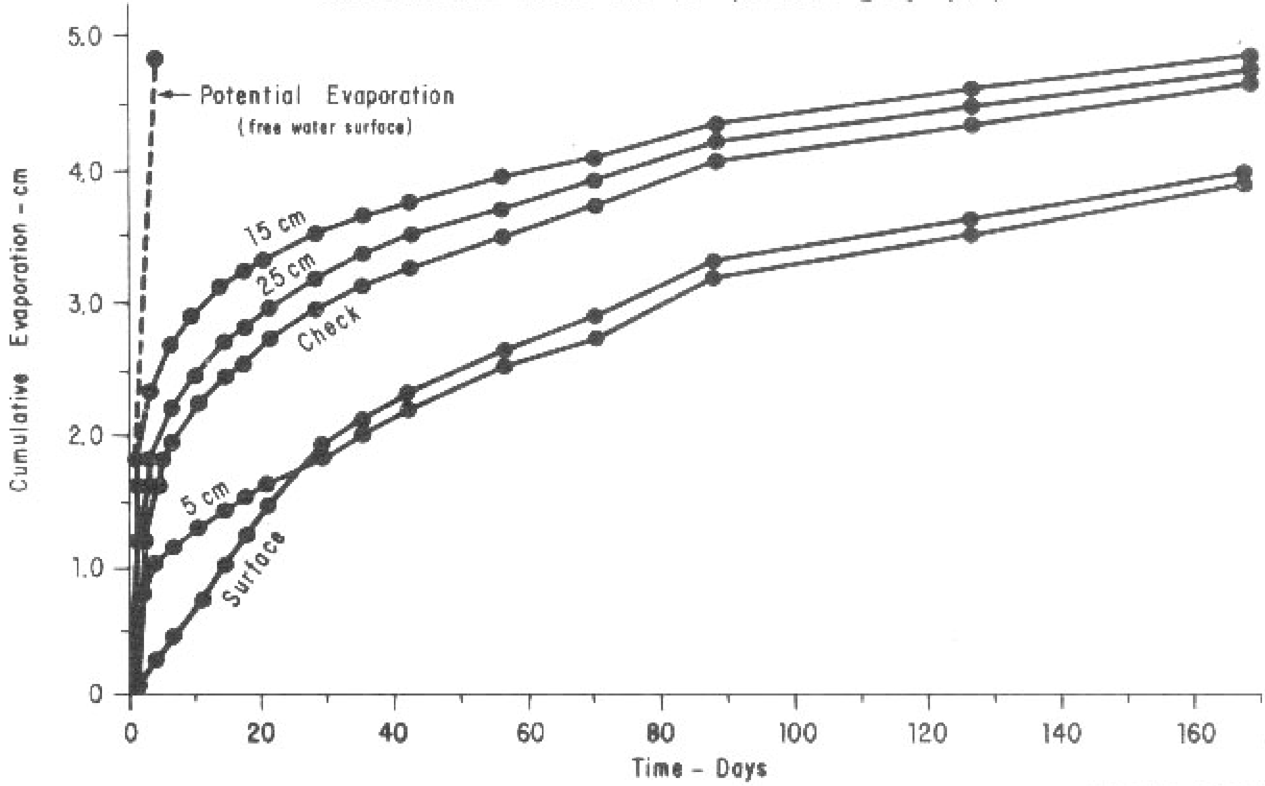

Fig. 11 CUMULATIVE EVAPORATION FROM LABORATORY COLUMNS OF AMARILLO FINE SANDY LOAM AS INFLUENCED BY DEPTH OF GRAVEL LAYER PLACEMENT AND TIME. POTENTIAL EVAPORATION WAS APPROXIMATELY 1.2 cm/DAY. (After Unger, 1971)

iii. Crop Residue

Crop residue maintained or spread over the soil can serve as a mulch surface. The effectiveness of this practice depends on the rate of application. Under laboratory controlled conditions, Bond and Willis (1971) found that unweathered bright wheat straw (1.3 cm long) when used as surface residue decreased evaporation losses from Parshall fine sandy loam soil, Table 8. For a given evaporation potential (EP) increasing the residue rate to about 18 t/ha generally decreased the total evaporation losses by about 300% and, similarly, within any one residue rate for either shaded (low EP) or unshaded (high EP) treatments total evaporation after 60 days generally increased as EP increased.

The results of the study also indicated that surface residue influenced soil temperature during first and third stage drying and decreased the range between maximum and minimum temperature and gave a generally cooler soil under high radiation conditions, Fig. 12 and 13 respectively. This is another favourable effect of using the crop residue technique under arid and semi-arid conditions where high temperatures aggravate the adverse effects of low moisture supply.

Table 8 TOTAL SOIL WATER EVAPORATION AFTER 60 DAYS DRYING AS INFLUENCED BY SURFACE RESIDUE RATE AND EVAPORATION POTENTIAL

Straw rate	Evaporation potential, cm/day					
	Shaded			Unshaded		
	0.47	0.56	0.65	0.70	1.11	1.34
kg/ha	Soil water evaporation, cm					
0	6.71	7.80	7.86	6.65	7.70	7.96
560	6.60	7.60	7.97	6.60	7.77	7.80
1 120	6.52	7.42	7.50	6.55	8.12	7.35
2 240	6.30	7.30	7.12	6.55	7.70	7.82
4 480	5.80	6.73	7.22	6.35	7.25	7.55
8 960	4.07	4.80	5.60	4.98	6.42	6.35
17 920	2.20	2.43	2.83	2.43	3.20	2.95

In a comprehensive study on conservation of sandy soils with a surface mulch, Fryrear and Koshi (1971) showed from their own results and from previous research by other scientists that a mulch surface cover on sandy soils will reduce wind erosion, Fig. 14, increase soil moisture storage, Fig. 15, improve dry aggregate stability and increase crop yields. The concept of mulch coefficient which they introduced (100% soil cover equals a mulch coefficient of 1.0) is of practical importance since it is the residue roughness and the amount of soil surface covered by the residue

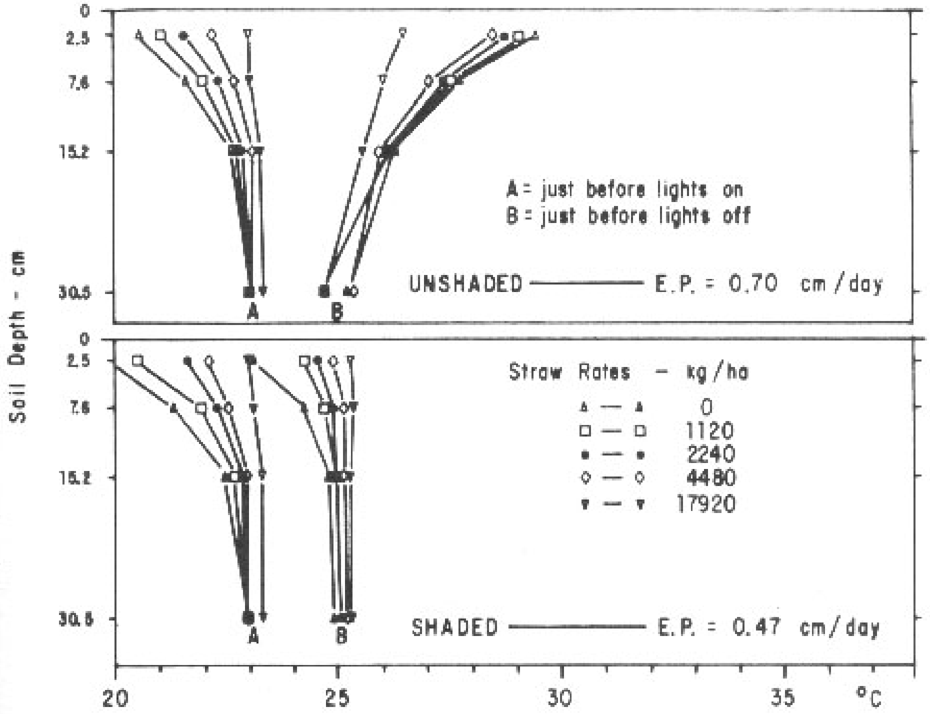

FIG. 12

MAXIMUM (JUST BEFORE LIGHTS OFF) AND MINIMUM (JUST BEFORE LIGHTS ON) SOIL TEMPERATURES WITH DEPTH IN SHADED AND UNSHADED COLUMNS DURING FIRST STAGE DRYING AS INFLUENCED BY SURFACE RESIDUE RATE. DATA ARE AVERAGES OF DAY 1 THROUGH 5 OF THE DRYING CYCLE. (After Bond and Willis, 1971)

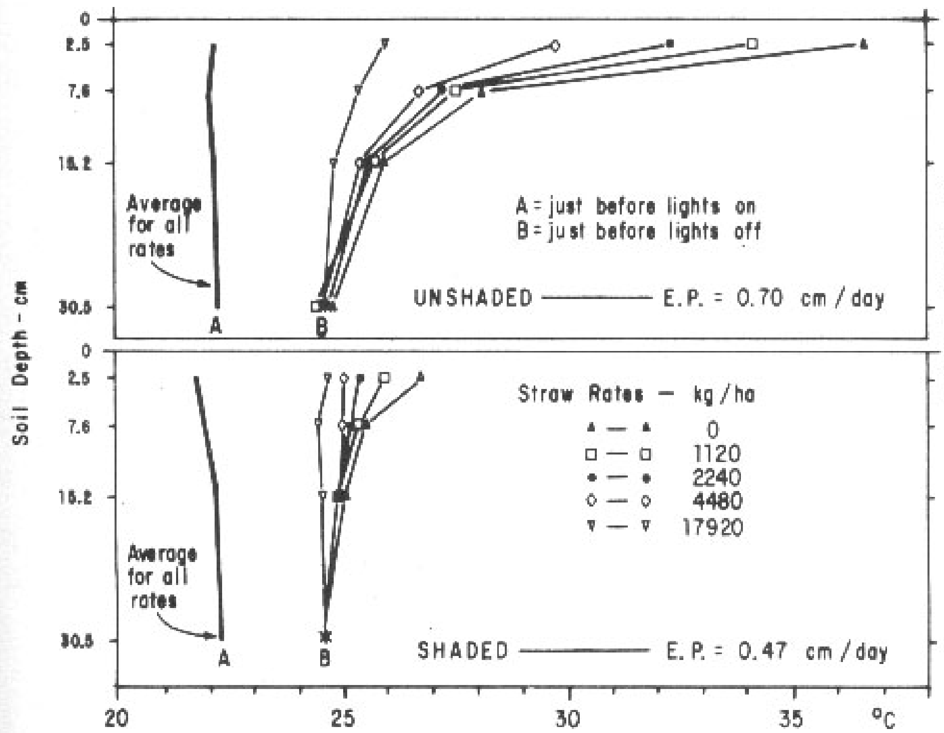

FIG. 13

SAME AS FIG. 12 EXCEPT TEMPERATURES WERE MEASURED DURING THIRD STAGE DRYING OF ALL BUT THE 17,920 kg/ha RESIDUE RATE. DATA ARE AVERAGES OF DAY 55, 57 and 59 OF THE DRYING CYCLE. (After Bond and Willis, 1971).

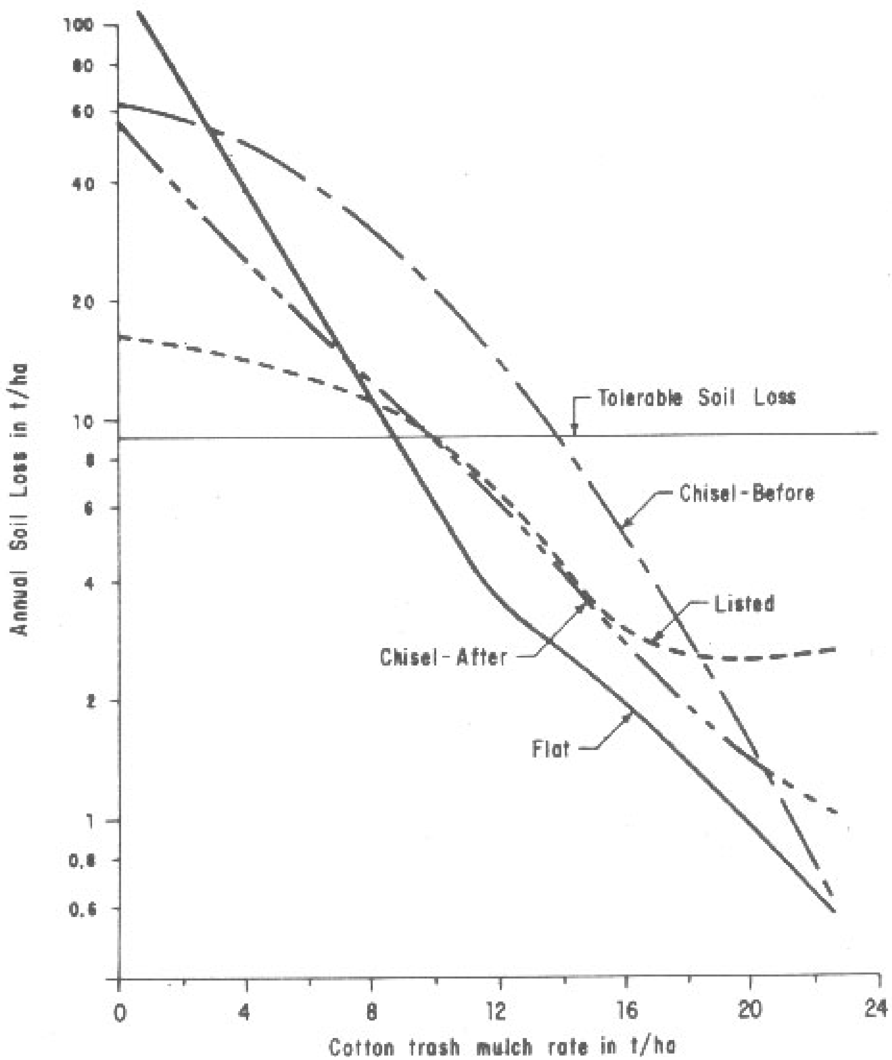

Fig. 14 RELATION BETWEEN ANNUAL SOIL LOSS AND COTTON GIN TRASH MULCH RATE (FRYREAR AND ARMBRUST, 1969)
(After Fryrear and Koshi, 1971)

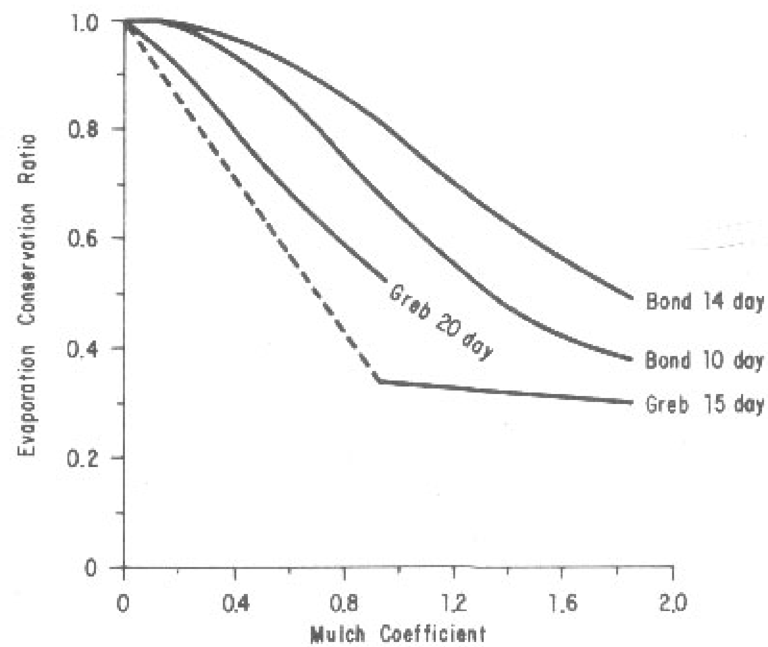

Fig. 15 ACCUMULATIVE EVAPORATION AS INFLUENCED BY A SURFACE MULCH ON A FINE SANDY LOAM SOIL (BOND AND WILLIS, 1969) OR ON A SILT LOAM SOIL (GREB, 1966). EVAPORATION CONSERVATION RATIO IS THE ACCUMULATIVE EVAPORATION LOSS FROM A MULCHED SOIL DIVIDED BY THE ACCUMULATIVE EVAPORATION LOSS FROM A BARE SOIL. MULCH COEFFICIENT IS THE WEIGHT OF SURFACE MULCH DIVIDED BY THE MULCH WEIGHT REQUIRED FOR 100 PERCENT SOIL COVER.
(After Fryrear and Koshi 1971)

that determines the effectiveness of this technique, Fig. 16. From the study they have shown that for a loamy fine sand wind erosion can be reduced to a tolerable level with a mulch coefficient of 0.6 to 0.8, Fig. 17. Crop yields (cotton and wheat) tend to increase with an increase in the mulch coefficient up to 1.0-1.2. To reduce effectively evaporation a mulch coefficient of at least one is required, above which a 34% linear increase in water storage can be obtained with a unit increase in mulch coefficient.

The effectiveness of the mulch coefficient needs to be tested under various climatic, soil and crop conditions as well as for different materials and methods of application on the surface or mixing with the top soil.

3.4 EROSION CONTROL

Beside the previously described techniques, which are directly aimed at improving water and nutrient storage of sandy soils and reducing evaporation losses from them, there are other fundamental practices such as fertilization, irrigation and erosion control which are essential for the successful agricultural development of these land resources. It is not intended to cover fertilization and irrigation aspects in this paper since they have been discussed respectively by Balba (1973) and Baudelaire (1973) elsewhere.

3.4.1 Cropping Management Practices for Erosion Control

Protection of agricultural sandy soils against erosion hazards not only saves them from being degraded but also prevents them from being a menace to adjacent productive lands. The susceptibility of sandy soils to erosion is attributed to their textural and structural characteristics, i.e. dominance of the sand size fraction, the cohesionless nature of the sand particles and the low stability of any formed clods. Under arid and semi-arid climates, sandy soils are more susceptible to wind than to water erosion. However, where the rate of precipitation exceeds that of infiltration sand becomes easily detached and washes away readily under high velocity runoff water.

It is possible to control erosion through certain cropping practices, such as surface mulch, which has already been discussed. Other practices which could be adopted include minimum tillage, planting of cover crops, strip cropping, crop rotations, and control of grazing and dunes, (FAO, 1965 and 1969).

Under minimum tillage, operations for seedbed preparation are limited as much as possible and can even be combined with seeding in one operation to minimize soil disturbance. The selection of tillage implements is important and, generally speaking, the use of mouldboard or disk plough should be discouraged in wind erosion areas, while the use of lister or chisel ploughs is more desirable. For tillage to be effective, it must be performed perpendicular to the prevailing winds and at a suitable moisture content so that a rough surface is created and clods are not pulverized.

Keeping the surface covered with crops on erodible soils, especially during the critical erosion periods, is an effective measure. Subject to the availability of water, solid planting or strip cropping can be used. Permanent vegetative covers such as alfalfa and rye grass, or short duration crops such as sorghum and barley, can be planted for fodder supply and soil protection. In sandy areas where fruit trees are planted with wide spacing and clean tillage is practised for moisture conservation, it is advisable to plant narrow strips of small grains for soil protection. Similarly, interplanted strips of cover crops provided protection for tender young seedlings.

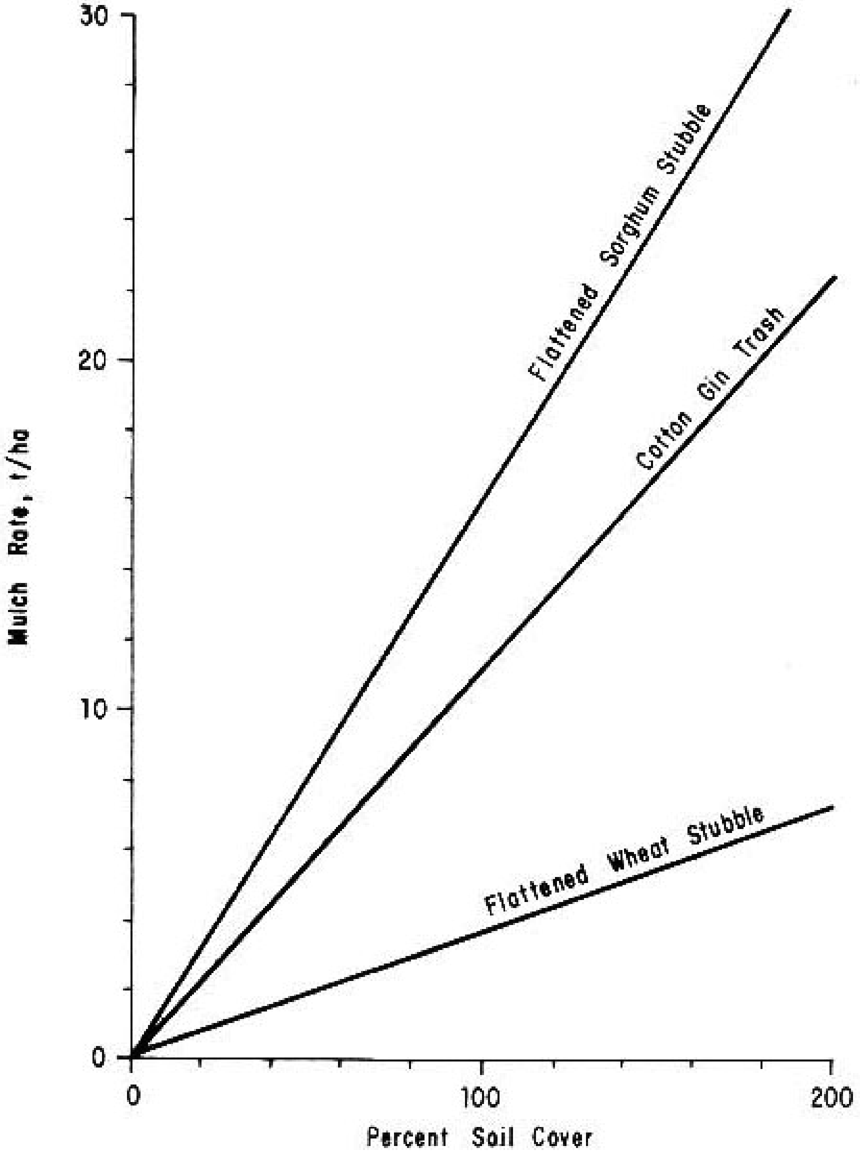

Fig. 16 PERCENT OF SOIL SURFACE COVERED WITH SORGHUM (GREB, 1967, SIDDOWAY ET AL., 1965), COTTON GIN TRASH, AND WHEAT MULCHES (GREB 1967) (After Fryrear and Koshi, 1971)

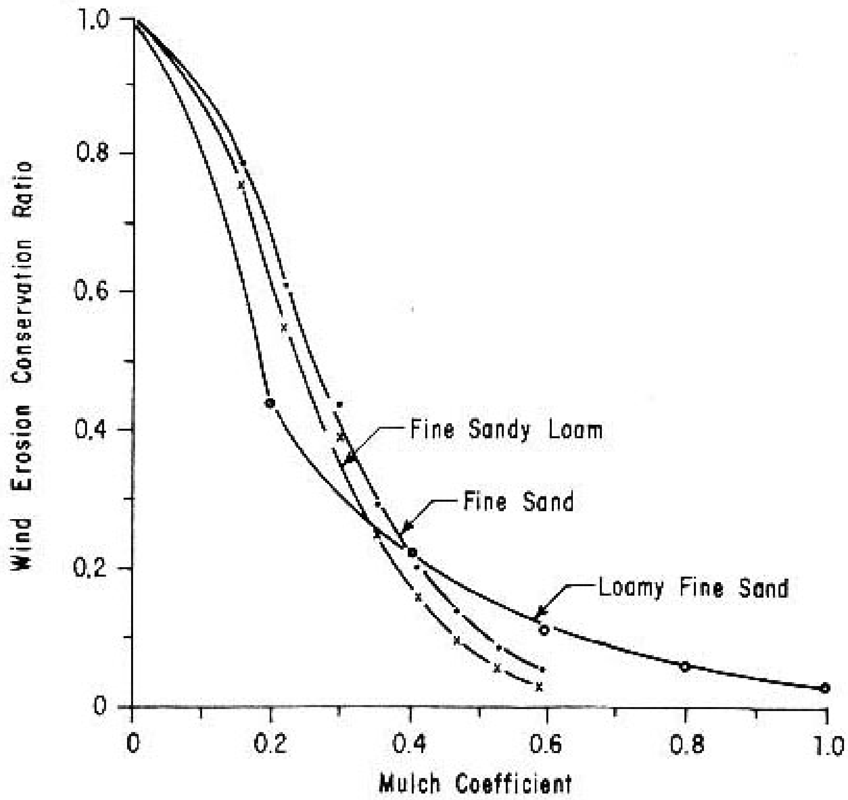

Fig. 17 INFLUENCE OF A SURFACE MULCH ON THE COMPUTED ANNUAL SOIL LOSS FROM WIND EROSION FROM A TIVOLI FINE SAND OR A DALHART FINE SANDY LOAM USING THE WIND EROSION EQUATION (WOODRUFF AND SIDDOWAY, 1965) AND AS MEASURED WITH A WIND TUNNEL FROM AN AMARILLO LOAMY FINE SAND. WIND EROSION CONSERVATION RATIO IS THE WIND EROSION LOSS FOR A MULCHED SOIL DIVIDED BY THE EROSION LOSS FOR A BARE SOIL. MULCH COEFFICIENT IS THE WEIGHT OF SURFACE MULCH DIVIDED BY THE MULCH WEIGHT REQUIRED FOR 100 PERCENT SOIL COVER. (After Fryrear and Koshi, 1971)

Adherence to a certain crop rotation on sandy soils should be evaluated on the basis of its economic net return, soil improvement capabilities and conservation benefits. An example is the growing of high value vegetable crops in sequence with legumes to improve the soil fertility and to maintain crop cover. Alternating shallow rooted crops with deep rooted ones would make stored water and nutrients more available to the latter and increase the organic content and biological activity within the soil. If a fallow or rest period in the cropping sequence is necessary, then measures must be taken for erosion control; in this respect, surface mulch by tillage or the leaving of crop residues on the surface could be practised. Should the case arise that erosion of a sandy soil becomes difficult to control, it should be permanently revegetated with grass, trees or shrubs.

Overgrazing on sandy soils must be avoided and efforts should be made to improve the productivity of pastures and range. The introduction of rotational grazing would help to combat this hazard and it might be better not to permit grazing but to feed animals cut fodder on feeding lots.

Windbreaks and shelterbelts can effectively reduce wind velocity by 60 to 80% near and in the lee of the belt, and about 20% at distances equal to 20 times the height of the belt. At about 30 to 40 belt heights to leeward they lose their effect. The orientation, shape and density or porosity of the shelterbelts should be carefully considered for the effectiveness of this method. The competition for water and nutrients and the shading effects on crops 15 to 30 m from the belt are limiting factors.

3.4.2 Stabilization of Sand Dunes

Dune encroachment is a menace which not only affects the agricultural potentialities of arable lands but also causes severe losses to human habitation, communication, transportation and manpower productivity. It is the result of climatic, soil and human factors such as aridity, high wind velocity, physical characteristics of the sand, overgrazing and burning of vegetation. Effective control of the climatic factors is beyond man's ability, but he could manage to modify and adjust the physical characteristics of the soil as well as his own role to halt or reduce the adverse effects of dune encroachment and sand drift on agricultural land. In this respect, stabilization of dunes and drift areas is closely related to the subject of this paper.

Keeping vegetative cover on sandy dunes is a sure measure against encroachment. But to enable either natural or planted vegetation to become established, sand movement must be prevented and, consequently, sand dunes stabilized. Of the various techniques which could be used, the following ones warrant some mention.

i. Use of Dry Vegetation as Vertical Hedges

In this conventional method, dry vegetation (*Imperata cylindrica*, *Aristide pungens*, *Artemisia herba alba*, *Retama raetam*) or palm fronds are buried in, preferably, moist trenches to a depth of 15 cm, leaving about 35 cm extended above the surface. The area enclosed by a checkerboard pattern of trenches varies with the slope and size of the sand particles, that is: about 5 m^2 on steep slopes and coarse sand compared to about 16 m^2 on gentle slopes and fine sand. Although this technique is promising, the availability of plant material and manual power are the limiting factors.

ii. Use of Artificial Surface Sealants

Petroleum, synthetic rubber, chemicals and water soluble plastics are examples of new products which have recently been used in dune and drift sand stabilization as a result of advancement in research and technology. In a recent review by the U.S. Agency for International Development (1972) the characteristics and applicability of different surface sealers were briefly reviewed. A model dune coated with heavy oil was reported to resist wind velocities higher than 70 mph (112 kmph), which is four times more than the control. Cited experiments on the application of free flowing water emulsion of synthetic rubber latex and oil showed considerable success in binding drifting sand. Similarly, spraying with newly developed synthetic resins was found to form a consolidated surface for a period sufficient to establish vegetative cover.

The use of chemicals as soil conditioners has been discussed by De Boodt (1972). An emulsion with strong acid groups (e.g. HSO_3 on the micelles) in an experiment increased the available water of a sandy soil four times and its cation exchange capacity more then ten times. Hydrophobic emulsions were found to be useful for stabilizing aggregates and conserving moisture. Spraying bitumen emulsion on a moist soil leads to the migration of the micelles to the contact points between particles and upon subsequent coagulation of the active material when it dries the soil particles become closer and form stable aggregates.

A large scale programme of sand dune stabilization is going on in the Libyan Arab Republic (L.A.R. 1973). The most promising one on continental type dunes is the hot crude oil spray method. Neither the use of chemicals sprayed from the air nor the use of a sprayed emulsion of synthetic rubber latex, mineral oil and water proved to be as successful as the use of petroleum oil.

It should be understood that afforestation with selected trees and shrubs is a complementary measure that ought to follow stabilization of dunes.

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III.4 QUALITY OF WATER IN RELATION TO IRRIGATING SANDY SOILS

by

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SUMMARY

Irrigation water is becoming more and more scarce to meet the needs of agricultural expansion in the region and as a result the intensity of using lower quality water is increasing. Such water should not be deemed unfit for irrigation without careful consideration being given to all facts concerned. This paper briefly discusses these factors and cites some examples where saline water is being used in the region.

Criteria such as the total salt concentration, sodium percentage, residual sodium carbonate and boron are used in setting standards of water quality for irrigation. Due to the influence of soil, climate, crop and water management practices there is no simple water classification scheme applicable in all cases. On permeable soils such as the sandy ones and where rainfall distribution and intensity prevent salt accumulation, water of lower qualities could be tolerated.

Yields and quality of crops are usually impaired by salts from irrigation water. Certain ions have specific effects when they are abundant and others are toxic even when they are found in minute concentrations. Plants vary widely in their tolerance to salinity, but most of them are more sensitive during germination and emergence than in the later stages of growth. It is through proper soil, water and cultural practices that the harmful effects of salty water can be reduced. The paper cites the results of work carried out in Tunisia as an example.

Salinity can be controlled by providing the required leaching and an adequate drainage system. The leaching requirement, as affected by the kind of soil and the salt content of irrigation water, is low in the case of sandy soils and increases rapidly with the salinity of the water. The relation between leaching and drainage requirements must be observed for proper drainage design and economic use of water. The efficiency and timing of leaching are discussed. The use of salty water in sprinkler and drip irrigation methods, which are more suitable than the other methods for irrigating sandy soils, has proved to be successful when properly managed. Shortage as well as over supply of irrigation water may cause salinization as a result of thin spreading of irrigation water in the former case and waterlogging in the latter.

Examples are given of the use of low quality groundwater to irrigate sandy soils in some countries of the region. Salt tolerant cereal crops, vegetables, alfalfa and date palms are being irrigated with water of 2 000 ppm or more in Bahrain, 2 400 to 6 000 ppm in Kuwait and 15 000 ppm in the Tagora area of the Libyan coastal plain. Soil reclamation and development projects in Saudi Arabia depend on groundwater of about 2 500 ppm for crop production. In the United Arab Emirates, forest plantations have been established on deep sandy soils, using drip irrigation with very saline groundwater of up to 10 000 ppm.

4.1 INTRODUCTION

In almost all countries in the Near East region, the provision of irrigation water is one of the most important factors for expansion of agricultural production. In some parts, with all available good quality water already being used, and with irrigation expansion approaching saturation point, the need to use saline waters is increasing. A study of the safe limits of salts in irrigation water and of the conditions under which saline water may best be used for irrigation is essential in order to utilize intelligently the resources of the arid region.

Saline irrigation water should not be deemed unfit for irrigation without careful consideration of all factors concerned. Permanent irrigated agriculture can be maintained using rather salty waters with proper management.

The concentration and composition of dissolved constituents in a water determine its suitability for irrigation use. Apart from the quality of irrigation water itself, the following factors are also involved: type of soil, climate, prevailing drainage conditions, methods of irrigation, land development and land preparation for irrigation and types of crop grown.

This paper discusses briefly the above factors and their interrelationship. Some aspects of the use of different levels of saline water in irrigating sandy soil in some countries of the region are also included.

4.2 STANDARDS FOR IRRIGATION WATER

Waters with conductivity below 750 micromhos/cm are satisfactory for irrigation insofar as salt content is concerned, although salt sensitive crops may be adversely affected by the use of irrigation water having conductivity values in the range of 250 to 750 micromhos/cm. Waters in the range of 750 to 2 250 micromhos/cm are widely used, and satisfactory crop growth is obtained under good management and favourable drainage conditions, but saline conditions will develop if leaching and drainage are inadequate. Use of water with conductivity values above 2 250 micromhos/cm is the exception and very few instances can be cited where such waters have been used successfully. Highly permeable soils, such as sandy ones, facilitate the task of obtaining a favourable salt balance in the soil, even with relatively saline irrigation water.

An irrigation water with a high sodium percentage $\frac{100\ Na}{Na + K + Ca + Mg}$

will, after a time, cause a soil with a large proportion of exchangeable sodium. The higher the cation exchange capacity of the soil, the greater the risk of alkalization and hence the deterioration of soil structure. It should be pointed out, however, that even on sandy soils with good drainage, waters with 85 percent sodium (expressed as a percentage of the total cations) or higher, are likely to make soils impermeable after prolonged use. With a higher total salt content, there is a flocculating action that tends to counterbalance the poor physical condition caused by a high sodium concentration in the water.

Residual sodium carbonate is another criterion for water quality and it is equal to the total carbonate and bicarbonate minus the total calcium and magnesium ions in milliequivalents per litre. Waters with residual sodium carbonates of 2.5 meq/l or more are considered unsuitable for irrigation, while those of 1.25 to 2.5 meq/l are classified as marginal and below 1.25 are considered as safe.

Boron is essential to plant growth and work on sand cultures has shown that many plants make normal growth with traces of boron (0.03 to 0.04 ppm) but that injury often occurs in cultures containing 1 ppm. Some crops, such as beans, are very sensitive to an excess of boron but others, like sugarbeet, will tolerate large quantities. However, water containing more than 2 ppm will usually cause trouble after a time.

The amount, intensity and distribution of rainfall plays an important role in the use of water for irrigation purposes. Heavy and intensive rain during winter reduces the amount of leaching water required during the irrigation season. This is very important for areas where the quality of available irrigation water is marginal and/or of short supply. Crops and cultural practices can be selected properly for effective utilization of precipitation stored as soil water. On the other hand, some crops become more sensitive to a given level of salinity during hot, dry weather than during cooler, more humid weather.

As mentioned before, because soil, crop, climate, drainage and soil management all influence the suitability of water for irrigation, no simple water classification scheme is applicable for all cases. Some writers have indicated that waters of 70% sodium are unsuitable under most conditions, yet on sandy soils in the Coachella Valley, California, waters of more than 80% sodium are used and the farmers are making a profit. Electrical conductivity of 2 250 micromhos/cm is considered as the upper limit for good production on most soils; however, good yields of alfalfa and some winter vegetables are obtained in the Arabian Gulf States with waters of a salinity content double or even triple the above level.

4.3 REACTION OF CROPS TO SALINITY

4.3.1 Effect on Yield and Quality of Crops

Studies on the effect of several moisture treatments and salinity levels indicate that plant growth is a function of total soil moisture stress, regardless of whether this stress arises primarily from salinity or moisture tension.

Salts generally decrease the yield and impair the quality of crops. Yields of tomatoes and pepper are reduced not only because of fewer fruits per plant, but also because of a marked decrease in fruit size. Conversely, salinity may increase the sugar content of some vegetables, especially carrots, but this gain in quality is more than offset by lowered yields. Cabbages from salty fields are generally more solid than those from non-saline fields, but again, lowered yields offset this favourable effect. Chloride fertilizers are generally believed to make potatoes less starchy and more watery; but on saline soils, high in chloride, the decreased water availability counteracts this effect so that the tubers produced are of normal starch content. Salinity accelerates the maturation of potatoes, although the tubers are smaller. In contrast, salinity delays the flowering and, therefore, the maturation of sweet corn (maize).

4.3.2 Water Composition and Plant Toxicity (Specific Ion Effects)

The quality of the irrigation water affects the mineral composition of the plants and this process of mineral uptake is intensified when water is applied by sprinkling, which is widely used for irrigating sandy soils. This can lead to a serious upset in the metabolism of the plant and to its intoxication which, no doubt, explains some failures observed in the case of sprinkling. It is also known that some ions are more toxic than others to certain crops. Excessive chloride ions are toxic to peaches and other stone fruits, pecan and avocados. Sulphate ions cause disturbances to the optimum cationic balance within the plant, as they limit the uptake of calcium and increase that of sodium and potassium.

Boron, although it is required for the nutrition of the plants in trace quantities, is toxic even at low concentrations (2 ppm or more). High concentrations of sodium not only cause adverse effects on soil structure and related properties, but also unbalanced uptake of nutrients.

4.3.3 Minimizing the Effect of Salinity

Most plants are more sensitive to salinity during the germination and emergence stage than in later stages of growth. Some crop species which are very salt tolerant during later stages of growth may be quite sensitive to salinity during germination, like sugarbeet.

Under field conditions, it is possible by modification of planting practices to minimize the tendency of salt to accumulate around the seeds and to improve the stand of crops that are sensitive to salt during germination. Planting on the side of the ridge, but well below the water line in the furrows, is one method to adopt. In Kuwait, since 1953 they have been producing vegetables rather successfully using brackish water with a salt content of 2 500 ppm but on deep, good permeable sandy soils. However, their practice is to produce the seedlings of vegetables, such as tomatoes, cauliflowers, cabbages, lettuce, beetroot, cucumbers, eggplants and pepper in pots made of organic material (jiffy pots) and to use sweet water (salt content less than 1 000 ppm). After 3 to 4 weeks and at 10 to 15 cm high, these seedlings are planted with the pots in the field. After that, they are irrigated with the brackish water (content mentioned above) until the crop is harvested.

4.3.4 Tolerance of Crops to Salinity

The U.S. Salinity Laboratory at Riverside, California, classified crops in three categories according to their tolerance to salinity: high, medium and low.

Comprehensive research work was carried out in Tunisia on irrigation with saline water (1962-1969). Various crops were grown from sowing to harvesting, utilizing four different water qualities (from 200 ppm to 4 000 ppm). Owing to the similarity of soil and climatic conditions between Tunisia and other north African countries, it is important to present the general conclusions of this work, which are that:

i. An agronomist can utilize the saline water available for irrigation in Tunisia, but must take greater precautions and accept lower yields than in normal cases. Higher salinity of the irrigation water results in a decrease in the yield. Salinity as it occurs in the irrigated areas of Tunisia is a surmountable barrier, but one cannot totally eliminate its unfavourable effect upon the vegetation. Compared to normal conditions, plants are more sensitive to suffocation, even temporarily, more frail during their critical periods and more exposed to lack of moisture supply during extreme weather conditions. Good preparation of the soil makes emergence less hazardous; but it should be realized that this is always a difficult stage. The salinity of the irrigation water affects mainly the summer crops, whereas the winter crops are strongly influenced by rainfall and the salinity of the soil in autumn.

ii. The effect of the quality of irrigation water on several agricultural crops under Tunisian conditions are now known; they can be summarized as follows:

a. The quality of irrigation water has little influence on the yield of alfalfa as long as salinity stays below 4 000 ppm.

b. Fodder sorghum seems moderately salt tolerant. The decrease in yield as well as in the productivity per cubic metre of water was approximately 40% for an increase from 200 to 3 500 ppm in salinity.

c. In the case of maize, a yield decrease of 40 to 50% occurred when water salinity increased from 200 to 3 500 ppm.

d. With 300 mm of winter rainfall, the water salinity (3 000 ppm) had very little effect on ryegrass.

e. Berseem was found to be very sensitive to the quality of irrigation water. With the climate of Tunisia (450 mm of rainfall), the yield decrease becomes serious as soon as the water salinity exceeds 3 000 ppm. Given a rainfall of 250 to 300 mm, the salinity should not exceed 2 500 ppm, especially if it is necessary to irrigate after sowing.

f. With regard to barley, the quality of the irrigation water does not seem to have a pronounced effect on the yield as long as the salinity does not exceed 4 000 ppm.

g. Summer tomatoes appear to be sensitive to the quality of irrigation water. The use of saline water causes blossom end rot which diminishes the quantity of marketable fruit. The yield decrease was from 50 to 70% with an increase in salinity from 200 to 3 400 ppm. The wastage from blossom end rot decreased with temperature.

h. Broad beans seemed moderately salt tolerant. The yield decrease was 30 to 40% for a rise in irrigation water salinity from 200 to 3 200 ppm.

i. Early asparagus seemed to be very salt tolerant. The yield obtained (4 to 8 tons/ha) where the salinity of the irrigation water was 6 500 ppm was about the same as in areas irrigated with fresh water.

4.4 CONTROL OF SALINITY AND WATERLOGGING

4.4.1 Leaching Requirements

The amount of percolation required (or leaching requirement) which is governed by the salinity of irrigation water, evapotranspiration, local rainfall and the permissible level of salts in the soil solution, which is determined by the kinds of crops grown and the soil type, may be calculated by the following formula:

$$P = (ET - R) \frac{Ci}{fCsm - Ci}$$

where: P = Percolation or leaching requirement

ET = Evapotranspiration

R = Rainfall

Ci = Salinity of irrigation water

Csm = Salinity of soil solution at field capacity

f = Leaching efficiency. It denotes the ratio between the salt concentration of the water draining from a soil layer and the salt concentration of the soil solution in that layer. This coefficient varies with soil texture and is taken to be about 0.4 for heavy soils, 0.6 for medium textured and 0.8 for sandy soils.

The data in Table 1 show the leaching requirement for different levels of soil salinity. The salinity of irrigation water is assumed to be 0.5 mmhos/cm and that of drainage water (Csm) twice that of the soil saturation extract (Cex), i.e. Csm = 2 Cex.

Table 1 LEACHING REQUIREMENT (P) AS % OF THE NET IRRIGATION REQUIREMENT (ET - R)

Leaching Efficiency (f)	Salinity (mmhos/cm) of the Soil Saturation Extract (Cex)			
	2	4	6	8
0.4 (for heavy clay soils)	45	19	12	8.4
0.6 (for medium loamy soils)	26	12	7	5.4
0.8 (for light sandy soils)	19	8	5.5	4.0

From Table 1 it can be noted that the leaching requirement increased sharply when the equilibrium of the soil salt content was set lower. It can also be observed from the table that the leaching requirement varies with the kind of soils and that it is low in the case of sandy soils as compared to heavier soils.

The effect of the quality of irrigation water on the leaching requirement is shown in Table 2, assuming a sandy soil with a leaching efficiency (f) of 0.80 and that the salinity of the drainage water is twice that of the soil saturation extract.

From Table 2 it will be seen that the leaching requirement increases rapidly with an increase in the salt content of the irrigation water. Theoretically speaking, certain levels of salinity could be obtained in the soil to suit different crops using relatively high saline irrigation water, provided that the water could flow through the soil without obstruction and that the natural drainage conditions and/or artificial drainage systems were capable of draining away the necessary leaching requirements. It is obvious that the level of salinity which could be maintained in the soil would always be higher than the salinity level in the irrigation water if no leaching was provided by rainfall.

Table 2 ANNUAL LEACHING REQUIREMENT (P)
AS % OF THE NET IRRIGATION REQUIREMENT (ET - R)

Salinity of Irrigation Water mmhos/cm	Salinity (mmhos/cm) of the Soil Saturation Extract (Cex)					
	2	4	6	8	10	12
0.3	19	8	6	4	3	2
1.0	45	19	10	9	7	6
2.0	167	45	26	19	14	12
3.0	1 500	88	46	31	23	19
4.0	N.A. 1/	167	71	45	33	26
5.0	N.A.	357	109	64	45	29
7.0	N.A.	N.A.	270	120	78	58
10.0	N.A.	N.A.	N.A.	360	167	109

1/ N.A. = Not attainable.

4.4.2 Drainage Requirements

According to general experience, about 30-60% of the water applied to the field is usually lost, resulting in an irrigation efficiency varying from 70-40%. Hence field drainage must be able to discharge these losses if waterlogging is to be avoided. If the leaching requirement for salinity control proves to be less than the normal irrigation losses, then the latter and not the former should be used in calculating the required field drainage system. Seepage from outside, if it exists, should be added to this.

In cases where irrigation water of high salinity is used, the leaching requirement for salt balance will be much higher than the normal field irrigation losses. In such circumstances, drainage facilities should be able to handle the leaching requirement plus seepage from outside, if any. The Qatif Oasis Project in north-east Saudi Arabia could be mentioned as an example of this. The average salinity of irrigation water is about 3.5 mmhos/cm and with the assumption of a salt balance at a level of salinity in the drainage water at 5.5 mmhos/cm, the leaching requirement will amount to about 60% of the net irrigation requirement, i.e. the consumptive use of the crops. The estimated consumptive use during the peak demand period is about 8.0 mm/day. This means a leaching requirement of about 5.0 mm/day and a total gross irrigation requirement of 13.0 mm/day. Seepage from outside the area has to be added to the leaching requirement to obtain the required drainage runoff. The amount of seepage from outside the farm was found to vary from 7.0 to 0 mm/day, depending upon the distance from the farm boundary. If 4 mm/day is taken as an average figure for seepage, the drainage factor will amount to about 9 mm/day. This is equivalent to about 70% of the total gross irrigation requirement.

4.5 WATER MANAGEMENT TO ACHIEVE SALT BALANCE

4.5.1 Leaching Practices

Under saline conditions or in areas where a potential danger exists from salinization, as is the case in most of the irrigated projects of the Near East, criteria must be selected to determine the level to which salinity may be allowed to increase during the growing period. Especially where water is scarce or expensive, leaching practices should be designed to maximise crop production per unit volume of water applied for irrigation and leaching.

It has been shown that, except where the salt is concentrated at the bottom of the rooting zone, the greatest amount of water is conserved when the practice of periodic leaching is followed rather than maintaining a salt balance by a regular application of extra water. Moreover, better results are obtained by leaching the salts with alternate ponding and drainage than by continuous ponding, also considerably less water is needed. In the case of low infiltration rates, it is advisable wherever possible to postpone leaching until after cropping.

4.5.2 Irrigation Methods

In general, irrigation methods and practices which provide uniformity of application and downward movement of water through soils favour salinity control. Consequently, furrow irrigation must be practised with considerable care, particularly during the germination stage.

Fewer problems are encountered with basin and border irrigation. It has proved beneficial to rotate crops irrigated by furrows with crops irrigated by the border method. Land levelling and especially land maintenance are essential to both furrow and border irrigation. The basin method provides better control of the depths of water applied and greater uniformity in application than the border and furrow methods.

Sprinkler irrigation ensures a close control of the depth of water applied and, when properly used, results in uniform distribution. However, sprinkler irrigation with saline water can cause appreciable damage due to burning of the foliage and defoliation. In the Netherlands, the upper limit of the salt content of water used for sprinkler irrigation ranges from 1 000 to 1 500 ppm. Foliar absorption of salts can severely restrict the use of even good quality water for sprinkler irrigation of some fruit crops (citrus). Night sprinkling has proved advantageous in a number of cases; also, the moving of laterals with the main wind direction may result in better washing of the salts from the leaves. Work in Tunisia has shown that crops irrigated by sprinkling had higher sodium and calcium contents than those irrigated by surface irrigation. This greater sodium and calcium absorption by the leaves, as well as by the roots, together with a decreasing absorption of the potassium may lead to too early maturity, stunted growth and consequently, to a decline in yield.

Drip irrigation has provided good results even when using highly saline water owing to the low moisture tension level in the soil maintained throughout the growing season. Due to the continuous supply of water, the high salt concentration, which would have built up with conventional irrigation by the time the irrigation date approached, is avoided. However, with this method of irrigation, salts are concentrated in the soil surface and at the edges of the wetted area, but plant roots appear to be concentrated in the wetted area where the salt content is minimal. However, in the case of annual crops, after harvest, leaching is required to lower the salt content in the soil before sowing the new crop.

4.5.3 Water Supply

Inadequate water supply is causing soil salinity problems in many projects, for instance in West Pakistan and in the Euphrates Valley in Syria and Iraq, where farmers try to irrigate too much land in relation to the water supply. If the irrigation water is already of poor quality, soil salinization will develop very quickly. The use of tubewells in Pakistan, where good to medium quality underground water was mixed with the surface irrigation water, improved drainage conditions and there was more water available for leaching purposes.

Reducing the irrigated area and changing the cropping pattern by selecting crops which are drought tolerant, have a short growing period, grow at a certain time of the year when the evapotranspiration potential is low, or are more salt tolerant, would result in a lower irrigation demand.

On the other hand, over supply of irrigation water, which may occur in surface irrigation of sandy soils, is indirectly responsible for waterlogging problems and soil salinization. The lining of canals or the replacement of open channels by pipes significantly reduces seepage losses and consequently salinity and waterlogging.

4.6 EXAMPLES FROM THE REGION OF THE USE OF VARIOUS QUALITY WATERS TO IRRIGATE SANDY SOILS

4.6.1 Bahrain

The soils of Bahrain are relatively shallow sandy soils overlying bedrocks, which are affected by salinity and waterlogging. The water available for irrigation is from groundwater with a salt content of 2 000 ppm or more (3 mmhos/cm or more). Waterlogging is caused by excessive losses of irrigation water on these very permeable sandy soils and also by the drilling of artesian wells with no proper casing. Natural drainage conditions are also poor due to flat topography and low elevation of ground surface in relation to the surrounding sea level. The depth of the water-table varies from 30 to 150 cm below the ground surface.

A very limited range of crops is grown on a commercial scale because of the high salinity both in irrigation water and soils and because of waterlogging. Beside date palms, which occupy more than 65% of the cultivated area, winter vegetables and alfalfa are the most important crops raised in the islands. The crops are usually grown in small basins and the practice is to irrigate once every 3 or 4 days in winter and once every 1 or 2 days in the summer.

4.6.2 Kuwait

Interesting work on the development of irrigated agriculture is taking place both in the north of the country (Al Abdali area) and in the south (Al Wafrah area) on local saline underground water. In Al Abdali the salt content of the irrigation water varies from 2 000 to 6 000 ppm. The soils are shallow and sandy overlying gypsiferous soils. Tomatoes, onions, garlic and water melons are grown. Shifting cultivation is being practised as the soils become saline after one or two seasons of cultivation. Irrigation is carried out twice daily during the hot season. Groundwater is 20 m deep.

At Al Wafra, the irrigation water is even worse than at Al Abdali as the salt content varies from 4 000 to 8 000 ppm, but the soils are deep, very permeable sandy ones. Groundwater is 10 to 20 m deep. Alfalfa, tomatoes, carrots and leafy vegetable crops like celery, mint and spinach, are grown. Shifting cultivation is not practised. As in Al Abdali, small basins are used and irrigation is carried out twice a day in summer and once daily in winter.

On deep sandy soils at Al Jahra, just north of Kuwait, a farm is using local groundwater of about 10 000 ppm and producing leafy vegetables such as spinach, celery, malvacea and alfalfa.

4.6.3 Libyan Arab Republic

Very highly saline underground water with a salt content as high as 15 000 ppm is being used in the Tagora area on the coastal plain about 20 km east of Tripoli. Date palms, pomegranates, alfalfa, tobacco and winter vegetables, mainly tomatoes, are grown on deep very permeable sandy soils. The water-table is about 20 m deep. The local rainfall is about 350 mm which helps greatly in leaching the salts. However, salinity in the irrigation water is increasing because of the change from hand dug wells and manual lifting to deep drilled wells with mechanical lifting devices. The salinity in the soils is also increasing and a gradual deterioration is taking place in gardens that were once prosperous.

In the Kufrah area, deep in the desert in the south-east of the country, a very ambitious sheep production scheme is being developed. At present, about 1 300 ha is under forage and grain production, but it is proposed to expand this area to 10 000 ha. The soils are deep sandy soils, irrigated by sprinkling. However, the irrigation water is a fossil water with a very low salt content (less than 100 ppm), which is creating nutrient problems as several elements have to be added beside the usual three major elements, i.e. nitrogen, phosphorus and potassium.

4.6.4 Saudi Arabia

In the Qatif area on the east coast, light sandy soils with a high salt and gypsum content (up to 40% gypsum) have been reclaimed through leaching and drainage. The available water for irrigation is underground water with a salt content of about 3.5 mmhos/cm (2 500 ppm). High yields of vegetables such as tomatoes, cabbages, cauliflowers and onions are produced. Wheat, alfalfa and sugarbeet are also grown. Fifty tons of chicken manure/ha are required to start plant growth.

In the Al Hassa Oasis a total gross area of about 20 000 ha (about 10 000 ha is now under cultivation) is provided with irrigation and drainage systems. Irrigation water of 2.5 mmhos/cm (1 750 ppm) is being used. Date palms, food crops and alfalfa are grown with success. Citrus orchards have also been established, but not too successfully. Owing to an impermeable marly layer at 1 to 2 m depth below the good permeable top soil of loamy sand and sandy loam, waterlogging is a serious problem. The existing drains at 150 m spacing are not sufficient to control the salinity and water balances in the soils. Once the required drainage facilities are provided, successful agriculture could be maintained with the use of relatively saline irrigation water, as mentioned above.

4.6.5 United Arab Emirates

Very saline groundwater up to 17.0 mmhos/cm (more than 10 000 ppm) has been used to establish 700 ha of forest plantations on deep sandy soils with an undulating topography in Abu Dhabi State. Drip irrigation, the only practical method under the local conditions, is being used. After 3 years of establishment the trees of different species, such as tamarix, Prosopis sp., casuarina, eucalyptus, acacia and Zizyphus spina christi, are doing rather well. However, some mortality has been observed recently at locations with groundwater of excessive salinity.

On the east coast in the Al Saaf area, groundwater with a salinity of 3 000 to 5 000 ppm (4.5 to 7.0 mmhos/cm) is being used for the production of winter vegetables, mainly tomatoes, on light to medium textured soils. However, the land has to be abandoned after 3 to 4 seasons of cultivation because of the accumulation of salts in the soil profile. No waterlogging problem exists in the area. Sometimes, after years of heavy rainfall, abandoned lands may be put under cultivation again due to the leaching of salts from the upper part of the soil profile.

6.6 Yemen Arab Republic

At Jumeisha Farm in Tihama area the problem is not salinity, but high temperature and high nitrogen content of the groundwater which is available for irrigation. The temperature of the irrigation water is about 30°C and the nitrogen content is 120 to 300 ppm of nitrate. Such a high nitrogen content is good for the production of fodder crops and leafy vegetables but it induces excessive vegetative growth in grains, fibre crops and oil seeds. The extent to which this high temperature of the irrigation water affects the crop yields needs to be investigated.

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III.5 REDUCTION IN CONVEYANCE LOSSES IN SANDY SOILS

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SUMMARY

A more economical use of water has become a doctrine in many countries. The extent to which this doctrine can or should be translated into action depends on available resources, socio-economic conditions and technological development. The economical use of water thus is a variable requiring continuous review and adaptation. This paper tries to outline the main factors governing efficient water conveyance, particularly in relation to sandy soils, and to relate these factors to each other.

Water conveyance losses in most gravity flow irrigation systems constitute a very considerable percentage of total available water resources. A recent survey revealed that even in projects which could be considered to perform well conveyance efficiency was only 60 percent or less. A close look at the causes of these losses shows that there is a great potential for improvement. Conveyance losses may result from seepage, leakage through structures, spills due to poor operation of gates and turnouts, evaporation, consumption by weeds and overdelivery due to faulty water measurement.

Efficient conveyance requires adequate and properly built structures, but more often is dependent on efficient operation and maintenance. The manual operation of large systems naturally inherits deficiencies which may only be overcome by mechanization or automation. If because of changes in delivery practices or an increase in the irrigated area larger capacities have to be conveyed in an already existing system, the introduction of modern technological means such as centralized electronic control of gate operation may be the only way of avoiding costly reconstruction of the existing network.

Perhaps the greatest and most common loss in conveyance is through canal seepage. This can always be controlled by some form of lining, but lining should be subject to economical feasibility. A well installed and maintained lining, such as concrete, brick or covered membrane, should not lose more than 30 l/m^2 of wetted perimeter per day. In sandy soils a soil-cement lining may be an economical solution having a low initial cost although a short serviceable life.

The use of pipelines for water conveyance should be considered as an alternative to open lined canal networks, especially in the terminal portion of networks where diameters are small but total lengths of conveyance are high, and where other advantages of pipes such as reduced interference with mechanized farming and saving of productive land are important.

5.1 REDUCTION IN CONVEYANCE LOSSES IN SANDY SOILS

It is common in gravity irrigation systems for large amounts of irrigation water to be lost in conveyance before reaching the point of use. Yet, is it justified to spend millions of dollars on canal lining, pipe distribution or sophisticated control systems to recover perhaps only enough water to irrigate a few hundred additional hectares of land? And will the anticipated water savings really be made? Is not the self-sealing effect of water sufficient to reduce seepage, in time, to a bearable degree? Is not an equal or even larger percentage of total flow wasted by inefficient application of water on the field? Would it therefore not have more effect to concentrate all efforts on improving water use efficiency at the field level and by so doing not only save water but simultaneously increase productivity on existing lands? Or could the investment required for efficient conveyance not be better made in development of additional water resources, such as groundwater? The answers to these questions naturally depend on individual circumstances but a few facts should be noted. In many irrigation systems, records which would permit an estimate of conveyance losses do not exist and there is a general tendency to underestimate them, as a recent as yet unpublished ICID world survey indicated. It was found that in about 60 projects surveyed, conveyance efficiency was only 60 percent or less, although most of the projects were considered to be performing quite well. Although field application efficiency has improved in recent irrigation projects, progress in most traditional gravity flow systems is slow. The number of cultivators is often too great in comparison with available funds and skills to introduce improved methods; traditional practices - relics from times when water was more abundant - are difficult to remove. Yet in most irrigated areas the stress on available resources will continue to increase. Higher peak demands due to more intensive agriculture and, socially, a trend towards more liberal delivery methods will have to be met.

This having been said, it is indeed of paramount importance to examine the various means of increasing the efficiency of water transfer between source and user and to consider all the means of today's technology in designing new systems and remodelling traditional ones so as to minimize losses. This is valid for most systems and locations, but is amplified in areas with sandy soils.

Sandy soils usually have a restricted suitability for agricultural production. Yet in some areas of the Near East Region, irrigation has to expand into sandy soil areas. Examples are found in the Arab Republic of Egypt along the Nile and coastal areas west of the Delta, in the Sudan, in many wadis of the Arabian Peninsula and in some coastal areas of the region.

5.1.2 Particulars of Sandy Soils to be considered in relation to Water Conveyance

In this paper sandy soils are discussed in relation to their engineering properties. The agronomic term of sandy soils is used as a cover for various coarse-textured soils. The most significant characteristics, as detailed in Table 1, are high hydraulic conductivity, low hydraulic and aeolean erosion resistance and flat gradient of stable slopes. Another factor to be borne in mind is the suitability of sandy soils as an aggregate for concrete.

Corresponding features to be considered in relation to efficient water conveyance are:

- lining of canals and reservoirs;
- water distribution in covered pipe systems;
- proper control structures and efficient operation including water measurement;
- wind sheltering and sand stabilizing measures along canals.

The relative importance of the various factors influencing conveyance losses is difficult to estimate because they can hardly be separated in measurements. An attempt in this respect is reported from Australia (Nelson, 1966). In summary, field tests on three distribution canals resulted in the following relationships, expressed as percentages of total inflow into the canals:

- channel filling, evaporation and unidentified losses: 11%
- leakage through outlets and spill due to poor operation: 14%
- over-delivery due to faulty water measurement: 9%
- seepage: 15%
- recorded deliveries: 51%

Similar studies conducted by the writer in Greece revealed greater seepage losses than operational ones, the total averaging 50% but the individual percentages being very scattered. The scarce information available demonstrates that conveyance losses are composite and as such need to be tackled from different angles.

Table 1 HYDRAULIC PROPERTIES OF SOME SOILS

Nature of soil forming the canal bed	Conveyance losses in canals m^3 per m^2 of wetted perimeter per day	Permissive (non-erosive) velocity m/sec	Safe side slope for unlined canals horizontal : vertical
Gravelly and sandy	0.60 - 0.75	0.50 - 0.75	3 : 1
Sandy	0.45 - 0.55	0.30 - 0.75	3 : 1
Sandy loam (clayey sandy soil)	0.30 - 0.45	0.75 - 0.90	2 : 1
Loam to clay loam	0.14 - 0.22	0.85 - 1.10	1 : 1
Uncemented gravels	> 0.90	1.20 - 1.80	1 : 1
Conglomerates, stiff clay	< 0.10	> 1.80	< 0.75 : 1

ICID, 1972 and Kraatz, 1971

.1.3 Increasing Conveyance Efficiency by Operational Means

Water measurement is an important requisite which is often badly neglected. Control structures are obligatory in irrigation conveyance from the very outset but measuring devices are not and once a project has become operational their installation is difficult and even more costly. Installation is only one side of the problem; the other is correct operation and maintenance which is often a question of availability of trained staff. Project financing should provide for both the installation of water measurement systems and training for their proper operation. In most conventional rotation systems it may not be feasible to provide all farm outlets with measuring devices but in order to improve scheduling and delivery of adequate water volumes a few representative outlets should be properly equipped. Often, existing farm outlets can be used as measuring devices with little or no modification if they are properly calibrated. This eventually requires a series of field trials sometimes supplemented by hydraulic laboratory research.

The proper sealing of gates has a great saving effect in comparison with extra cost. Materials are now available which make slide gates permanently watertight. One such material is an extruded neoprene plastic strip. Strips may be fitted into concrete irrigation structures formed on site, or incorporated into prefabricated concrete or metal. Existing structures can be readily remodelled to incorporate guide and sill strips. This is but one example of structural improvement for better flow control.

Remote control and automation of conveyance and delivery are an important means of making water economies. A distinction should be made between automatic control of headworks and conveyance networks on the one hand, and automation at the farm level on the other. The latter is as yet implemented on a very limited scale and is feasible only where both water and labour saving are determining factors. A question of considerable current interest with regard to automation is the modificatic of strictly rotational systems to more demand oriented ones. Probably the first step towards this goal is to substitute the non-stop delivery system with only daytime delivery. The main problem to be solved here is how to provide for the larger capacities required whilst minimizing modification of existing civil engineering works for economic reasons. This requires reconsideration of existing safeguards with a view to increasing water levels and velocities, i.e. capacity and reduction of spill and other losses, especially in the terminal portion of the system. In other words, an elaboration of the entire physical as well as the organizational system is required, which can only be accomplished with some form of automation or remote control. The most appropriate solution is a centralized computer-operated control. Current developments of this technique in some countries open good prospects for improvement of existing as well as new irrigation systems. The chief advantage is that the computer can indicate in a very short time the most suitable gate operation. It can also be arranged for the computer itself to initiate these operations automatically on the basis of simultaneous knowledge of levels and flows at all crucial points of a canal network. Thus canal volumes can be reduced to a minimum which, in areas of highly permeable soils, has the added advantage of reducing seepage losses. Likewise, maximum water levels need not be constantly maintained when flow demands are small. Such advanced control systems are currently in operation or planned in several projects throughout the world. The project for hydro-agricultural development in Southern Lebanon may be mentioned as an example for the region.

5.1.4 Lining of Canals

The decision on whether or not to line a canal depends essentially upon the permeability of the soil in which the canal is to be excavated. In many practical cases this decision can be reached from visual observations of the soil, provided that it is of a type which is obviously very pervious or impervious. When permeability is in doubt the decision may be reached either by applying comparative seepage data, by performing seepage tests in nearby canals or by calculating seepage. Seepage calculation has been considerably facilitated by the graphical solution derived from electric analogy by Bouwer (1969). An explanation of the application of the method is given in the appendix to this paper. Further data required prior to deciding on whether or not to line include the amount of water which can be expected to be saved by lining and the unit value of the water. As a rule of thumb, a properly lined canal should not lose more than 30 l/m^2 per day (compare with Table 1). With this information, the annual savings and the annual cost of lining can be compared. Eventually, other benefits derived from lining such as erosion protection, prevention of waterlogging, smaller cross section, less silting, quicker response to demands, greater safety, etc., can be taken into account. In areas of instable soils lining for erosion protection is often more important than reducing seepage.

5.1.5 Choice of Type of Lining

There is hardly any material which has not been used for lining canals. A general subdivision can be made into hard surface, membrane and earth linings. The latter type is of little interest in regard to sandy soils since it requires cohesive and impermeable soils such as loams which are usually not available within economical hauling distance. When considering membrane lining attention must be paid to the fact that they must be covered and the cover material should be stable. Where both sand and gravel are available nearby, a plastic membrane with a sand-gravel cover may be a feasible lining for reservoirs and large canals when fencing and periodic inspection is provided. In sandy soil areas, unreinforced concrete is usually the most economical material for any size of canal in view of its long serviceable life (40 years and more). In two pilot farms in the People's Republic of Yemen it was recently found that lining supply ditches with concrete was more economical than covered PVC membrane. The use of reinforcing in concrete is not justified except when failure would endanger life or property other than the canal itself.

However, concrete lining is expensive in initial cost and a cheaper and less durable type, such as soil-cement lining, may have to be selected. Since sandy soil is the basic ingredient (up to 95%) of soil-cement lining, it merits some attention in this paper. Soil-cement linings are constructed with mixtures of sandy soil, cement and water, all of which hardens to a concrete-like material. For the construction of soil-cement linings two general methods are in use: the dry-mix and the plastic-mix.

The dry-mix soil-cement, which is also called standard soil-cement or compacted soil-cement, is commonly mixed in place and compacted with the moisture content of the mix at or just above the optimum as determined by the Proctor test. Lining thicknesses commonly applied are 7.5 to 15 cm. This lining is constructed by placing bags of cement at predetermined intervals on the bottom and sides of the canal or reservoir; the bags are broken and the cement distributed to a uniform depth by hand-raking or by mechanical cement spreaders. While the cement is being mixed into the soil, water is added simultaneously to the mixture from a tank truck or hose. After the cement and soil have been thoroughly mixed and the moisture content judged correct (e.g. by the "hand squeeze" method), the mixture is compacted by rubber-tyred road compactors or heavily loaded trucks. Mixing in place with travelling mixing machines has proved satisfactory on slopes not steeper than 4 to 1. For economic reasons sideslopes of irrigation canals normally have to be much steeper so that mixing in place as well as compaction must be done manually.

The durability and watertightness of the dry-mix soil-cement lining is essentially dependent upon the soil used. Although other soils can be considered, laboratory tests indicate that, for ease of mixing and placing and a low cement content, the soil should be a well-graded, sandy, gravelly material. If the soil is poorly graded or lacking in fine material, the cement content should be higher, which also increases the cost. Since soils excavated from the canal are not necessarily the most suitable, others located within a reasonable hauling distance may be used. In general, a well-graded mixture of gravel, coarse sand and fine sand either with or without small amounts of silt and clay material will require 5 percent of cement by weight. Poorly graded one-size sand materials with a very small amount of non-plastic silt, typical of desert blow sand, will require about 9 percent. The non-plastic or moderately plastic silty soils generally require about 10 percent. The use of one of the available testing procedures (Kraatz, 1971 and Cyprus, 1972) is recommended to determine the required cement content. Dry-mix soil-cement compaction should be completed within one hour after the soil-cement is spread. The moisture content of the material must be at or very near optimum when compaction begins. Compaction must be sufficient to obtain specified density. At the start of the project, in-place density tests are made of compacted soil-cement. From these tests the required number of passes of each type of compaction equipment can be ascertained. After the dry-mix soil-cement mixture has been compacted to the minimum density, curing should start immediately. Proper curing is just as important with soil-cement as it is with concrete. Improper or no curing can result in excessive shrinkage cracking, reduced durability, increased permeability and lower strength. Joints are not provided in dry-mix soil-cement linings.

Plastic soil-cement has higher water and cement contents than dry-mix soil-cement and a consistence comparable to that of concrete used for slipform lining. The soil is mixed with cement and water in a paver or mixer travelling along the canal, or in a stationary plant. The mix is then poured by hand or by slipform on to the subgrade to produce the lining similar to conrete linings. Lining thicknesses range from 7.5 to 15 cm. It is recommended that joints similar to concrete linings be provided. Cement requirements are about the same as for dry-mix soil-cement.

5.1.6 Covered Pipe as an Alternative to Lined Open Channels

We will only touch on low pressure pipe distribution systems here. High pressure pipe (up to 7 atm and more) is used exclusively in conjunction with overhead or trickle irrigation, which are discussed in a separate paper. Conveyance under high pressure, despite its merits in relation to demand delivery and water saving, is not economical for gravity flow irrigation, which accounts for more than 90 percent of total irrigation in the region. In gravity irrigation, water is often conveyed in open canals and is distributed inside the irrigation area by low pressure pipe networks. Pipe is frequently also used where water is pumped from a stream, a well field or for a farm distribution system from a single well.

The best conditions in the region for the use of low pressure pipe instead of conventional lined channels are probably found in small groundwater irrigation schemes, in areas of irregular topography and where canal silting from windblown sands is a problem. A detailed comparison of the costs and benefits of both open canals (or flumes) and pipe is warranted in most such cases. The lowest total annual cost over the expected useful life of the system will determine the most economical choice.

Benefits to be considered in addition to those of lining canals are water saving by eliminating evaporation, better water management, little maintenance, better weed and insect control, reduced length of conveyance, reduced interference with mechanized farming, and saving of labour and of productive land. The latter two benefits, however, may not be of great significance in the region, where arable land is usually not the limiting factor and labour is inexpensive. Due to the importance of the details of correct design and installation, pipe systems should be handled by an experienced engineer and a field crew thoroughly accustomed to the work. Relevant skills and experience may often be obtained from sources dealing with domestic water supply and sanitary public works. A problem not to be overlooked is pipe failure and the difficulty to detect and repair as they occur failures owing to chemical deterioration including corrosion, tension caused by rapid temperature and moisture changes, water hammer effects, seismic activities or poor workmanship. Once a pipe is installed, modifications are more difficult than on open systems. Water losses in pipelines are difficult to evaluate. A design value of 1 m^3 per hour per km per m of internal diameter is frequently adopted for major pipeline conveyance systems.

Precast unreinforced concrete and asbestos cement are the most commonly used materials, but plastics are becoming more and more competitive. In the U.S.A., jointless in situ concrete pipe is widely used; slipforms are commercially available.

The Paphos Irrigation Project (Cyprus, 1972) may be taken as a case study for the region, where low to medium pressure asbestos pipe will be installed both on part of the conveyance system (20 km) and for the distribution network on about 1 060 ha of surface irrigated land with fragmented smallholdings. In the conveyance system, preference was given to a pipeline for operational reasons (24 hours operation with night storage). For the distribution network, low pressure asbestos pipe and precast concrete canaletti were found to be similar in cost but buried pipe was preferred in view of its advantage in reducing headlands and interference with mechanized operations. The estimated cost for the installation of main conveyance pipelines ranges from $14 per running m for 350 mm pipe to $70 per m for 1 000 mm pipe. The cost for the distribution pipe network is estimated at $980 per ha. The replacement period for the pipe has been estimated at 30 years.

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APPENDIX

Graphical method for calculating seepage from canals

The practical application of Bouwer's graphical solutions (1969) for predicting seepage rates for a given canal imply that the following factors governing the flow system be known:

- hydraulic conductivity (K) of the subsoil
- geometry of the canal
- position of the groundwater table

According to Bouwer, there are three basic conditions to which the multitude of natural profiles of soil hydraulic conductivity can be reduced for theoretical treatment of seepage flow systems:

Condition A: The soil in which the channel is embedded is uniform and underlain by more permeable (considered as infinitely permeable) material.

Condition B: The soil in which the channel is embedded is uniform and underlain by less permeable (considered as impermeable) material.

Condition C: The soil in which the channel is embedded is of much lower hydraulic conductivity than the original soil for a relatively short distance normal to the channel perimeter (clogged soil, semi-permeable linings).

The case of seepage to a free draining permeable layer in the subsoil is a special case of condition A, and it is obtained by allowing the water table to be at or below the top of the permeable material. This condition is labelled A'.

The studies of canal seepage by resistance network analogue included analyses under the conditions A, B and A'. The geometry and symbols for canals under these three conditions are shown in Fig. 1.

Dw is the head, which affects the seepage flow. For conditions A and B this is equal to the vertical distance between the free water surface and the horizontal water table. In the analogue the horizontal water table was simulated at a horizontal distance (L) of 10 times the bottom width (Wb) from the canal centre. For condition A', the effective Dw value is equal to Hw + Dp, although the actual depth of the water table may be greater than Hw + Dp. The analyses were performed for trapezoidal canals with 1:1 side slopes (α) and three different water depths (expressed as Hw/Wb). The graphical solutions resulting from the resistance network analogue are shown in Figures 2, 3 and 4.

Use of the graphs

The dimensionless value Is/k can be obtained from the graphs. From this the seepage rate q per metre canal per day is computed by using the expression:

$$q = \frac{Is}{K} \cdot K \cdot Ws$$

To apply the graphs to canals of other shapes, Wb is computed from the actual values of Ws and Hw as if the canal were trapezoidal with 1:1 side slope, or the cross section can be replaced by the best-fitting trapezoidal cross section with 1:1 side slope.

In practice, the underlying soil material is treated as "permeable" if its K value is 10 times greater than the K value of the soil above (Condition A). Accordingly, the state of impermeable floor can be presumed if the hydraulic conductivity of the material is 10 times less than for the soil above (Condition B).

It can be seen from the graphs that the influence of the permeable layer (Condition A) on the seepage rate becomes rather small when it is more than 5 times the bottom width (Wb) below the canal. The closer to the canal bottom the permeable layer lies, the higher is the seepage rate. The rate also increases with an increase in the watertable depth (Dw).

For Condition A' it is seen that the seepage rate remains almost constant for a wide range of depths of the permeable layer (= effective head Dw). When this depth becomes less than 3 times the canal depth (Hw) the seepage rate increases rapidly.

For Condition B it is evident that the impermeable floor has a significant effect on seepage only if its distance below the canal (Di) is less than 5 times the bottom width of the canal (Wb).

The following example may illustrate the use of the graphs:

Given: The soil in which the canal is embedded is a sandy loam which can be considered uniform. The mean hydraulic conductivity K = 0.50 m per day. This soil is underlain by at least 10 times less permeable (considered as impermeable) material. Thus Condition B is given.

Hw = 0.75 m Di = 5.00 m

Wb = 1.00 m Dw = 2.00 m (at distance 10 . Wb from canal centre)

Ws = 2.50 m

Side slope 1:1

From this: Di/Wb = 5:1 = 5

Dw/Wb = 2:1 = 2

Hw/Wb = 0.75:1 = 0.75

which, using Fig. 2 gives: Is/K = 0.58

$$q = \frac{Is}{K} \cdot K \cdot Ws = 0.58 \cdot 0.50 \cdot 2.50 = \underline{0.73\ m^3 \text{ per m/canal per day}}$$

Conclusive remarks

A difficult aspect of calculating seepage via an analysis of the underground flow system is the proper evaluation of the soil hydraulic conductivity, K. Measurement of K should be done at different soil depths to a distance of at least five channel-bottom widths (for trapezoidal channels with 1:1 side slopes) below the channel bottom, or until much more, or much less, permeable material than that immediately below the channel is reached. The various field techniques for measuring K, either below or in the absence of a watertable, are reviewed, Kraatz (1971) and "Planning and interpreting soil permeability (1969), J. Irrigation and Drainage Div. ASCE. Because sedimentation and other "aging" processes causing reduced seepage rates are not taken into account, the seepage rates evaluated with the above method should be considered as the maximum that can be expected. Such rates may occur when the canal begins operating or after it has been cleaned.

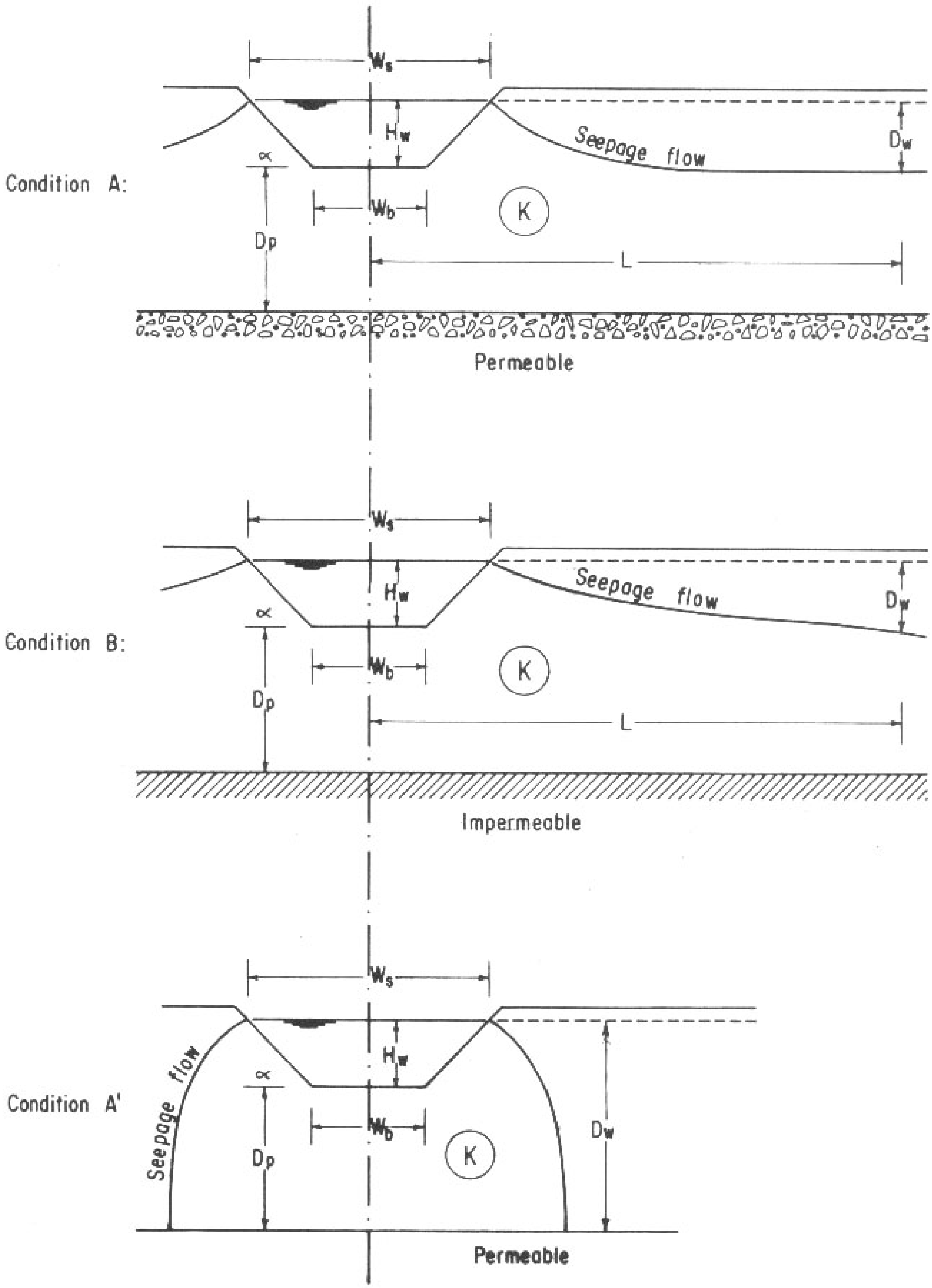

Fig. 1 GEOMETRY AND SYMBOLS FOR CANALS UNDER CONDITIONS A, B and A'

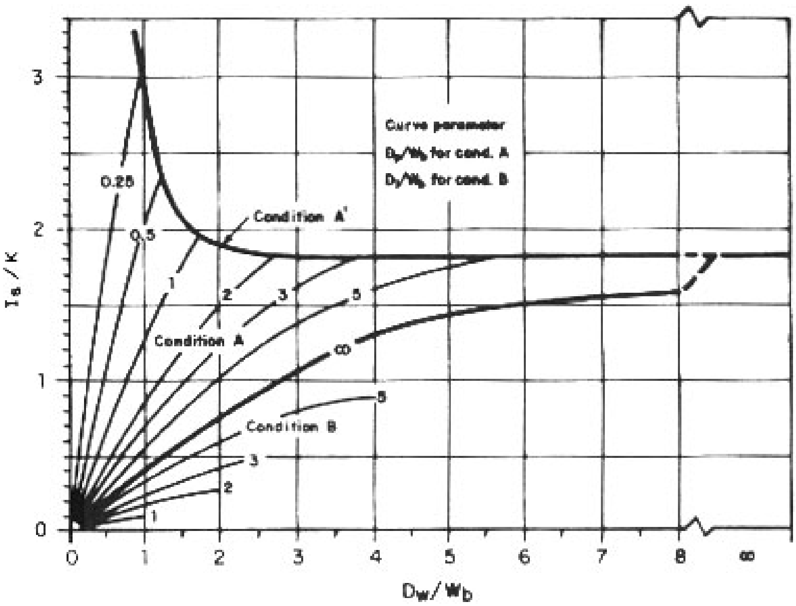

Fig. 2 RESULTS OF SEEPAGE ANALYSES WITH ELECTRIC ANALOGUE FOR TRAPEZOIDAL CANAL WITH 1:1 SIDE SLOPE AND Hw/Wb = 0.75

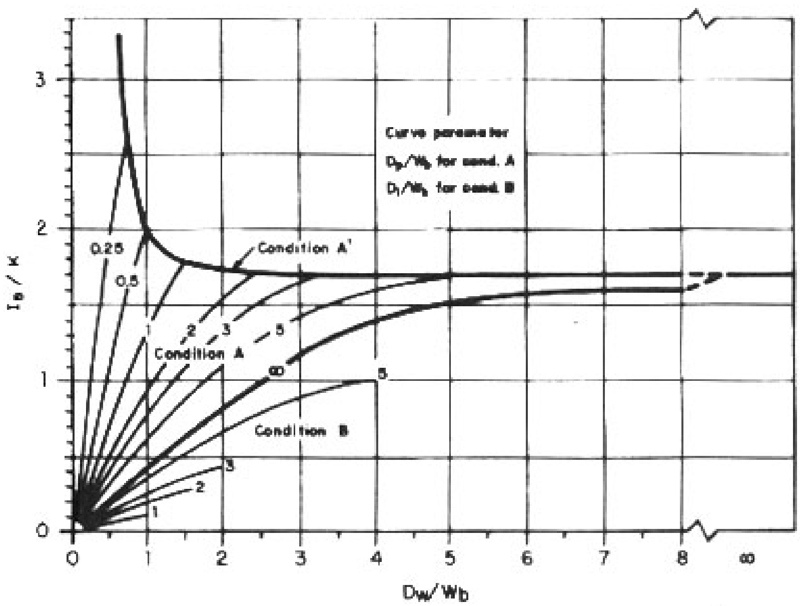

Fig. 3 RESULTS OF SEEPAGE ANALYSES WITH ELECTRIC ANALOGUE FOR TRAPEZOIDAL CANAL WITH 1:1 SIDE SLOPE AND Hw/Wb = 0.5

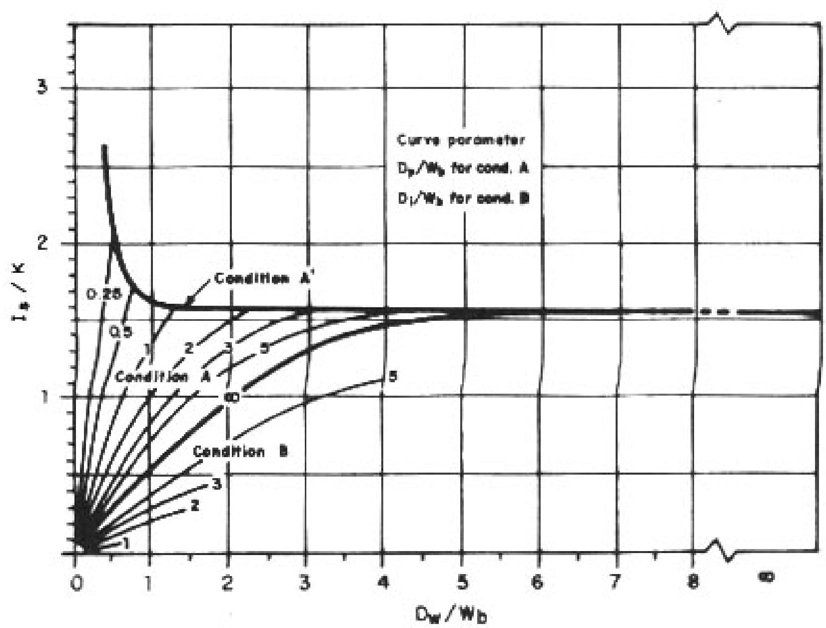

Fig. 4 RESULTS OF SEEPAGE ANALYSES WITH ELECTRIC ANALOGUE FOR TRAPEZOIDAL CANAL WITH 1:1 SIDE SLOPE AND Hw/Wb = 0.25

IRRIGATION OF SANDY SOILS

by

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SUMMARY

In irrigation development projects involving sandy soils the irrigation method must be considered very carefully. This paper proposes the best irrigation techniques but even with these the risks of low irrigation efficiencies remain. It is therefore very important that farmers be well informed on special irrigation techniques through a suitable educational programme.

In this paper an analysis is made of the physical characteristics and water-soil relationships of sandy soils, and the various irrigation methods reviewed with recommendations given as to proper water management at field level.

Two important characteristics of sandy soils are their coarse texture and high rate of hydraulic conductivity. An understanding of these characteristics is necessary for the design and operation of farm irrigation systems. These characteristics control the determination of the type of farm irrigation system to design, the size of design, the amount of water necessary for proper utilization of the system and the frequency and amount of irrigation.

In general surface irrigation methods are not the most suitable for sandy soils whether by basin, border or furrow. The high permeability and the low water storage capacity make it very difficult to apply the correct amounts of water. Irrigation of sandy soils may lead to water wastage by deep percolation and low irrigation efficiencies of less than 50 percent. Moreover the yield of crops may also be affected by bad uniformity application. The lowest parts of fields often do not receive enough water to meet their requirements whereas the upper parts are generally over-irrigated. Nutrients are carried away and micro-elements are frequently lacking. Usually, under normal conditions, surface irrigation methods are not recommended for sandy soils.

Nevertheless there exist special cases when these negative aspects may become useful to crops. This is particularly true for irrigation with brackish water where the excess salts brought by the irrigation water are rapidly leached out of the rootzone. No special on-farm measures such as drainage systems may be needed.

Despite what has been said, the irrigation of sandy soils is sometimes inevitable because good arable lands are lacking.

Sprinkler irrigation has built-in features which make it particularly well adapted to sandy soils. Transport of water is by pressure pipes and water losses are low. But perhaps the most interesting feature of sprinkler irrigation is its ability to apply small volumes of water with a very good distribution pattern. Matching water applications to soil water holding capacities is no longer a constraint. Deep water percolation can therefore be controlled to the strict minimum admissible by the method. Furthermore the size of the plots or the depth of the crops have no influence on the application efficiency and crops of any type, deep or shallow-rooted, broadcast or planted in rows, can be irrigated with equal success.

Drip irrigation is one of the latest irrigation methods to be developed. Although it had been known for many years it was only used in very special cases by some horticulturists and nursery gardeners. Its application at the farm level became possible by the extensive use of polyethylene plastics in manufacturing the various components of the equipment. This has reduced its cost which, although rather high, is now acceptable for some crops. Trickle irrigation really started in agriculture less than 10 years ago. The real success of this new method is based on a certain number of advantages which are claimed by the enthusiastic promoters of the method: water saving, higher yields, utilization of brackish waters, manual labour extremely reduced, decreases in diseases, weed control, etc. In fact most of these promising results have been obtained in experimental conditions by highly qualified specialists. Comparative field trials are still too few to say in what proportion these advantages are applicable to large scale irrigation. The method is still in its initial stages and many developments are expected in the near future.

A well designed irrigation scheme may not yield the expected returns if water is not managed in the proper way by farmers. This may be even more true in the case of sandy soils for which irrigation must be handled with special care. The human aspect is often unduly disregarded during the planning period whereas it plays a decisive part during the whole lifetime of a project. It is therefore necessary to provide these farmers with the minimum knowledge that they need so badly. This of course can only be done by an intensive education programme of demonstrations, advice, rewards, etc., carried out by a well organized extension service. The extension workers to be efficient should receive special training in the irrigation of sandy soils based on a very good knowledge of the local soil conditions.

6.1 INTRODUCTION

In irrigation development projects involving sandy soils the irrigation method must be considered very carefully. This paper proposes the best irrigation techniques but even with these the risks of low irrigation efficiencies remain. It is therefore very important that farmers be well informed on the special irrigation techniques through a suitable educational programme.

In this paper an analysis is made of the physical characteristics and water-soil relationships of sandy soils, and the various irrigation methods reviewed with recommendations given as to proper water management at field level.

6.2 WATER-SOIL RELATIONSHIPS OF SANDY SOILS

Two well known physical features of sandy soils are their coarse texture and their high rate of permeability. Other features that play an important part in irrigation are the pore space, the bulk density and the water content.

6.2.1 Texture

The distribution of the soil particles according to their size is called the texture. Sand is usually defined as particles having a diameter between 0.05 and 1.00 mm. If the amount of particles within this range is greater than 50 percent the soil is said to be sandy. According to the exact percentages of sand and other particles contained in a sandy soil its texture will vary from sandy-clay to coarse sand. The texture of sandy soils has a very important influence on the infiltration rate, the water holding capacity and consequently on its value for irrigation. Since, generally, the more loam and clay contained in the soil the better it will be for irrigation, a mechanical analysis is a necessary tool for soil classification. Coarse soils are easily eroded by running water which is one of the obstacles to successful surface irrigation.

6.2.2 Infiltration Rate

The infiltration rate is the velocity at which water percolates into a soil and usually decreases the longer water is in contact with the soil. It will reach a relatively steady value equal to the permeability or hydraulic conductivity of water through the soil. This variation of infiltration rate with time differs from one type of soil to another. In the case of sandy soils the final rate is reached rapidly and is usually high.

Sandy soils have high infiltration rates varying for sandy clay and sandy loam from 4 to 25 cm/h, but in very permeable sandy soils values as high as 100 to 400 cm/h are easily reached. High final infiltration rates are responsible for important water losses both in the conveyance systems and in the fields. Soils having a final infiltration rate of 10 cm/h and above are generally not recommended for surface irrigation systems. In other words, to keep the conveyance and application efficiencies at an acceptable level the length of the ditches and the size of the fields may be too small for proper cropping. A 30 l/s flow could irrigate no more than 1 080 m^2 at any one time. The uniformity of application will be poor if the fields are large since upper parts would receive more water than the lower ones. High infiltration rates may be an important constraint to efficient surface irrigation schemes.

High infiltration rates also have an action on the soil structure in that often the clay particles contained in the upper layers are conveyed to deeper layers where they accumulate and form a less permeable horizon. This horizon may impede the deep percolation of excess water coming from rain or over-irrigation and may form a perched water table which will require field drainage.

6.2.3 Porosity and Apparent Specific Gravity

The porosity or pore space is that space between the soil particles which is equal to the ratio of the volume of voids either filled with air or with water to the total volume of soil, including air and water. The porosity or pore space of sandy soils is less than for clay soils.

The apparent specific gravity or bulk density is the ratio of the weight of a given volume of dry soil, dry space included, to the weight of an equal volume of water. The apparent specific gravity varies with soil types as does the porosity. Mean and extreme values are indicated in the following table abstracted from the book "Irrigation Principles and Practices" by Israelsen.

Table 1 APPARENT SPECIFIC GRAVITY AND PORE SPACE

Soil Texture	Apparent Specific Gravity	Pore Space
Sandy		
mean	1.65	38
extremes	1.55-1.80	32-42
Sandy loam		
mean	1.50	43
extremes	1.40-1.60	40-47

The more sandy a soil the higher is its apparent specific gravity and the lower is its pore space. Thus sandy soils which are often designated by farmers as "light soils" are in fact the ones that weigh the most per unit volume. The term "light" refers to their ease in working with agricultural implements.

6.2.4 Water Content and Water Holding Capacity

The water content of a soil depends on the amount of water stored in the pore space. Since sandy soils do not have a very large total pore space, their water content will never be very high. The water content can be expressed either as a percentage on a dry weight basis or as a percentage on a volume basis. The moisture content on a dry weight basis is equal to the ratio of the weight of water contained by a soil at field capacity to the weight of this same soil after having been dried in an oven at a temperature of 105°C. The moisture content on a volume basis is equal to the ratio of the volume occupied by the water stored in the pore space to the total volume of the soil.

Field capacity (FC) is defined as the percentage of water retained in the pore space of a soil after the excess water from an irrigation has percolated to deeper layers. In practice the field capacity is determined one or two days after an irrigation.

Permanent wilting point (PWP) is defined as the percentage of water still remaining in a soil once the plants are no longer able to extract sufficient moisture to meet their needs.

The available moisture in percentage is then the amount of water which is available between these two values.

This relation can be converted to a depth of water available in soil which is usable in determining quantitative water requirements of individual crops grown in specific soils and is called the readily available water.

In irrigation practice it is not recommendable to wait for the soil water to reach the permanent wilting point before replenishing the soil reservoir. In this way the plants will not suffer from an eventual lack of water. In principle, water applications should never be greater than the readily available water as any excess will automatically be lost by deep percolation.

The following table adapted from "Irrigation Principles and Practices" by Israelsen gives some practical values of water applications in sandy soils.

Table 2 MOISTURE CONTENT AND PRACTICAL WATER APPLICATIONS

Soil Texture	Field Capacity	Permanent Wilting Point	Practical Water Application for a soil depth of	
	%	%	0.5 m mm	1.0 m mm
Sandy loam				
mean	14	6	45	90
extremes	10-18	4-8	35-55	70-110
Sandy				
mean	9	4	30	60
extremes	6-12	2-6	22-37	45-75

The conclusion can thus be drawn that deep-rooted crops are better for sandy soils than shallow-rooted ones.

6.3 IRRIGATION METHODS

6.3.1 Surface Irrigation

In general surface irrigation methods are not the most suitable for sandy soils whether by basin, border or furrow. The high permeability and the low water storage capacity make it very difficult to apply the correct amounts of water. Irrigation of sandy soils may lead to water wastage by deep percolation and low irrigation efficiencies of less than 50 percent. Moreover the yield of crops may also be affected by poor uniformity of application. The lowest parts of fields often do not receive enough water to meet their requirements whereas the upper parts are generally over-irrigated. Nutrients are carried away and micro-elements are frequently lacking. Usually, under normal conditions, surface irrigation methods are not recommended for sandy soils.

Nevertheless there exist special cases when these negative aspects may become useful to crops. This is particularly true for irrigation with brackish water where the excess salts brought by the irrigation water are rapidly leached out of the root-zone. No special on-farm measures such as drainage systems may be needed. Irrigation with waters containing up to 4 000 ppm on oasis sandy soils in Tunisia has been reported with no damage to crops. Another special case would be underground irrigation by perfect control of the water table, made possible in sandy soils by their high transmissivity. But this type of irrigation requires the construction of drainage canals or pumping wells and would increase the initial investment.

Despite what has been said, the irrigation of sandy soils is sometimes inevitabl because good arable lands are lacking. The following recommendations should then be considered: First of all the water distribution system should either be lined or piped as indicated in the previous paper (III.5) and should be able to deliver water at very short intervals. The smaller canals will therefore have to be increased in size and so will be the cost of the systems. The size of the fields should be reduced and the streams available at the headgates be large enough to enable a quick filling of the plots.

The best irrigation method would be by small basins of only a few quare metres in size (10 to 20 m^2). The main drawback of this method is its high requirement in manual labour, first to prepare the small basins and then to irrigate them one after the other. This method also precludes any kind of mechanization. A way of further reducing the water losses within the farm would be to convey the water from the headgate to the basins by using light aluminium or plastic pipes laid on the soil like those utilized in hand-move sprinkler irrigation systems. This way of irrigating is sometimes called the "hose basin irrigation method". It is probably the best adaptation of surface irrigation to sandy soils but it also increases the cost.

Finally, when a water table is present it is absolutely essential in a large scheme to keep close track of its fluctations. Should there be a tendency to rise, a drainage system might have to be installed. This particular aspect will be dealt with in the following paper (III.7)

6.3.2 Sprinkler Irrigation

Sprinkler irrigation has inherent features which make it particularly well adapted to sandy soils. The transport of water is by pressure pipes and water losses are low. But perhaps the most interesting feature of sprinkler irrigation is its ability to apply small volumes of water with a very good distribution pattern. Matching water applications to soil water holding capacities is no longer a constraint. Deep water percolation can therefore be controlled to the strict minimum admissible by the method. Furthermore the size of the plots or the depth of the crops have no influence on the application efficiency and crops of any type, deep or shallow-rooted, broadcast or planted in rows, can be irrigated with equal success.

These features only become a reality if the sprinkler irrigation system is designed and managed properly. Some engineering aspects are dealt with in the following paragraphs.

First of all, the designer should take advantage of the high infiltration rates of sandy soils and use high application intensities. This will reduce cost which is higher in sprinkler than in surface irrigation. But high application rates for a small water holding capacity imply more frequent shifts of lateral lines, so in order not to lose the benefits of high application rates by an increase in the labour requirements, it is recommended that the shifts be limited to 4 per day or the system placed on wheels.

The application efficiency should be considered about 70 percent to account for losses in the field and in the atmosphere.

The spacing of sprinklers has little influence on the irrigation of sandy soils. However, larger spacings of 18 x 18 m or 24 x 24 m are less expensive than smaller one of 12 x 12 m. Spacing limitations will be dictated mainly by atmospheric conditions. If the site is windy it is better to use closer spacings either rectangular 12 x 18 m, the 12 m side being perpendicular to the main wind direction, or 12 x 12 m.

The periods of irrigation per day should be as long as possible to reduce the investment costs. The fact that shifting laterals during the night is very difficult must be considered. Since the frequency of lateral shifting is high in sandy soils practically, it will not be possible to envisage night irrigation. Irrigation time will thus be limited to the daylight hours plus the duration of one position which can be started just before sunset and stopped during the night. The effective duration of the irrigations take into consideration the time required for shifting the lateral lines and, eventually, the time during which the installations would have to be stopped because of high wind velocities. It is to be borne in mind here that irrigations should be stopped when the wind velocity is above 5 mi/s (18 km/h). Above this figure water losses caused by wind drift are very high and application uniformity and efficiency are considerably reduced. If the number of hours left for operation is too small it may then be necessary to consider the plantation of windbreaks. In practice the number of effective irrigation hours per day should not be under 12.

Operational pressure of the sprinklers depends essentially on the spacings. Large spacings require higher pressures in the magnitude of 4 to 5 bars. In sites where energy is expensive and where water must be pumped from deep wells high pressures are not economical. Medium pressures of 2 to 3 bars are the most commonly used. Low pressures of 1.5 - 2 bars can be used in conjunction with small spacings for vegetables or in orchards. Irrigation under the leaves is always recommended when the irrigation water is brackish.

The frequency of irrigation is determined by the low water holding capacity of sandy soils. Rotations will therefore be relatively high, from a few days to a week, depending on the soil characteristics and the root depth of the crop to be irrigated.

All sprinkler irrigation systems can be improved in order to reduce the manual labour requirements. The field equipment may be mobile, semi-permanent or completely permanent; motorization of shifts can be introduced by using tractors and trailers, or self-propelled lines. Automation of irrigation may also be introduced by the use of automatic metering valves or even computer monitoring but all these improvements increase the installation costs considerably. Their use will be limited to high return crops or to special cases where insufficient manual labour is a major constraint. In governmental projects it is better to start the irrigation developments with the simplest equipment which can be well handled and understood by the farmers and to let each farmer improve his own system as his financial capabilities increase.

6.3.3 Drip Irrigation

Drip irrigation is one of the latest irrigation methods to be developed. Although it has been known for many years it was only used in very special cases by some horticulturists and nursery gardeners. Its application at the farm level became possible by the extensive use of polyethylene plastics in manufacturing the various components of the equipment. This reduced its cost which, although rather high, is now acceptable for some crops. Trickle irrigation really started in agriculture less than 10 years ago. Israel already claims to have 10 percent of its arable land (around 1 500 ha) irrigated in this way. At present the method is developing quite rapidly, especially in the U.S.A., Australia, South Africa and Mexico. Other countries have shown a definite interest in the method, mainly Senegal (200 ha in just one farm), Italy, U.K., France, Spain, Tunisia, Lebanon, and probably many other countries. Several FAO projects have experimental plots equipped with drip irrigation. These are in Senegal, Spain and Tunisia where the method is going to be tested on olive trees. The real success of this new method is based on a certain number of advantages which are claimed by the enthusiastic promoters of the method: water saving, higher yields, utilization of brackish waters, manual labour extremely reduced, decreases in diseases, weed control etc. In fact most of these promising results have been obtained in experimental conditions by highly qualified specialists. Comparative field trials are still too few to say in what proportion these advantages are applicable to large scale irrigation. The method is still in its initial stages and many developments are expected in the near future. The Americans are developing various systems among which is one without drippers consisting of a double wall perforated pipe; the French are promoting a system in which the water is distributed into a large furrow by a perforated pipe; the Italians are experimenting some very ingenious devices. Nevertheless the method most widely used consists of small tubes along which are the drippers (or tricklers, or emitters).

The dripper is a small device that allows the water to discharge from a lateral supply line at a very low and constant rate, from 2 to 10 l/hour. As water flows out of a dripper it moistens the soil surface in a circle and the underneath layers according to a bulb shaped volume. The spacing of the drippers along a line should permit the various wetted bulbs to come into contact with one another. The flow and spacing of drippers are determined by field tests.

In sandy soils the wetted bulbs under the drippers are narrow and deep. Since the wetted bulbs should be in contact with one another along the lateral lines their number will be high. The cost of equipment, which is proportional to the length of pipes and number of drippers, will then be high and in the magnitude of US $ 1 700 to 2 000 per ha not including the pumping plant. These systems usually operate at a low pressure of 1 to 1.3 bars.

The spacing between the lines will depend on the type of crops irrigated. If the rows are very close, such as in the case of vegetables, a line for every two rows may be sufficient. On the contrary if the rows are very far apart, such as in the case of orchards, it may be necessary to install two or more lines per row of trees. In any case drip irrigation is most convenient for row crops.

The water savings come from the fact that there is a non-irrigated zone in between the lines. But the consumptive use of a crop being a factor independent from the type of irrigation used the water savings are not as high as often claimed. In fact deep percolation may occur along the lines and irrigationists recommend designing the systems with an 80 percent application efficiency.

The irrigation water must be filtered to prevent the clogging of drippers. Brackish water may be used because the roots of the plants develop inside the wetted bulb where the salt concentration stays constant and equal to that of the irrigation water itself. The salts tend to accumulate in the outer parts of the wetted bulb and often white circles denoting the presence of salt can be seen on the soil surface. The excess salts must be leached either in a natural way by the winter rains or artificially with a spare sprinkler irrigation set when rain is not sufficient.

6.4 IRRIGATION EDUCATION

A well designed irrigation scheme may not yield the expected returns if water is not managed in the proper way by farmers. This may be even more true in the case of sandy soils for which irrigation must be handled with special care. The human aspect is often unduly disregarded during the planning period whereas it plays a decisive part during the whole lifetime of a project. Most farmers have no precise idea of the relationships existing between the consumptive use of water, the rate of infiltration, the water storage capacity, etc., in a soil. Their only guide lies in traditions, instinct and sometimes wrong beliefs. They know when the plants need to be irrigated because they see them wilt but they are not too versed in the idea of how much is needed or how much is applied. Errors leading to over-irrigation and wastage of water occur just because of lack of knowledge. It is therefore necessary to provide these farmers with the minimum knowledge that they need so badly. This of course can only be done by an intensive educational programme comprising demonstrations, advice, rewards, etc., carried out by a well organized extension service. The extension workers to be efficient should receive special training in the irrigation of sandy soils based on a very good knowledge of the local soil conditions.

6.5 CONCLUSION

Sandy soils have a low pore space and a high infiltration rate. The consequences of these two features on irrigation systems and methods are of paramount importance.

The low pore space is responsible for a low water holding capacity. Consequently the frequency of irrigation and the labour requirements are high independently of the irrigation method used. Labour requirements can be reduced but the initial cost of equipment is then considerably increased.

The high infiltration rates make surface irrigation very difficult as an important task is to avoid losses when applying water to the fields. The adaptation of surface irrigation, when possible, requires higher investment costs for increased length and size of canals, canal lining, large number of small plots and eventually special on-farm equipment.

On the contrary high infiltration rates have little influence on sprinkler irrigation. This method can therefore be considered as the best for sandy soils. It will lead to acceptable efficiencies if properly designed and managed.

Drip irrigation is a promising method but its cost is still quite high. It is recommended to set up field trials before embarking on large scale developments with drip irrigation.

In any case irrigation of sandy soils requires a good deal of knowledge and skill. Guidance should be provided to farmers by a well organized irrigation education programme.

DRAINAGE OF SANDY SOILS

by

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SUMMARY

Sandy soils are found in deserts as well as in valleys, alluvial fans and deltas. In the lowlying areas they may have natural high watertables, and irrigation usually results in the need for drainage.

The type of drainage to be applied depends largely on the type of sand. Sands may be coarse and pervious or fine and containing some silt and clay particles which may make it less pervious. Such other physical characteristics as infiltration rate, water retention and effective porosity differ widely from one type of sand to another and have a great impact on the design drainage rate. In general designed sub-drainage systems will tend to be deep and relatively narrowly spaced on fine sands that have a high silt and clay content, whilst they may be shallower and more widely spaced as the coarseness of the sand increases and silt and clay decrease. Surface drainage may be important on soils that run together easily on wetting. Vertical drainage possibilities may be limited by low soil permeability.

Fine sands are often layered and may contain thin layers of silty or poorly pervious materials. The horizontal permeability of such a soil is usually much greater than the vertical permeability. Subsurface drainage systems should permit and promote the lateral flow of perched water through the more pervious layers to the drains. When pipe drains are used, care should be taken to use backfill material that remains permeable through which water may reach the drains.

Cover or envelope materials should be well selected in relation to the type of sand. Indications are that there is no difference between the performance of plastic and clay or concrete pipes when adequate cover materials are used and when pipes are laid under favourable working conditions. It appears, then, that it is the combination of pipe and cover materials in relation to the soil type, rather than the pipe only, that governs the drain performance. Thin sheets of fibre glass appear unsuitable as cover material. More voluminous materials would seem preferable but a series of practical tests is needed for a more accurate basis for advice.

Open ditch drains in unstable sands, especially in salty areas, are very difficult to maintain. The installation of pipe drains in these soils, however, is not always easy. The sand may run into the ditch before the drainpipe has been blinded or filters have been placed, causing displacement of the pipes. The problem is not easy to solve without high monetary expenditures. Using plastic pipes that have been prewrapped in the plant, or that are simultaneously provided with cover material by the trenching machine will in many instances facilitate the installation and reduce the risk of failure.

7.1 NEED FOR DRAINAGE

Sandy soils are not only found in desert areas but valleys and flood plains, alluvial fans and deltas also normally contain sandy deposits. They are found in old stream beds, in lenses, in stratified profiles and in deep extensive layers.

Not all of them are in need of drainage. Sandy soils along streams and river ridges may have adequate natural drainage under good irrigation practices. Parts of the sandy areas in alluvial fans may have deep watertables and sufficient groundwater drainage toward lower parts of the fan.

Pervious sands may overlie relatively impermeable fine textured soils. Upon irrigation a perched watertable may be formed which can be lowered by a drainage system. Such soils may be found in transitional zones between deserts and deltas, coastal and other plains, valleys or smaller topographical depressions.

7.2 TYPES OF DRAINAGE

From a theoretical point of view the drainage of sandy soils does not basically differ from that of more finely textured soils. The mathematical expressions describing groundwater flow to parallel drains apply equally well or equally poorly, depending on whether the soil profile lends itself to a realistic simplification to suit the expressions. The problems of hydrologic simplification are probably no more or less complicated than for other types of soil. Both clayey and sandy soils may have a high or low hydraulic conductivity or permeability. They may be deep and uniform or shallow and layered. Especially on the latter type will it be difficult to describe water flow in quantitative terms, and a drainage system design will need to be largely based on practical experience.

Coarse textured sandy soils generally have a high hydraulic conductivity. Surface runoff following rain or irrigation will be small or absent altogether. Drainage of these soils, therefore, is a matter of watertable control. Whether this is to be achieved by interceptor drains, by a grid system of drains or by pumping from wells depends on the prevailing topographic, hydro-pedologic, climatic and economic factors. A coarse sand does not automatically imply that vertical drainage will be applicable. Much depends on the depth of the profile, the presence of poorly pervious, cemented materials and deeper aquifer systems. Fine sandy soils may be in need of surface drainage, especially when the surface soil runs together during rains or when poorly pervious materials occur close to the ground surface. Vertical drainage possibilities may be limited by low permeability of the soil.

7.3 CHARACTERISTICS OF SANDY SOILS IN RELATION TO DRAINAGE

Though the planning of drainage systems in sandy soils does not basically differ from that in other soil types, sandy soils have a few rather special qualities that should be taken into account. The discussion of these and their effects will be limited to soil profiles that are sandy from the ground surface down to at least the depth of subsurface drains, about 2 metres.

7.3.1 Swelling, cracking, compressibility

The clay content of sandy soils is low and the expansion of clay minerals on wetting (if any) will have little impact on the profile. Sandy soils are hard to compress and very little cracking occurs during drying.

These features contribute largely to the stability of the larger pores through which saturated water movement takes place. Therefore, apart from those parts of the soil profile that are subject to mechanical impact, that is by flowing water and raindrops, the hydraulic properties of sands may be considered as fairly constant.

A practical consequence of the low compressibility of sands is that trenchless drainage machines, which operate on the basis of forming a mole by pressing soil outwards, may be less suitable for sands.

7.3.2 Permeability

The permeability of sandy soils may vary from as low as a few centimetres per day to as high as tens of metres per day. The lowest permeability is usually found in very fine loamy sands and sandy loams. It follows that the density of a subsurface drainage network in sands is not necessarily low. On the contrary, the drains will sometimes have to be narrowly spaced, which renders the system expensive. Coarse sands, on the other hand, are usually quite pervious and generally require widely spaced drains.

The measurement of permeability of sand in situ is not an easy task as the walls of boreholes easily cave in and may need to be protected by special filters. The evaluation of the result of measurement may be complicated by the layering of the profile. A high permeability measured in layered sand may result from the contribution made by a tiny layer of coarser materials and provides little information on over and underlying strata. Permeability measurements, therefore, should always be coupled with profile studies in pits. It is noted that the permeability of nearly pure sands may also be calculated from grain size analyses.

7.3.3 Infiltration rate

The infiltration rate is usually high on coarse sands. On fine sandy to loamy soils, especially those that are unstable, the infiltration rate may be considerably reduced when the surface soil runs together following wetting. This easily occurs in arid and semi-arid areas where the soils contain little organic matter. Rains, as a consequence, may start flowing overland and a surface drainage system may be required on sloping lands. The irrigation efficiency may also be affected by unstable surface soil and this, in turn, will influence the required subsurface discharge rates.

7.3.4 Soil water retention

Sandy soils in arid and semi-arid zones where the organic matter content is low usually retain little water. Whereas the available water in clayey soils is normally in the range of 10-20 percent on a dry weight basis, it is often less than 10 percent in fine sands and loamy sands. Coarse sands may retain less than 5 percent of water.

These differences in waterholding capacity strongly affect the timing of irrigation and the depth of water to be applied. Both factors are an influence on the volume and rate of water losses. As a general rule, the coarser the soil the lower the application efficiency and the more water must be drained through the subsoil. Under specified conditions, however, sprinkler and other special systems of irrigation may be applied and they result in considerably smaller losses. This is mentioned further in paper III.6 Irrigation of Sandy Soils.

In more humid areas where irrigation is supplemental in character, sandy soils are often drought sensitive. Rapid drainage increases the need for irrigation. To save on irrigation water the drains are sometimes wholly or partly blocked in early spring, causing the watertable to drop more slowly. Thus plants may obtain a larger portion of their needs from groundwater.

7.3.5 *Porosity*

The porosity or drainable pore volume refers to the volume of water released or taken up by a unit volume of soil in the zone which may be under the influence of a fluctuating watertable. This latter zone in a well drained irrigated soil is found roughly between 1 and 2 metres in depth. Pore size is greater in sandy than in clay soils; this results in larger channels for water conveyance through coarse soils than through fine textured ones. This characteristic is of considerable importance for the establishment of design criteria, as will be discussed later.

7.3.6 Structure stability

Sandy soils are often unstable, which consequently requires that side slopes of ditches and canals be relatively flat, 1 : 2 or 1 : 3, and flow velocities low.

Flat side slopes imply that much land is lost to agriculture, especially when drain spacings are close. An open field ditch 1.5 m deep in sandy soils may easily have a top width of 10 m. Land loss and high maintenance costs of open ditches make it attractive to install pipe drains in sandy soils.

7.4 DESIGN DISCHARGE RATE AND DRAIN DEPTH

Since the pore size of sandy soils is large, the watertable rise following irrigation or rainfall may be relatively small. It will be limited to 15-30 cm for a soil at field capacity before water application, having an effective porosity of 10-20 percent and deep percolation losses of 30 mm per application. Such losses easily result from surface irrigation methods if 100 m of water are needed per application to cover crop requirements and the field application efficiency is 60-65 percent.

Similarly, the drainage of 30 mm of water will also cause only a slight lowering of the watertable. The coarser the soil, therefore, the smaller the watertable fluctuations for a given set of recharges and discharges.

In humid areas the drain depths do not vary much with the type of mineral soil. The small watertable fluctuations imply that for a given set of recharges stemming from rainfall,the watertable will not attain a certain high level as frequently as on finer textured soils. As a result the design discharge rate may be smaller resulting in wider drain spacings.

In irrigated areas the drainage rate is also affected by the storage capacity but the conditions of recharge and discharge are now slightly different. Irrigation deep percolation losses and the required leaching are normally drained off before the next water application. These losses cause relatively small fluctuations of the watertable in soils having large pore spaces. As a consequence the average hydraulic head will tend to be higher during the peak irrigation season and so will the discharge rate. A wider spacing would therefore be theoretically justified. In practice, however, the difference often appears to be small. The usually lower farm irrigation efficiency on coarse soils and the subsequent higher losses may even lead to closer spacings.

The small watertable fluctuations on coarse textured soils make it possible to place the drains at a higher level without running the risk that the watertable would exceed a predetermined highest level. Losses of 30 mm cause the watertable to rise by 15 cm on sands whereas it may be 60 cm on fine sandy loam soils. With a higher allowable level of 1 m, and adding a 20 cm "rest value" to the hydraulic head, the drain depths should be at least 1.35 m and 1.80 m respectively. Obviously when drain depths are raised the drain spacings will need to be closer.

It will not always be practical to install drains at higher levels in sands. First deep drains provide the advantage that the watertable will not rise to its highest permissible level after one irrigation. The watertable could be allowed to rise gradually and reach its highest level in the peak irrigation season. As a consequence not all water losses need to be drained off between two water applications. The design discharge rate, therefore, can be lower and the drain spacing may be made somewhat wider.

A second reason to keep the drains deeper is related to capillary phenomena in fine sandy loam soils. Whereas capillary water does not rise high in coarse sands there may be considerable upward flow to heights of over 50 cm above the phreatic level in fine sandy loam soils. The danger of capillary salinization is therefore greater in these latter soils and deep watertables are preferable. A drain depth of at least 2.0 m would seem practical whilst it may be as little as 1.4 m in coarse sands.

In conclusion, the type of sandy soil, its physical characteristics and the method and practices of irrigation appear to have a considerable impact on the design discharge rate and the drain depth.

In general, drainage systems will tend to be deep and relatively narrowly spaced on fine sands that have a high silt and clay content, whilst the drains may be shallower and more widely spaced as the coarseness of the sand increases.

7.5 DRAINAGE OF LAYERED SANDS

Sandy profiles, though they may look fairly homogeneous at first sight, often appear to consist of layers that differ widely in physical hydrological properties. There may be thin layers of finer sands that are more silty and whose permeability is low, or there may be small layers of cemented materials which are almost impermeable.

The horizontal permeability of such a layered soil is usually much greater than the vertical permeability. As a result, the "internal" drainage of the soil may be slow and perched watertables may develop after irrigation or rains.

The internal conditions may sometimes be improved by such soil amelioration measures as subsoiling, deep ploughing, etc. In some instances, adapted cultural practices may help improve water percolation.

Subsurface drainage systems should permit and promote the lateral flow of perched water through the more pervious layers towards the drains. This requirement is met by open ditch field drains in which water can flow out freely.

When pipe drains are used, the trenches should be filled with pervious material to ensure that perched water can move rapidly downwards in the trench to reach the drain. As in some stratified heavy clay soils, the satisfactory functioning of the drainage system may depend largely on the possibility of water flow in the backfill. Trenchless pipe-laying techniques, therefore, should not be used on such soils before their applicability has been demonstrated in field trials.

7.6 PIPE DRAIN AND COVER MATERIALS

The costly and difficult maintenance of open ditch drains in unstable sands makes it often attractive to use pipe drains.

Opinions differ as to the suitability of clay or concrete and plastic pipes for various types of sandy soils. Experiments in several countries indicate that clay or concrete pipes would be preferable to plastic pipes of the same inner diameter where no or inadequate envelope material is used or where the pipes are laid under unfavourable weather conditions1/. This applies notably to fine sandy loam soils and is largely due to differences in circumference between clay and concrete pipes on the one hand and plastic on the other. Increasing the diameter usually leads to improved flow conditions in and around the pipe. Considerations of pipe strength and cost, which increase with diameter, have in many countries resulted in the tendency to keep plastic pipes small.

Where adequate envelope materials are used and pipes are laid under favourable working conditions, i.e., no rain and watertable below the trench bottom. it is believed that clay, concrete and plastic pipes are equally suitable. It appears, then, that it is the combination of pipe and envelope materials in relation to soil type rather than the pipe only that governs the performance of the drains. Such combinations have been studied in several countries but it is often difficult to compare the results due to variations in climatic, topographic and soil conditions. Moreover, there is no uniform methodology for the investigations and experiments which renders evaluations of results difficult. Standardization of test procedures and processing techniques is very desirable.

Provisional experience with plastic pipes indicates that corrugated pipes have a good inflow capacity. It would seem however, that their transport capacity is slightly lower than that of smooth plastic pipes. Larger diameters are needed which can be used for main drains as well as laterals.

Envelope materials are permeable materials placed on and around the drainpipe to prevent the finer particles of surrounding soil from being washed into the drain and to improve the flow conditions around the pipe. It is particularly important to prevent deposits in the drains in sandy soils of flat areas. The slope of the drains in such areas is small and the deposited particles - especially the silty and larger ones - cannot be flushed out easily. Application of adequate cover material is therefore indispensable.

There is a great variety of materials being used in various countries: sand and gravel, fibrous peat, shells, flaxband, fibreglass, plastic fibres. The type that functions best for a certain type of soil depends largely on the qualities of that soil.

Experience shows that thin sheets of fibreglass become easily clogged by the finer soil particles and are not usually considered successful in fine sandy soils. Fibreglass sheets may do well, however, on coarser textured soils that contain few fine particles. Fibrous peat appears to be effective under a variety of conditions and so do other more voluminous materials.

To enable further mechanization and also prewrapping of pipes, some materials are combined with carrier-layers of various fabrics into bands. Experience gained so far with flaxband (about 2 cm thick) seems promising. In arid lands sands and

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1/ Drainage Materials, Irrigation and Drainage Paper No. 9, Water Resources and Development Service, FAO, Rome 1972 gravels are locally available and are much used cover materials. They are considered highly effective when well designed, that is when their gradation characteristics are designed for the soil to be drained. Handbooks on drainage engineering usually contain the specifications.

7.7 INSTALLATION OF PIPE DRAINS

Sandy soils often present special problems during the installation of pipe drains: the side walls of the trench tend to cave in easily; sand may run into the trench before the drainpipe has been blinded or filters have been placed. This may cause the drain to be displaced. Blinding is done to protect the drain line against the excavated soil when this is pushed back into the trench. In humid areas, when the topsoil is stable and pervious, the upper part of the trench is shaved off and placed on the drain for that purpose. Caving in may occur in dry sandy soils as well as in wet sands. It happens more easily and rapidly when the watertable at the time of installation is above the drain.

The problem is not easy to solve. Often the protective shield at the rear of the pipe laying machine is made longer, but on modern machines that have a higher working speed this does not always solve the problem. Using plastic pipes that have been prewrapped in the plant or that are simultaneously provided with a filter by the trenching machine will in many instances facilitate the installation and reduce the risk of failure.

In spite of some problems, pipe drainage appears to be the predominant future system of farm drainage throughout much of the Near East area. Bearing this in mind, programmes for solving problems and answering questions still to be asked concerning pipe drainage are necessary for a continuation of successful agriculture in the Region.

III.8 USE AND MANAGEMENT OF SANDY SOILS IN CYPRUS

by

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SUMMARY

Sandy soils in Cyprus are very limited in extent and amount to approximately 9 000 ha representing only 1% of the total area of the island or about 2% of the cultivated land.

Airborne sand depositions lie on various geological and soil formations and vary considerably in thickness. These are mainly calcareous (10-30% $CaCO_3$) and poor in organic matter (< 1%).

Systematic observations on the distribution of citrus roots in the Morphou area have established that fine roots (< 1 mm in diameter) are more uniformly distributed in sandy profiles than in fine textured ones. In addition the total number of fine roots in a sandy soil is double that occurring in a fine textured soil. Citrus orchards established on sandy soils usually yield 20-30% more than those on fine textured soils.

It has been experimentally established that saline water (EC 4-5 mmhos/cm, chloride concentration 1200-1400 ppm) may be used for irrigating orange trees on sandy soils without obvious adverse effects on the yields. The absence of salinity damage was apparently due to the frequency of irrigation at 50 mm evaporation and the winter rainfall.

The predominant irrigation systems for citrus and vegetables grown on sandy soils are the border strip irrigation and the hose short-furrow or trickle, respectively. Efforts are being made to replace the border strip irrigation with improved systems such as pipe basin, hose basin, sprinkler or trickle.

Crops grown on sandy soils respond to nitrogen and phosphorus and to a lesser extent to potassium. Zinc and manganese deficiencies have been observed on sandy soils as well as on heavier textured soils. Farmyard manure is commonly used but green manure and other organic sources are also applied on a smaller scale.

The main sources of nitrogen, phosphorus and potassium are chemical fertilizers and under irrigation there is a downward movement of soluble nutrients such as nitrates and potassium and, therefore, frequent low rates of these nutrients are more efficiently utilized.

8.1 LOCATION, EXTENT AND USE OF SANDY SOILS

Cyprus is the third largest island in the Mediterranean with an area of 3 572 mi^2. The climate is typically Mediterranean with hot, dry summers and mild wet winters.

Sandy soils occurring in Cyprus are almost exclusively of aeolian origin. There are, however, a few isolated patches of alluvial sand depositions in some plains and valleys. These cover but a very small percentage of the total area of sandy soils.

Airborne sand depositions mostly occur in narrow coastal strips around the island. The most extensive area of sandy soils is confined to the north-western part of the island around the villages of Morphou and Ayia Irini and along the eastern coast around Famagusta town (Fig. 1). In some instances, airborne sand in Morphou extends inland to 10 km from the coast. An extensive area of sandy soils near Morphou was occupied by low sand dunes which were levelled down and brought into cultivation by farmers of the region, over 30 years ago.

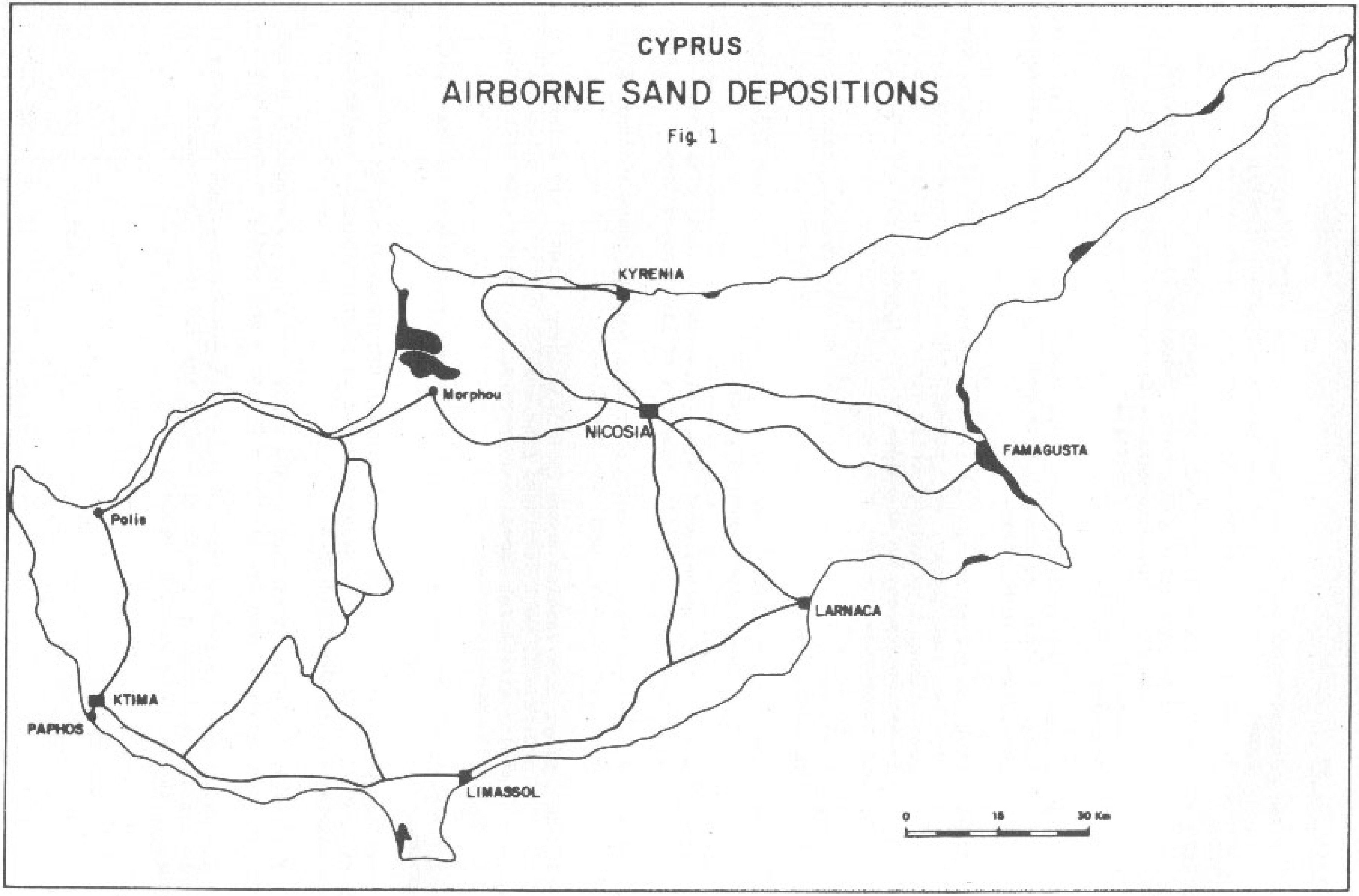
The total area of sandy soils amounts to approximately 9 000 ha representing only 1% of the total area of Cyprus or about 2% of the cultivated land. Out of these, approximately 2 500 ha are forest land under pine (Pinus pinea and P. brutia) and acacias (Acacia cyanophylla) and 4 000 ha are cultivated with citrus, cereals and vegetables. Early vegetables under plastic cover are produced in such soils in the coastal strip, south of the town of Famagusta. Most of the remaining 2 500 ha are stabilized and fixed by various types of vegetation such as Juniperus, Cistus, Pistacia lentiscus etc., and, therefore, any movement or encroachment of sand over the cultivated areas is negligible. In some special cases the private sector is allowed to exploit the sand for construction and other purposes. It is worth mentioning that many citrus producers in Morphou place a thin layer of salt free sand on top of heavy textured soils. Through this "mulching", soil moisture evaporation is reduced and fine roots, developing near the surface which normally would have been destroyed by ploughing, may now develop freely, hence making better use of water and nutrients. In addition, the damage caused to the fine roots by the cracking of heavy textured soils is very much reduced. This practice, therefore, contributes to a better and faster development of the trees with a favourable effect on yield performance.

8.2 MORPHOLOGY, MINERALOGY, PHYSICAL AND CHEMICAL PROPERTIES OF SANDY SOILS

Blown sand deposits vary in thickness from a few centimetres to a few metres, overlying various geological or soil formations. The geological formations occurring along the coast and overlain by sand deposits are mostly surface limestones and calcarenites of the Pleistocene age. The soils overlain by sand are almost exclusively of alluvial origin in the Morphou area, whilst in Famagusta, red soils of rather heavy texture are often found at some depth. The texture of the buried alluvial soils varies from sandy clay loam to clay. Older airborne sand depositions may also be overlain by more recent alluvial ones of variable texture. Intercalation of thin soil layers or isolated soil pockets heavier in texture may also be observed frequently within the sandy profile.

The description of a sandy profile occurring in an 11 year old grapefruit orchard in Morphou is given below:-

CYPRUS
AIRBORNE SAND DEPOSITIONS
Fig. 1



Profile No. S8

0 - 8 cm	Coarse loamy sand, dull yellowish brown (10YR 5/2.5); dry, very friable, very weak fine and medium subangular blocky, with tendency to single grained structure; no roots, gradual boundary.
8 - 27 cm	Coarse loamy sand, dull yellowish brown (10YR 4/3); just moist, friable to slightly hard, becoming loose on moistening, very weak structure with massive appearance due to slight mechanical compaction; porous, abundant citrus roots, gradual boundary.
27 - 57 cm	Coarse loamy sand, dull yellowish brown (10YR 5/3.5); moist, loose single grained; abundant citrus roots, faint lime veins throughout, porous gradual boundary.
57 - 77 cm	Fine sandy clay loam, dull yellowish brown (10YR 5/4); moist, very friable, weak blocky; very porous, few lime veins and many lime concretions; many citrus roots, clear smooth boundary. (This layer is not continuous in all sides of the pit but it is often replaced by the overlain sandy layer).
77 - 99 cm	Loamy sand, dull yellowish brown (10YR 4/3); moist, loose, single grained; few pores, many roots, diffuse boundary.
99 - 134 cm	Coarse sand to loamy sand, dull yellowish brown (10YR 4/2.5); very moist, loose, single grained, few roots.
134 - 137 cm	A very thin discontinued layer (alluvium). Sandy clay loam, yellowish grey (1YR 5/3); presence of lime concretions.
137 - 162 cm	Patchy appearance of sandy clay loam soil as above intermixed with coarse loamy sand; few roots.
162 - 180 cm	Clay, dark reddish brown (5YR 3/3); very moist, very friable, moderate to well developed fine angular blocky with slightly shiny structural faces; very porous, many faint lime veins, few fine roots.

The analytical results and soil moisture characteristics of the same profile are given in Tables 1, 2 and 3.

The infiltration rate is very high and amounts to about 120 mm/h. The apparent specific gravity of the sandy horizons is around 1.5 g/cc whereas that of the heavier layers about 1.3 g/cc.

The prevailing clay, contained in the sandy horizons, as suggested by the Cation Exchange Capacity results, is of the 2:1 type and mostly montmorillonite.

The water used for irrigating the grapefruit grove comes from a private borehole and the watertable lies at 24 m below the surface. The chemical analysis of the water is given in Table 4.

Table 1 MECHANICAL ANALYSIS, pH, LIME AND ORGANIC MATTER MATTER DETERMINATIONS OF SOIL PROFILE No. S8

Depth in cm	Moisture content %	Clay %	Silt %	Coarse sand %	Fine sand %	$CaCO_3$ %	Active lime %	pH	Organic matter %
0- 8	2.7	13.2	6.8	46.4	30.8	12.57	65	8.4	1.04
8- 27	2.3	13.2	4.8	52.8	26.8	12.57	60	8.7	-
27- 57	2.5	13.2	4.8	51.4	28.0	15.50	60	8.9	-
57- 77	2.5	20.2	12.8	24.6	39.8	18.70	80	8.7	-
77- 99	2.3	11.2	6.8	49.8	29.8	12.12	70	8.8	-
99-134	3.0	9.2	3.8	56.0	27.8	13.53	50	8.9	-
137-162	2.9	23.2	12.8	27.6	33.4	12.12	70	8.7	-
162-180	3.0	47.2	15.8	6.6	25.6	2.38	75	8.6	-

Table 2 SOIL MOISTURE CHARACTERISTICS OF THE SOIL PROFILE NO. S8

Depth in cm	Field Capacity (on dry weight basis)			P.W.P. (on dry weight basis) 15 Atm pressure %
	1/3 Atm pressure %	Moisture Equivalent %	Gravimetric moisture determination %	
0- 8	10.20	12.22	10.34 (0–27)	4.51
8- 27	8.83	10.68		5.02
27- 57	8.74	10.07	13.00	5.33
57- 77	13.69	16.41	10.22 (57–99)	7.09
77- 99	7.85	8.92		4.07
99-134	4.61	4.88		2.19
137-162	14.70	17.89		9.14
162-180	29.50	30.16		18.92

Table 3 CHEMICAL ANALYSIS OF SOIL PROFILE No. S8

Depth in cm	pH	Soluble salts in ppm									Exchangeable bases meq per 100 gr soil				C.E.C.
		Cl^-	SO_4^{--}	CO_3^{--}	HCO_3^-	Ca^{++}	Mg^{++}	Na^+	K^+	ECe in mmhos/cm	Ca^{++}	Mg^{++}	Na^+	K^+	
0- 8	8.4	107	358	Nil	960	250	66	160	57	1.58	5.5	6.5	1.09	0.62	13.7
8- 27	8.7	107	41	Nil	960	208	31	125	50	0.80	5.0	3.0	0.98	0.50	9.5
27- 57	8.9	107	20	Traces	912	200	36	100	52	0.75	0.9	6.0	1.09	0.50	8.5
57- 77	8.7	143	195	"	864	220	48	160	16	1.40	6.0	6.0	1.30	0.25	13.5
77- 99	8.8	143	164	"	864	232	43	140	16	1.10	5.1	4.0	1.30	0.18	10.6
99-134	8.9	107	143	"	864	220	36	130	18	1.20	0.3	5.5	1.09	0.18	7.0
134-162	8.7	143	348	"	864	210	59	220	26	1.90	9.8	5.0	1.52	0.31	16.6
162-180	8.6	251	369	"	912	210	47	340	22	2.05	25.9	2.5	0.87	0.12	29.4

Table 4 CHEMICAL ANALYSIS OF WATER (No.S8)
Date of Sampling 29.9.73.

		meq/l
Cl^-	265 ppm	7.5
SO_4^{--}	300 ppm	6.2
CO_3^{--}	traces	
HCO_3^-	201 ppm	3.3
Ca^{++}	131 ppm	6.5
Mg^{++}	56 ppm	4.5
Na^+	135 ppm	6.0
K^+	2 ppm	
EC	1.413 mmhos/cm	
Boron	0.09 ppm	
pH	8.0	
S.A.R.	2.6	

According to the Agriculture Handbook No. 60 of the U.S. Salinity Laboratory Staff this water is classified as "High-Salinity and Low-Sodium Water". In the same Handbook it is stated that "even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected". There is in fact a slight salt accumulation in the deeper horizon between 162-180 cm which is due to the fine soil texture of this layer, however, it is emphasized that the overall appearance and performance of the grapefruit trees growing on this soil and irrigated with such water is absolutely first class.

As will be pointed out later in this paper, most of the fine citrus roots develop within the first 60 cm of soil. It is therefore obvious that in this particular orchard, salt accumulation in the deeper layers apparently could not affect adversely the performance of the citrus trees.

In order to follow the vertical movement of water in this orchard, three tubes each 180 cm long, were placed in the same irrigation strip, 20 m apart. It should be mentioned that the border strip irrigation method is followed in irrigating this orchard. Soil moisture content was measured by the neutron probe and readings were taken at 15 cm vertical intervals in each tube.

Four measurements were taken:

i. just before irrigation
ii. one day after (the soil considered to be at field capacity)
iii. three days, and
iv. nine days after irrigation.

The graphs obtained from the three locations (Fig. 2), indicate that some differences in the soil moisture content in corresponding soil layers exist. These may be attributed to differences in soil texture in the three locations. Movement of water appears to follow a uniform pattern in all three locations. However, at the locations B (centre of strip) and C (lower end of strip) an inconsistency in the pattern of the soil moisture content below 120 cm may be observed for the first day after irrigation curve. The explanation offered is that the time period between irrigation and moisture measurement (one day after irrigation) might not have been sufficient to allow for the moisture to reach below the 120 cm depth.

Another selected sandy soil profile is that of the Famagusta Government Nursery. On this nursery, an experiment on irrigation of Shamouti Oranges with saline water which will be discussed in detail in the next chapter, has been carried out by the Cyprus Agricultural Research Institute. Sand to a depth of 180 cm has been deposited on top of a red clayey soil. The structure of the sand is single grained and horizons cannot be differentiated. The sand is mainly coarse and reddish in colour (7.5YR 5/6). Calcium carbonate content amounts to approximately 25% in the sand but it drops down abruptly to about 3% in the heavier layers and even to almost nil in deeper horizons below three metres.

The mechanical analysis and other relevant data for this profile are given in Tables 5 and 6.

Table 5 TEXTURE, pH AND LIME CONTENT OF THE SOIL PROFILE, FAMAGUSTA GOVERNMENT NURSERY

Depth cm	Clay %	Silt %	Coarse sand %	Fine sand %	$CaCO_3$ %	pH
0- 30	5.8	1.1	69.8	23.3	23.9	8.0
30- 60	5.3	0.5	72.2	22.0	24.7	8.4
60- 90	5.1	0.2	74.5	20.1	26.1	8.6
90-120	4.8	0.3	71.2	23.5	26.1	8.7
120-150	5.2	0.3	71.5	23.0	25.9	8.8
150-180	5.5	0.9	67.5	26.0	26.5	8.8
180-210	40.8	9.7	25.1	24.4	2.9	8.2
210-240	56.0	8.7	19.1	16.6	3.1	8.0
240-270	54.0	7.6	21.0	17.4	3.5	7.9
270-300	46.2	7.3	25.4	21.0	2.9	7.6
300-330	38.0	5.2	34.0	27.3	0.3	7.6
330-360	32.2	3.9	32.7	31.3	0.1	7.7

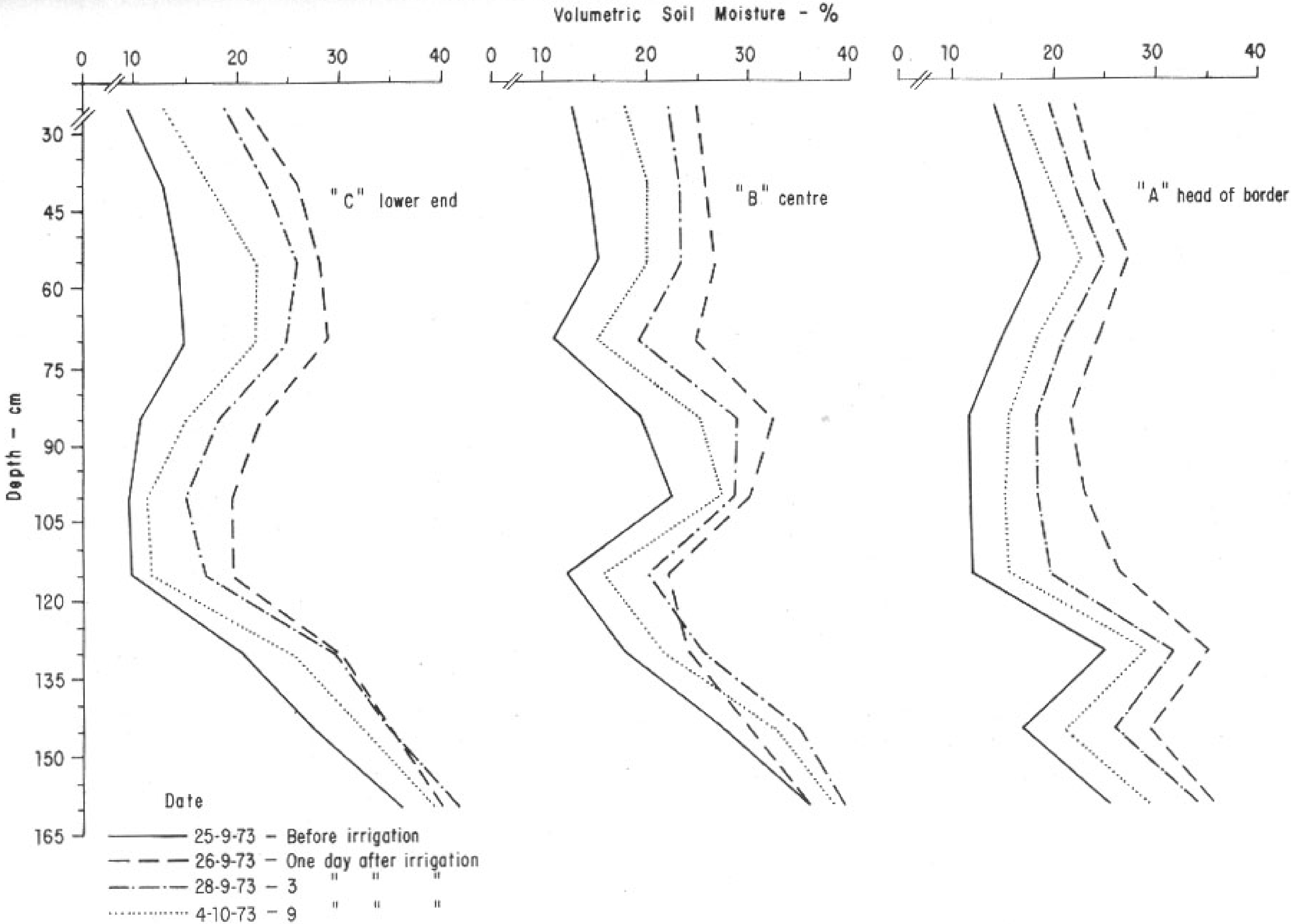


Fig. 2 SOIL MOISTURE CHANGES IN BORDER IRRIGATED GRAPEFRUIT, PAPETTAS GROVE, S8, MORPHOU
Source: Cyprus Agr. Res. Inst.

Table 6 MOISTURE CHARACTERISTICS OF THE SOIL PROFILE FAMAGUSTA GOVERNMENT NURSERY

(Average Values for the 0 - 180 cm profile)

Field Capacity 1/	(24 hours (after irrigation	8.8% (dry weight basis)
	(48 hours (after irrigation	7.5%
Water held by soil at:		
0.1 atm tension		4.8%
1 atm tension		3.4%
5 atm tension		3.0%
9 atm tension		2.8%
13 atm tension		2.5%
15 atm tension 2/		2.4%
Average bulk density 3/		1.6 g/cm^3
Available water capacity 4/		1.0 inch/foot

1/ determined on bare soil

2/ determined by the pressure membrane apparatus and confirmed by the sunflower method

3/ determined by the gamma density probe and confirmed by sampling undisturbed soil cores

4/ difference between field capacity (48 hours after irrigation) and water held by soil at 15 atm tension.

A detailed microscopical study of four samples of sandy soils taken from Morphou and Famagusta areas has revealed the presence of both light and heavy minerals in all samples. Light minerals identified include calcite and some flakes of gypsum as well as traces of quartz. Heavy minerals identified consist of iron oxides (mainly magnetite and subsidiary limonite) and remnants of intensively corroded pyrite partly altered to limonite. In addition pyroxenes have also been identified.

More analytically the results are as follows:

Code No.		Calcite	Iron Oxides	The rest of the samples
I Angoulos	Morphou	24.20%	5.26%	It mainly includes ferromagnesian and clay minerals
II Red sand	Morphou	23.80%	4.15%	
III S8	Morphou	35.00%	2.00%	
IV Nursery Famagusta		14.60%	5.26%	

8.3 MANAGEMENT OF SANDY SOILS

Sandy soils in Cyprus are limited in extent, however, their part in intensive agriculture is quite important. This is partly due to the fact that most of these soils occur in areas relatively rich in underground water and therefore irrigated crops may be successfully grown. The crops produced are citrus, cereals, and many kinds of vegetables - both on and off season - the latter grown under plastic covers.

Since these crops are high yielding and their contribution to the national economy is of paramount importance, the Ministry of Agriculture and Natural Resources has given priority to various studies concerning the optimization of all production factors including soils and irrigation. The introduction of improved systems of irrigation wherever applicable, the study connected with the soil-citrus relationship and soil salinity problems, as well as the soil fertility and plant nutrition work carried out in connection with these crops, will be discussed in detail in the following paragraphs.

8.3.1 Soil-Citrus Relationships

Systematic observations and investigations carried out in citrus orchards in Morphou in order to study soil factors which affect critically citrus growth and performance, have revealed some interesting features. For the purpose of this study 50 Valencia and grapefruit orchards representing the most important and widespread soil series of the area were selected. The distance between rows and adjacent trees ranged from 4.50-5.10 m.

i. The distribution of fine roots in the soil profile reflects plant adaptability to soil conditions. The information obtained from the investigation of root development and distribution in various soil series in the Morphou area cannot only be used for development projects in this particular area, but also could be very helpful in similar development projects in other parts of the island. Information obtained through this investigation could be important too in facing problems connected with irrigation, fertilization and management.

The procedure used in this study was as follows:

Five representative trees were chosen from each of the selected orchards. Uniform samples were taken crossway from 4 sites of each tree at 0-30, 30-60, 60-75 and 75-105 cm depth, using an auger sampler with a 10 cm diameter. The two opposite sites were taken at a distance of 120 cm from the tree trunk while the other two at a distance of 180 cm. In this way twenty uniform soil samples were taken from each orchard, ten at a distance of 120 cm from the trunk and ten at a distance of 180 cm. All roots were collected and put together according to depths, irrespective of distance from the trunk. Roots were then separated into fine ($<$mm in diameter) and medium ones (1-5 in diameter), washed carefully with water, dried in the oven at 65°C for 24 hours and finally weighed. The dry weight of roots was calculated in g/m^2 per 10 cm depth.

In Fig. 3 the cumulative fine root distribution in three types of soils is presented for both Valencia and grapefruit.

The following conclusions may be drawn:

a. The greatest fine root activity occurs within a 30 cm layer from the surface. This holds especially true for the fine and medium textured soils where about 60% of the total fine roots are found in this layer. In light textured soils this percentage is reduced to 40-50.

b. About 80% of the total fine roots occur within 60 cm from the surface in all soils, irrespective of soil texture. This information should be very useful when considering the introduction of suitable irrigation methods.

c. Statistical analysis of the results reveals that the amount of fine roots present in fine textured soils is significantly less than that of corresponding depths in medium and light textured soils. The reason for the limited root distribution in fine textured soils is the relatively low porosity, which causes aeration problems and the mechanical impedance preventing fine roots from penetrating deeper layers. Contrariwise, the friability and the satisfactory aeration conditions existing in medium and light textured soils favour normal root distribution in the soil profile.

d. No significant difference was observed between corresponding depths when comparing medium with light textured soils except in the case of the 60-75 cm layer. There was however, a tendency for light soils to accumulate lesser amounts of fine roots than medium soils within the first 30 cm.

e. The cumulative presentation of results (Fig. 3) indicates that the total amount of fine roots is approximately the same in the cases of medium and light textured soils. In the case of fine textured soils fine roots amounted to approximately 50% of those in medium and light textured soils.

f. In fully grown orchards the age of trees did not affect significantly root distribution. Nevertheless, a very small increase in the amount of fine roots in deeper layers may be expected.

g. The employed method of auger sampling for root investigation has proved to be inadequate in determining medium root distribution (1-5 mm diameter) within the soil profile. The non-uniform distribution of medium roots both horizontally and vertically, may be responsible for this inadequacy. The circle segment method of root investigation in some orchards showed that trees on fine textured soils tend to accumulate more medium roots in deeper layers than lighter soils.

It is evident from the above that the greatest activity of fine roots is concentrated in the surface soil layers. This fact should be given due consideration so that management practices which may damage the root system of the trees may be avoided.

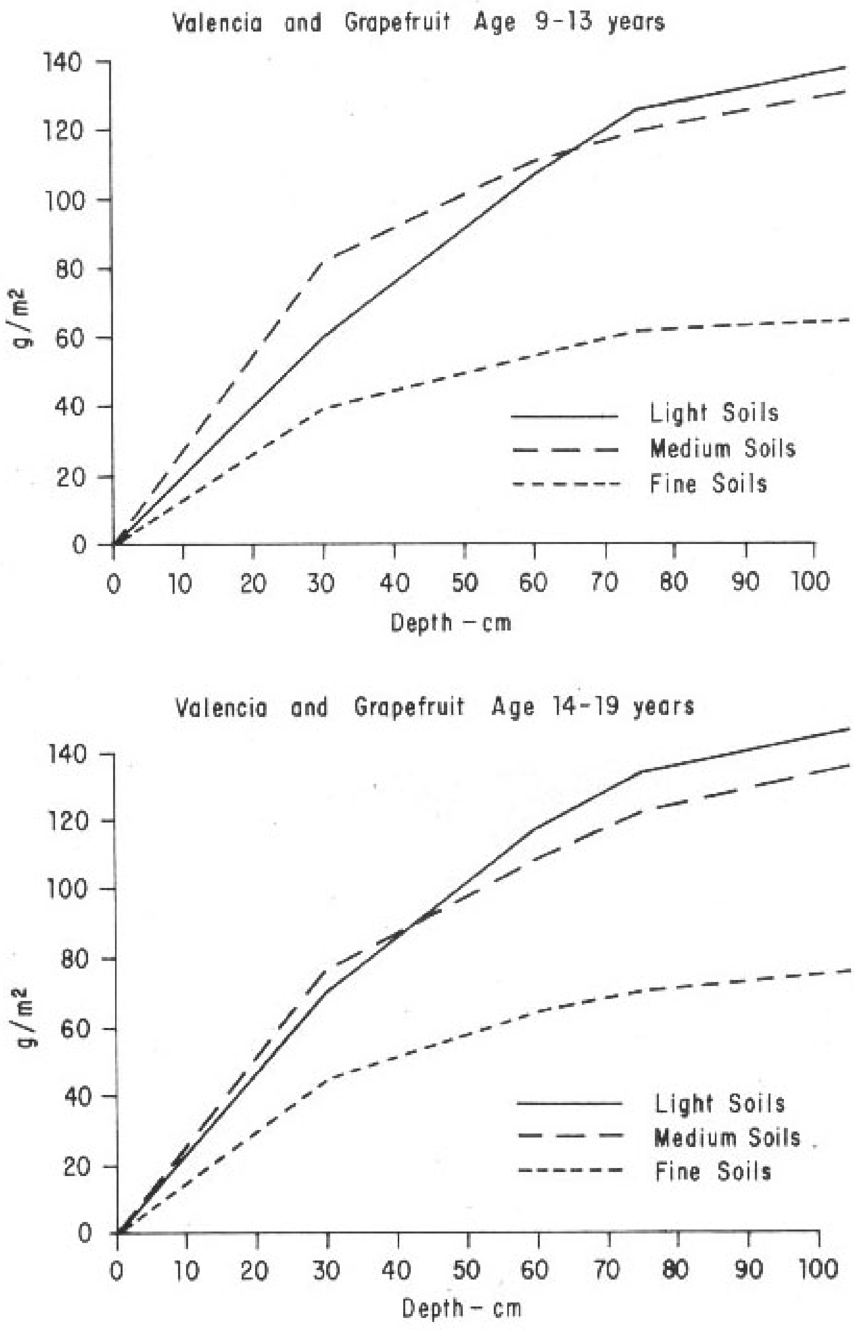


Fig. 3 CUMULATIVE FINE ROOT DISTRIBUTION IN VARIOUS SOIL TYPES (g/m^2)

ii. Fine root distribution in relation to citrus growth and productivity

Canopy volume and production records obtained from the same trees used for root investigation in about 25 Valencia orchards showed very significant correlation between total fine roots and crown volume ($r = 0.76$) and significant correlation between total fine roots and number of fruits per tree ($r = 0.59$) and with the weight of fruits per tree ($r = 0.54$). The results obtained suggest that Valencia at full bearing age could yield on the average 600 fruits per tree in fine textured soils and around 800 in medium and light textured soils i.e., a difference of 33%.

8.3.2 Soil Salinity Status in the Morphou Citrus Area

In the Morphou area a tremendous expansion of citrus plantations has taken place during the last decade. As the safe yield of the underground aquifer could not satisfy the newly planted areas overpumping has led to sea-water intrusion of the aquifer which resulted in an increase in the salt content of the water in many boreholes, thus increasing the salinity hazard for the soils irrigated with such water.

In this respect, systematic observations for two consecutive years concerning the soil salinity status in the Morphou citrus area were undertaken. About 40 full bearing Valencia and grapefruit orchards (10-19 years old), with various types of soil were selected. Composite soil samples from 4-5 sites in each orchard were taken from depths of 0-30, 30-60, 60-75, 75-90 and 90-105 cms. Sampling was carried out at the end of the irrigation season i.e., in September-October.

The chloride content of waters ranged from less than 200 to over 400 ppm. The electrical conductivity results of the various soil samples, lead to the following conclusions: (Fig. 4).

i. EC_e values tend to increase with depth and this is more obvious in fine textured soils. The percentage of fine textured soils having EC_e values over 2.5 mmhos/cm is 40 in the 30-60 cm layer, 75 between 30-75 cm, and 85 between 75-105 cm whilst in medium and light textured soils this is 10, 26, and 31 respectively. Satisfactory leaching of salts in heavy soils by winter rains is not to be expected since rainfall in the area is one of the lowest in the island and amounts to an average of 315 mm/year.

ii. EC_e values usually remain below 2.5 mmhos/cm up to a depth of 60 cm in almost all orchards sampled, irrespective of soil texture. This is very encouraging because such values are not high enough to cause problems and also, as has already been established, the great majority of active fine roots (about 80% in such soils) is found at this depth.

iii. EC_e values of corresponding depths between fine textured soils on one hand and medium and light soils on the other, reveal no significant difference for the depths of 0-30 and 30-60 cm whilst in the case of 60-75 and 75-105 cm depths, fine textured soils show significantly higher EC_e values than those of medium and light textured soils

iv. Fine textured soils although irrigated with water containing <200 ppm chlorides, still had EC_e values recorded in their subsoil exceeding 2 mmhos/cm. On the contrary most of the soils irrigated with waters containing >400 ppm chlorides are very sandy and the EC_e values recorded in their subsoil (60-105 cm) are below 3 and even 2 mmhos/cm. Fine textured soils irrigated with this water show EC_e values exceeding 4 mmhos/cm.

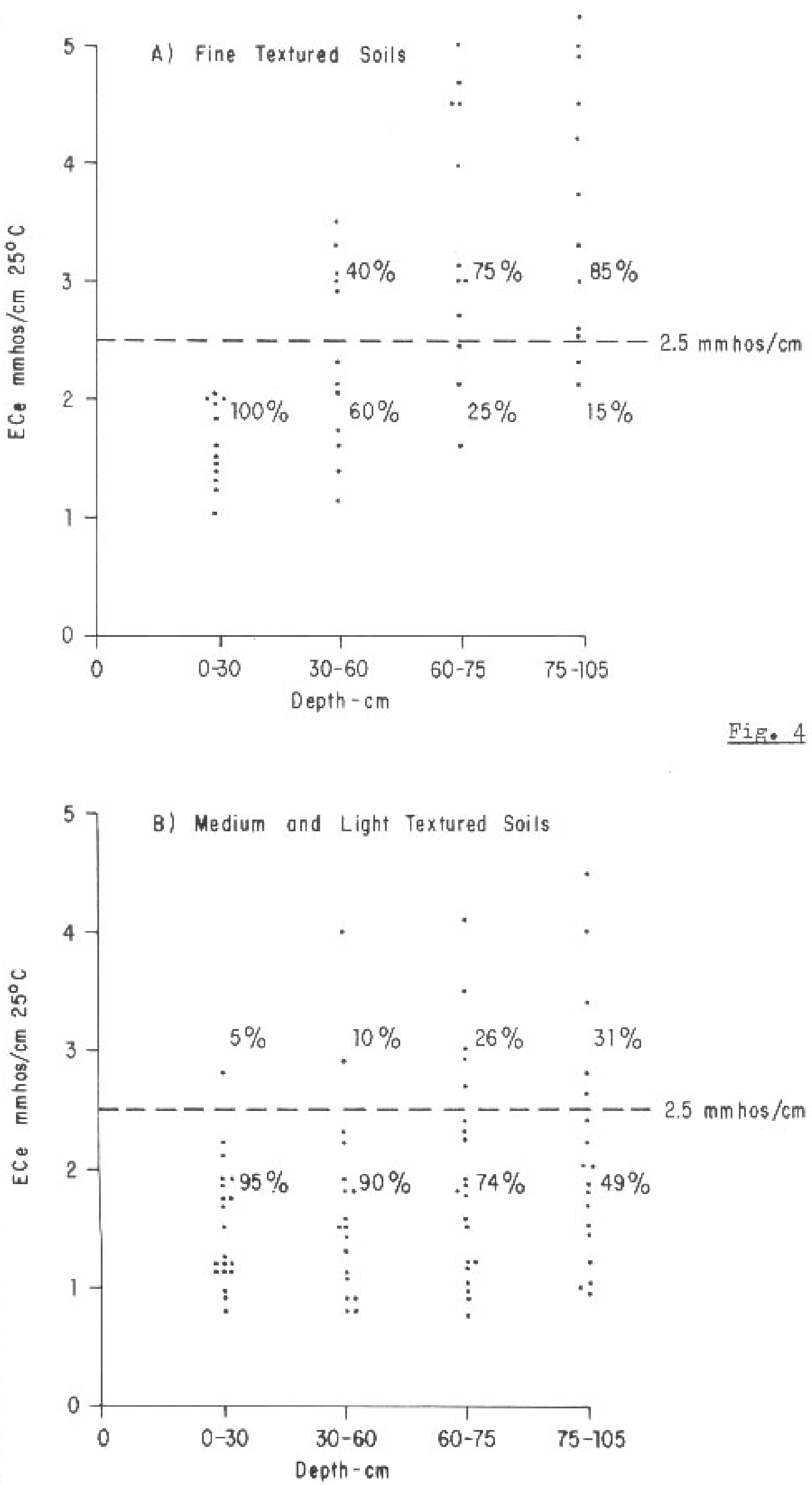


Fig. 4 SALT DISTRIBUTION WITH DEPTH IN MORPHOU CITRUS SOILS (ECe mmhos/cm 25°C)

8.3.3 Irrigation of Shamouti Oranges with Saline Water in Famagusta

Shamouti (Jaffa) oranges, together with other citrus fruits, have been extensively grown in Famagusta for the last 60 years. This area is still the largest Jaffa orange producing centre on the island.

The area under citrus within a 5-mile radius from the coast of Famagusta amounted in 1969 to approximately 1 300 ha half of which was under Shamouti oranges. The quality of the irrigation water had been good over the entire area until 1960 when, due to overpumping, sea-water intruded into the aquifer. The ill effects of saline water on citrus have already been felt in many areas in Famagusta where a substantial number of groves have already been destroyed and it may not be too long before the remaining groves share the same fate, unless the estimated deficit of 4 to 5 million cubic metres of fresh water could be supplied to the aquifer or if exploitation could be drastically reduced. However, since neither is likely to happen, it must be expected that citrus in the Famagusta area will have to be irrigated with water of gradually increasing salinity. Since citrus is sensitive to salt, the use of saline water would require special irrigation management, some aspects of which have been the objectives of a study undertaken by the Cyprus Agricultural Research Institute between 1965–1969. The work was carried out in a Shamouti orange grove situated at the Government Nursery of Famagusta. The trees were spaced at 5.10 m both in the row and between rows and had been grafted on sour organge in 1930.

Description of the soil profile, texture and moisture characteristics were presented in the previous chapter in Tables 4 and 5.

The quality of the irrigation water, which came from a borehole, was still reasonably good in 1963 but deteriorated rather rapidly thereafter.

Table 7 CHEMICAL ANALYSIS OF THE IRRIGATION WATER (sampled on 27 August 1968)

Cations		Anions	
meq per litre			
Ca	11.9	HCO_3	1.2
Mg	21.7	CO_3	NIL
Na	14.1	SO_4	3.6
K	0.3	Cl	37.3
pH	8.2		
ECe	4.5 mmhos/cm at 25°C		
Boron	0.18 ppm		
S.A.R.	3.44		

The water was conveyed to the orchard through a pipeline and applied to the basins of the trees through hoses. Each tree received 1.3 kg of triple superphosphate in December and 5.2 kg of sulphate of ammonia in four split applications in March, May, July and September. Evaporation measured from 1967 until 1969 ranged in average from 1-2 mm/day in December-January and 7.5-8.5 mm in July.

The soil was sampled in spring and in autumn, and in 1967 at more regular intervals throughout the irrigation season. The yield was recorded as number and weight of fruit. The peel thickness and the juice content of the fruit, and the sugar and acid content of the juice were determined as well.

The monthly rainfall over the period 1965-1969 is presented in Table 8.

Table 8 MONTHLY RAINFALL (mm) FAMAGUSTA GOVERNMENT NURSERY

Month	Average for 1916-1965	1965/66	1966/67	1967/68	1968/69
October	29	88	16	37	35
November	45	4	125	65	68
December	107	59	52	50	124
January	90	59	72	82	202
February	61	32	57	34	2
March	33	21	62	5	78
April	17	3	39	10	2
May	14	8	29	Nil	5
June	5	Nil	12	Nil	Nil
July	Nil	Nil	Nil	Nil	Nil
August	Nil	Nil	Nil	Nil	Nil
September	3	Nil	Nil	Nil	Nil
TOTAL	404	274	464	283	516

Four experiments were carried out from 1965 to 1968.

Experiment 1. Comparison of Four Frequencies of Irrigation Based on Soil Water Tension - 1965

Four tension values were selected representing 1, 5, 9 and 13 atm average tension over the 0-1.50 m profile; irrigation was applied whenever water tension in the soil had reached these values. Differential irrigation began in late May and its average frequency was 11, 13, 16 and 18 days respectively from moisture tensions of 1, 5, 9 and 13 atm. The volumes of water applied between late May and October ranged between 3 750 and 4 275 m^3 per ha.

Differences in yield among the plots under the various frequencies of irrigation were not statistically significant (Table 9 and Fig. 5).

Table 9 NUMBER AND WEIGHT OF FRUIT HARVESTED FROM SHAMOUTI ORANGE TREES (SINGLE-TREE PLOTS) OVER THE PERIOD 1965-68 FAMAGUSTA GOVERNMENT NURSERY

Year	Treatment code 1/	Block I		Block II		Block III		Block IV		Block V		Mean ± S.E.			
		No.	Weight (kg)	No.	Weight (kg)	No.	Weight (kg)	No.	Weight (kg)	No.	Weight (kg)	No.		Weight (kg)	
1965	A	433	88	500	104	550	117	788	164	407	88	535	± 49	112	± 10.5
	B	317	61	340	71	466	119	661	127	401	81	437		92	
	C	682	140	493	102	438	95	501	103	426	89	508		106	
	D	566	133	447	104	696	148	575	116	451	87	547		118	
	Total	1998	422	1780	381	2150	479	2525	510	1685	345				
1966	A	571	158	285	85	288	87	467	115	324	81	387	± 74	105	± 12.8
	B	588	112	479	106	1046	188	481	110	138	44	546		112	
	C	539	126	131	46	734	142	348	92	261	75	403		96	
	D	749	177	348	101	701	144	606	156	266	72	534		130	
	Total	2447	573	1243	338	2769	561	1902	473	989	272				
1967	A	988	197	778	147	915	168	1078	209	974	178	947	± 71	180	± 10.8
	B	567	109	744	138	192	54	862	161	709	144	615		121	
	C	828	156	838	154	299	70	748	142	926	177	728		140	
	D	909	174	716	154	779	148	1243	214	917	174	913		173	
	Total	3292	636	3076	593	2185	440	3931	726	3526	673				
1968	A	1087	223	620	142	416	104	762	184	488	131	675	± 97	157	± 18.0
	B	685	122	708	143	882	183	787	186	409	108	694		148	
	C	538	133	188	67	903	183	475	129	532	141	527		131	
	D	943	198	841	187	780	163	477	133	552	152	719		167	
	Total	3253	676	2357	539	2981	633	2501	632	1981	532				

1/ Explanation of treatment code

1965 The trees were irrigated with sufficient water to return the top 5 ft of soil to field capacity whenever the soil moisture content (dry weight basis) reached: A 3.4%, B 3.0%, C 2.8%, D 2.5%.

1966 The trees were irrigated with sufficient water to return the top 5 ft of soil to field capacity A every 5 days, B every 10 days, C every 15 days, D every 20 days.

1967 All trees were irrigated whenever cumulative pan evaporation reached 50 mm (approximately at weekly intervals) with amounts of water in excess of the water requirement in order to leach the soil profile. These leaching regimes expressed as a percentage of the water requirement were A nil, B 20%, C 40%, D 60%.

1968 The trees were irrigated as in 1967 but received higher leaching treatments as follows: A nil, B 33%, C 67%, D 100%.

Experiment 2. Comparison of Four Frequencies of Irrigation Fixed on a Calendar basis - 1966

From the experience gained with the previous experiment the four irrigation frequencies were fixed at 5, 10, 15 and 20 days. In this way soil samples had to be taken only before each irrigation. The assumption was made that evapotranspiration was not affected by the frequency of irrigation. Therefore, amounts of water twice, three and four times that applied with the 5-day frequency were given with the 10, 15 and 20-day frequencies, respectively. The amount of water applied with the 5-day frequency of irrigation was determined, by soil sampling, to bring the soil to field capacity to a depth of 1.50 m.

The volume of water applied from 23 May, when differential irrigation began, until 9 December was about 7 500 m^3/ha in all treatments.

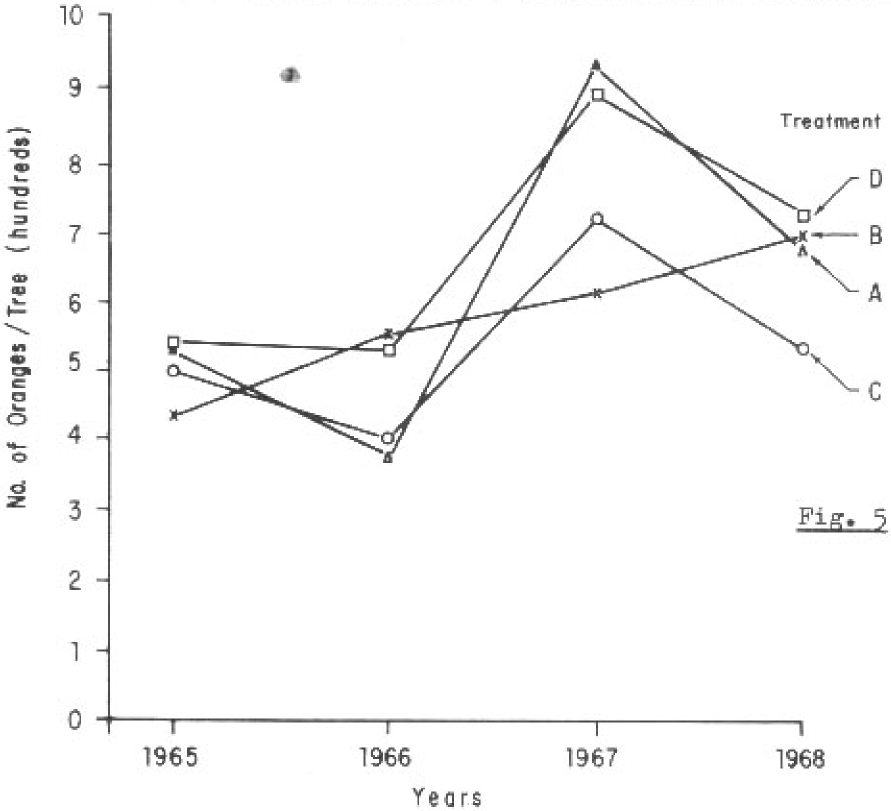


Fig. 5 YIELDS OF SHAMOUTI ORANGES UNDER FOUR IRRIGATION TREATMENTS, FAMAGUSTA GOVERNMENT NURSERY, 1965-68

Source: Cyprus Agricultural Research Institute Techn. Bull. 6

Differences in yield among the trees under the various frequencies of irrigation were not statistically significant (Table 9 and Fig. 5); the average yield per tree over all treatments was 427 fruits. However, it was observed that the peel of fruit borne on the most frequently irrigated trees was noticeably rougher than that on trees irrigated less frequently but with higher amounts of water.

Experiment 3. Comparison of Four Leaching Regimes - 1967

In 1967, irrigation was timed on pan evaporation so that weather changes could be taken into account. Pan evaporation of 50 mm was chosen as a reasonable and convenient measure of the interval between irrigations. With an average evaporation of 7mm/day from June to August, the interval between irrigations was 7 days.

As the irrigation water was saline, it was considered desirable for the experiment to be modified into a leaching experiment.

The water requirement of the trees was assumed to be 60% of pan evaporation. Thus trees under "no leaching" were irrigated with 30 mm of water (300 m^3/ha) whenever cumulative pan evaporation reached 50 mm. Trees receiving leaching treatments were irrigated with amounts of water 20%, 40% and 60% in excess of this basic water requirements.

All trees were irrigated uniformly from March to May with a total of 2 275 m^3/ha given in nine irrigations. Differential irrigation began on 8 June and ended on 20 November. During this period 17 irrigations were given and the volumes of water applied were 4 875, 5 850, 6 825 and 8 550 m^3/ha.

These treatments did not result in any significant differences in yield except in the case of treatment B (20% leaching) (Table 9 and Fig. 5). It must be pointed out, however, that the low mean production of 615 fruits per tree obtained with the 20% leaching treatment, resulted from the extremely low production (192 fruits) of one tree under that treatment. The same tree produced 1 046 fruits in 1966, which indicates how pronounced biennial bearing can be.

The concentration of salts in the soil profile as evidenced by the electrical conductivity and the chloride concentration of the saturation extracts is presented in Fig. 6.

Experiment 4. Comparison of Four Leaching Regimes - 1968

The leaching regimes applied were higher than those tested in Experiment 3, the highest being 100% of the estimated water requirement of 4 275 m^3/ha during the period of differential irrigation (May-mid-November).

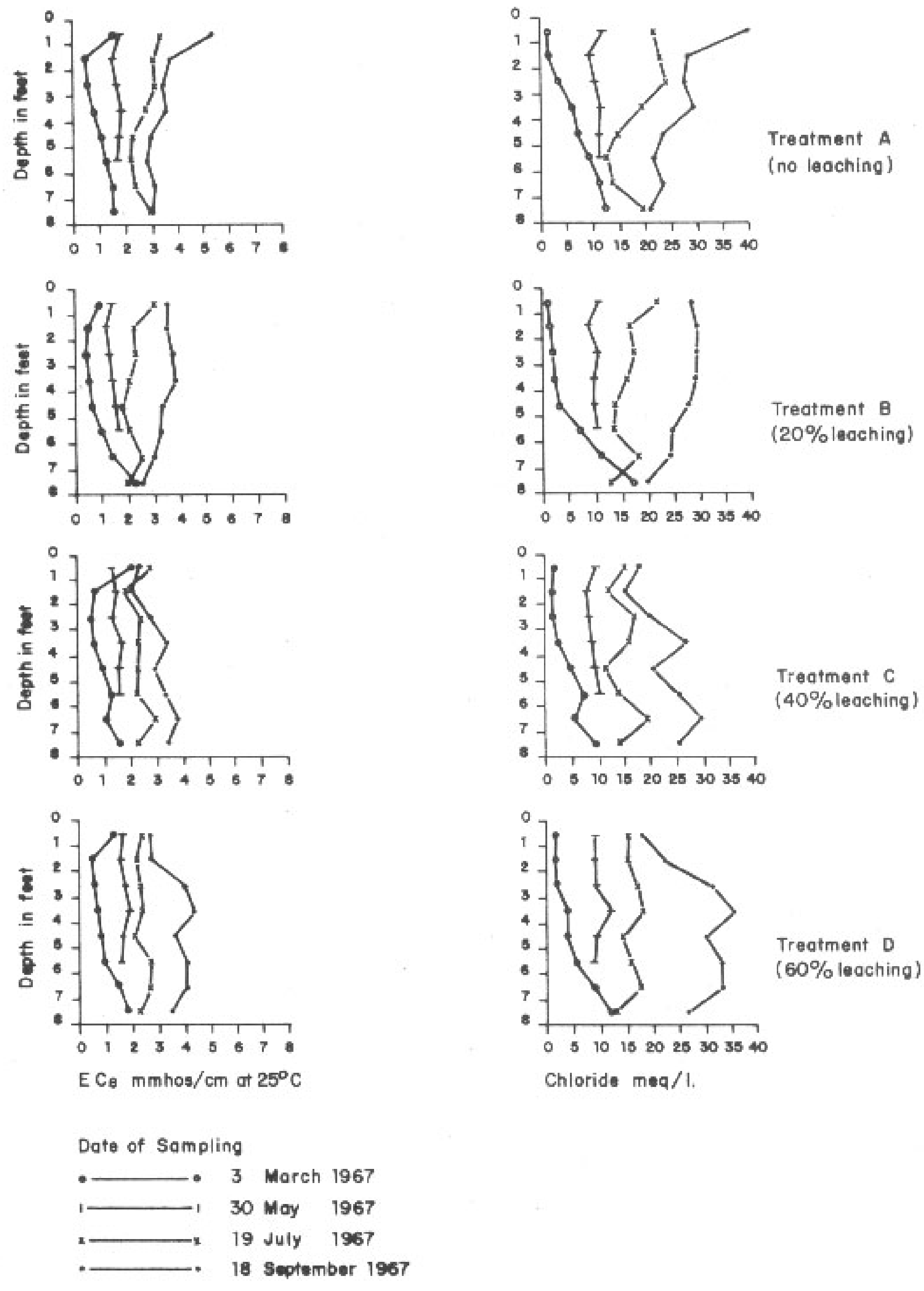
Again the trees were irrigated whenever cumulative pan evaporation of 50 mm had been reached. Irrigation was uniform in March and April when all trees received 6 225 m^3 of water per ha in two applications. Differential irrigation began in later April after fruit set, and ended in mid-November. In all, 23 differential irrigations were given.

As the plantation was found to be infested with the virus Tristeza, the trees were uprooted in March, 1969. It was quite remarkable to observe relatively thick roots extending beyond 2 m in depth and 5 m laterally.

Discussion of the Results

Citrus is considered sensitive to salt (U.S. Salinity Laboratory Staff, 1954) although this sensitivity has not been satisfactorily expressed in quantitative terms. However, it is fairly well established that some rootstocks may withstand higher salt concentrations than others. Thus Bernstein (1965) suggested the following safe maxima of chloride concentration in the soil saturation extracts: for sweet orange and citrange 10 meq/l, for sour orange, rough lemon and tangelow 15 meq/l, and for Rangpur lime and Cleopatra mandarin 25 meq/l.

Bernstein also suggested as safe highest conductivities of soil saturation extracts 2.5 mmhos/cm for lemon and 3.0 mmhos/cm for orange and grapefruit. He also suggested that in gypsiferous soils, lemon could withstand conductivities up to 4.5 mmhos/cm, and orange and grapefruit up to 5.0 mmhos/cm. Lahaye and Epstein (1969) demonstrated the beneficial effect on plant performance of Ca ions in saline solutions.



<u>Fig. 6</u> SALINIZATION OF THE SOIL PROFILE DURING THE 1967 IRRIGATION SEASON UNDER FOUR LEACHING REGIMES

Source: Cyprus Agr. Res. Inst. Techn. Bull. 6

The water used in these experiments contained more than 1 000 ppm (30 meq/l) chloride and had a conductivity value of 4 to 5 mmhos/cm. That such saline water did affect the trees to a certain extent may be almost certain although our own data do not permit this conclusion. However, the performance of the trees under the circumstances is remarkable. The adverse effects of the saline water used on the trees must have been mitigated by one or more of the following factors:

a. the sandy texture of the top 180 cm of the soil

b. the low sodium adsorption ratio (SAR 3.4) of the irrigation water

c. the deep root system of the trees

d. the relatively frequent irrigation

e. the effective leaching of salts by the winter rainfall.

The available water held in the top 180 cm of the soil following each irrigation was 15 cm. Assuming an average ratio of evapotranspiration pan evaporation of 0.55, it may be shown that the trees which were irrigated whenever pan evaporation of 50 mm had been reached, did not deplete more than about 18% of the available moisture between one irrigation and the next.

Furthermore, it may be shown that with an average value of the EC_e of 4 mmhos/cm over the 180 cm profile occurring during the later part of the irrigation season, the osmotic pressure of the soil solution at field capacity was about 3.8 atm.

During the irrigation season salts accumulated in the top 180 cm of the soil in amounts inversely proportional to the volumes of water applied (Fig. 6).

It is interesting to note in all cases a relatively lower concentration of salts at the depth of 1.50 m. This may have been caused by the temporarily perched water table at the sand/clay interface at 1.80 m.

The efficacy of even relatively limited winter rainfall, as that in 1967/68, in leaching the top 180 cm of the soil is noteworthy. This clearly shows that intermittent leaching under conditions of unsaturated flow can be very efficient as demonstrated by Biggar and Nielsen (1967).

Though winter rains may be efficient in leaching the salts, our results suggest that in order to secure a satisfactory level of leaching a certain excess of water should be applied during the irrigation season. Under the conditions of this work an excess of water equal to 30% of the water requirements would seem adequate.

It may be worth pointing out here that flowering and fruit set occurred when soil salinity was at its lowest level (April-May).

Overall yield varied considerably from year to year (Table 9 and Fig. 5). Yields of trees under treatment B though, did not follow this pattern. However, a close examination of individual tree yields revealed appreciable differences from year to year in all cases, treatment B included. It may also be worth mentioning, that in certain cases these variations in yield were so considerable that yields of trees receiving the same treatment and in the same year differed as much as fourfold (c.f. treatment B, Blocks III and IV, 1967, Table 9). But not even a trend of a treatment effect on yield could be discerned.

Leaching reduced peel thickness of the fruit significantly (Table 10), and it is apposite to mention in this connexion that, according to the European Common Market standards, peel thicknesses in excess of 11% of equatorial fruit diameter are not acceptable.

Table 10 LEACHING REGIMES AND PEEL THICKNESS OF SHAMOUTI ORANGES, 1968 1/

Leaching regime (% of water requirement)	Peel thickness mm	Peel thickness as a percentage of equatorial fruit diameter
0	8.0	10.4
33	7.2	9.5
67	8.0	9.9
100	6.9	8.8

1/ Determined on 20 fruits from each tree (five single-tree replications)

Source: Cyprus Agr. Res. Inst. Techn. Bull. 6

The juice content of the fruit was about 30%, considerably lower than it is of Valencia oranges (about 45%). The citric acid content of the juice was about 1.6% and the sugar/acid ratio about 7.8. In none of these traits were any treatment effects observed.

Chloride concentration in the leaf dry matter ranged between 0.4 and 1.0% and it followed closely the leaching regimes applied, being highest where no leaching had been allowed (Table 11), and being in all cases in the "high" to "excess" range. The concentration of sodium was also in the "excess" range but was not affected by leaching. In contrast, boron did not accumulate in the leaves to reach the "excess" range.

Some leaf bronzing and leaf burn was observed but its severity could not be easily related to leaching. Excessive leaf drop, and twig dieback were also observed but these, too, could not be easily related to the treatments applied.

In conclusion, it may be pointed out that despite leaching, the nitrogen, phosphorus and potassium concentration in the leaf dry matter increased slightly with the higher volumes of water applied.

Table 11 LEACHING REGIMES AND CHEMICAL COMPOSITION OF SHAMOUTI ORANGE LEAVES SAMPLED FROM NON-FRUITING TERMINALS ON 23 SEPTEMBER 1968

Leaching regime (% of water requirement)	Concentration of element in leaf dry matter 1/									
	percent							ppm		
	N	P	K	Ca	Mg	Na	Cl	B	Fe	Zn 2/
0	2.61	0.13	0.77	4.91	0.78	0.26	1.01	86	102	277
33	2.65	0.14	0.79	5.20	0.78	0.26	0.82	91	104	267
67	2.70	0.14	0.93	4.79	0.71	0.27	0.64	95	88	260
100	2.73	0.16	0.98	4.62	0.68	0.30	0.52	95	99	217
S.E.	±0.02	±0.003	±0.04	±0.11	±0.06	±0.02	±0.07			
Significance	**	**	*	*	N.S.	N.S.	**			

1/ Means of five replications except for B, Fe and Zn, which were determined on one compound sample from each treatment.

2/ The foliage had been sprayed with Zn in spring 1968.

Source: Cyprus Agr. Res. Inst. Techn. Bull. 6.

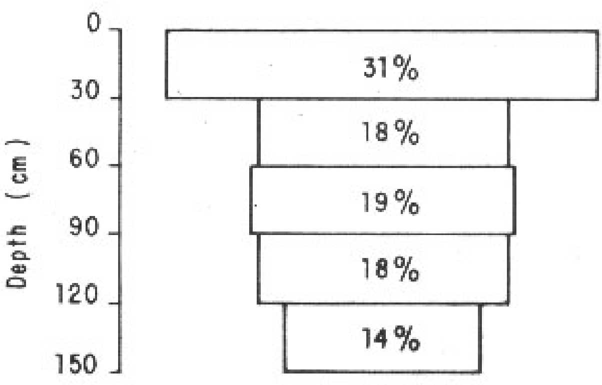


Fig. 7 RELATIVE EXTRACTION OF MOISTURE FROM THE TOP 150 cm OF SANDY SOIL BY SHAMOUTI ORANGE TREES, FAMAGUSTA GOVERNMENT NURSERY

(Extraction was determined gravimetrically in four profiles, one from each treatment, throughout the 1967 and the 1968 irrigation seasons)

Source: Cyprus Ag. Res. Inst. Techn. Bull. 6

From the experiment already described we may conclude that Shamouti orange trees grafted on sour orange growing in sandy soil may continue to produce satisfactory yields when irrigated with saline water (EC 4 to 5 mmhos/cm) provided they are irrigated relatively frequently (weekly) and the soil is thoroughly leached by the winter rainfall.

Under the conditions of this experiment, the leaching requirement during the irrigation season would be about 30% in excess of the actual water requirement. This is much lower than the calculated leaching requirement for an assumed maximum of permissible electrical conductivity of the saturation extract of 4 mmhos/cm (U.S. Salinity Laboratory Staff, 1954). However, under different soil conditions and/or summer evapotranspiration, the leaching requirement might have to be increased.

8.3.4 Water Management of Sandy Soils

In Cyprus water is scarce and limited and every effort should be made to utilize it in the most efficient way.

The continuing overpumping of almost all aquifers and the corresponding lowering of the water table, raised pumping costs considerably the last two years. In Western Mesaoria the cost of pumped water is 10-12 mils/m^3. In Eastern Mesaoria it is 10-40 mils/m^3

With respect to surface water, the geological formations and the topography of river basins have increased considerably the cost of construction of dam reservoirs, thus irrigation water from these sources costs 30-50 mils/m^3.

In view of the above and the dangers involved from sea water contamination that takes place in most of the aquifers, the use of certain water management measures has become mandatory.

In the following lines an effort is made to analyse these measures in relation to past and present water management.

i. Source of water and water quality

a. Eastern Mesaoria

The only source of water for irrigation is a fairly shallow aquifer that is severely overpumped.

Several water analyses showed that in most of the cases the chloride content of the water (during the drought years) is in the range of 450-600 ppm. However, cases with 900 - 1 200 ppm chloride content are not rare. Only in very few cases the chloride content of the water is around 200 ppm.

b. Western Mesaoria

The sandy soils of this region are also irrigated from groundwater. The chloride content of irrigation water varies from borehole to borehole and it lies within the range of 350-900 ppm. About 75% of the area is irrigated with water containing chlorides below 500 ppm.

ii. Use of Water

The main losses of water during irrigation are due to:-

a. Conveyance of water in earth channels and

b. Inefficient irrigation practices and schedules.

a. Control of conveyance losses

Conveyance losses are a function of soil type, length and slope of channel, flow of water, and kind and growth of vegetation present in the channel.

Ten years ago conveyance of water in sandy soils was done through unlined earth channels. As a consequence substantial amounts of water were lost due to deep percolation and evapotranspiration. The problem was more acute in Eastern Mesaoria where the discharge of individual boreholes and wells was in the range of 15-30 m^3/hr. The water conveyance efficiency was estimated at 60-65% because of the relatively short distances involved.

In Western Mesaoria where the discharge of the boreholes was 90-120 m^3/hr the problem was not so acute in terms of water availability for irrigation after conveyance, but the losses of water were very high since water had to be conveyed for long distances to reach the irrigated fields. It is estimated that 10 years ago the conveyance efficiency in this region was 40-50%.

Now in both regions water is conveyed from the source to the field through pipes. Only in a very few cases is water conveyed in concrete channels. The present conveyance efficiency is estimated at 90-95% in both regions.

b. Irrigation practices

The developments which have taken place in the irrigation methods in Cyprus during the last decade may be clearly observed today in many instances where old and traditional surface methods coexist with modern efficient irrigation methods. This is more common in Western Mesaoria.

1. Traditional surface methods of irrigation

i. Border strip

This system, in its different forms and variations, is the predominant one in Western Mesaoria sandy soils. The land is divided into a number of strips 5-8 m wide and 40-50 m long separated by low levees or borders. In the case of trees, every row of trees is included in each strip.

Advantages

a. By this method an individual can handle 60-100 m^3/hr. This is the major reason why this method is used in Western Mesaoria where fairly big flows of water are available.

b. Small initial investment is required.

Disadvantages

a. High water losses due to deep percolation especially at the beginning of each strip. Water discharge, length of run and land slope, do not provide the best possible combination for an efficient and uniform water application. From tests carried out, it appears that the application efficiency for young trees is 15-20% and for mature trees 45-50%.

b. Non-uniform water application due improper levelling.

ii. Furrow basin

This practice is followed in Eastern Mesaoria and it basically refers to the construction of individual basins for each tree and the diversion of water to each basin from a distribution system of furrows. Thirty percent of the citrus grown on the sandy soils of Eastern Mesaoria is irrigated with this method.

Advantages

a. Irrigation can be made with small water discharge.

b. Limited initial investment.

c. Reduced losses of water as compared to the border strip method. The application efficiency is estimated to be in the range of 60-65%.

d. More uniform distribution of water in the soil as compared to the border strip method.

Disadvantages

a. Through this method it is not possible to measure the water diverted into each basin, hence, deep percolation or under-irrigation cannot be controlled.

b. Losses of water in the distribution system of furrows due to the growth of weeds and deep percolation.

iii. Furrows

The convential furrow method is not practised in the sandy soil of Cyprus. However, for the irrigation of vegetables in Eastern Mesaoria short furrows (3-5 m long) are used.

Advantages

a. Irrigation can be done with small discharge.

b. Low initial investment.

Disadvantages

a. Losses due to deep percolation and weed growth.

b. Non-uniform distribution of water.

2. Improved methods

i. Hose and pipe basin

This is an improvement of the furrow basin method and is used for trees. The water is diverted into individual basins through hoses attached to a semi-permanent, closed conduit distribution system. The discharge of each hose is measured and therefore the grower can be advised on the time required to leave the hose discharging in each basin. The pipe basin method operates on the same principle. Portable pipes instead of hoses are used to divert water into each basin.

Seventy and ten percent of the citrus grown on Eastern and Western Mesaoria sandy soils respectively, are irrigated through these methods.

Advantages

a. Water losses are eliminated. The application efficiency is around 80%.

b. Leaching of salts can be done very efficiently.

c. Reduced weed growth especially in young orchards.

Disadvantages

a. High initial investment.

b. A grower can handle 30-35 m^3/hr and, therefore, the number of persons required to operate a system with high discharge (90 m^3/hr) is increased. Still the labour cost of this method is not higher than that required for conventional methods.

ii. Hose furrow

This is an improvement of the short furrow method. The water is diverted into each furrow through hoses connected to a semi-portable, closed conduit distribution system.

Advantages

Controlled water application as compared to short furrow method and therefore reduced losses of water. The application efficiency is estimated to 65-70%.

Disadvantages

High initial investment.

iii. Sprinkler irrigation

In Cyprus, there are two types of semi-portable sprinkler systems in use: one is the drag system and the other the conventional system with portable pipes. However, due to the relatively high concentration of sodium, chlorides and boron in the water used for the irrigation of different crops grown on sandy soils, and the dangers involved with respect to leaf burn and defoliation this method is not common.

iv. Trickle Irrigation

Trickle irrigation has been introduced in Cyprus the last few years and it is used successfully for the irrigation of vegetables. Due to the economic advantages of this method there is a tendency in Eastern Mesaoria to replace other methods with trickle in irrigating early vegetables.

Advantages

a. Reduced losses of water during irrigation. Application efficiencies around 90% are common.

b. Reduced weed growth.

c. Increased yields as compared to other irrigation methods.

d. Reduced labour cost.

Disadvantages

a. Very high initial investment especially in sandy soils where an increased number of emitters should be used. This is demonstrated in Fig. 8 which shows the horizontal and vertical movement of water in sandy soils irrigated with this system.

b. If the salt content of the water is relatively high, leaching of salts from the soil is required. This can be achieved by either leaving the irrigated land stand fallow so that winter rains may take care of leaching, or by using sprinkler systems to leach the salts after the irrigation season is over. In the latter case the trickle system is designed in a flexible way so that sprinklers may also be used.

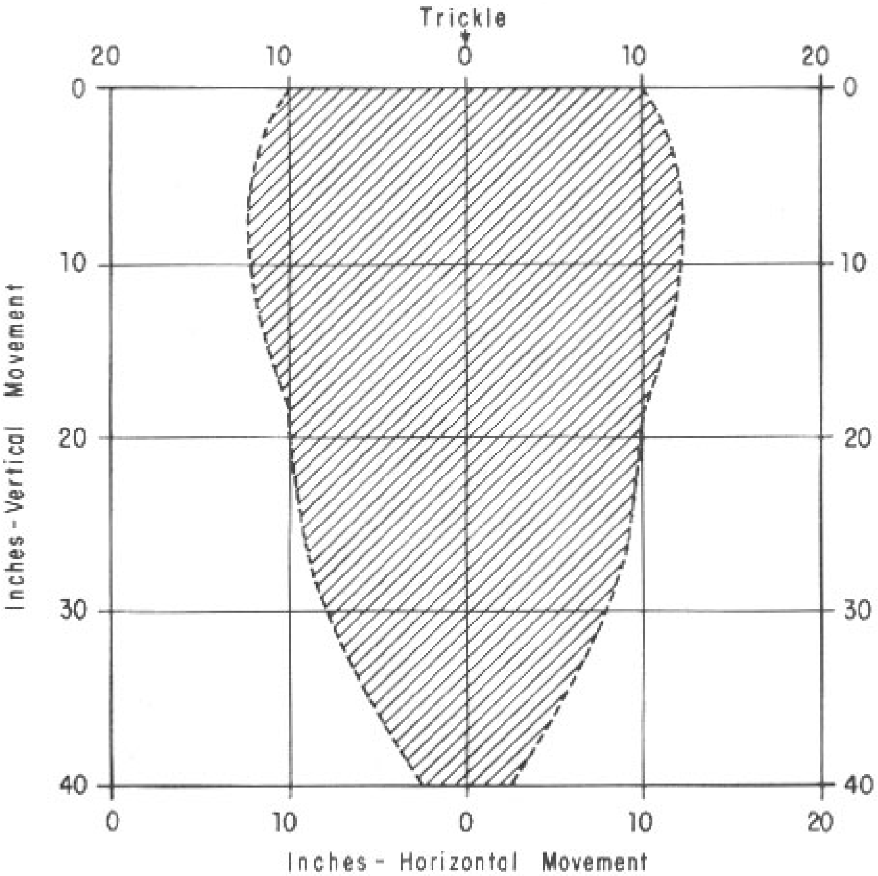
iii. Water management measures aiming at efficient water use

An assessment of the various irrigation methods has led to the promotion of of improved irrigation practices (hose and pipe basin, sprinkler, hose short furrow and trickle) and schedules which were considered necessary. Therefore, the Government acting through the Water Use Improvement Project provides both technical and financial assistance to all interested farmers in order to install improved irrigation methods and follow the appropriate irrigation schedules.

As technical assistance the water use personnel prepare the designs of improved irrigation systems, supervise the installation and prepare the necessary irrigation schedule.

As financial assistance the Government provides subsidies that cover 15% of the cost of the improved irrigation system and offers long term loans at 4½% interest in order to cover the remaining 85% of the cost.

The benefits derived from this Project may be summarized as follows:



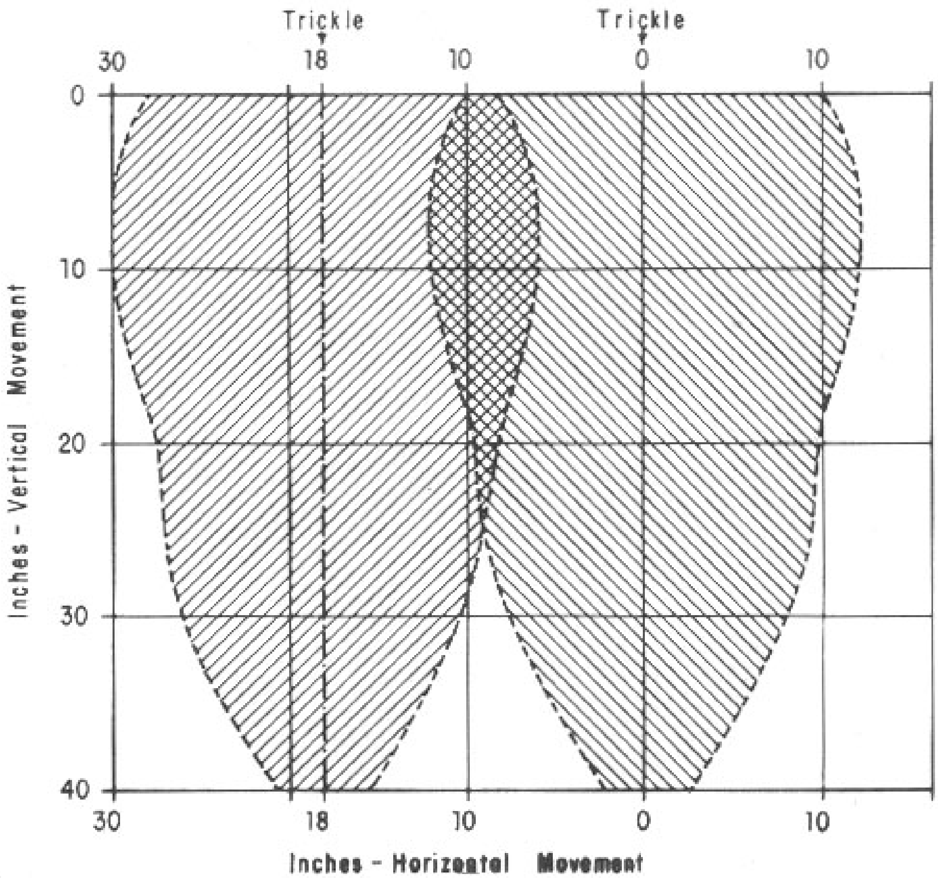


Fig. 8 VERTICAL AND HORIZONTAL MOVEMENT OF WATER IN SANDY SOILS DURING TRICKLE IRRIGATION

a. Due to the economy of water achieved some irrigated crops may be saved from destruction. This acreage will be proportional to the amount of water saved.

b. Saving in pumping cost and labour.

c. Increase in yield due to uniform distribution of water in the root zone and the use of appropriate irrigation schedule.

8.3.5 The Fertility Status of Sandy Soils

The sandy soils encountered in Cyprus are mostly calcareous (10-30% $CaCO_3$), poor in organic matter ($<1\%$) and indigenous phosphorus. Crops grown on such soils respond to nitrogen and phosphorus and to a lesser extent to potassium. Farmyard manure is commonly used by growers for improving the structure of sandy soils, however, green manure and other sources of organic matter are also applied but on a smaller scale. Chemical fertilizers, such as sulphate of ammonia, calcium ammonium nitrate, urea, triple superphosphate, potassium sulphate and potassium nitrate as well as mixed chemical fertilizers are the main sources of nitrogen, phosphorus and potassium.

Under irrigation there is an unrestricted downward movement of soluble nutrients such as nitrates and potassium and, therefore, frequent low dressings of nitrogen and potassium are more efficiently utilized.

A survey of citrus groves in Cyprus concerning their nutrient element status, allows the following main conclusions to be drawn:

i. No significant correlation exists between the nutrient contents of plants grown on light and medium, and heavy textured soils. The human factor apparently is responsible for this, since each citrus grove is managed by its individual owner, hence, even if there were any differences that might have occurred due to the soil factor, these have been offset by the grower's management practices.

ii. With the exception of potassium where "low" values ($<0.6\%$) have been observed in approximately 40% of the groves sampled, all other major elements appear to lie within permissible limits. Due to the high calcium carbonate content of the soil the calcium contents of citrus leaves were high as well (4-6%).

iii. Zinc and manganese trace element deficiencies are widespread. Approximately 50 and 80% respectively of the groves sampled show zinc and manganese levels below 24 ppm with the majority lying in the 10-15 ppm range.

iv. The boron contents of the groves sampled lie within permissible limits but in many instances these values are considered as "high" (100-200 ppm). The main source of boron appears to be the irrigation water used by the growers.

Leaf contents of the other nutrient elements appear to lie within "optimum" limits. It should be noted that through the Leaf and Soil Analysis Project of the Ministry of Agriculture and Natural Resources the citrus groves are being closely watched in order that any nutritional problems arising may be effectively dealt with in time.

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b. The Water Use Section, Dept. of Agriculture.

c. The Soils and Water Use Section, Agricultural Research Institute.

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III. 9

REGIONAL APPLIED RESEARCH ON SANDY SOILS

by

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SUMMARY

Sandy soils, characterized by specific physical, chemical and nutritional properties, require the application of special soil and water management practices and adherence to certain cropping patterns to render their utilization economic. Their widespread occurrence in the Near East region, as well as in other parts of the world, entails the need to pool available information and to coordinate research work on their effective utilization.

An applied research programme on sandy soils should be oriented to assure protection against wind erosion, improvement of water holding capacity and fertility, selection of efficient irrigation methods and discovery of the proper cropping systems. The paper cites a number of possible lines of research on sandy soils. A proposed approach, based on regional cooperation to solve sandy soil problems, is suggested on the following lines: delineation through soil survey of sandy soils susceptible to wind erosion, establishment of representative pilot stations for field, greenhouse or laboratory experiments, establishment of representative pilot areas for land and water development studies on sandy soils, collection and exchange of information and execution of fundamental research.

9.1 INTRODUCTION

A wide range of varying levels of productivity can be expected from soils that are sandy, loamy sand or sandy loam, depending on their inherent physical, chemical, mineralogical, microbiological and pedogenetic properties. Sandy soils are characterized by the dominance of the sand fraction, low water holding capacity, low nutrient status and organic matter content, small surface area and low exchange capacity. Such properties require the application of special soil and water management practices and adherence to certain cropping patterns to render the utilization of sandy soils more economic.

Realizing that sandy soils occur widely in the Near East region as well as in some other parts of the world, there is a need to pool information and coordinate research activities on these soils on a regional basis. In formulating an applied research programme for sandy soils, provisions should be made for soil and hydrological surveys, mapping combined with land evaluation, laboratory investigations experimentation programmes and implementation of these.

9.2 BASIC REQUIREMENTS FOR RECLAMATION, IMPROVEMENT AND MANAGEMENT OF SANDY SOILS

For optimum utilization of sandy soils, five main requisites need to be assured:

i. Protection from the effects of wind erosion through the establishment of windbreaks and strip cropping.

ii. Improvement of their structural conditions, particularly their water holding capacity, by the application of a combination of soil and water management practices and selection of appropriate cropping systems, preferably with an animal production component.

iii. Improvement of their inherent fertility through fertilizer use in conjunction with grass and legume structure building practices.

iv. Selection of an irrigation method which maintains the timely availability of water to crops coupled with the maintenance of an optimum salt and water balance.

v. Selection of the cropping system which satisfies requisites (ii) and (iii) with a view to achieving the maximum economically profitable return.

The applied research programme on sandy soils must, therefore, be oriented so that it provides solutions to these five basic requisites for the utilization of sandy soils.

9.3 POSSIBLE LINES OF RESEARCH ON SANDY SOILS

Field experimentation is necessary to arrive at pertinent decisions on the details of soil and water management practices in relation to crop production factors. The field experimentation programme, however, will have to be supplemented with applied research of a more fundamental character, bearing on the main relevant physical and biological phenomenon that determine the practical success of land and water use in arid and semi-arid environments. The following are cited as possible applied research subject matters:

i. Origin of sandy soils in terms of geomorphology, lithology, effects of past climates upon their pedogenesis, use of heavy mineral and micropedological techniques and granular analysis and interpretation.

ii. Behaviour of organic matter under arid and semi-arid conditions, microbial activity under drought and moist cycles and role of organic matter and humus in sandy soil fertility and structural conditions.

iii. Hardpan and compacted layers in sandy soils: their physico-chemical constitution and measures for their amelioration.

iv. Optimum cultural practices for sandy soils.

v. Effect of the prevailing agroclimate upon sandy soil temperature and moisture conditions, availability of nutrients, particularly nitrogen and phosphorus and soil structural conditions.

vi. Soil temperature in arid environments dominates the soil properties, crop behaviour, effects of water in accelerating the weathering cycles of minerals, activity of soil microflora and microorganisms, solubility of nutrients,

vi. (continued)

insulation and soil moisture conservation effects of crop residue mulches, etc. Hence, research on the interaction of soil temperature effects on the forementioned areas would be relevant.

vii. Quality of irrigation water in relation to sandy soil salinization.

viii. Criteria and standards of soil salinity and quality of irrigation water are required especially in relation to the tolerance of crops and crop productivity in sandy soils.

ix. Effects of wind erosion on sandy soils and measures for their control.

x. Nutrient availability and fertilization under varying crop and water quality systems in sandy soils

9.4 PROPOSED APPROACH FOR SOLVING SANDY SOILS PROBLEMS

To realize effective solutions to the field problems of sandy soils, it is necessary that a concerted cooperative and regional approach be taken by the countries of the Near East along the following lines of action:

i. Delineation through soil survey of sandy soil areas that are acutely afflicted with wind erosion problems. This field study would have to be combined with a detailed characterization of the soils in relation to their environment through land evaluation survey and mapping.

ii. Establishment of representative pilot experimental areas for the conduct of laboratory, greenhouse or field experimentation on: (a) multivariant single or double factor experiments, (b) multivariant multifactor experiments. The subject matter of this programme could be selected from the relevant facets of soil physics, soil chemistry, soil microbiology, soil fertility and plant nutrition. As an integral part of this approach, field experiments on the following factors are proposed: cultural practices, crops and cropping patterns, irrigation and drainage practices, amendment and fertilizer applications.

iii. Establishment of representative pilot development areas incorporating the alternative land and water use systems of sandy soils whereby cropping patterns of relevance to the local rural community can be implemented. To achieve this care should be taken to apply the pertinent reclamation, improvement and management practices for sandy soils. Since these field operations should be carried out to obtain profitable agricultural production on economic grounds, it is imperative to keep the input/output record of the major field operations. This information must be duly analysed and interpreted in terms of the criteria for realizing economic profitability.

iv. Test/Demonstration field operations on the basic soil and water conservation and management improvement practices of sandy soils both at the farm and state farm levels, whereby combinations of effective measures are applied on as large a number of farms as is feasible. Close cooperative and coordinative links should be maintained between this activity and that of the applied research field experimentation and pilot development activities through organizing regular field meetings and discussion sessions between the technicians and the farmers and definition of the roles of the participants in the cooperative action programme.

v. Collection, review, analysis and dissemination of the literature on relevant problems of sandy soils published in the countries where progress has been achieved in this line of action.

vi. Applied research of a more fundamental character should supplement the work on sandy soils in the pilot experimental and development areas.

IV. COUNTRY REPORTS

IV.1

AFGHANISTAN

by

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1.1 INTRODUCTION

Most of the soils under arid and semi-arid climatic conditions in Afghanistan are significantly characterized as zonal soils. These are grouped in the Great Soil groups such as desert soils, grey desert soils, red desert soils, sierozem, reddish brown soils and brown soils. Some other Great Soil groups under the orders of Azonal and Interazonal are comprised of regosols, lithosols, alluvials, solonchak, and solonetz soils.

Mainly these desert soils are unstable regarding structure stability and more porous than alluvial soils. Water holding capacity is low, permeability and infiltration rate are high due to coarse texture, and limited content of organic matter.

Where calcification and gypsification are the main chemical processes, the predominant cation is calcium which has given a calcareous characteristic to the soils in most cases.

Due to the limited amount of precipitation, especially on the alluvial deposits in arid regions of Afghanistan, these soils owe their distinctive character to the fact that they contain excessive amounts of either soluble salts or exchangeable sodium or both. For agricultural purposes such soils are regarded as problem soils which require special management practices.

1.2 PHYSICAL AND CHEMICAL PROPERTIES

1.2.1 Physical Properties of the Soil

Among the most important physical characteristics of these soils under arid and semi-arid regions are: structure, soil-water, temperature, aeration, infiltration rate, permeability, density and pore-size distribution. There is a wide range of variation regarding physical properties of these soils in the country. For example, alluvial soils, sierozems and brownsoils are more productive and have more moderate physical properties than desert soils, regosols and lithosols. We can conclude that most of the soils in arid and semi-arid regions are unstable in structure, low in organic matter and high in apparent density.

In general, organic matter content even in the alluvial deposits is not higher than 2.5 percent, while the organic content in sandy soils is less than 0.2 percent.

1.2.2 Chemical Properties of the Soil

Soil reaction is one of the most important factors which affects the uptake of plant nutrients in a large extent. The pH of the soils, except in forest areas is generally higher than 7. Soil reaction is dependent upon the composition of exchangeable cations, the nature of the cation exchange materials, and the composition and concentration of soluble salts in the soils.

Soils having pH greater than 8.5 indicate an exchangeable sodium percentage of 25 or more. Soils having pH value lower than 7.5 contain almost no alkaline earth carbonates.

In our case, due to the arid and semi-arid climatic conditions, pH is generally greater than 7, because of the high amount of alkaline earth carbonates and high exchangeable sodium percentage.

On the basis of the above-mentioned data salt affected soils in this region are classified as follows:

		$EC \times 10^3$	ESP	pH
1.	Normal soil	< 4	< 15	< 8.5
2.	Saline soil	> 4	< 15	< 8.5
3.	Sodic soil	< 4	> 15	> 8.5
4.	Saline sodic soil	> 4	> 15	> 8.5

Soil reaction combined with other factors such as cation exchange capacity which consists for the most part of various clay minerals, soluble salts, and organic matter are the most important factors considering chemical properties of the soils.

In Afghanistan due to the high pH of the soil and the high amount of alkaline earth carbonates and low organic matter content, fixation of phosphorus makes it less available to plants.

1.3 ORGANIC MATTER CONTENT AND MICROBIAL ACTIVITY

1.3.1 Organic Matter Status in the Soils

In the arid and semi-arid regions where precipitation is a limiting factor, lack of vegetative cover and the decomposition of organic matter is an effective problem in these regions.

It has been recognized that organic matter and clay fractions are both responsible for the major portion of soil aggregation. Organic matter has also an effective influence on the release of macronutrients which makes them more available to the plant use.

In Afghanistan where annual precipitation is limited, organic matter content is very rare in the desert soils, lithosols and regosols, but in the sierozems, brown and alluvial soils, the organic matter content is present up to 2.5 percent.

All these beneficial effects on soil aggregation stability, formation of the clay particles and release of micro-elements are originated from the integrated activity of soil micro-organisms, decomposition of organic matter and other related factors.

1.3.2 Microbial Activities in the Soil

The decomposition of organic matter is very important for the stability of soil structure. Organic matter without mological transformation by fungi actinomycetes, bacteria and yeasts has little, if any effect, on soil aggregation. Organic matter itself is a source of energy for soil micro-organisms without organic matter, organisms are ineffective in producing soil aggregation.

These micro-organisms under suitable conditions produce a large number of mycelia, therefore, these mycelia under metabolic processes synthesize more complex organic molecules.

Polysaccharides, organic acids humus, aminoacids, lignin and other more complicated organic compounds are the results of micro-organism activities after the decomposition of organic matter under a specific condition in the soils.

In the arid regions precipitation and vegetative cover are not enough to increase the population and kinds of micro-organisms as well as their activity. These problems are added to the others.

1.4 CONCLUSION

i. In arid and semi-arid regions most of the Great Soil Groups are desert soils, brown and sierozems. Some other soils such as lithosols, regosols, alluvials, solonchak and solonetz are associated under the orders of Azonals and Interazonal soils.

ii. Physical and chemical properties are affected by the climatic factors. Structure and texture are not satisfactorily developed. These soils are more susceptible to water and wind erosion with their low water-holding capacity.

iii. Chemically, these soils have low cation exchange capacity. High pH is due to the high amount of alkaline earth carbonates and high content of sodium ions. Accumulation of soluble salts needs special management practices.

iv. Because of the limited precipitation and insufficient vegetative cover, the content of organic matter and soil micro-organism activities are low.

v. Considering all the above-mentioned limitations, these soils need special agronomical practices. The addition of organic and mineral fertilizers is important from the standpoint of fertility status. Crop rotations combined with good irrigation practices and water management should be used.

ALGERIA

by

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Algeria has more than 2 000 000 km^2 in the arid zone which is about four-fifths of the total land area.

The following are the characteristics of this zone:

Relief: is very variable: there are as well as vast stretches cut by wadis, ranges of mountains (volcanic origin) in Hoggar and Tassili, and also dunes.

Climate: with rare exceptions, is very hot in summer (48°C in the shade), cold in winter (-5°C) with great fluctuations in temperature between day and night. Rain is extremely rare.

Soil: the sandy soils have different natures:

- Soils in wadis are the richest and this enables the growing without difficulty of a large range of market garden, fodder and fruit crops.
- Soils with a high clay content are rare and form an exception.
- Sandy soils are found with a gypsiferous crust between 20 and 100 cm deep and they are very difficult to work because regular breaking of the crust is necessary.
- Sandy soils of variable texture exist and cover most of the area requiring appropriate improvements.

Water: is of various origins:

- Rain: very rare over the whole zone, it forms the main water contribution for certain regions which often suffer great difficulties in dry years. This is the case at present in the extreme south which generally receives the tail of the monsoon and is now in the same situation as the adjacent countries (Niger, Mali, etc). Some oases use "foggaras".
- Groundwater: it is from this source that 95% of the area is irrigated. It collects at a depth varying from 100 to 1 800 m, sometimes flowing, sometimes not. Thus for groundwater collected at shallow depth there is no particular difficulty; the groundwater at 1 800 m is very hot (60°C), rich in carbonate and sulphate salts; this causes inconveniences, particularly in the choice of equipment.

From studies carried out, mainly in the UNDP/Unesco project REG 100, we know the underground water potential which could enable the presently cultivated area of 50 000 ha to be doubled.

The cultivation of date palms is now the principal source of wealth because, in the very difficult Sahara conditions, it is the only perennial plant which can resist the harshness of the climate.

Recently, great efforts for intensification have been made and we can foresee the future from another angle. In effect, the growing of market garden and fodder crops has allowed economic aspects to be introduced into agriculture, which confirms our hypothesis. For example, the export of early tomatoes, from 15 January, to the high consumption markets (Paris, Brussels, Frankfurt). Efforts to cultivate melons in "fertile pots" has given conclusive results and has made production in open fields possible in this country. The technique consists of raising the plants in "fertile pots" under a plastic tunnel. The soil is covered with black plastic sheets or gravel in order not to break the roots at transplantation. The leaf mould is well spread out and disinfected beforehand. Farmers are given plants which have had the first pinching out of shoots. The time for transplanting must be carefully chosen because it has been found that when soils are saline, it is preferable to transplant before the roots have passed through the pots in order not to lose the benefit of the operation by stopping temporarily the growth of roots.

In our country activities are also carried out to revive old palm groves as well as new irrigated areas. The old palm groves are characterized by deficient drainage because they are very often located in low places and lack organic manure. The new areas to which great attention has been paid, very often suffer from a lack of organic manure, sandy winds and hot water. To overcome these, different methods have been used:

i. Organic manure: introduction of stock farming and of alfalfa in an appropriate crop rotation; utilization of sediment obtained from purification plants for residual water.

ii. Wind breaks: the following materials are used:

- live hedges: canes, eucalyptus, casuarina, acacia cyanophyla, date palms, tamarix articulata.
- dry hedges: dry palm fronds
- "tabias": these are embankments raised around the oases with wind circulation corridors which form an exit for the sand dunes which are a hindrance.

During the first year of development work it is very often found that the deposits of sand originate from the irrigated area itself, therefore alfalfa is grown for three reasons:

- soil stabilization,
- enrichment of the soil,
- fodder production.

iii. Hot water: it is 50 to 55°C at exit from the bore hole and about 35°C at the time of its use. Its carbonate and sulphurous nature have necessitated the use of semi circular channels (seguias). The lack of technical knowledge of farmers and the distance added to the previous points, demonstrates the complexity of the situation. General systematic formulae do not exist; each oasis has its own peculiarities.

The group of actions to be undertaken must bear in mind the human factor in order to reach a harmonious development. In Algeria, the settlement of the nomads is one of the main preoccupations in the arid and semi-arid zone. The agrarian revolution, by its principle that the soil belongs to those who work it and remembering also the nationalization of groundwater, has permitted a number of difficulties to be resolved. Integrated action is being undertaken to develop the environmental conditions of these zones.

BAHRAIN

IRRIGATION AND SOILS

by

Ghaffar Habib

1. INTRODUCTION

The total agricultural area in Bahrain is estimated to be 15 000 ac, in other words, about 10% of the total area which amounts to 622 km^2. Two-thirds of this agricultural area is planted with date palms and this is considered the main crop. The rest includes vegetable crops, berseem, some orchards and some flowers. The total agricultural area at present has been reduced to 4 000 ac due to irrigation and drainage problems and soil deterioration.

The climate is characterized by high temperatures and humidity in the summer; the average annual temperature is 27°C and rainfall is 72 mm. The maximum diurnal humidity reaches 85% and the minimum 48%. Wind is mostly north-western.

2. MOST IMPORTANT CHARACTERISTICS OF THE SOILS AND IRRIGATION WATER

Concerning the soil, it is mostly sand, poor in organic matter and with impervious layers at depths between 75 and 300 cm in various regions of the country. For this reason there are large areas of agricultural land submerged with water or where the water table is very close to the surface at depths varying between 37 and 300 cm. With the presence of factors leading to salinization, such as the excessive use of irrigation water, absence of good drainage systems and sea-water intrusion, all these factors have to be considered when land is improved for better agricultural production or else the case will be worse.

The sand percentage in most of the soils is more than 90% as can be seen in Table 1 which shows the different physical characteristics of the soil. The technique used in the country is to add sand over soil to decrease the effect of salinity and to provide a salt free zone for the growth and development of roots, but this is an uneconomic practice due to costs.

As to the water, the main source is groundwater which extends from the northern coast of the Kingdom of Saudi Arabia where the water is found in three aquifers in which the salinity is respectively 2 000, 3 200 and 8 000 ppm. The total water consumption is estimated at about 165 million m^2, 80% of which is used in agriculture and the balance for domestic and industrial use. For irrigation purposes 6 m is used per year which is rather a large volume. The monthly distribution of this quantity for vegetable production is given in Table 2.

Table 1 PHYSICAL CHARACTERISTICS OF THE SOIL

Hole No.	Depth cm	Particles Size			Text	Moisture %			Hydraulic Conductivity mm/h	
		Sand	Silt	Clay		Saturation	F. Capacity	W. Point	Initial	24 hrs
2	0- 35	94	1	5	S	28	11.8	6.4	> 125	> 125
	35- 45	93	4	3	S				> 125	> 125
	45-115	93	4	3	S				> 125	> 125
	45-140	96	3	1	S				> 125	> 125
4	0- 50	90	6	4	S	36	9.2	5.0	115	108
	50- 90	64	21	15	SL				98	90
	110-130	82	13	5	LS				> 125	> 125
	130-160	81	14	5	LS				68	63
7	0- 20	96	2	2	S	21	10.0	5.4	> 125	> 125
	20- 60	98	1	1	S				> 125	> 125
10	0- 35	93	4	3	S	24	13.4	7.3	> 125	> 125
	35- 95	96	3	1	S				> 125	> 125
	95-135	83	12	5	LS				106	83
13	0- 50	69	16	15	SL	36	18.8	10.2	> 125	> 125
	50- 90	73	15	12	SL				> 125	> 125
	90-130	91	5	4	S				77	73
18	0- 40	73	17	10	SL	40	19.2	10.4	56	51
	40- 80	59	19	22	ScL				57	31

Table 2 MONTHLY DISTRIBUTION OF WATER FOR VEGETABLE PRODUCTION

January		0.294 meters
February		0.350 meters
March		0.437 meters
April		0.375 meters
May		0.442 meters
June		0.313 meters
July		0.618 meters
August		0.827 meters
September		0.592 meters
October		0.571 meters
November		0.528 meters
December		0.560 meters
	Total:	6.071 meters

3. METHODS USED TO CHECK SOILS AND WATER PROBLEMS

The main procedures to check these problems were experimented in Badie Experimental Station hoping that they would be applicable on a wider scale.

3.1 Canal Lining

It has been found that more than 30% of the flowing water is lost from unlined canals due to the high permeability of the sandy soils. The most effective method used for canal lining is polythene and cement. There is no doubt that apart from saving water losses, canal lining also reduces the conditions leading to salinization.

3.2 Use of Modern Irrigation Methods

The traditional method of basin irrigation increases the problems of irrigation and soils and since there is a pressing need to adopt other methods, drip irrigation has been introduced and has proved successful, having the advantages of water control, regulation of irrigation frequencies and intervals and saving on labour.

3.3 Windbreaks

Windbreaks were established to reduce erosion which caused the loss of the fertile surface layer.

3.4 Water conservation

Studies were carried out on the possibility of collecting and conserving water resources, especially from the natural springs which have been affected by decreasing water level and increasing salinity due to sea-water intrusion. The coordination and cooperation between Bahrain and the Kingdom of Saudi Arabia is enough to overcome these problems.

FAO in cooperation with the Agriculture Department in Bahrain and within the frame of the FAO/UNDP Project BAH/71/501 has carried out a soil and water survey and consequently it was possible to evaluate the location and extent of the agricultural areas in the north and western parts of the country with the objective of defining suitable drainage and land reclamation measures. The execution of this project will certainly lead to increasing the available agricultural land which amounts to 15 000 ac.

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Special consideration has been given to studies and research on the utilization of sandy soils since large areas of the potentially irrigable lands belong to this category. The total area reclaimed of these soils is 300 000 ac, of which 50 000 ac in in Upper Egypt and 250 000 ac in the Delta. With the exception of small scattered areas in the Delta and Nile Valley most of the sandy soils are in the desert which makes up more than 95% of the total area of Egypt.

The sandy soils vary in their properties according to their origin and formation. Those soils dominant in the western desert are made up of quartz formed from weathering of the standstone after exposure of this area to tectonic movements that resulted in the formation of the large depression in the western desert - the Qattara Depression.

The northern coast of this desert region is an exception because the sandy soils are of marine origin made of oolitic limestone with the calcium carbonate content up to 98%. The sandy soils predominant in the eastern desert and the north of Sinai are composed of quartz developed from sediments carried by Nile water over the ages; this has been confirmed by the similarity of the heavy mineral composition to that of Nile mud, the delta and the valley soils. On the contrary, sandy soils in the other parts of Sinai originated from geologic formation found in the El Tih plateau.

Although sandy soils differ in their origin, formation and properties, yet they can be considered as one group having common problems. Due to the differences previously mentioned, the studies in Egypt to solve the problems of sandy soils deal with inter-related factors and conditions which govern the possibilities of attaining the best economic utilization of these lands. Such studies include water relations, use of low quality water, physical, chemical and biological properties of these soils and their different environmental and agricultural systems beside the geologic and hydrogeologic studies.

The research planned to find solutions for sandy soil problems with the objective of increasing their economic utilization, includes studies of means to raise their water holding capacity and fertility, to improve structure by application of physical and chemical amendments and fertilizers.

With the aim of providing for macro and micro nutrient requirements surveys are carried out to find the limit of nutrients in different areas and furthermore, the fertilization techniques most suitable to each soil at appropriate times according to crop and agricultural practices.

It is worth mentioning that the reclamation of sandy soils in Egypt was dependent upon the annual addition of Nile mud besides that which was added from clearing irrigation canals and drains as well as the organic material. But the reduction in quantities of clay and silt after the construction of the High Aswan Dam has led research to be directed toward application of different methods such as asphalt emulsions, chemical amendments, whether by direct mixing or in barriers.

Regarding the management of these soils, consideration has been given to practical applications that limit the probable occurrence of rising water table, spread of salinity and erosion effects. In spite of this reclamation of sandy soils, Egypt is still faced with many problems that await correct solution. It seems that the attention paid to these soils does not agree with the normal economic measures used for evaluating other agricultural systems but due to the increasing rate of growth of population and the pressure on horizontal expansion of land resources, the utilization of these soils is a "must". It is our hope that through study and research timely solutions can be provided for the problems of sandy soils.

IV.5 SANDY SOILS: DISTRIBUTION, RESEARCH AND DEVELOPMENT

by

M. H. Banai and A. Kowsar

5.1 DISTRIBUTION

Iranian territory covers an area of some 1 650 000 km^2 and extends between latitude 25° and 40° N., and longitude 44° and 63° E.

Iran is covered to a large extent by the mountains (over 50% of the total land surface is highly broken in topography) which surround the saline, sandy or rocky deserts of the central plateau, thus making the plateau a closed basin. There are four main physiographic systems in Iran, these are:

i. The great Zagros and Alborz mountain ranges, which together form a great V shape;

ii. The area within the V, which begins as a high plateau with its own secondary ranges, and gradually levels towards the interior deserts;

iii. The low lying plain of Khuzestan, which is a continuation of the Mesopotamian plain; and

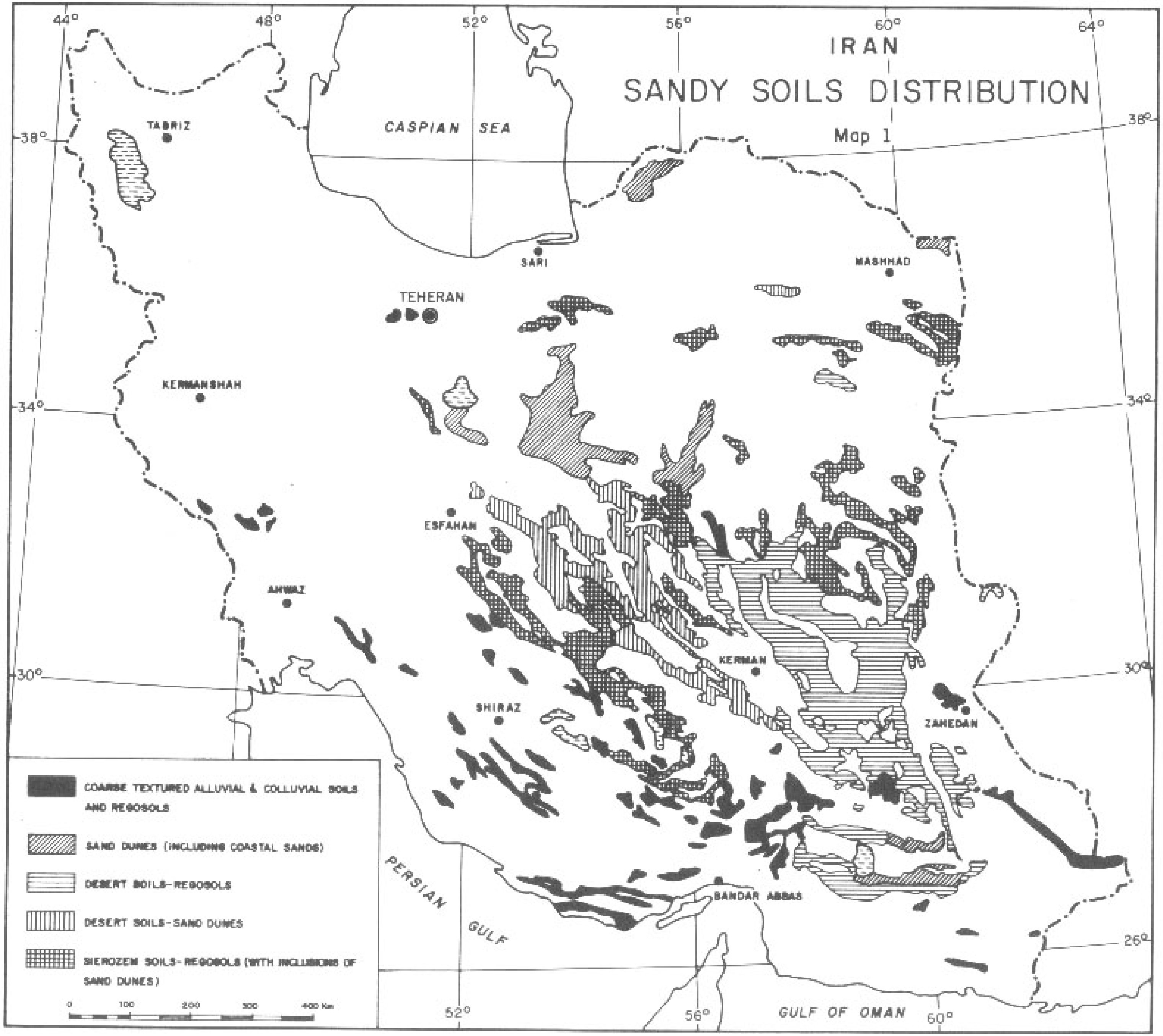
iv. The Caspian coast, which lies below the sea level and forms a separate climatic zone.

The major part of the country is arid or semi-arid. Rainfall is restricted to the winter months, except on the northern flanks of the Alborz mountain ranges where it varies from 1 000 to 2 000 mm annual rainfall. On the plateau the average annual rainfall of over 200 mm in the north decreases to less than 120 mm in the south and south east.

The sandy soils described in this context are soils in which the percentage of particles between 2-0.05 mm exceeds 60% of the total constitution. Thus these soils cover the loamy sand and sands. This is a grouping of soil units geographically associated in the landscape and selected in order to correspond to broad climatic and physiographic units, Map 1.

The areas of each of the soil associations mapped is given below:

	Area in 1 000 ha	%
I. Soils of the plains and valleys		
Coarse textured alluvial and colluvial soils and regosols	5 000	3.6
Sand dunes (including coastal sands)	3 000	1.3


IRAN
SANDY SOILS DISTRIBUTION
Map 1
CASPIAN SEA
TABRIZ
SARI
MASHHAD
TEHERAN
KERMANSHAH
ESFAHAN
AHWAZ
KERMAN
SHIRAZ
ZAHEDAN
BANDAR ABBAS
PERSIAN GULF
GULF OF OMAN
44°
48°
52°
56°
60°
64°
38°
34°
30°
26°
COARSE TEXTURED ALLUVIAL & COLLUVIAL SOILS AND REGOSOLS
SAND DUNES (INCLUDING COASTAL SANDS)
DESERT SOILS-REGOSOLS
DESERT SOILS-SAND DUNES
SIEROZEM SOILS-REGOSOLS (WITH INCLUSIONS OF SAND DUNES)
0
100
200
300
400 Km

	Area in 1 000 ha	%
II. Soils of Plateau		
Desert soils - regosols	8 000	5
Desert soils - sand dunes	8 000	5
Sierozem soils - regosols (with inclusions of sand dunes)	9 000	5.6

5.2 DESCRIPTION OF MAPPING UNITS

5.2.1 Soils of the plains and valleys

Soils of the plains and valleys are formed by soil material which is not residual but is brought by the usual agencies of water and wind.

i. Coarse textured alluvial and colluvial soils and regosols including sand dunes

These are colluvial soils and soils of coalescing alluvial fans which have been and in most cases are still being built up by material carried by flood waters from the mountains to relatively narrow valleys. They are usually developed on coarse to medium textured material with inclusion of finer textured soils in places (Regosols). Because of much gravel, low water holding capacity and infertility, they are not of great use for agricultural development. The distribution of these soils are in foothill areas throughout the arid and semi-arid parts of the country.

ii. Sand dunes (including coastal sands)

Sand dunes are common in most of the arid and semi-arid regions if Iran. They consist of loose sand, occurring within or near the margins of deserts and coasts, and are composed largely of quartz or fragments of many different minerals. Sand dunes may be mobile or fixed. Unstabilized mobile sand dunes may migrate over the land, destroying crops, agricultural areas, villages, etc. Mobile sand dunes are normally devoid of any vegetation. Stable or fixed dunes usually have short growth of grass or scattered shrubs in arid and semi-arid regions. In coastal sands in the humid and sub-humid areas, some shrubs and low lying tree species are also found to occur. In this case a slight profile development may occur. In some cases where sand dunes are fixed or stabilized they may be used for pastures although their carrying capacity is low. Sand dunes cover a large area in the central, southern and south eastern parts of Iran.

5.2.2 Soils of Plateau

The last mapping units are desert soils and sierozem soils in association with sand dunes and regosols in arid regions.

To summarize, most of the sandy soils in Iran occur as sand dunes which are not being cultivated due to limitations on physico-chemical properties such as low water holding capacity and nutrient deficiencies, etc. Though at present these soils are not so important for crop production point of view, since the mobility of these sands is threatening farms, urban areas, industrial centres and communications, the stabilization of these dunes is of very great importance to the country.

5.3 RESEARCH AND DEVELOPMENT

Considering the vastness of the area covered with active and potentially hazardous sand dunes, 182 900 km^2 in all, the immensity of the responsibility for carrying on the research and development activities becomes obvious.

Sand dune stabilization activities are relatively young in Iran; it was only around 1959 that two small areas, one of 2 ha and another of 3 ha were selected on active sand dunes 30 km north of Ahvaz. Palisades made of stalks of the grass Imperata cylindrica, one meter high were erected in rectangles of 10 x 7 m. Seedlings, seeds and cuttings of different plant species and slips of grasses were planted in these rectangles.

It was in 1965 that a more active interest was taken in the moving sand problem. Under the authorization of the Forest Act a hazardous area of 2 000 km^2 was declared restricted in the Khorasan Province. No grazing or other means of destroying the vegetative cover was allowed in the area. Windbreaks made of the stems of Ferula galvanifera (a biennial umbellifera) and Aristida pennata (a perennial tall grass) were erected and seedlings of Haloxylon persicum were planted in these windbreaks. Seeds of Haloxylon were first imported from the U.S.S.R., but later they were collected locally. Sowing seeds both by hand and by plane were tried and the former was successful in years of normal precipitation.

In 1966 two 10 ha experimentalareas were selected and palisaded in two locations near Ahvaz. The successful species of previous trials, namely: Tamarix pallisii, Calatropis procera, Calligonum polygonoides and grasses like Panicum antidotale, Pennisetum dichotatum were planted in these areas with irrigation. It is estimated that the cost of palisading alone was about 19 000 Rials per ha. The results of these treatments were encouraging and very good covers of vegetation were obtained in both places.

The spraying of petroleum mulch for sand dune stabilization was started on a trial basis in one of the pilot areas 75 km south of Qazvin in 1968. The stabilized area was then planted with suitable species. The remaining area (about 5 km^2) was sprayed with the mulch in 1969.

Since the start of the developmental activities the achievements have been excellent and there has been near-perfect stabilization of large areas of moving sand dunes by the following actions:

i.	Protection of the hazardous areas in	24 177.5 km^2
ii.	Erection of mechanical windbreaks for	14 744 km
iii.	Repair of broken windbreaks for	68.5 km
iv.	Planting of 94 million seedlings	
v.	Sowing seeds in	2 203 km^2
vi.	Collection of 1673 metric tons of seeds of trees, shrubs and grasses used in the planting process.	

The proposed work load for the current year should cover 402 km^2 of planting and 793 km^2 of seeding.

In conjunction with the above named activities over 73 km^2 of sand dunes near towns, railroad tracks and airports have been sprayed with petroleum mulch and planted with suitable species.

The Research Institute of Forests and Rangelands which was established in 1968 took a very active interest in sand dune fixation and with the help of an FAO expert started doing research in the related areas (Map 2). The main objectives of 28 trials (some terminated) have been:

a. Finding the most effective and the most economic means of stabilizing moving sand dunes.

b. Utilizing the stabilized areas according to their potentials.

c. Conducting basic studies concerning the nature and the extent of the problem.

Two main stations were established in two quite different climatic conditions. One is in Ahvaz, which is very dry and very hot, (average annual precipitation is 190 mm, and the maximum temperature 54°C). The other one is in Sabzevar, which is very dry and very cold (average annual precipitation is 150 mm, and the minimum temperature -16°C).

Studies are conducted by these stations or substations in the nearby areas. Movement of sand dunes, soil moisture conservation, different heights, patterns and the materials used in erecting windbreaks, effect of media on establishment of seedlings, different planting and sowing periods, size of cuttings, spacing, pretreatment of seeds with pesticides, cultural practices, effect of chemical mulches on sand dune fixation, heritability of the resistance to fungal attack of Haloxylon persicum species trial, and ecological studies are some of the subjects on which research is being carried out.

A paper reporting the results of studies on mechanical windbreaks, their effectiveness and cost is in press. About a 50% reduction in cost compared with the old method, has been achieved by a new design. Another report covering the Tamarix plantation and its economic values is being prepared for print. A basic study on the dynamics of moving sand dunes in the Qazvin area is also ready.

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IRAN
SAND DUNE FIXATION CENTRES
Map 2
TABRIZ
CASPIAN SEA
TEHERAN
SEMNAN
MASHHAD
KERMANSHAH
KASHAN
ESFAHAN
BIRJAND
YAZD
AHVAZ
KHORRAMSHAHR
SHIRAZ
KERMAN
BUSHEHR
ZAHEDAN
BANDAR ABBAS
IRANSHAHR
PERSIAN GULF
JASK
CHAH BAHAR
GULF OF OMAN
0 100 200 300 400 Km
NAMES OF CENTRES
1 - BANDAR ABBAS
2 - BARAZJAN
3 - BADRUD - NATAHANS
4 - KERMAN
5 - NARAMSHIR
6 - RAFSANJAN
7 - SIRJAN
8 - ZARAND (KERMAN)
9 - FERDOWS
10 - GONABAD
11 - KASHMAR
12 - KHAF
13 - NEYSHABUR
14 - SABZEWAR
15 - TABAS
16 - TORBAT-E-JAM
17 - AHWAZ-KHORRAMSHAHR
18 - ALBAJI
19 - DHAMGAN-SORKHDEH
20 - SARVAN
21 - ZABOL
22 - ZAHEDAN
23 - ABARDEZH
24 - ABUZAIDABAD
25 - ARAN-KASHAN
26 - BOUINZAHRA
27 - ZARAND-SAVEH
28 - ASHKGARH
29 - BAFQ
30 - YAZDGERD

IRAQ

by

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This report will not deal with morphology and classification of sandy soils since these have already been mentioned in the paper on Classification and Distribution of Sandy Soils in the Near East Region prepared by Dr. Kadry for this Seminar. It will deal with the following points.

1. Types of sandy soils.

2. Their problems and effect on agricultural development in Iraq.

3. Facilities available in Iraq for the development of these soils.

6.1. Types of Sandy Soils

The sandy soils of Iraq can be grouped into four categories according to texture, composition, presence on surface or subsurface and their physical and chemical characteristics; also method of utilization.

i. Sandy soils on river banks and water courses

In this type of sandy soil the percentage of fine fraction such as silt is dominant. The soils are frequently inundated either by floods from the river or high water table levels. Such soils are utilized for vegetable crops, legumes and rice production. Inorganic fertilizers are used to improve their productivity. In most cases these soils are not irrigated since they obtain their water requirements through capillary rise.

ii. Levee soils

These are of widespread occurrence in the alluvial plain in central and southern Iraq. Usually these soils are of light texture or contain a sandy layer which differs in thickness and depth. Some problems have appeared when executing land reclamation projects in this type of soil, especially in the construction of irrigation schemes and tile and open drains. There is a need for a comprehensive study of the effect of these layers on the basic principles of irrigation and drainage design up to the farm level.

iii. Sandy soils in the plains of central and southern Iraq

The area has a width of 5 to 25 km and extends from north-west to south-east, starting from Mussayeb project down to Zubair. In these areas the soils are characterized by an additional problem which is salinity and high water table level.

iv. Sandy soils in the northern and southern deserts of the Ghezira

Here the soils are characterized by the high gypsum content.

6.2 Problems and Effect on Agricultural Development

The most direct and indirect problems of sandy soils in agricultural development in Iraq could be summarized as follows:

i. Management and development of sandy soils either in the fields of irrigation, fertilization or erosion control. This is particularly necessary close to highly populated rural areas, since this type of soil could be the only source for agricultural land.

ii. Difficulties facing the construction of irrigation and drainage systems due to the presence of sandy layers which require special studies for design, execution and management of the systems.

iii. The effect on agricultural and grazing lands of sandy dunes and their movement due to wind erosion.

iv. The dual problem of salinization and poor management of sandy soils which has resulted in shifting agriculture as is the case in Zubair region where poor quality groundwater was used for vegetable crops.

v. The difficulties of sandy gypsiferous soils and rainfed lands in the northern and southern deserts where a land settlement project for Bedouins is being carried out and small scale dams are being constructed for irrigation and drinking water.

6.3 Facilities available in Iraq for development of these soils

i. The Institute of Natural Resources which belongs to the Organization of Scientific Research is carrying out some studies on the characteristics of these soils in addition to ecological studies and groundwater quality in these sandy areas.

ii. Recently the State Organization for Soils and Land Reclamation was established with a special Division for studying the problems of desert and rainfed lands. An experimental station has been established to carry out studies on the management of these soils. It is hoped that the Organization will expand its efforts in this field, especially after the support given by the higher authorities of the country.

iii. The General Department of Forestry which carries out studies on sand dune fixation in relation to wind and water erosion.

Conclusion

We would suggest the setting up of a special committee of those specialized in soil science, irrigation and management of sandy soils to look into the major problems of these soils, to set up guidelines and procedures for reclaiming and utilizing them, making use of existing studies and experts at the national and world level.

Coarse-textured soils have only recently begun to attract attention in Jordan. The geological stratigraphy has been such that coarse-textured soils are of limited extent in the central plateau area where the traditional agriculture is based on either rainfall or irrigation from perennial springs.

In the desert southern and north-eastern parts of Jordan, agriculture has recently become possible due to national efforts to tap the available groundwater or peak spring flows. Recent studies have shown good supplies of water, but many of them are in the vicinity of coarse-textured, alluvial and colluvial soils, as in Wadi Rum, Wadi Araba and Azraq basin.

In Wadi Rum, the ongoing pilot studies indicate the feasibility of agriculture but the suitable soils are extremely limited in extent. Here the landscape is characterized by mud-flats with no visible surface drainage and is surrounded by an undulating area dominated by shifting sand dunes and towering sandstone hills. The intervening area is transitional in texture but is frequently very stratified; though sandy textures appear to dominate the surface layers, sandy layers are also encountered between the clayey layers. Only a small proportion of the area located in the transitional zone has a medium texture and can be used with the conventional technology. The mud-flats are highly saline and alkaline, having a very low permeability, and have no feasible drainage outlet due to unfavourable topography. Only the fringes surrounding the mud-flats appear to be usable and this too requires the addition of 10 to 15 cm of sand and deep ripping to improve water penetration. The outlying sandy soils which are of considerable extent have a great potential if techniques for stabilizing the shifting dunes, and for irrigating and managing sandy soils can be developed.

The Azraq basin in the north-eastern desert also has extensive areas of sandy soils, and here too good quality groundwater that can be used for agriculture is known to be available.

In Wadi Araba, which extends from the Dead Sea southwards to the Gulf of Aqaba, coarse-textured soils are widespread on the undulating valley floor. Water for agriculture is available from the Wadi Mujib as well as from wells.

Up to the present, coarse-textured soils have been classified as non-arable as far as irrigated agriculture is concerned. They can have a great potential if the use of techniques for frequent applications of small amounts of irrigation water, the use of artificial or natural surface mulch to conserve moisture, and a choice of climatically adapted economic crops, which will also protect the soil and improve its structure and water-holding capacity, are found feasible.

It is hoped that the deliberations of this Seminar willprovide guidelines for the economic utilization of the scarce, good quality, groundwater found in the vicinity of the coarse-textured soils.

RECLAMATION AND MANAGEMENT OF SANDY SOILS

by

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8.1 INTRODUCTION

Sandy soils in Lebanon cover an area of about 70 000 ha of which 80% is sand and 20% loamy sand and sandy loam. This area is about 1/5 of the total cultivated land. The sandy soils are not affected by salts compared to most of the Middle East. The 80% fall under sub-humid conditions and their origin is mostly sandstone, thus they are not calcareous; whilst the 20% originated from sand dunes and are calcareous.

8.2 ORIGIN AND DISTRIBUTION

Sandy soils in Lebanon are formed on Nubian sands of the lower Cretaceous and are found between sea level and about 1 000 m height in the direction of west-east. From the north they start after the basaltic flow in Akkar and extend up to Jezzin (Saida) in the South.

The sand dunes are found interruptedly along the coastal line and extend inward about 3 km in the Akkar region. They originated from the Miocene and Pleocene deposition.

8.3 MORPHOLOGY

In general the sandy soils are classified as entisols and xerorthents in the 7th Approximation and as <u>Sols Mineraux Bruts</u> in the French system with A-C horizons.

Between 800 and 1 000 they tend to develop to para podzolic under pine and natural vegetation with a thin organic layer (O) and albic horizon. The severe erosion prevents them forming true podzols. They are very steep from 20% to 60%. The pH is about 6.

Below 800 m the climatic conditions will not allow the para podzolic formation; they are classified as xerorthents. Most of the sandy soils in the coastal region are deep with A-C or A(B)C horizons and are classified as calcixerollic xerorthents or xerochrepts respectively, whilst the others are shallow, formed on consolidated sand dunes (Ramleh). The composition of the consolidated parent material is quartz, shale fragment, and other materials which are cemented by calcium carbonate. The organic matter content is low. The pH is about 7.5 to 8.0. The calcium carbonate content is about 10 to 20%.

8.4 LIMITING FACTORS

8.4.1 Erosion

The erosion in the mountainous region is caused by the high rainfall, 800 to 1 200 mm, which comes with great intensity, whilst in the coastal region the erosion is due to wind.

The measures which are being taken to prevent erosion are to build terraces in the mountain region and to plant wind-break trees in the coastal region.

The sand dunes are being fixed by planting shrubs and pine trees.

8.4.2 Fertility

The fertility of these soils is poor, thus high rates of inorganic fertilizers, crop residues and manure are applied. In addition, some of the micronutrients are applied. The fertilizers are split into 4 to 6 applications during the growing season. These soils are being utilized for orchards and cash crops.

8.4.3 Water Consumption

Due to the low water holding capacity of these soils (6-10%) and to the high evapotranspiration, irrigation water is frequently applied.

There is an intrusion of sea-water into the coastal underground water due to its high intensity of use for irrigation. This low quality water is used safely on the sandy soils.

8.5 INVESTIGATIONS

Recently there have been investigations at some sub-stations to study the evolution of structure through the application of high rates of organic matter.

The Irrigation Department is studying water consumptive use. Concrete lysimeters, 10 by 10 meters, are being utilized in this study. The crop used is banana.

Research on soil conditioners will start this coming year in cooperation with the Soils and Irrigation Department of the American University of Beirut.

ARAB REPUBLIC OF LIBYA

RECLAMATION AND DEVELOPMENT OF SANDY SOILS IN AL GEFARA PLAIN

by
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Ministry of Agriculture and Agrarian Reform

1. INTRODUCTION

There is great concern for agricultural development and land reclamation in Libya at present with the objective of increasing agricultural production. There have been numerous studies in scattered areas of the country for soil and water resources, mainly based on soil survey and classification and water inventory for ground or surface water. On the basis of these studies several areas have been given priority for reclamation and development. The Gefara Plain is one of these selected areas.

2. LOCATION AND TOPOGRAPHY

The total area of the Gefara Plain is 17 000 km^2 starting from the Tunisian borders in the west and extending east to Al Khums, to the Mediterranean in the north and southward to Gebal Nafusah where the elevation reaches 400 to 700 m above sea level. The length from east to west is 170 km, the breadth in the north-south direction is about 100 to 110 km. It is divided into two areas: the first is known as the coastal strip, which runs parallel to the sea shore varying from 1 to 15 km wide. This strip is one of the most important agricultural areas at present as there are many forms of agricultural activity. The second or inner part is the plain which extends from the coastal strip to the southern mountains; within this plain there are valleys varying in elevation and width. Most of these wadis are found in the eastern and central part of the plain.

3. CLIMATE

The dominant climate is Mediterranean but to the south it is semi desert. The annual rainfall at Tripoli varies from 300 to 380 mm and decreases towards the south until it reaches 50 mm and where it could be rainless for several years. The average temperature on the coast is 19.5°C and increases to the south until it reaches on the average 30.5°C.

4. GEOLOGIC FORMATIONS

Geological and morphological studies of the Gefara Plain indicate that the land utilized at present or that is under reclamation and development developed from transported sands or material deposited in the middle and late Quaternary. In the sub layers of the soil profile there is an accumulation of lime in varying formations of old pedological origin.

5. DOMINANT SOILS IN AL GEFARA PLAIN

Weathering by wind, heat and water followed by chemical weathering are the dominant soil forming factors responsible for the formation of the soils in the Plain which are generally sandy and vary in texture from pure sand to loamy sand, dominant on the northern coastal strip. In the wadis soils are sandy clay.

Sand dunes in many areas form a belt extending along the coast where the sand grains vary from coarse to medium size and are rarely fine. The soil is often immature and the profile is very deep; pH of all the soils is greater than 7 and reaches 8.5 in some cases. The soil survey studies indicated that the dominant soils are:

i. Brown podzolic regosols

They are sandy, pervious, have a deep profile, are free of salts, with no gravel or stones and the soil needs protection against erosion. These soils are found along the coastal strip and in some parts of the inner valley as is the case in Al Aziziyah. The following table gives an analysis representative of the profile of these soils.

Location: Sidi Al Misri

Profile: No. 34

Depth:	0-30 cm	30-80 cm
Mechanical analysis		
Sand	88	82
Silt %	9.6	15.6
Clay %	2.4	2.4
Texture	Sand	Loamy sand
Chemical analysis		
pH	7.9	8.1
EC mmhos/cm	.50	.81
$CaCO_3$ %	2.1	1.0
OM	.32	.14
Carbon %	.18	.08
Total Nitrogen %	0.02	0.01
Soluble phosphorus ppm	55	24
HCO_3 meq/l	1.1	2.4
Cl	2.0	3.1
SO_4	2.0	2.7
Ca + Mg	3.2	5.6
Na	1.8	3.0
K	.6	.53

ii. Alluvial soils of the interior plain

These soils are formed by deposition of sediments carried by water from the northern mountains forming fans and then plains in the wadis. They are the most fertile and the profile is free from salts but is less pervious than the previous type. Silt is the dominant size fraction with a higher clay content relative to the previous type. The following is the analysis of a representative profile:

Location: Wadi Al Meganeen

Profile: No. 4

Depth:	0-25 cm	25-62 cm	100-130 cm
Mechanical analysis			
Sand percentage	63.6	63.6	69.6
Silt %	34.2	32.2	25.2
Clay %	2.2	4.2	5.2
Texture	Sandy loam	Sandy loam	Sandy loam
Chemical analysis			
pH	7.6	7.9	8.0
EC mmhos/cm	.71	.63	1.07
$CaCO_3$ %	6.0	9.0	6.3
OM	.08	.02	.01
Carbon %	.45	.12	.06
Total Nitrogen %	.04	.01	.06
Soluble phosphorus ppm	114	134	195
HCO_3 meq/l	3.8	3.2	2.0
Cl	2.8	2.5	6.4
SO_4	3.8	3.2	2.0
Ca + Mg	3.3	3.8	4.2
Na	3.0	2.6	6.5
K	.1	0.0	0.0

iii. Solonchak soils

This type of soil is found in certain areas along the coastal strip, closer to the sea shore, especially in the west near Zuwarah where there are large areas forming bare lagoons separated by sand dunes. These soils have not yet been thoroughly studied.

6. THE MOST IMPORTANT PROJECTS IN AL GEFARA PLAIN

The projects vary in location and objectives; some are dependent on groundwater resources, others on surface water flow from the wadis and others again depend on rainfall (rainfed agriculture). The most important of these projects are:

i. The Green Plateau Project

The total area of this project is 2 000 ha divided into small farms of 6 ha each. This project is located 5 km south of Tripoli and depends mainly on the use of sewage water after purification for irrigation by sprinkler. The project is to produce vegetables, fruits and certain field crops because of its proximity to markets and the possibility of food canning; there is also cattle breeding and bee keeping. It is under the supervision of the General Organization for Land Reform and Rehabilitation and the land has been distributed to farmers.

ii. Bir Al Ghanam

This project is divided into two parts:

a. Al Aziziyah-Al Amryah Project

The objective of the project is to reclaim and cultivate 1 100 ha to be divided into 100 farms, 75 of which have already been established. The project uses groundwater in the area.

b. Bir Terfas (South Az Zawiyah)

This project has just started and aims to establish 400 farms on an area of 6 000 ha as the first phase; work has started by digging wells in the area.

iii. Wadis Al Heera-Al Deeka-Al Meganeen Project

The first phase of the project is to reclaim 30 000 ha in the Al Heera-Al Deeka area south of Tripoli and will depend mainly on rainfall. Work is in progress on the establishment of 1 520 farms. A second part (Wadi Al Meganeen) depends on the water stored in the reservoir and is for 11 000 ha.

iv. Wadi Al Maiet and Al Athl Project

The objective of the project is to reclaim 25 000 ha in Wadi Al Maiet and 10 000 ha in Wadi Al Athl. It is also a rainfed project apart from the establishment of 625 farms for permanent irrigated agriculture which will depend on groundwater.

v. Al Karaboli Project

This is in the eastern part of the plain and consists of establishing 850 farms on an area of 20 000 ha. Some of the farms will be for rainfed agriculture and the others will be irrigated.

vi. Crop Development Project

This project is to improve the winter crops, mainly wheat and barley, on an area of 100 000 ha, including the wadis, over a period of 3 years which started in 1973. The project depends on rainfall.

vii. Forest Development and Rangeland Project

There is a project each for forestry and rangeland to utilize lands bordering the southern part of the plain in scattered areas of 5 000 ha each. The forestry project is to increase the vegetative covering where other traditional crops cannot grow and will therefore serve as an erosion control measure.

7. PROBLEMS OF LAND RECLAMATION IN AL GEFARA PLAIN

There are problems involved in land reclamation and development, especially in areas where soil is sandy, low in organic matter and nutrients and where water is scarce, of low quality and continuously degrading as is the case in Al Gefara Plain. The most important problems are:

i. Irrigation Water

The quantity and quality of irrigation water is the most critical factor for horizontal and vertical expansion. Rainfall is on the low side,besides being of seasonal distribution and evapotranspiration is very high. Also a great deal of the irrigation water is lost to the sea by run off and only the remainder can be utilized by the crop, with the continuous demand for this water, especially in summer, the level to groundwater has increased and the quality deteriorated. For water conservation measures dams have been built on the wadis to limit water loss to the sea and to recharge groundwater. Additional measures have been introduced to limit the growing of summer crops, e.g., groundnuts andothers with a high water consumption during this season.

ii. Erosion Control

Large areas of the Al Gefara Plain suffer from erosion, especially by wind and sand dune encroachment on the agricultural land where southern winds in spring and summer cause much damage to agriculture. Efforts have been made to stop sand dune encroachment from south to north and of these measures the following have been used:

a. wind breaks and afforestation;

b. use of certain plants as surface cover;

c. use of dried plant material as sand dune stabilizers; and

d. recently, petrochemicals have been used as stabilizers followed by afforestation.

Up to the present it has been possible to control sand dune encroachment on large areas where forests have been developed.

iii. Soil Fertility

This is one of the serious problems since the sandy soils are low in nutrients as well as organic matter. Measures are being taken to use nitrogenous and phosphate fertilizers and, in some cases, potash, but until now micronutrients have not been used.

IV.10 MOROCCO

10.1 GEOGRAPHIC AND CLIMATIC CHARACTERISTICS

10.1.1 Relief

Morocco covers 450 000 km^2 between the latitudes 27° and 36°N. It is traversed by two mountainous formations which give it very diverse geographic and climatic characteristics.

In the north the chain of the Riff borders the Mediterranean from east to west. In the centre crossing the whole country from south-west to north-east the Anti Atlas, the Middle Atlas and the High Atlas form a strong barrier against the Saharan influences. The High Atlas rise to a height of more than 4 000 m. Morocco consists of several plains crossed by rivers; the main ones are:

- the plains of Gharb, Tadla, Haouz, Souss, Tafilalet, Ouarzazate, Moulouya, Loukkos, etc. They are the subject of big hydro-agricultural development schemes.

10.1.2 Climate

January is the coldest month of the year. The mean minimums are all lower than 10°C and go down to 0°C in the mountains. The maximums occur most often in July and occasionally in August. They are over 30°C except on the Atlantic coast.

Rainfall varies according to the region from 400 to 800 mm annually.

10.2 MAIN TYPES OF SOIL

The main types of soil are:

- isohumic, found in the Mediterranean region. These soils are characteristic of the plains, foothills and plateaux of Atlantic Morocco (with the exception of the coastal strip).
- red and brown Mediterranean soils (mountainous zones).
- vertisols called "tirs" cover vast areas in Atlantic Morocco, mainly Gharb, Chaouia and Loukkos.
- hydromorphic soils in the periphery of the Gharb and the central plateau.
- halomorphic soils found in the arid and Saharan regions.

10.3. AGRICULTURAL POLICY

The deficiency of water inherent because of the long dry season, the irregular rainfall in the humid zone and the size of the arid and semi-arid zones with an almost permanent lack has led Morocco to search for means to improve and intensify agricultural production by using the maximum water resources possible.

The numerous areas with small or middle size water works represents on the national scale an important potential (40%) but their size and dispersion do not allow development of an industrial character.

Anxious to create as soon as possible a highly productive sector, Morocco has decided on large scale hydraulic works.

Since 1960, a huge effort has been made in the construction of dams and the equipment of large areas for irrigation for an integrated development. The potential national total available is estimated at 7.5 thousand million m^3 which ought to permit irrigation of a million hectares. This perspective forms the principal objective of Moroccan agricultural policy.

In 1973, it was estimated that an area of 600 000 ha was irrigated every year, 400 000 ha permanently irrigated and 200 000 ha depending on contingencies.

In the 1973-77 Plan we expect to extend this area at the rate of 25 000 ha annually.

The equipment undertaken constitutes only an indispensable phase. But the real objective is the effective improvement of production and of the level of life of the farmers.

The scheme has been undertaken systematically in order to ensure an integrated management of the rural zones.

The areas which will be developed are:

- industrial crops (cotton, sugarbeet, sugarcane)	1/4
- fodder crops	1/4
- cereals	1/4
- tree crops	1/8
- market garden	1/8

In view of the shortage of water due to the aridity of the climate, the volume of water used annually is extremely high. The practice of gravity irrigation imposed by the land capability and local necessity does not allow, in spite of the efforts by the Moroccan experimental service, the limiting of losses by infiltration to a satisfactory level.

The rising of the watertable is therefore inevitable and requires effectua intervention as soon as the watertable effects the upper horizons and inevitably causes their salinization.

Thus one must put in hand at the same time the equipment for hydro-agriculture and the drainage of these areas.

It should be noted that sprinkler irrigation has just been introduced recently over a large area (30 000 ha in the perimeter of Massa).

Drip irrigation is in the experimental stage and great hopes are being placed in this technique.

SANDY SOILS IN WEST PAKISTAN

by

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11.1 INTRODUCTION

West Pakistan has a total area of 312 000 mi^2 (about 800 000 km^2) and supports a population of about 60 million. It lies between latitudes 23° and 37° north and longitudes 61° and 76° east. There are three broad physiographic divisions: (i) the mountainous area, (ii) the Indus plains and (iii) the Thar desert. The mountainous area covers more than two-thirds of the total area on the western side. The Indus plains occupy an area of about 80 000 mi^2 (205 000 km^2), whereas the Thar deser covers about 25 000 mi^2 (64 000 km^2).

11.2. CLIMATE

West Pakistan has an arid to semi-arid subtropical continental climate. According to the precipitation data, 67% of the area receives rainfall/snow below 10 inches (250 mm), 24% between 10 and 20 in (250 and 500 mm), 5.3% between 20 and 30 in (500 and 750 mm) and only 3.7% area gets rainfall above 30 in (750 mm). The highest precipitation occurs in the north-east and decreases rapidly in the south-west direction. The rainfall/snow is greatly variable in time as well as space. In the area east of the Indus above two-thirds of the annual rainfall is received during summer, mainly in July, August and September, the remaining one-third occurring during winter months. May and June are the hottest months when the maximum temperature may rise to 113°F (45°C). In the area west of the Indus river about two-thirds of the precipitation occurs in winter and the remainder in summer. The hilly areas in the west and north have mild summers and severe winters.

11.3 SANDY REGIONS

There are three sandy regions in West Pakistan. The location of these regions is shown on the accompanying map. The potential, use and management problems of each region are described below.

11.3.1 Thal Sandy Area

The Thal is the most important sandy region in the country. It occupies an area of some 9 000 mi^2 (23 000 km^2) between the Indus and Chenab rivers. It presents a complex pattern of alluvial deposition of sandy materials in Late Pleistocene, mainly by the Indus river and locally by the Chenab; progressively followed by wind resorting of the sediments into various forms of sand ridges; resorting and further deposition of sandy materials by water within spill channels passing through the sandy ridges; locally, modification of the sand ridges by river action; deposition of silty and clayey sediments by river spill channels; and present-day wind resorting of the sandy materials and locally, dune formation.

Most of the area is under longitudinal sand ridges; their size and orientation is variable depending upon wind regimes of the localities where they occur. The inter-ridge valleys have loamy soils under a semi-arid climate, but sandy loam soils in the arid area (classification: yermosols, FAO/Unesco; typic camborthids, USDA). The sand ridges are several feet higher than the valleys between them and have developed sandy soils. The subsoil is firm when dry and is slightly brighter than the surface soil or the sub-stratum. The proportion of fines in the sandy soils is higher under the semi-arid climate as compared to the ones under the arid condition, (classification: calcaric regosols, FAO/Unesco; ustipsamments and toripsamments in semi-arid and arid regions respectively, USDA).

The sandy soils of Thal are used at present for raising crops as well as for grazing. In the northern part of this region where annual rainfall is more than 10 in (250 to 300 mm), most of the area is sown to dry-farmed gram (Cicer arietinum) and mustard (Brassica juncea). The sandy soils in the arid part are exclusively used for grazing. In considerable areas over-grazing has transformed the surface of the sand ridges into shifting sands.

Around 1947, canal irrigation was introduced in the northern and western parts of this region. Subsequently, the irrigation was extended to areas further south. This development has affected the use and management of sandy soils in a number of ways.

i. In spite of the fact that the main canal was lined with bricks to check exclusive seepage losses, a rapid rise in watertable was noticed. This can be attributed to large-scale seepage losses from the unlined distributaries, water courses and also over-irrigation of highly permeable sandy soils having sandy substrata. There are some places where the sand ridges can be seen surrounded by marshes. In areas close to the main canals and where the sand ridges are not well marked, the sandy soils were subjected to high watertable and salinization.

ii. Irrigated valley bottoms were extended into the sandy ridges by disturbing the sandy soils and their sandy substrata, and then spreading the material on the loamy soils. In many places this caused deep burial of the productive soils with unproductive sand.

iii. The pressure of population has been responsible for bringing large areas of sandy soils under irrigation in this region. The flood irrigation has severely impoverished the soils of their nutrients by excessive leaching. Before irrigation the sandy soils were sown to gram which has a deep root system and builds up the nitrogen content of the soil. Cultivation of other crops under irrigation has incapacitated those soils from producing gram. This may also be due to the use of nitrogenous fertilizers only, causing acute deficiencies of phosphorous in the soil. Under these conditions the yields of other crops, especially wheat, sugarcane and guara (Cyamopsis psoralioides) are showing a steep decline and the plants indicate nutrient deficiency symptoms of all sorts. The irrigated sandy soils in Thal are going to pose a serious fertility problem in the coming years.

iv. The uncultivated sandy soils had a fair cover of vegetation under natural conditions and were used for grazing. In areas where valley soils are irrigated, the natural vegetation is rarely found in an undisturbed state, much of the original vegetation having been subjected to cutting, lopping and over-grazing. This has given rise to formation of active dunes which may pose a serious threat to the adjoining irrigated interdunal valleys.

11.3.2 Thar Sandy Area

The Thar is the most extensive sandy region in the country. It comprises the deserts of Cholistan and Thar, a band of about 50 mi wide and extending over a distance of some 500 mi in the south-east, along the Indian border. It covers about 25 000 mi^2 (64 000 km^2). The Thar is actually the western part of the Rajputana sandy desert of India. The origin of the sand is not certain. The oldest part is probably older than the Last Glacial period, in view of the elevation of the sand ridges far above the probable levels of the Indus and Sutlej in the Late Pleistocene. The landscape consists of mainly stabilized hilly sand plain, with longitudinal ridges in the south but alveolar (honey combed) and transverse ridges in the north. The sands are calcareous, rich in weatherable minerals and typically pale brown. They contain less mica, but more quartz than the sands of the Indus river and its tributaries.

The Thar has two distinct climatic zones, i.e. the southern semi-arid zone and the northern arid part. The semi-arid part has well developed soils. The interdunal valleys have loamy soils with a fair amount of organic matter. The subsoils are brighter in colour than the surface soil or the substratum. Towards the southern side the rainfall increases and the temperatures are mild due to the influence of the Arabian sea. These soils are under cultivation for growing sorghum (Andropogon sorghum).

The sandy soils in the semi-arid part occur on the sandy ridges. The soils are sands and loamy sands with bright subsoils. The sandy ridges are 100-200 ft (30-70 m) higher than the interdunal valleys. Very little cultivation is practised on the sandy soils. Natural vegetation provides some grazing for cattle and sheep. Over-grazing and lopping of natural vegetation is the major problem. The crests of the sandy ridges have been transformed into shifting sand dunes.

The arid part of the Thar is far more extensive than the semi-arid part. In this area the interdunal valleys have sandy loam and sandy soils. Due to scanty and uncertain rainfall no cultivation is practised. The sandy ridges have sandy soils and about 10% of their surface is shifting sand. This entire area provides some grazing for cattle and sheep.

The main problem of this great region is the scarcity of water. Only after the rains cattle and sheep herds find their way into the interior of the area and stay there as long as drinking water is available in ponds. These ponds are located on such sites where substratum is tight enough to hold water and can collect considerable run-off from large areas. Areas close to the water points are severely grazed whereas the remote areas are probably under-utilized. After the ponds dry out, the herds move away from the interior towards the margins, partly depending upon the adjoining irrigated floodplains for their supplies of water and fodder. Groundwater in most of the area is highly saline and unfit even for drinking. There are a few narrow belts of land where groundwater is sweet. The exact location and extent of such areas needs investigation. The information would be very useful in the development of this large region.

11.3.3 Western Sandy Desert

The western sandy desert comprises four units separated by hill ranges. These sandy areas together occupy an area approximately equivalent to that of the Thal. The sands of this desert are also of alluvial origin, deposited as sandy piedmont slopes, mostly of Holocene age. The climate is extremely arid and soil development is virtually nil. The vegetation covers less than about two percent of the total area. Almost the entire area is in the form of shifting sand dunes and the reworking by wind is continuing. Groundwater as well as surface water is very scarce and often brackish. So this area has little potential for development.

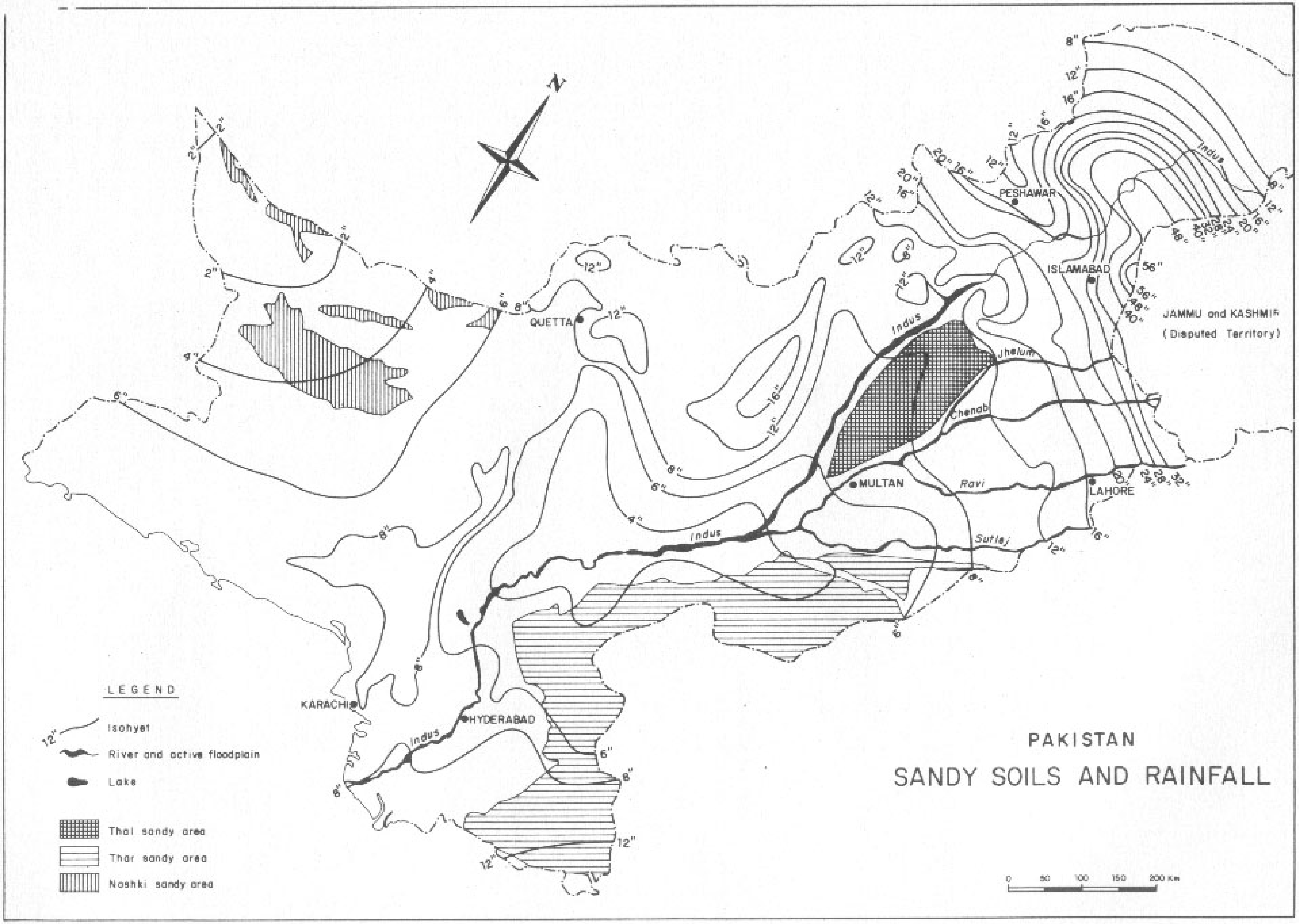
11.4 CONCLUSION

The extensive sandy soils in West Pakistan have a potential mainly for grazing. The soils occurring in the semi-arid zone of Thal as well as Thar are partly used for grazing and partly for dry-farming of crops such as gram, mustard, guara (Cyamopsis psoralioides) and sorghum. The soils within the arid zone are exclusively used for grazing. The present use seems to be most suitable under the local conditions.

In Thal where sandy soils occur in close association with irrigated loamy soils, the cropping patterns of the irrigated area should be changed in favour of the crops that have a low water requirement and could also provide feed, fodder and hay for the cattle and sheep during the period when the un-irrigated sandy soils are not able to provide grazing but need rest. The grazing potential of the sandy soils should be developed as a part of the development potential of the irrigated loamy soils, for the production of cattle and sheep.

Canal irrigation cannot be extended to additional areas of Thal due to the unfavourable relief and sandy nature of the soils. In such areas, pockets of usable groundwater exist and efforts have been made to irrigate isolated patches of loamy soils here and there. Due to the extreme aridity, and desiccating winds, the cost of production of sugarcane and wheat is very high in terms of irrigation water. The agriculture in such areas should be entirely complementary to the cattle and sheep production, and only such crops should be grown which would provide feed, fodder and hay for the animals. Similarly, in Thar desert grazing potential could be realized by extending canal irrigation to loamy soils in the desert margins for the production of feed, fodder and hay. This could supplement the forage on the sandy soils.

Irrigation of sandy soils in West Pakistan has remote possibilities, because there is a great disparity between land and water resources in the country, there is far more land than water. Water is insufficient to meet the requirement of even good quality land. The country has to think in terms of maximum returns per unit of water rather than per unit area. Sandy soils have a much lower potential than many other soils presently lying barren for want of irrigation. Their economic utilization is related to their favourable capacity for conserving scanty rainfall in a more efficient manner for the growth of natural vegetation for grazing or dry-farmed crops.



PAKISTAN
SANDY SOILS AND RAINFALL

SUDAN

by

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12.1 INTRODUCTION

Sandy soils in the Sudan are widely extended and cover most of the Northern, Kordofan and Darfur provinces. They are rain-cultivated and there is the problem of the short rainy season which lasts for three to four months only, leaving the rest of the year as a dry hot period. Due to the availability of vast areas which are suitable for agricultural expansion, relatively little attention has been given to the proper development of these sandy soils.

12.2 TYPES AND ORIGIN

Most of the sandy soils are of aeolean origin and are believed to be derived from the northern desert which occupies a large part of Libya and extends southwards into the Sudan. Geomorphologically, these soils are found in the form of slightly undulating sand sheets, transverse dunes or longitudinal sand ridges. They are very deep and have usually uniform texture throughout the profile with the clay content ranging from about 5 to 10%. The ratio of the coarse to fine sand, which are the main components of the mechanical analysis of these soils, seems to narrow from north-west to south-east. Their pH is about neutral. As would be expected from their low clay and organic matter contents, the sandy soils are inherently poor in nutrients especially phosphorus and nitrogen.

The other type of sandy soils has been formed in situ from the Nubian sandstones or from the Basement Complex rocks. This type is different from the former in that it shows more differentiation in the profile, has high clay content which increases with depth and it is distinctly acidic.

12.3 LAND USE

The rainfall varies considerably over the extensive area of the sandy soils, and it ranges from traces in the north to about 800 mm in the south. For convenience, the area covered by the sandy soils can be divided into the following three zones:-

i. The Northern Zone with rainfall less than 250 mm; this zone is usually used by nomadic pastoralists and the animals kept here are mainly camels, sheep goats and, to a lesser extent, cattle.

ii. The Central Zone with rainfall ranging between 250 and 450 mm; this is a cropping zone and the main crops grown here are sesame (Sesamum orientale), dukhn (Pennisetum typhoideum) and groundnuts. Shifting cultivation with four years continuous cropping followed by twelve years bush fallow is practised. The main component of the bush fallow is the Gum Arabic Hashab Tree (Acacia senegal) which is a leguminous tree and is claimed to fix atmospheric nitrogen. However, with the increase of the population, farmers are now compelled to deviate from this practice and tend to cultivate the same piece of land more frequently. This over-cultivation coupled with the decrease in rainfall in recent years has no doubt resulted in increased wind erosion and encroachment of the desert on arable land.

iii. The Southern Zone with rainfall ranging between 450 and 800 mm; this zone is occupied mainly by the Baggara, the famous cattle nomads. About 70% of the Sudan cattle are raised here. However, with the recent anti-thirst campaign, water points (mainly boreholes) were constructed in this zone, thus making drinking water available for opening more land for cultivation and grazing. Similar wells were also constructed in the other two sandy zones. As a result of this, many Baggara nomads are now settling and giving more attention to crop production.

In conclusion, attention must be given to the proper management of these extensive rainfed sandy soils in order to check the desert encroachment on arable lands.

SYRIAN ARAB REPUBLIC

The total area of the Syrian Arab Republic is 18.5 million ha with widely varying soils; it includes Mediterranean red, dark yellow, reddish brown, yellow desert, gypsiferous and levee soils. Sandy soils are scattered in the different soils mentioned above in small areas that have not yet been surveyed.

Syrian soils vary in their characteristics according to origin and mode of formation of each. Work is now being concentrated on soil surveying in areas which benefit or will benefit from the major irrigation projects. The current work is devoted to some detailed surveying to identify soil groups and basic characteristics of each. Up till now a total area of 280 000 ha has been surveyed in the Euphrates Valley, Ghab and El Sen. Work is in progress on the classification of the present irrigated areas and on those which are planned to be irrigated from the Euphrates dam.

The total area that could be cultivated exceeds 7 million ha of which 600 000 ha is irrigated. The rest is under rainfed agriculture using a crop rotation with fallow. Of course the area under irrigation will be doubled after completion of the Euphrates dam.

The Syrian Government pays considerable attention to water resources since a sound knowledge of the water balance is essential for the planning of agricultural development when the water resources are rather limited in comparison to the water requirements of the crops. About 60% of Syria has a rainfall of less than 250 mm where the evaporation reaches 2 500 mm per year. Therefore it is necessary to adopt wise measures and techniques for management and utilization of irrigation water.

Experimental farms have been established to find out the best irrigation methods, crop rotations and determination of crop water requirements.

In the past, because of the misuse of irrigation water coupled with the introduction of cotton, the salinity problem became apparent especially in the Euphrates and Khabour valleys and some parts of El Ghab. The problem is being aggravated year after year. This has led to the need for planning land reclamation on a large scale in the country. Such work is in hand at present and we have reached conclusions of value in the successful and economic utilization of these lands. A final plan is now being drawn up for an integrated irrigation and drainage system for all the Euphrates valley, having an area of 640 000 ha.

Horizontal expansion in the agricultural development of Syria, based on an increasing total area of irrigation, goes hand in hand with vertical expansion by applying modern techniques to crop management and using fertilizers according to scientific patterns; concerning the latter, a new policy has been established for fertilizing cotton, sugarbeet and wheat and there are also plans for improving soil properties.

DEVELOPMENT AND MANAGEMENT OF SANDY SOILS

Sandy soils in Tunisia cover a large area, particularly in the centre and the south. In the north, they are in the form of dunes limited to the litoral.

14.1 CLASSIFICATION OF SANDY SOILS

In Tunisia, the sandy soils are part of the following classes:

- undeveloped soils: regosol type of aeolian origin
- weakly developed soils: in this class the sandy soils are of aeolian origin, or alluvial and included in these sub groups:
  - saline
  - calcareous
  - gypsiferous
  - hydromorphic
- isohumic soils: in this class the sandy soils appear in the groups:
  - modal
  - sierozems
- halomorphic soils: in particular in the saline group.

14.2 AGRICULTURAL DEVELOPMENT

This is one of the preoccupations of the Tunisian Government at present which is making considerable efforts with a view to improving the productivity of these soils and meeting the needs of a constantly increasing population.

This development includes the following actions.

14.2.1 Dry farming

- Improvement of the olive grove productivity by fertilizing the soil with mineral fertilizers.
- Extension and creation of different types of tree plantations.
- Limiting the growing of cereals in regions with poor annual rainfall and those exposed to erosion, particularly by wind.

14.2.2 Irrigated Crops

Operations carried out in the irrigated areas are:

- Orchards, mainly citrus, in the north-east and date palms in the south.
- Market gardening and fodder crops.

In order to achieve optimal development of these soils various study and research projects have been undertaken among which should be mentioned:

- Determination of water resources at deep levels in southern Tunisia under the regional project REG 100 UNDP/Unesco.
- Elaboration of a master plan for the exploitation of water in the centre and south of the country.
- Further improvement of the hydraulic works in the irrigated areas.
- Realization of new irrigated areas.
- Study of irrigation with saline water (1.5 g/l to 6.5 g/l) and determination of water requirements for different crops. This study was undertaken with the help of UNDP and Unesco and was the subject of a report published in 1970.
- The creation of an agricultural research organization in the south of the country to study the problems brought to light by the development of sandy regions.

14.2.3 Forestry activity

These actions concern:

- The stabilization and fixation of the litoral dunes.
- Protection of the oases and the campaign against invasion by sand in the south of Tunisia.

i. Stabilization and fixation of the litoral dunes

These are situated in the north of the country and their development began in 1904. The technique used comprises the following operations:

a. establishing a coastal protective cordon with the help of brushwood and branches.

b. establishing complete squares of earth with the help of "saccharum".

c. fixing them with the help of a cover of branches.

d. reafforestation with appropriate species: acacia, eucalyptus, pines.

ii. Protection of the oases and the campaign against invasion by sand

The problem of defense of the oases and the fight against sand invasion was traditionally carried out with date palms which assured also protection of the nearby crops. But the oases are more and more menaced in their entirety by the sand. Their protection is therefore a paramount necessity.

The technique of fixation used is relatively different to the first in that the immediate aim sought is the protection of the oasis, buildings and substructures by placing them in the shelter of artificial dunes or tabia (earth levees) of 0.80 m high supporting a fence of palm fronds or slabs of fibro-cement raised at regular intervals. The distance arranged between these dunes placed perpendicular to the wind direction and the zone to be protected is about 200 m. This band is reforested with certain local species (tamarix, calligonum, acacia and atriplexis).

The forestry activities have led to the following results:

- from the soil improvement point of view: the forestry plantations have contributed to the enrichment of the soil with organic matter and have improved its structure. These improved dune soils could be suitable in certain cases for more profitable tree growing operations.

- from the sylviculture production point of view: the reforestation carried out on the coastal dunes has an actual annual production of between 3 and 5 m^3/ha of resinous trees and 6 to 8 m^3/ha for the foliaged ones. This production has by far surpassed that of natural forests in the same climate (600 mm/a).

- from the protection point of view: the results achieved are very encouraging. They can be seen as a noticeable improvement in the production from the oases and irrigated areas. This is why a particular effort was made regarding the same problem in the centre and south of Tunisia in the framework of the four-year plan 1973-76, because the fight against the invasion by sand fills a vital need in putting a brake on the process of desertification which is set in motion as a consequence of thoughtless exploitation of the natural vegetation, the intensity of grazing and cultivation.

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

by

Anwar Girgirah
Abdulla Al-Dukail
Martin Smith

15.1 INTRODUCTION

The People's Democratic Republic of Yemen (P.D.R.Y.) is situated on the south-western side of the Arabian Peninsula and stretches over 750 miles along the Indian Ocean covering a total area of about 112 000 mi^2 with a population of about one and a half million. The country lies within the arid region and the climate is tropical, characterized by hot and humid conditions in the coastal region with a very low rainfall of about 25-65 mm per annum, whereas the mountainous and semi-mountainous areas encounter a somewhat cooler and less humid climate with annual rainfall that might reach 350 mm.

Only about one percent (600 000 ac) of the total area of the Republic can be considered as cultivable land and is situated in the numerous wadis intersecting the country from north to south. Due to the total lack of rainfall, especially in the coastal region, agriculture is completely dependent on irrigation. Most of the research up to now was concentrated in the Wadi Tuban and Wadi Abyan deltas, both classified within the coastal region; therefore this paper will be restricted to these two areas.

Traditionally the main source of irrigation water is that of the spate floods (which flow from April to September in most of the wadis of the second and third governorates). These floods occur in two seasons; the main one being from July to October when the south-west monsoon brings heavy thunderstorms in the northern mountainous catchment areas, three-quarters of which lies in the sister country of the Arab Yemen Republic. A second season of minor importance caused by north-eastern winds occurs in April to May. This system of spate irrigation usually affords one single irrigation just enough to raise one crop of cotton or sorghum per year. Due to these conditions the actual cultivated area is dependent upon the amount and frequency of the spate floods. Consequently only about 30% of the total cultivable area is utilized for agriculture production. A vast area is under long fallow or is abandoned agricultural land owing to the deficiency of the irrigation systems and scarcity of irrigation water.

Since independence in 1967, the Government of P.D.R.Y. is giving increasing importance to agriculture, which employs 80% of the working population, but contributes only 20% to the national gross product of the country. Hence the essential problem remaining to be solved in the immediate future is an overall agriculture development, improvement of irrigation water sources and soil reclamation. This problem was taken into consideration in the 3 year plan and will be the ultimate goal to be achieved in the forthcoming 5 year plan (1974-79).

15.2 SOILS OF WADI TUBAN AND WADI ABYAN DELTAS

Most of the agricultural areas in the coastal plain and wadi beds consist of alluvial deposits formed from the annual sedimentation of the suspended load carried by the floods. Basically the texture of the alluvium mainly consists of silt and sand with a few clays. Due to the lack of rainfall, the soil profile shows no feature of any pedogenesis; hence the soils are immature and show no genetic horizons.

The only real soil forming process is that imposed by human activities. Each year the spate water spreads a thin layer of mainly fine particles on the irrigated fields, thus forming the so-called anthropic soils with a clay to silty loam texture. A third soil forming factor is that of the aeolian activity. Strong winds form sand dunes of uniform fine sandy texture and carry or erode alluvial and anthropic soils. In the upper reaches of the wadi there are anthropic soils with a silt loam to loam texture. The lower part of the wadi has natural alluvial soils with loamy sand to sandy loam textures.

As mentioned above, scarcity of water is the limiting factor which hinders agricultural development, so the main task of the Ministry of Agriculture and Agrarian Reform is therefore to investigate the possibilities of extending the agricultural area by exploitation of the groundwater resources by drilling wells in the lower parts of the deltas in the coastal region (Wadi Tuban and Abyan) and Wadi Hadramawt in order to assure a more permanent and reliable source of irrigation water to reclaim the sandy soils and render them productive. In this respect we have to overcome the following problems:

i. the low fertility of these virgin and sandy soils;

ii. the low irrigation efficiency due to high infiltration rate and the frequent irrigation due to low water holding capacity of the soil and high evaporation;

iii. the wind erosion and wind deposits which are seriously affecting the cultivated land.

In the Wadi Tuban Project, which is one of the large scale FAO/UNDP projects, the establishment of two pilot farms (120 ha) of mostly virgin sandy loam to loamy sand soils, will face challenges in the process of reclamation, due to the rather high salinity of these soils which was made evident by the salinity and management problems encountered in the reclamation work attempted prior to the construction of these pilot farms. In spite of that the following work will be undertaken to reclaim these soils:

a. During the first 2 years selected crops suitable for cultivating virgin soil will be planted, such as sorghum and millet, in order to minimize the poor yield expected and characteristic of soils under such conditions. Also other crops will be tried for reclamation.

b. To increase the fertility of virgin and sandy soils, the following trials will be laid out:

   (a) green manure of local and imported species

   (b) animal and chicken manure

   (c) compound fertilizers especially with nitrogen and phosphorus

c. To reduce the salinity of the soils, extra amounts of irrigation water will have to be applied to reduce the salinity hazard. At the present time up to 800 mm of irrigation water is applied for leaching salts. Trials have been laid out to establish the right amount for leaching requirements.

d. In order to prevent unnecessary loss of precious irrigation water and to improve the current low irrigation efficiencies, new irrigation methods and practices are to be tried out. The introduction of furrow irrigation and the improvement of levelling techniques for basin irrigation seems to be promising. Also water requirement experiments are carried out to find the exact amount of water needed for irrigation.

e. At an early stage of reclamation, windbreaks and shelterbelts are going to be established so as to prevent serious damage by wind erosion and sand deposition. Hence rows of tamarix, parkinsonia, conocarpus and casuarina species are going to be planted around and inside the pilot farms at Jawala and Fiyush.

Like the Wadi Tuban area, most of the soils of Wadi Abyan are alluvial and their texture exhibits about equal proportions of fine sand and silt with no coarse sand fraction and less than 10% clay fraction, hence they are considered light soils. The textural classes of these soils together with their percent distribution, are shown below:

1. Sandy soils	22%
2. Loamy sand soils	33%
3. Sandy loam soils	27%
4. Silty sand loam soils	2%
5. Silty clay loam soils	16%
	100%

The soils of Abyan delta were classified as uniform to slightly stratified with no distinct genetic horizons due to the uniformity of the sediments brought by the annual floods. The characteristics of the analysed samples were as follows:

Saturation percentage:	23-45% by weight
Soil colour:	Light brown to yellow
Permeability:	5-15 cm/hr
Gypsum:	0.5-1.7%
Calcium carbonate:	10-20%
E C of saturated extract:	1-60 mmhos/cm
pH:	7.2 to 8.8
Organic matter:	0.35 - 1.0%
Total Nitrogen:	60-550 ppm
Total P_2O_5	1.4 - 8.7 ppm
Total K_2O	1 000-4 000 ppm

The Government has one major research station at El-Kod in the Abyan delta in the third province. This was formerly the Cotton Growing Research Station but after independence the station was reactivated and has been developed by FAO/UNDP Agriculture Research and Training Project into an Agriculture Research Centre for the whole Republic. The current studies of the Soil and Forestry sections of this centre are devoted to:

I. Experiments on infiltration rate, water holding capacity, salinity and salt balance due to the addition of various amounts of irrigation water of different quality.

II. Sand Dune Fixation and Afforestation

In 1971, Dr. E. Costin, Forestry Expert and Project Manager of FAO/UNDP Agriculture Research and Training project, started research on sand dune fixation and afforestation. Experimental plots were set up on maritime and continental sand dunes, whereby a network of pre-planted mechanical devices was established in order to protect the seedlings from burial or uncovering by the blowing sands. The distance between the strips as well as the size of the checkerboard differs according to wind speed, the steepness of the slopes and form of dunes. The fences were built of dead materials locally available such as reeds (Phragmitis communis). During this time movement of sands inside the fences was recorded monthly by special sticks. From the research that has been done up to now it can be concluded that checkerboard fences acted not only as a mechanical device for stopping the sand movement, but also improved ecological conditions by reducing the evaporation from the soil and providing better conditions for the survival and growth of the seedlings.

Afforestation of sand dunes was related to ecological studies, especially the moisture content of the soil. From the studies that were performed in this field the following can be concluded:

- moisture content increases with depth with the top layer being very dry;
- the sands have a low water holding capacity but preserve the moisture for a long time;
- dew is one of the very important water resources for plants growing in sands and deserts.

From the experiments carried out both on maritime and continental sand dunes, deep planting up to 1.50 m gave the best results, especially for long cuttings of tamarix. The planting should be done according to site conditions - shallow on depressions and deeper on high sites.

Regarding the tree species, the following are the most suitable for desert conditions:

- On top of high dunes:
  Tamarix aphylla, Acacia tertilis, Calligouum somosym
- On slope of dunes:
  Tamarix aphylla, Prosopis juliflora, Acacia cyanophylla, Parkinsonia aculeata
- On depressions between dunes:
  Parkinsonia aculeata, Tamarix, Azadirachta indica, Acacia arabica, Salvadora persica
- On sandy soils from depressions:
  Casuarina equisetifolia, Azadirachta indica, Eucalyptus camaldulensis

15.3 CONCLUSION

Our country needs to undertake more research in agriculture and irrigation as a whole on various crops and on different agricultural and irrigation practices at different areas. We would like to mention that not less than 60% of the cultivated land of P.D.R.Y. consists of sandy soils. Indeed the reclamation of such soils will be one of the major problems we have to overcome in order to obtain an expansion in the cultivated area hand in hand with the vertical expansion to be gained from research to increase the yield/acre and the irrigation efficiency. Therefore, there is no doubt that this Seminar, with the fruitful discussions of a panel of experts, will enrich our knowledge and will be of great benefit to P.D.R.Y. in this field.

V.1 FIELD WATER BALANCE IN CROPPED LUCERNE PLOTS

by

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SUMMARY

The instantaneous profile method was applied in successively cropped and fallow (covered) plots in order to assess the drainage component in a field water balance study.

Moisture changes in a layered medium textured soil were frequently monitored with a neutron moisture gauge with concurrent measurements of matric suction by mercury tensiometers placed at 30 cm intervals up to a depth of 240 cm. From these data it was possible to determine the unsaturated hydraulic conductivity of the draining fallow (covered) plot over a period of 100 days from which the drainage component occurring over a series of crop-irrigation cycles over a whole year was calculated. Thus the actual evapotranspiration of lucerne was determined from soil moisture changes adjusted for drainage.

Yields of dry matter, changes in soil moisture, drainage and evapotranspiration values during each crop cycle are presented and discussed. Actual evapotranspiration is compared with potential evapotranspiration (Penman) and pan evaporation and it is concluded that this relatively simple procedure provides a realistic estimate of crop water requirements and may be adopted for water use efficiency studies.

4.1 INTRODUCTION

Irrigated agriculture in arid and semi-arid regions is of vital importance to their national economies. It is not uncommon that the increase in agricultural productivity is not restricted by the availability of land resources but rather by the very limitation imposed by low rainfall and the short supply of good quality irrigation water, (Fried and Barrada, 1967). This is particularly true for countries like Cyprus where irrigated crops, representing only 13 percent of the cultivated land but contributing over 50 percent of the total value for agricultural production, impose a severe burden on the rapidly depleting underground water resources of the island.

Thus the critical question poised starkly over Cyprus is whether the remaining balance of its water crop can indeed sustain the requirements of existing plantations excluding any thought, for the moment at least, of expanding irrigated agriculture. This need for "survival", therefore, confers a new dimension on the necessity for the most efficient use of its water resources. To be sure, it requires as precise a knowledge of the optimum crop water requirements as could possibly be acquired.

Field studies on crop water requirements carried out in Cyprus prior to 1971, such the one presently reported (Stylianou and Krentos, 1972), were pervaded, as elsewhere, by the prevailing concept of "field capacity" with its consequent confines on the thinking of soil moisture availability. Gardner (1966 and 1967) has pointed that this concept, based on the assumption that no downward movement of soil water occurred at water contents below this upper limit, disregards the physical processes known to take place continuously within a soil profile. It is now well recognized that, even without changes in soil moisture, downward movement of soil moisture is operative for much longer periods of time than could be inferred by the concept of field capacity, and that losses below the root zone should be accounted for in field water balances (Rose and Stern, 1965).

However, drainage of irrigation water below the root zone should not necessarily always be considered as a mere loss but also as a desirable process in alleviating the hazards of salinity, another preponderant consideration in arid and semi-arid lands. On the other hand controlling drainage is important in regulating the movement of soluble nutrients such as nitrates for a more efficient utilization of fertilizer nitrogen and for avoiding nitrate pollution of underground potable water supplies. Thus a precise determination of the drainage component in the field is necessary both for a more accurate estimate of the water balance of a vegetated field and for devising ways and means to regulate the downward movement of irrigation water.

The theoretical aspects of soil water movement have been extensively studied in recent years and the physical principles and the nature of such processes have been reviewed and placed in a logical perspective by Rose (1966) and more recently by Hillel (1971).

The application of theory to field situations awaited the development of tested methods for the determination of soil hydraulic properties in situ. Rose et al (1965) have described one such field method for determining the hydraulic conductivity at any water content by monitoring the internal drainage of a profile in its transient-state. This method was subsequently applied by Rose and Stern (1967) to determine the rate of water uptake by cotton from different depths and at different growth stages. Similarly van Bavel et al (1968 and 1968) have applied a similar approach for the field measurement of unsaturated hydraulic conductivity of fallow, fallow-covered and vegetated plots in an effort to assess the water balance within the root zone of a sorghum crop.

Watson (1966) applied the instantaneous profile method for the determination of the unsaturated hydraulic conductivity of a coarse sand column and concluded that Darcy's Law is applicable to unsaturated flow in similar materials. To determine the hydraulic properties of a draining soil profile Hillel et al (1972) adapted and tested Watson's method for field situations.

The work described in this paper is an attempt to apply the simplified instantaneous profile method to the same plot in a fallow (covered) - lucerne rotation for the determination of the hydraulic properties, allowing the assessment of the drainage component for which the actual evapotranspiration of lucerne, as determined from soil moisture changes was adjusted.

4.2 EXPERIMENTAL PROCEDURES

4.2.1 Field site characterization

The experimental site selected was within the Institute's farm at Athalassa, near Nicosia, in the central plain where most of the agriculturally exploitable land lies.

The climate of the site bears the accentuated arid character of the central plain in particular and of Cyprus and the eastern Mediterranean basin in general. In dry years the central region receives less than 200 mm of total annual rainfall between November and April and during the dry months of the year the large moisture deficit has to be supplemented by irrigation. The mean monthly maximum temperatures reach as high as 35°C in July-August accompanied by low relative humidity. Evaporatio during the summer months is thus particularly favoured reaching 10 mm/day. Fig. 1 typifies this high evaporative demand of the surrounds of the experimental site.

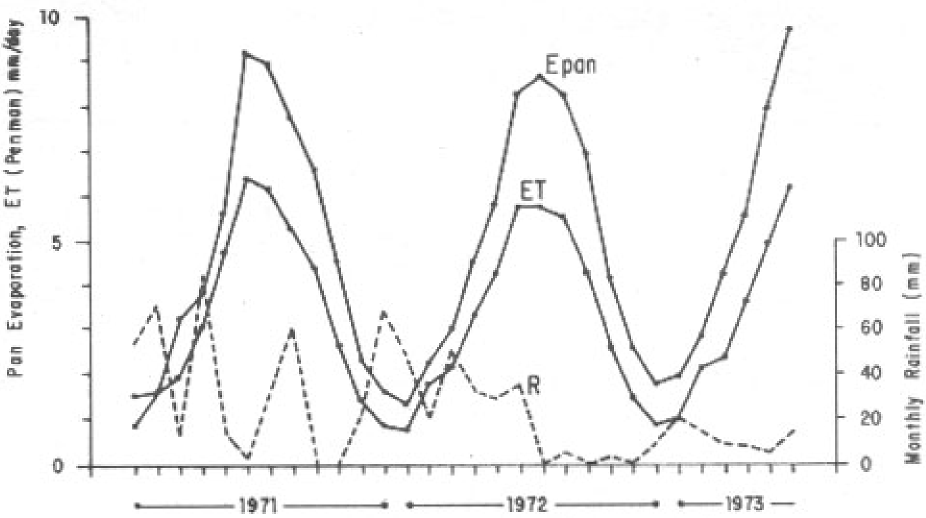

Fig. 1 PAN EVAPORATION (USWB 'A'), CALCULATED ET (Penman) AND MONTHLY RAINFALL (R), ATHLASSA

The soils of the experimental site are medium textured calcareous alluviums classified as calcaric lithosols according to the system adopted by the European Commission on Agriculture of the United Nations. The textural characteristics of the profiles in the experimental plots, referred to hereafter as plot 'A' and plot 'B', are presented in Table 1. It will be noted that texturally neither profile is uniform throughout and that the defined soil layers range from clay loams to sandy loams. In addition, the layer sequence in profiles 'A' and 'B' is not closely comparable although the two plots are only 25 m apart. This is partly the result of land levelling in 1962, but in general most soils in Cyprus would show such variabilities within short distances in the same field.

4.2.2 Plot layout, crop rotation and instrumentation

At the commencement of the study in August 1971 plot 'A', located within an established field of lucerne sown in April 1970, covered a 6 x 6 m area. Soon after harvest of lucerne, in the centre of the plot a 270 cm long aluminium access tube (2 inch O.D.) was installed vertically in a hole drilled with a hydraulically operated coring probe of slightly smaller diameter. Mercury tensiometers were installed, with the aid of a screw auger, 50 cm away from the access tube, at 30 cm intervals up to a depth of 240 cm. After each harvest of lucerne the plot and the surrounding buffer zone were irrigated once only to ensure initially a thorough wetting of the profile down to 240 cm. Frequent concurrent moisture and tensiometric records were taken throughout each cycle and until July 1972.

The lucerne was then carefully cut, leaving intact the major portion of the roots, generously irrigated overnight and subsequently covered with a plastic sheet on top of which a mulch of straw followed by a layer of loose soil was placed. The access tube and the battery of tensiometers were left intact. The internal drainage of the fallow (covered) profile was monitored by making frequent moisture measurements and taking tensiometric records over a period of 100 days.

On the other hand plot 'B', 25 m away from 'A' was located in an adjacent fallow field. Plot 'B' was ridged as a 4 x 4 m area surrounded by an outer ridge forming a 2 m-wide buffer zone. Water was ponded on the surface on successive days until steady-state infiltration conditions, as indicated by the tensiometers, were attained.

Table 1 MECHANICAL ANALYSIS, CALCIUM CARBONATE CONTENT AND TEXTURAL CLASS OF SOIL PROFILES 'A' AND 'B' ATHALASSA

	Profile depth (cm)	pH (1:2.5)	Clay %	Silt %	Sand %		$CaCO_3$ %	Textural class
					Fine	Coarse		
Athalassa Plot 'A'	0–30	8.6	37.9	25.0	32.2	5.5	20.6	CL
	30–60	8.6	18.9	13.0	56.7	10.3	19.3	SL
	60–90	8.0	22.3	13.8	52.3	8.0	21.1	SCL
	90–120	8.3	32.2	22.9	41.2	3.5	24.3	SCL
	120–150	8.3	23.8	16.2	51.7	7.1	19.5	SCL
	150–180	8.6	23.7	17.7	50.5	6.4	17.7	SCL
	180–210	8.6	39.5	33.5	25.2	2.5	21.7	CL
Athalassa Plot 'B'	0–20	8.4	33.4	32.3	30.5	3.9	19.8	SCL
	20–40	8.2	18.9	17.9	57.3	6.0	16.4	SL
	40–90	8.1	12.0	13.8	60.4	11.8	19.7	SL
	90–120	8.2	26.6	28.3	41.0	4.1	23.0	L
	120–140	8.4	33.3	21.9	40.1	4.9	20.4	SCL
	140–150	8.6	24.0	21.2	50.5	4.3	20.4	SCL
	150–190	8.8	15.7	16.4	56.5	11.4	18.3	SL
	190–210	8.7	21.0	16.4	56.9	5.9	19.2	SCL
	210–250	8.7	35.4	32.7	30.5	1.5	19.4	CL
	250–270	8.5	32.4	31.5	28.7	2.5	18.7	CL
	270–290	8.8	37.9	36.9	25.0	0.4	20.0	CL

CL = Clay loam
SL = Sandy loam
SCL = Sandy clay loam
L = Loam

Both the main plot and buffer area were covered as in plot 'A'. Frequent moisture and tensiometric measurements were made over a period of 80 days.

In April 1972 fallow plot 'B' and the surrounding buffer zone were uncovered, hand cultivated, fertilized with superphosphate and sown to lucerne. The neutron access tube and the battery of tensiometers were left intact. Once the lucerne was established, regular records were taken during each irrigation cycle from July 1972 to July 1973.

In both fallow (covered) plots an additional tensiometer was installed at 5 cm depth. This was not possible in the cropped plots because of the fast drying of the surface top layer. In both cropped plots lucerne was harvested at about 10 percent flowering stage, and the fresh and dry matter of fodder production was recorded and analysed for N, P and K.

4.2.3 Measurement of soil water

With the exception of the top 15 cm, soil water measurements were carried out in situ with the neutron gauge at depth intervals at 15 cm down to 240 cm. The neutron gauge was calibrated against gravimetric sampling and, although in absolute values the instrument indicated higher soil water contents, both the displacement of the calibration curve and of the moisture profiles were parallel over the ranges of soil moisture encountered. Thus the soil moisture changes as determined by the neutron gauge have been accepted as valid.

4.2.4 Measurement of hydraulic head

The hydraulic head was taken as soil suction,measured by tensiometers, plus depth with respect to the soil surface.

4.2.5 Processing of data

The step-by-step handling of the field records of soil moisture changes and suctions, obtained from the fallow (covered) plots, and their subsequent processing followed exactly the same procedural sequence as described by Hillel et al (1972).

Typical measurements in fallow plot 'A' showing the changes of volumetric moisture content and matric suctions with time are depicted in Figs. 2 and 3 respectively. From the moisture-time curves the soil moisture flux through each depth increment down to a specified depth of 195 cm was calculated.

The hydraulic conductivity, K, at each depth and for different soil water contents was calculated by dividing fluxes by the corresponding hydraulic gradients. A plot on semi-log paper, as in Fig. 4, shows the relationship of K to the volumetric moisture content in the various soil layers.

The drainage component in the cropped plots occurring below the depth of 195 cm was computed from the hydraulic conductivities (found from Fig. 4 by reference to the particular moisture contents prevailing in this depth at different days) multiplied by the corresponding hydraulic gradients in the 180-210 cm layer. A typical calculation of the drainage component is given in Table 2.

The changes in soil moisture content occurring in each crop cycle were adjusted for drainage and the rate of actual evapotranspiration (ETa) was calculated and compared to pan evaporation (USWB Class A) as shown in Tables 3 and 4.

4.3 RESULTS AND DISCUSSION

From the mechanical analysis of the various soil layers in both plots it becomes evident that neither profile is texturally uniform throughout the depths considered. Furthermore, the hydrologic characteristics of the constituent layers as depicted in Fig. 2 (changes in soil moisture with time), Fig. 3 (changes in matric suction with time) and particularly by the plots of the relationships of hydraulic conductivities with soil water contents, Fig. 4, show wide variability from layer to layer to the extent that not a single curve but a family of curves will suffice to characterize the profile as a whole. This is true for each profile separately and in comparison to each other.

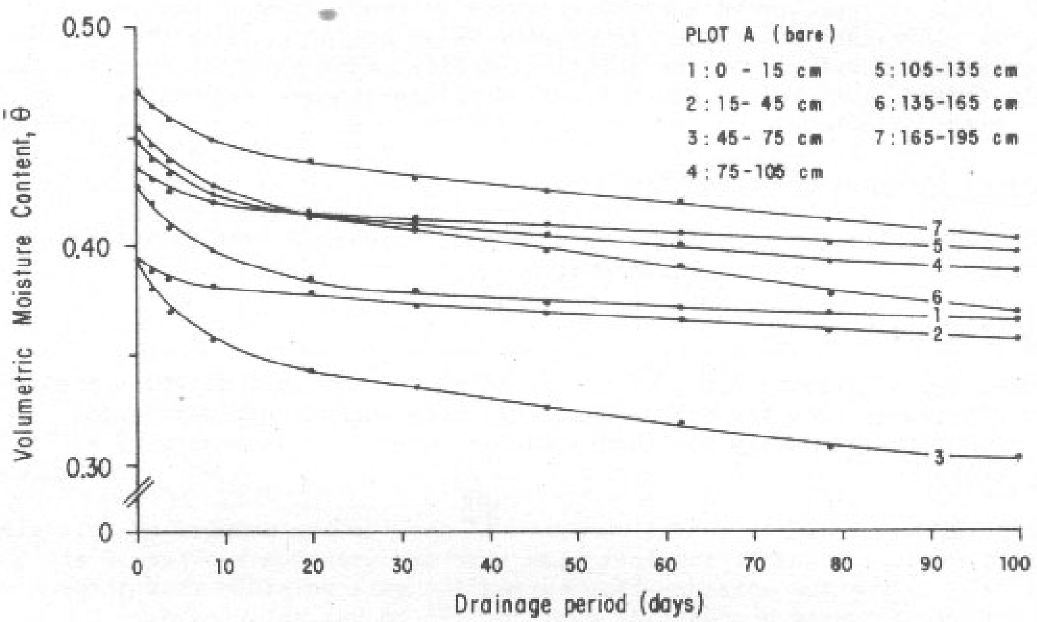

Fig. 2 CHANGES IN SOIL WATER CONTENT WITH TIME

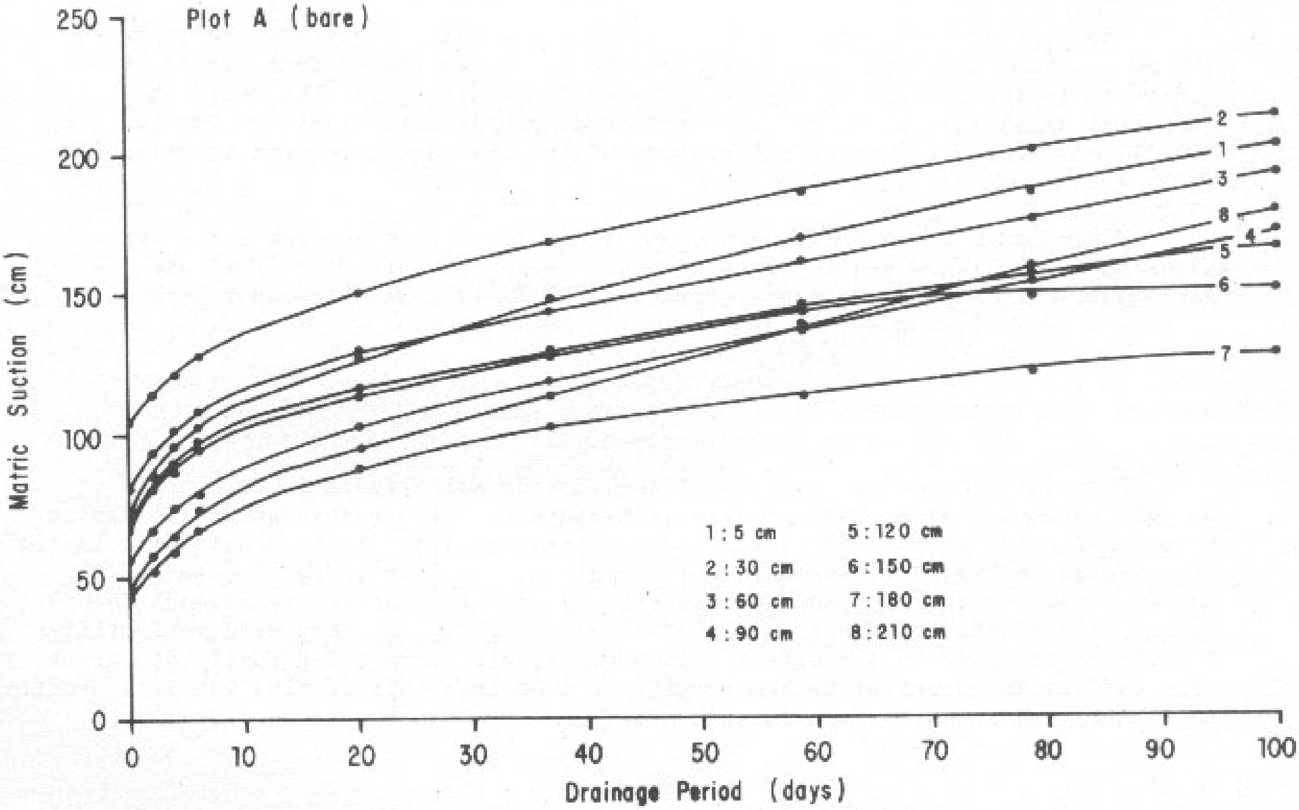

Fig. 3 CHANGES IN MATRIC SUCTION WITH TIME

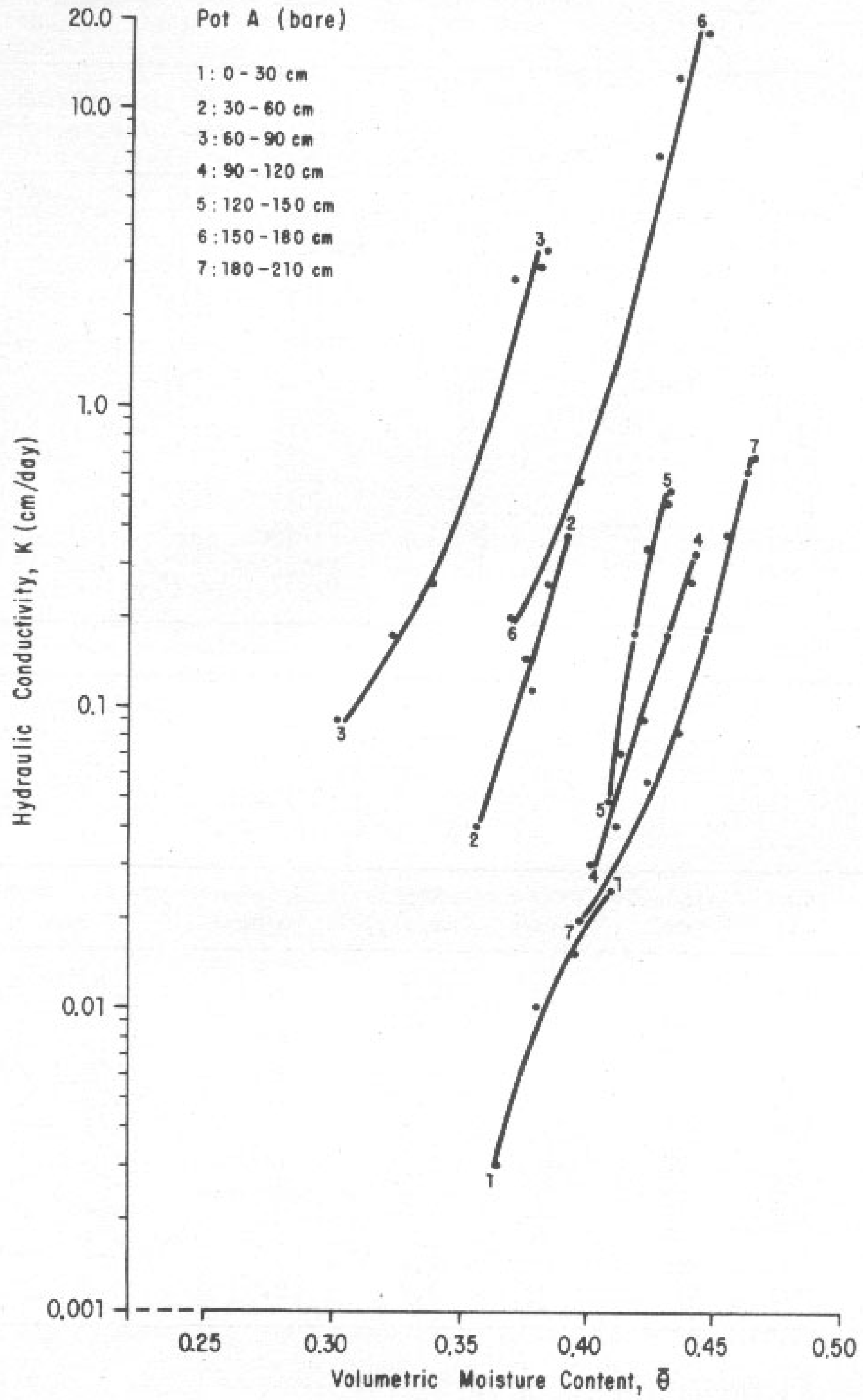

Fig. 4 HYDRAULIC CONDUCTIVITIES IN DIFFERENT LAYERS

Table 2 CALCULATION OF THE DRAINAGE COMPONENT, U, DURING AN IRRIGATION CYCLE OF LUCERNE PLOT 'A', ATHALASSA

Period (days)	$\overline{\theta}$ (%)	Hydraulic head, H, at z=180 cm	z= 210 cm	K (cm/day)	$\frac{\partial H}{\partial z}$	$U=(\frac{K\partial H}{\partial z})$ 195 (cm)
1	45.2	227	306	0.255	2.63	0.67
1	45.7	228	306	0.360	2.60	0.94
1	45.7	228	301	0.360	2.43	0.87
2	44.9	231	293	0.200	2.07	0.83
1	44.7	236	296	0.175	2.00	0.35
1	44.6	238	303	0.160	2.17	0.35
1	44.0	242	309	0.105	2.23	0.23
1	44.0	246	316	0.105	2.33	0.24
1	43.6	250	321	0.085	2.37	0.20
2	43.1	255	325	0.065	2.33	0.30
1	43.1	260	332	0.065	2.40	0.16
1	42.7	265	342	0.053	2.57	0.14
1	42.3	271	351	0.044	2.67	0.12
1	42.2	277	357	0.042	2.67	0.12
1	41.9	282	371	0.037	2.97	0.11
17						5.63

Table 3 CALCULATION OF ACTUAL EVAPOTRANSPIRATION (ETa) ADJUSTED FOR DRAINAGE AND RATE OF DRY MATTER PRODUCTION IN DIFFERENT CROP IRRIGATION CYCLES OF LUCERNE PLOT 'A' (JULY 1971-JULY 1972)

Cycle (days)	dW (mm)	Rainfall (mm)	U (mm)	ETa (mm/day)	E pan (mm/day)	ETa/E pan	Dry matter (kg/day/ha)
17	196	41	56	10.7	7.4	1.45	86.3
19	193	20	31	9.6	6.9	1.39	89.3
26	212	NIL	27	7.1	6.1	1.16	60.0
37	170	NIL	70	2.7	3.6	0.75	49.5
48	114	91	152	1.1	1.4	0.79	27.0
51	125	68	110	1.6	1.9	0.84	39.8
30	113	48	89	2.4	3.1	0.77	69.0
22	133	12	65	3.7	4.5	0.82	90.0
28	198	17	62	5.5	6.0	0.92	96.0
17	116	38	46	6.3	6.7	0.94	130.5
17	178	NIL	21	9.2	9.1	1.01	176.3
17	200	NIL	33	9.8	8.9	1.10	94.5

dW = change of soil water content within each crop irrigation cycle

U = accumulated drainage in each cycle

E pan = evaporation from open pan USWB Class 'A'

It was in cognizance of these differences that it was considered unrealistic to use parameters such as the hydraulic conductivity obtained from fallow plot 'B' to arrive at the drainage component of cropped plot 'A' and vice versa. It was thus thought more realistic to alternate the rotation, lucerne-fallow in plot 'A' and fallow-lucerne in plot 'B'. In this way the functional relationship of the hydraulic conductivity with soil water content was obtained for the particular depth of 195 cm (assumed to be below the main root zone) in the fallow plot (Fig. 4, curve 7). Subsequently by reference of the soil water contents encountered in this zone during each crop irrigation cycle the hydraulic conductivity, k, was obtained and by multiplying this with the hydraulic gradient $\frac{\partial H}{\partial Z}$ at 195 cm, determined from tensiometric measurement above (180 cm) and below (210 cm) this depth, the accumulated drainage below the root zone was computed.

A typical calculation by this procedure is given in Table 2. It will be observed that the average water content at 195 cm increases slightly 2 or 3 days after irrigation while the hydraulic gradient of the layer 180-210 cm shows a corresponding decrease. This situation is also reflected in the drainage below 195 cm which increased in 2-3 days after irrigation and thereafter diminished to reach a value of 1.1 mm/day on the 17th day.

The distribution and movement of water within the profile after application is demonstrated in Fig. 6 showing that major changes in the cropped plot occur down to a depth of 120 cm while at the depth of 195 cm only comparable minor changes in water content are observed when the plot is cropped or fallow (Fig. 5). In spite of this the hydraulic gradient in the 180-210 cm zone always favoured downward movement of soil water from the depth 195 cm. It is thus concluded that irrespective of any root activity in this zone a net downward movement takes place. This pattern is operative in each and every crop irrigation cycle as shown in Fig. 7 where successive changes in hydraulic head in the different layers and in a number of crop irrigation cycles are plotted against time. In this case too, irrespective of the rate of surface evaporation, the hydraulic gradient between 180 cm and 210 cm always indicates downward movement.

Thus the rate of actual evapotranspiration (ETa) was calculated from the relation proposed by Hillel <u>et al</u> (1972)

$$\left(\frac{dETa}{dt}\right) = \left(\frac{dW}{dt}\right)_{Zr} - \left(K\frac{\partial H}{\partial Z}\right)_{Zr}$$

where $\left(\frac{dW}{dt}\right)_{Zr}$ is the change of soil water content within each crop irrigation cycle from the surface down to 195 cm and

$\left(K\frac{\partial H}{\partial Z}\right)_{Zr}$ is the net accumulated drainage from the same depth, namely the drainage component. The computation of actual evapotranspiration along these lines is shown in Table 3 for lucerne plot 'A' and in Table 4 for lucerne plot 'B'.

It will be observed from Table 3 that the rate of drainage below 195 cm ranges from 1-3 mm/day representing 10-30 percent of actual evapotranspiration during the shorter summer crop cycles, but can reach 100-300 percent during the rainy season. By comparing actual evapotranspiration with pan evaporation as shown by ETa/Epan ratios it was observed that for the first two cycles in plot 'A' the ratios were unexpectedly high. This was attributed to the possibility of lateral movement within the copiously irrigated profile at the initiation of the study.

Similar comparisons for lucerne plot 'B' show that the drainage was in general lower than in profile 'A' but the actual evapotranspiration occuring in seasonably corresponding crop cycles were comparable.

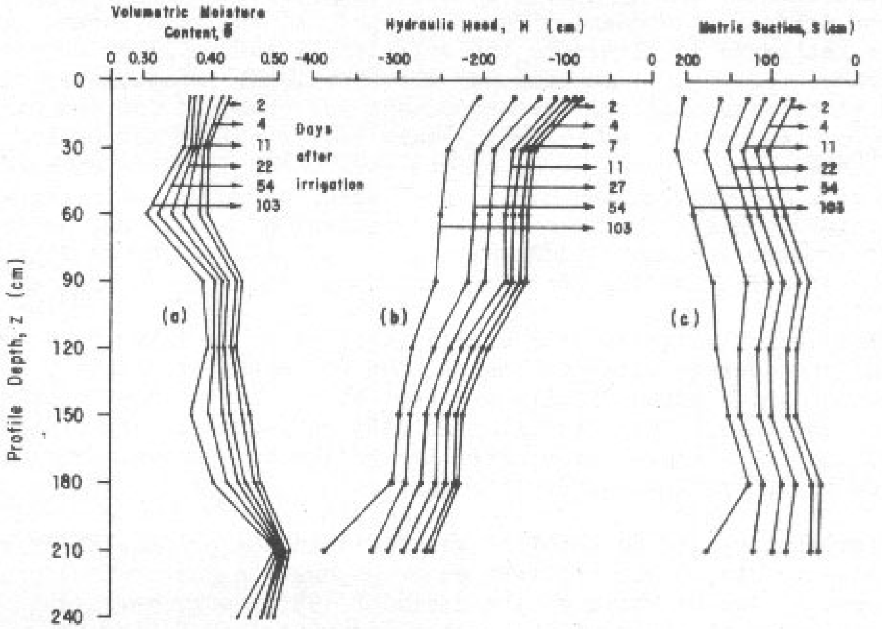

Fig. 5 SUCCESSIVE SOIL MOISTURE (a) HYDRAULIC HEAD (b) AND MATRIC SUCTION (c) IN FALLOW (COVERED) PLOT 'A' ATHALASSA

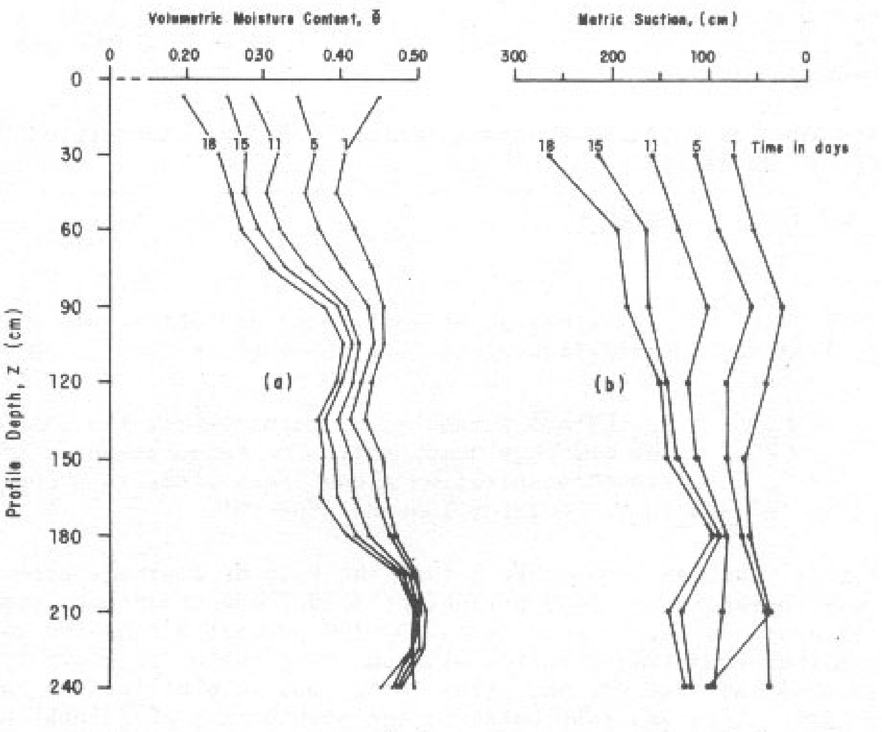

Fig. 6 SUCCESSIVE SOIL MOISTURE (a) AND MATRIC SUCTION (b) PROFILES OF PLOT 'A' FOLLOWING IRRIGATION OF LUCERNE 16 JUNE - 3 JULY 1972

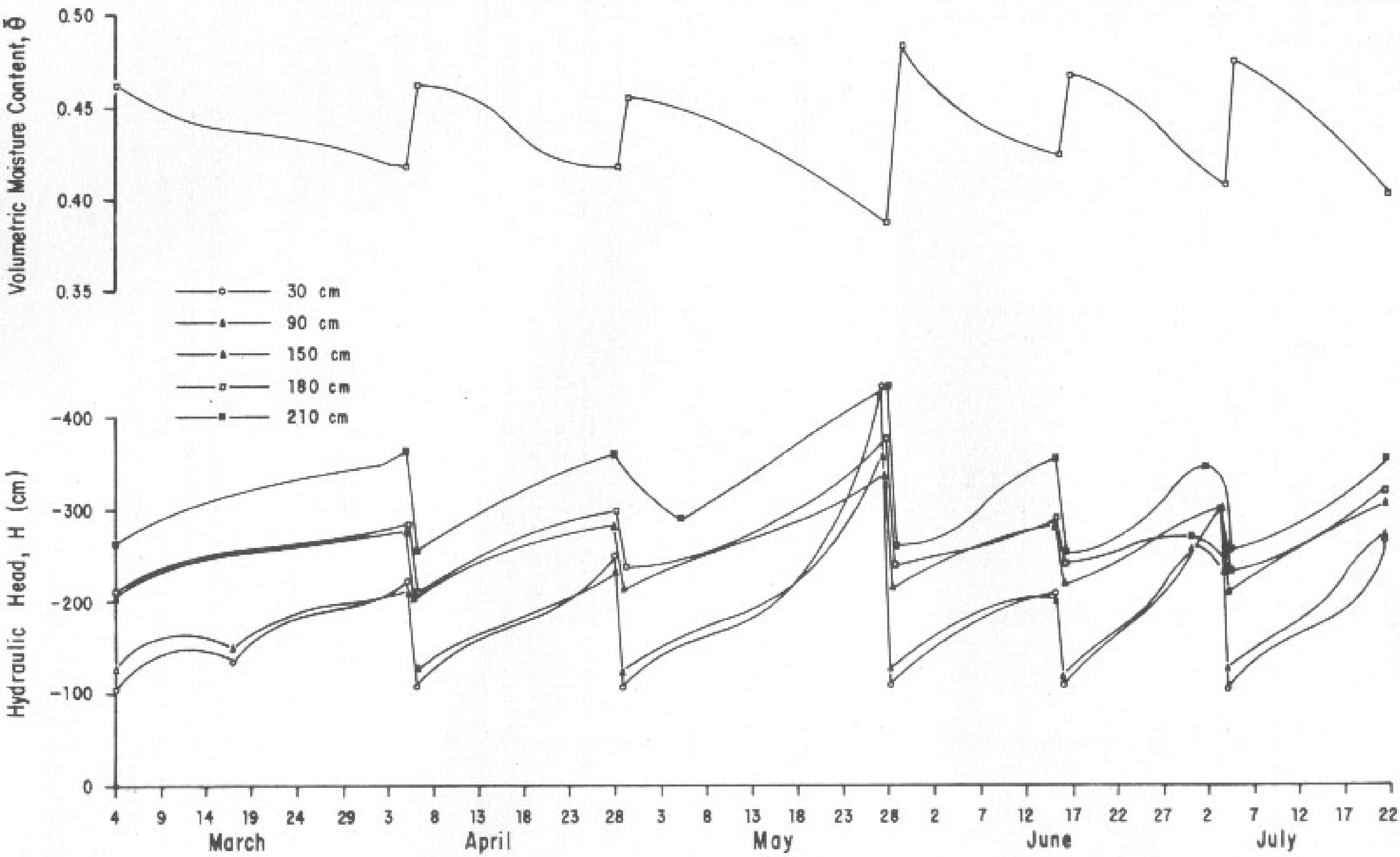

Fig. 7 HYDRAULIC HEAD vs. TIME AT FIVE DEPTHS AND MOISTURE vs. TIME AT 180 cm IN LUCERNE PLOT 'A' DURING SIX IRRIGATION CYCLES, ATHALASSA 1973

Table 4 CALCULATION OF ACTUAL EVAPOTRANSPIRATION (ETa) ADJUSTED FOR DRAINAGE AND RATE OF DRY MATTER PRODUCTION IN DIFFERENT CROP IRRIGATION CYCLES OF LUCERNE PLOT 'B' (JULY 1972-JULY 1973)

Cycle (days)	dW (mm)	Rainfall (mm)	U (mm)	ETa (mm/day)	E pan (mm/day)	Eta/E pan	Dry matter (kg/day/ha)
22	239+	NIL	18	10.1	8.8	1.15	83.3
20	224+	5	46	9.1	8.5	1.07	111.0
27	230+	NIL	48	6.8	7.5	0.91	69.5
26	150	NIL	34	4.5	6.3	0.71	51.0
41	141	3	25	2.9	3.2	0.91	42.0
62	77	16	23	1.2	1.8	0.67	27.8
48	91	38	43	1.8	2.8	0.64	63.8
30	191	8	58	4.7	4.8	0.97	114.0
30	171	1	27	4.8	7.2	0.67	130.5
18	115	5	26	5.2	7.5	0.69	192.0
20	164	14	28	7.6	9.4	0.81	169.5
15	179	NIL	17	10.8	10.4	1.04	207.8

+ Received supplementary irrigation of 100 mm

dW = change of soil water content within each crop irrigation cycle

U = accumulated drainage in each cycle

E pan = evaporation from open pan USWB Class 'A'

In general, in both plots the ratio of ETa/Epan approaches or even exceeds unity during the hot summer months and ranges from 0.7 to 0.8 in the winter and cooler periods. A plot of the relationship between ETa and Epan for both plots is shown in Fig. 8. It will be noted that although there is a linearity up to a daily pan evaporation of 7 mm, at values approaching 10 mm per day there seems to be a proportionally higher increase in the rate of actual evapotranspiration.

In this study the field water balance of two lucerne plots was computed from the depletion of soil moisture within each irrigation cycle. This change in soil water content was adjusted for net drainage losses below the root zone. Although the uptake of water from an assumed depth of 195 cm cannot be precluded, yet the net result is that drainage occurs below this depth, albeit at a diminishing rate as depletion of soil moisture increases from regrowth to harvest of lucerne in each crop cycle.

It is realized that in absolute values the calculated drainage component may fluctuate because of its dependence on the hydraulic conductivity which in itself may not be precisely defined in a layered soil. However, this procedure provides an estimate of the actual evapotranspiration of a vegetated field.

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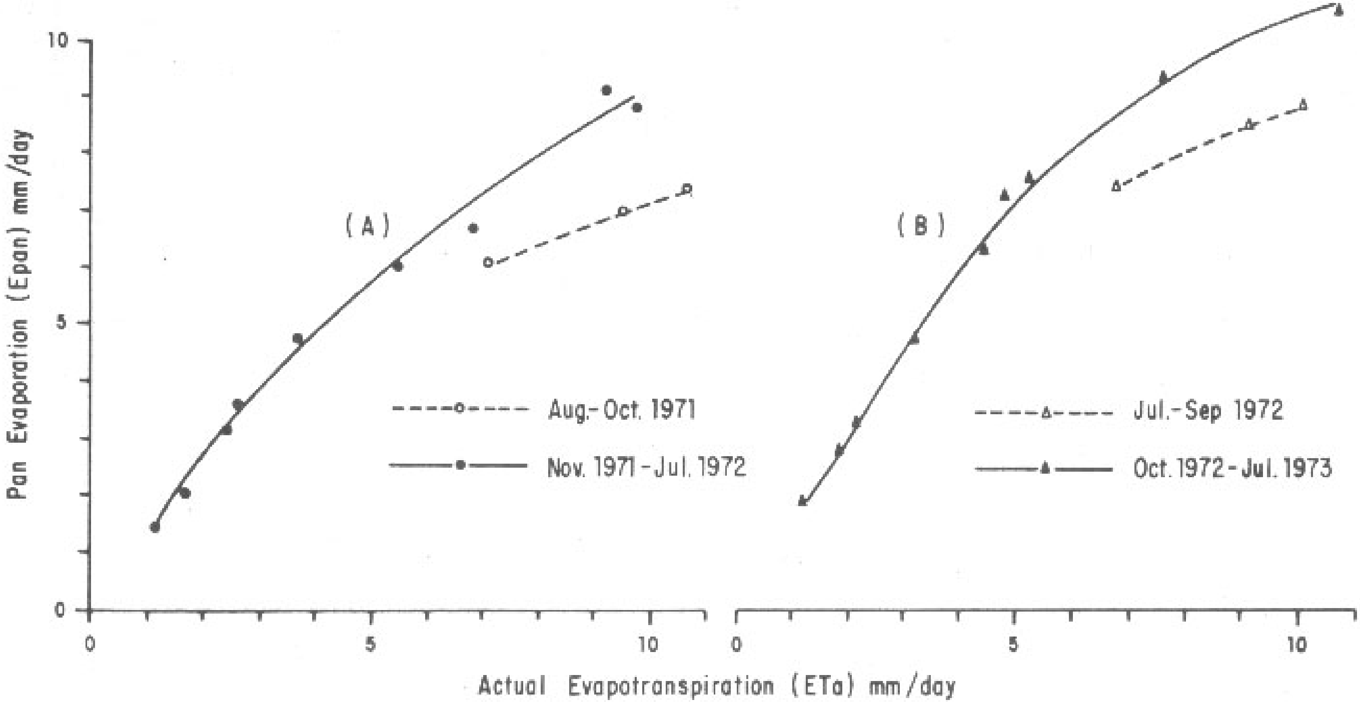

Fig. 8 RELATIONSHIP BETWEEN PAN EVAPORATION (Epan) AND ACTUAL EVAPOTRANSPIRATION (ETa) FROM TWO LUCERNE PLOTS, ATHALASSA

A. Constantinou and Chr. Xylaris for neutron measurements and other records in the field.

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V.2 SOME PHYSICAL PROPERTIES OF SANDY SOILS AND SAND DUNES IN IRAQ

by

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2.1 INTRODUCTION

In Iraq, sandy soils and sand dunes are located around Baiji in the north, in an area north-east of Hilla - Diwaniyah and in a sand belt, more or less parallel to the Euphrates situated in a NW-SE direction south of a line Najaf Zubair with a width ranging from 5-25 km. The general movement of dunes is in a south-easterly direction as a result of prevailing north-westerly winds (Map 1).

Among the many factors responsible for soil drift and the consequent formation of sand dunes are drought, over-exploitation of natural vegetation, the unprotected dredged material along canals and improper operations. These factors led to serious socio-economic problems, the engulfing of agricultural fields and grazing lands, irrigation systems and lines of communication by blown sand from adjoining areas.

Before attempting large scale phyto-reclamation of sandy soils and shifting dunes, it is well worth investigating their plant growing conditions with special emphasis on soil moisture characteristics in relation to particle size distribution, rainfall distribution and intensity in relation to soil moisture distribution at different depths and after each rain. These relationships plus the information on natural vegetation and climate will provide a better understanding of the ecosystem from the point of view of its reclamability through vegetation as well as a sound criterion for the choice of plant species to be used during the process of reclamation.

This report deals with the results of investigations carried out by the author on the sandy soils and sand dunes of Iraq.

2.2 MATERIAL AND METHODS

Soil moisture characteristics of graded silica sands were determined in triplicate samples on suction tables. The measurements were made at the same intervals from 0-60 cm suctions (Dougrameji, 1965).

Soil moisture characteristics, bulk density and percent porosity were obtained in triplicate samples of Zubair soils using suction tables in the intervals of 0-100 cm water suction, and pressure plate and pressure membrane extractor for pressures ranging from 1/3 to 15 atmosphere (Dougrameji, 1970)

Soil moisture characteristics and particle size distribution were determined on soil samples from dunes in Baiji, Mussayeb, Najaf, Muggaishi, Nassiriyah, Amara and Zubair. In addition, two samples from the sediment of the Mussayeb and Hamir canals in the Greater Mussayeb project were also studied in order to determine whether these sediments constitute the source of the material forming dunes in the project (Dougrameji and Kaul 1971).

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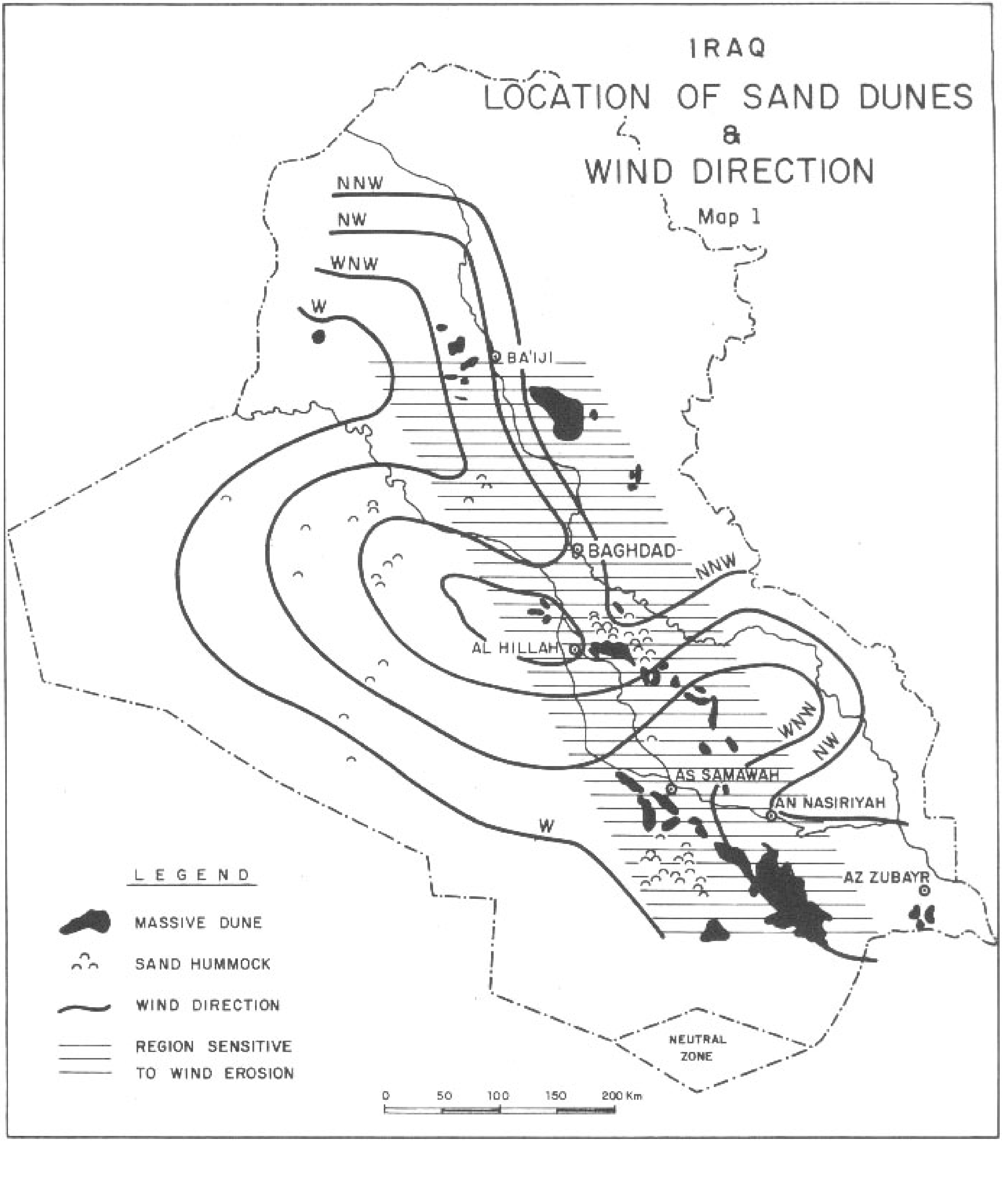
IRAQ
LOCATION OF SAND DUNES
&
WIND DIRECTION
Map 1
NNW
NW
WNW
W
BA'IJI
BAGHDAD
NNW
AL HILLAH
WNW
NW
AS SAMAWAH
AN NASIRIYAH
W
AZ ZUBAYR
NEUTRAL
ZONE
LEGEND
MASSIVE DUNE
SAND HUMMOCK
WIND DIRECTION
REGION SENSITIVE
TO WIND EROSION
0
50
100
150
200 Km

2.3 RESULT AND DISCUSSION

The data in Table 1 show an increase in soil moisture content for the uniform sand separates as the particle size of the separates decreases. The suction required to drain the pores in the sand separate increases with decreasing particle size.

The percent soil moisture for layered samples in Tables 2 and 3 indicates the presence of two breaks in soil moisture suction curves. The breaks become more pronounced the greater the difference in particle size of the two layers. But when the fine sand underlay the coarse sand, the coarse sand layer drained out through the fine layer at almost its normal suction, then the bottom fine layer drained when the suction was raised. On the other hand, when the coarse sand underlay the fine sand there was no significant amount of water removed from the sample until the suction necessary to drain the fine layer was reached. However, after approaching this critical point, a small increase in suction caused removal of a large amount of water from the sample due to draining of both layers at once.

Table 1 PERCENT MOISTURE BY WEIGHT AT VARIOUS SUCTIONS IN CORES OF UNIFORM SAND SEPARATE

Average size particle mm dia	Moisture suction - cm water							Moisture distribution ratio at 60 cm suction
	0	10	20	30	40	50	60	
	Percent moisture by weight							
2.20	21.1	2.3	1.4	0.9	0.7	0.6	0.5	1.0
1.34	22.1	2.5	1.2	0.8	0.6	0.5	0.7	1.0
0.63	29.7	16.6	3.2	2.2	1.6	1.0	0.8	1.0
0.23	34.7	34.0	33.3	21.9	7.2	4.2	3.3	1.0

Table 2 PERCENT MOISTURE BY WEIGHT AT VARIOUS SUCTIONS IN CORES CONSISTING OF TWO LAYERS (COARSE SAND OVER FINE SAND SEPARATES)

Average particle size of top and bottom layers mm dia	Moisture suction - cm water							Moisture distribution ratio at 60 cm suction
	0	10	20	30	40	50	60	
	Percent moisture by weight							
2.20/0.63	18.7	13.5	2.3	1.5	1.1	0.8	0.7	0.55
2.20/0.23	22.3	17.7	17.0	15.3	4.4	2.6	2.1	0.10
1.34/0.63	23.9	13.9	2.4	1.6	1.2	0.9	0.7	0.70
1.34/0.23	27.5	17.9	17.1	15.6	4.5	2.6	2.1	0.10
0.63/0.23	32.4	22.2	17.9	15.1	4.5	2.7	2.1	0.10

Table 3 PERCENT MOISTURE BY WEIGHT AT VARIOUS SUCTIONS IN CORES CONSISTING OF TWO LAYERS (FINE OVER COARSE SAND SEPARATES)

Average particle size of top and bottom layers mm dia	Moisture suction - cm water							Moisutre distribution ratio at 60 cm suction
	0	10	20	30	40	50	60	
	Percent moisture by weight							
1.34/2.20	24.6	2.5	1.6	1.1	0.9	0.8	0.6	0.0
0.63/2.20	26.4	13.5	4.4	9.7	8.8	8.2	7.6	15.2
0.23/2.20	27.0	26.2	24.7	15.9	14.9	14.5	14.3	28.6
0.63/1.34	26.9	26.3	14.5	12.7	11.7	10.8	10.3	26.3
0.23/1.34	28.8	28.2	27.7	17.5	16.9	16.3	16.1	87.1
0.23/0.63	31.6	30.5	19.0	17.8	16.8	16.0	15.2	23.6

The moisture distribution in the drained sand layers indicated the presence of a large amount of water in the fine layer overlying the coarse layer. The moisture content was 75% higher when the fine sand of 0.23 mm average particle size was underlain by a very coarse sand of 1.34 mm in diameter.

Zubair soils consist of gravelly sands developed by aeolian sorting and deposition. The soil profiles studied were characterized by light greyish brown loamy sands surface soil underlain by light brownish yellow sands. In the dominantly coarse-textured soils mechanical composition of the various profiles ranged from 80-95% sand, 1.5-12.8% silt and 2.7-10.5% clay. The range of available moisture of different layers is given in Table 4. The amount of soil moisture retained was mostly available at suctions less than 6.0 atm.

Table 4 SOIL MOISTURE CHARACTERISTICS OF SOIL PROFILES OF ZUBAIR (IRAQ)

Soil depth cm	Soil Texture	Range of moisture % by weight			Range of available moisture % by weight	
		1/3 atm	6 atm	15 atm	1/3-6 atm	1/3-15 atm
0- 30	L.S.	8.9-10.9	2.7-3.6	2.3-2.9	6.2-7.3	6.6-8.0
30- 60	L.S. to S	6.0- 8.3	2.3-2.4	1.8-1.9	3.7-5.9	4.2-6.4
60- 90	S	4.7- 6.7	1.9-2.2	1.5-1.8	2.8-4.5	3.2-4.9
90-120	S	4.2- 4.8	1.8-1.9	1.4-1.6	2.4-2.9	2.8-3.2

The texture of non-clay soil separates ranged from coarse silt to very coarse sand. The bulk density ranged from 1.4 to 1.64 g/cc and decreased with decreasing particle size. The particle density was almost constant and averaged 2.69 g/cc.

Table 5 PERCENT MOISTURE BY WEIGHT AT VARIOUS SOIL MOISTURE SUCTIONS IN CORES OF DIFFERENT NATURAL SAND SEPARATES (ZUBAIR, IRAQ)

Particle Size mm. dia	Soil moisture suction - cm water or atm									
	0	10	20	30	60	1/3 atm	1 atm	3 atm	6 atm	15 atm
	Percent moisture by weight									
2.00 - 1.00	26.53	6.14	4.58	4.10	3.06	1.68	1.28	0.74	0.38	0.29
1.00 - 0.50	27.69	10.29	6.29	5.14	3.56	1.83	1.60	1.00	0.61	0.51
0.50 - 0.25	29.22	24.80	21.24	9.92	5.05	2.49	1.99	1.48	1.24	0.68
0.25 - 0.105	30.44	28.25	26.94	25.25	16.43	4.95	3.34	2.20	1.75	1.22
0.105 - 0.053	31.95	30.35	29.37	28.93	28.10	19.45	11.85	4.58	2.90	2.45
0.053 - 0.020	34.75	33.75	33.38	32.87	32.15	27.38	18.75	8.30	3.84	2.98

Table 5 gives the **moisture** content expressed in percent by weight for each sand separate over the entire soil suction range that permits plants to grow. The data illustrate that the percentage of moisture was increased and the suction required to drain the pores in the sand separates increased with decreasing particle diameter.

The data show that the amount of soil moisture retained at equal suctions differs from one sand separate to another. The separate with a particle diameter larger than 0.5 mm released most of its water at a soil water suction range from 0-10 cm, but the separate 1.0-0.5 mm retained 4% of its available moisture at a range of 10-20 cm soil water suction. The separate 0.25-0.105 needed higher suction to release its water (30-100 cm water suction).

In the separate with a particle diameter smaller than 0.105 mm no significant amount of water was released below 100 cm soil water suction, and most of the moisture was retained in the range between 100 and 300 cm soil water suction.

The data in Table 6 show that the calculated available moisture between 1/3-6 atm and 1/3-15 atm are almost the same and to a lesser extent the data in Table 7. These results suggest that further studies be made on the upper limits of available water in sandy soils.

Table 6 PERCENT AVAILABLE MOISTURE IN UNIFORM SAND SEPARATES OF ZUBAIR WHEN COMPARED AT TWO RANGES OF SOIL WATER-SUCTION

Particle size - mm	Percent available moisture between	
	1/3 - 6 atm	1/3 - 15 atm
2.0 - 1.0	1.30	1.39
1.0 - 0.5	1.22	1.32
0.5 - 0.25	1.25	1.81
0.25 - 0.105	3.20	3.73
0.105 - 0.053	16.55	17.00
0.053 - 0.002	23.54	24.40

In the studied sand dunes a wide variation in the distribution of particle size was found. The soil from all the dunes is sandy except that of Amara 2, Muggaishi and Mussayeb 1 and 2 which are formed of sandy clay loam, loamy sand clay, loam and sandy loam respectively. Comparing the particle size distribution in the Mussayeb dunes and the dredged sediments from the two irrigation canals in the Mussayeb project revealed that more than 50% of the particles constituting the dunes are similar. The dunes in Zubair and Najaf compared to the dunes in other localities showed a higher percentage (8.0 and 8.7 respectively) of coarse sand. Except the dunes of Amara 2 and Mussayeb 1 and 2, the dunes in all other localities are largely composed of very fine sand to medium sand (80% of the particle size being 0.1-0.5 mm).

Table 7 SOIL MOISTURE CHARACTERISTICS OF SOILS FROM DUNES AND MUSSAYEB CANAL SEDIMENTS IN IRAQ

Location	% moisture by wt - atm			Bulk density	% available moisture by volume atm	
	1/3 atm	6 atm	15 atm	g/cc	1/3-6 atm	1/3-15 atm
Baiji-1	7.9	2.6	1.9	1.6	8.5	9.6
Baiji-2	6.1	2.2	1.6	1.6	6.24	7.2
Mussayeb-1	18.5	12.0	9.5	1.3	8.45	11.7
Mussayeb-2	15.0	8.8	6.8	1.27	7.87	10.4
Muggaishi	12.8	4.4	3.6	1.42	12.93	13.1
Nassiryah-1	7.3	2.2	1.5	1.63	8.3	9.5
Nassiryah-2	5.4	1.6	1.0	1.69	6.4	7.4
Amara-1	6.6	2.5	1.8	1.48	6.07	7.1
Amara-2	15.4	5.4	3.7	1.33	13.3	15.6
Najaf	7.7	2.0	1.1	1.71	9.75	11.3
Zubair-1	5.9	1.6	1.0	1.69	7.27	8.3
Zubair-2	13.4	6.7	5.2	1.30	8.71	10.6
Mussayeb	12.5	3.6	2.3	1.44	12.8	14.7
Canal Sediments	13.1	4.2	2.8	1.44	12.8	14.8

The maximum available moisture by volume in the different dunes (Table 7) varied from 7.2 in Baiji to 15.6 in Amara 2. As expected, the dunes composed of sandy clay loam and clay loam with a high percent of clay exhibited a high water holding capacity and higher available moisture compared to those composed of sand.

The results of these studies explain the importance of soil texture in determining soil moisture holding capacity, available moisture to plants and irrigation requirements; for example, the early concept of field capacity excluded from generalization those soils which are known to restrict downward flow of water. The texture changes in the profile were usually disregarded in describing field capacity; furthermore it was found that the flow of water will continue from the surface layer downward beyond the defined field capacity. Also growing plants play an important role in extracting the available water (Dwane and Loomis, 1967). For this reason, the field capacity should be considered as a soil moisture profile and the growing plant function rather than a property of soil in the root zone or the plough layer. Therefore, it appears that in sandy soils and non-clay sand separates, the available moisture has different ranges of pressure for which the moisture is available for plant growth and should be considered in irrigation practices. The available moisture of these soils when compared with the mean annual rainfall of 150 mm in the region (during the winter season) indicates moisture as the most important limiting factor, especially during the dry summer months, for plant establishment and growth.

.4 SUMMARY AND CONCLUSIONS

Soil moisture characteristics of graded silica sand, Zubair sandy soils and sand dunes from different locations in Iraq were studied.

The results of these studies indicate that:

a. although the moisture suction required to drain a soil depends on its particle size, in stratified soils the size of particle in a coarse stratum can govern the movement and retention of water;

b. in the sandy soils and the soils studied, most of the available moisture is retained at suctions less than 6 atm and it seems that this value is the maximum value to use under favourable field conditions for the sandy soils in estimating available moisture.

c. study of rainfall characteristics and the soil moisture regime through the soil profile should always be thoroughly considered in sand dune reclamation.

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V.3 THE SANDY SOILS OF THE KINGDOM OF SAUDI ARABIA

by

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and Water Use in the Kingdom of Saudi Arabia

The Kingdom of Saudi Arabia is one of the hottest and driest regions of the earth. In the mountain and coastal areas of the south-western part of the country rainfall rises to 300-400 mm. This allows dry farming to be practised. Over the greatest part of the country, however, average rainfall amounts to only 20-150 mm and agriculture is only possible under irrigation.

In the inland regions summer temperatures in the day-time regularly exceed 40°C, while in winter freezing temperatures frequently occur. Relative humidity in the day-time during summer drops to 10-20%. In the coastal regions relative humidity is much higher and temperature differences between summer and winter less pronounced. Strong dry winds frequently blow especially in summer.

Irrigated agriculture has been practised for thousand of years from shallow wells tapping the shallow unconfined aquifers of the alluvial deposits along the numerous wadi beds or from springs, notably those of the el Hassa oasis, the flow of which amounts to 15 m^3/sec. The shallow aquifers are regularly replenished by wadi floods and recharge usually exceeds extraction. Recharge may be increased by flood control structures but the development potential of the small unconfined aquifers is limited.

During the last few decades huge quantities of underground water have been discovered. They are stored in confined aquifers of the Cretaceous to Pleistocene formations dipping off the ancient crystalline rocks of the Arabian shield towards the Arabian Gulf 500 km to the east. The water is fossil having accumulated during an earlier pluvial period and very little replenishment is now taking place. Properly managed it may perhaps allow in area of 100 000 ha to be irrigated over a period of 50-100 years in addition to the 100 000 ha or so now under irrigation. If pumping is done from depths greater than 150-200 m and if desalinization of the more brackish waters is practised much bigger areas could probably be irrigated.

The main crops are date palms, cereals, fodder crops such as alfalfa and sorghum and vegetables. In certain areas deciduous fruit trees, citrus and vines are also grown.

The quality of water varies but in general the salt content of the deep confined waters is 800 to 6 000 ppm rising towards the coast of the Arabian Gulf. The quality of water in the small wadi aquifers is even more variable increasing downstream as well as away from the wadi bed. Little information is available about the boron content of the irrigation waters.

No basic soil survey has been carried out in the Kingdom. Reconnaissance land capability surveys based on the U.S. Bureau of Reclamation system provide incomplete information on the soils of the Kingdom. Agricultural soils belong to the loamy-sand to sandy loam textural classes with the lighter soils predominating. Infiltration rates are high amounting to 5-16 cm per hour while the field capacity determined in the field varies from 7% to over 15% by volume. The soils are always calcareous and often contain gypsum. A horizon of lime accumulation is often present.

The main problem in the management of those soils is efficient irrigation. Evapotranspiration during summer probably exceeds 10 mm per day. In order to avoid high percentage depletion of available water in these soils of low field capacity it is necessary to irrigate every 2-3 days. Taking into account the leaching requirements in order to control salinity, the depth of water per application should not exceed 4-6 cm in the lighter soils and 6-8 in the heavier soils. It is extremely difficult to ensure uniform distribution of such small depths by surface methods of irrigation, especially since land preparation is often unsatisfactory. As a result, much water is wasted. Even in the small irrigation basins often used for irrigation, which in theory should result in high efficiencies, the farmer tends to give much more water than is needed to meet evapotranspiration plus leaching requirements.

Sprinkler and for row crops, trickle irrigation would presumably result in much higher efficiencies but such methods have not yet been tried in the Kingdom.

Certain areas suffer from a high water-table. This problem is especially acute in parts of the important agricultural region of Qassim, 400 km N.W. of Riyadh, the el Hassa Oasis and the flat coastal region along the Arabian Gulf near Dammam. Drainage is necessary for dealing with this problem. In el Hassa a drainage system has been laid down as part of a big project which has also provided for the distribution of water by means of concrete channels. However, field drains have not yet been laid.

At the Qatif Agricultural Research Station near Dammam the drainage system is working satisfactorily. In Qassim the drainage problem remains acute. An interesting attempt at reclaiming a saline soil with a high water-table was made by a farmer in this area. He applied a layer of sand 5-10 cm deep to his land and has since succeeded in obtaining much higher yields of cereals and alfalfa than before. It would seem that this success is due to the fact that only a small part of the depression is under crops so that under irrigation there is a net movement of water away from the irrigation fields, while the added sand provides more favourable conditions for germination and growth than the original saline soil. If the entire depression is to be reclaimed an efficient drainage system is needed.

Occasionally, problems may arise due to impermeable calcareous hardpans. This is perhaps true of parts of el Hassa. At the Qatif Agricultural Research Station a hardpan consisting mainly of gypsum originally caused trouble but after some years of drainage and irrigation it has largely dissolved away and drainage is now, if anything, excessive.

Soil salinity is easily controlled under irrigation in well drained soils of light texture but the return flow to the shallow unconfined aquifer may cause salinization of the irrigation water unless this is compensated by sufficient underflow. This appears to be happening in the large el Harj aquifer, 100 km S.E. of Riyadh which is recharged by a number of wadis. As a result of overpumping the water-table is falling and there is no longer any underflow away from the aquifer. The water is therefore being continuously concentrated by evaporation and its salinity is rising.

Certain soils, notably those of Qatif, contain gypsum to the extent of 30% or more. Germination and growth of many vegetables is very poor in such soils. It has been found that heavy applications of poultry manure result in highly increased yields. Since this material contains no more than 10% of organic matter its effect is probably purely mechanical by preventing the formation of a thin gypsum crust by evaporation between irrigations. Excellent yields of many vegetables are obtained at this station. The result should prove of interest to other Middle East countries where similar gypsum soils occur.

Moving sand dunes cover huge areas. They often constitute a hazard by invading agricultural lands. In el Hassa they have been successfully fixed by planting tamarisc after spreading a thin layer of heavier soil over the sand dunes. Irrigation is given for a few years. The success of this system is probably due to the proximity of a watertable which is eventually tapped by the deep-rooted tamarisc, otherwise it would not survive under a rainfall of 30-50 mm. More recent work in this area indicates that it is not necessary to apply a layer of heavier soil before planting but protection against wind is necessary. Alongside highways asphalt is used for fixing moving sand dunes.

Certain hydrologists believe that considerable recharge of the aquifers takes place in these sand dunes since during the occasional heavy rains a large part of the rainfall percolates deep into the soil, escapes evaporation from the surface and can only continue moving downwards. The FAO hydrologist, Mr. Turgut Tincer, measured the tritium content of soil water at various depths and concluded that recharge in the dunes along the Riyadh-Dammam road may be of the order of 20 mm per annum over an area of 25 000 km^2.

The fertility of the soils of Saudi Arabia is surprisingly high. Experiments carried out by the FAO experts, Messrs. Bolle-Jones and Boswinkle indicate, as expected, a high response of most crops to nitrogen, but phosphorus fertilizers did not always raise yields while in only one experiment did potassium fertilizers raise the yield of late cuts of alfalfa. Fertilizer experiments are now in progress at the Qatif Station but a comprehensive programme covering all important agricultural regions and crops is indicated. In particular, experiments are needed on split applications and on new forms of nitrogen fertilizers with a view to reducing the considerable loss of nitrogen that takes place in sandy soils by leaching. The design of the experiments and the level of dressings should be such as to allow the economic optimum to be estimated.

During summer, nodulation of alfalfa is restricted or absent. It is not yet known whether this is due to the absence of suitable strains of bacteria or to the high soil temperatures. The problem is worth studying in view of the importance of this crop.

Trace element deficiencies are present, in particular zinc deficiency in citrus and probably other fruit trees. On the other hand, iron deficiency is of minor importance, being observed only in sensitive plants such as lemon trees growing in the presence of a high watertable. This is to be expected in view of the good aeration of the roots and the fact that the calcium carbonate content of sandy soils occurs mainly in the coarse fractions. It is a matter of experience that iron deficiency is most common in soils of high water holding capacity and in which a large proportion of the calcium carbonate is present in the silt and clay fractions. In general, in spite of the light texture of the soils, minor element deficiencies appear to be of less importance in Saudi Arabia than in other countries of the Middle East.

Both zinc and iron deficiencies are easy to correct; the first by zinc sulphate sprays and the second by means of soil applications of sequestrene Fe 138 chelate. Although this material is very expensive its use is probably justified economically for fruit trees but not for field crops.

In conclusion, mention should be made of a serious disability militating against efficient land and water use. This is the extreme parcellation of holdings and small size of plots especially in areas of traditional agriculture. A radical removal of this disability would be extremely difficult to achieve but perhaps some form of cooperation between owners of neighbouring plots may be reached so as to ensure a more efficient arrangement of plots for irrigation and a more efficient lay-out of irrigation canals and field drains. This problem is widespread in the Middle East and the experience of other countries in solving it may prove of value under the conditions of the Kingdom of Saudi Arabia.

VI. RECOMMENDATIONS

1. Exchange of Information

The Seminar, recognizing that sandy soils are extensive in the Near East and North Africa, feels that soil survey and estimation of the total area and its cultivable portions, based on the available information in each country, will help in evaluating the importance of these soils on factual bases and recommends that compilation of basic soil maps and available information on the effective use of these soils be carried out under the auspices of FAO and be disseminated among the countries of the region.

2. Characterization and Classification

The Seminar realizing that, although the soil textural class names of the sandy soils are "sands" and "loamy sands", soils of the "sandy loam" class might suffer from similar problems, therefore recommends that:

a. "sandy loams" be considered for practical purposes as sandy soils;

b. in the classification of these soils, the mineralogical constituents, e.g. calcium carbonate, gypsum, quartz, clays, etc. be taken into consideration; also that characteristics of hard pans be stated;

c. a sound land and water utilization programme of these soils be formulated on the basis of a sequence of land and water resources evaluation surveys (taking into account the environmental conditions) carried out on a suitable scale.

3. Panels of Experts

The Seminar feels that it is time to organize panels of experts under the auspices of FAO to study in an integrated manner, to set guidelines and to establish priorities on the different aspects, methods and practices of utilization of salt-affected, calcareous and sandy soils, as well as the efficient utilization of water under irrigated and rainfed agriculture.

4. Training and Extension

The Seminar realizing that training and extension services in soil and water management and agronomic practices are critical issues in most of the region, recommends intensifying these aspects among extension workers as well as farmers.

5. Pollution

Since sandy soils are pervious and usually receive excess amounts of water, the Seminar recommends that a study be directed toward factors involved in, and practices to avoid, pollution of the groundwater due to heavy fertilization, use of sewage water, application of asphalt and chemical sealants and grazing animals on these soils.

5. Suggested Research Programmes

The Seminar recognizing the progress achieved in the techniques of sandy soil utilization, especially in the fields of (a) Soil and Water Conservation and Management, (b) Fertility, and (c) Irrigation and Drainage, recommends that a regional programme of research be carried out. A part of this programme might be directed toward a better understanding of the theoretical bases of the problems, and the other part should be applied research.

a. Soil and Water Conservation and Management

i. Sand dune stabilization

Knowing that sand dune encroachment is a continuous threat to adjacent agricultural lands, recognizing the beneficial effects of stabilization and afforestation of sand dunes and being aware of the recent developments in the use of petroleum, synthetic rubber and chemicals for stabilization of sands, the Seminar would like to recommend that, before investing heavily in the application of these materials as surface sealants, they should be tested under conditions for effectiveness, durability and economy in comparison to traditional methods, using dry vegetation or other techniques. More research should be carried out on the collection and selection of plant varieties most adapted to local conditions, especially forest species. Similarly, studies on the hydrological effects of afforestation should be considered.

ii. Erosion Control

Noting that sandy soils are susceptible to erosion and therefore erosion control measures not only save them from being degraded but also prevent them from being a menace to adjacent productive lands, it is recommended that the application of the best suited agronomical management practices be stressed. In this regard, the minimum tillage practice is worth evaluation.

iii. Mulching

The Seminar, recognizing that studies on mulching techniques, such as tillage, gravel placement, application of crop residues and plastic or cellophane covers, are lacking in the region, recommends the carrying out of studies on:

- depth and time of tillage;
- effectiveness of different crop residues, and other materials used in mulching;
- methods of application.

iv. Placement of barriers within the soil

The Seminar, being aware of the recent techniques of barrier placement in the soil and noting the limited application of these techniques in the region, recommends the initiation of studies and experiments in pilot areas on barriers of asphalt, organic manure and other materials with special emphasis on:

- susceptibility of barriered soils to salinity, especially when brackish water is used for irrigation;

- comparison of this technique as a conservation measure for water and nutrients with that of irrigation by sprinkler and drip methods;

- economic evaluation, based on cost of material and placement of the barrier and crop yields.

b. Fertility Studies

The Seminar being aware of the fertility problem of sandy soils and recognizing the impact that recent fertilization techniques could have on the development and utilization of these resources, recommends that research be directed toward:

i. movement, reactions and transformation of different fertilizer forms (including inorganic fertilizers) in the soil;

ii. techniques and forms of fertilizer application;

iii. developing a suitable system for soil fertility evaluation;

iv. interaction between fertilization and irrigation.

c. Irrigation and Drainage

i. Water quality

Realizing that good quality water is getting scarcer and scarcer in the region, and low quality water is widely found, the Seminar recommends that more research be carried out on the use of saline, sewage and desalinated water which will ultimately lead to the establishment of criteria for safe, efficient and economic use of such waters on sandy soils. Particular attention should be given to carrying out experiments on the critical level of salts and their composition in irrigation water by different irrigation methods on different crops under specified climatic conditions using a wide range of application rates.

ii. Irrigation efficiences

Considering the role of irrigation efficiency in economizing in the use of scarce water resources and noting the high efficiency of newly developed techniques, the Seminar recommends carrying out:

a. trials on the methods of improving application efficiency of different irrigation methods taking into cossideration the leaching requirements, land levelling a d drainage aspects;

b. trials for the improvement of the conveyance efficiency of the irrigation system;

iii. Integrated experiments

The Seminar recommends carrying out practical experiments at the field level on the relation between crop production and soil moisture regime as induced by irrigation and drainage under optimum conditions of crop varieties, fertilization, optimum salinity conditions and good farming operations.

iv. Drainage testing

The Seminar recommends the inclusion of sandy soils in studies on optimum combination of drainage material in relation to soil types and methods of installation of drain pipes.

v. Lining of canals

The Seminar recommends the undertaking of practical studies on the application of low-cost local material for canal lining.

vi. Control of algae and microflora in the irrigation system

The Seminar recommends carrying out studies to develop safe chemical methods of controlling algae and microflora in the different irrigation systems in order to avoid dangerous contamination of irrigation water and water losses.

7. Utilization of Sandy Soils under Dryfarming Conditions

The Seminar realizing that large areas of sandy soils in the region depend on rainfall, recommends that a programme of studies be directed toward the following points:

a. methods of water and soil conservation;

b. fertilization practices;

c. breeding plant varieties most adapted to such conditions, especially drought-resistant varieties.

8. Regional Applied Research Programme for Land and Water Use on Sandy Soils

The Seminar recognizing the vital importance of this regional programme for promoting improved land and water use on sandy soils in the countries of the region and noting that a decision has not been taken so far in support of this regional programme by the UNDP, the Seminar urges that immediate action be taken by the UNDP to expedite the early implementation of the regional programme's objectives.

It is further requested that coordination should be made between the applied research programme and other regional centres dealing with applied soil and water research.

FAO/UNDP Seminar on Reclamation and Management of Sandy Soils in the Near East and North Africa

Nicosia, 3 to 8 December 1973

PROGRAMME

3 December Monday

1. Procedural Matters

   a. Registration

   b. Official opening of the Seminar

   c. Election of Chairman, Vice-Chairman and Drafting Committee

2. Classification, Distribution and Agricultural Potentialities

   Classification and distribution of sandy soils in the Near East Region and their agricultural potentialities

3. Fertility and Fertilization

   Organic and inorganic fertilization of sandy soils under irrigated arid conditions

4 December Tuesday

4. Soil Management and Conservation

   a. Physical properties of sandy soils in relation to cropping and soil conservation practices

   b. Quality of water in relation to irrigating sandy soils

   c. Country Reports - Afghanistan, Algeria, Bahrain, Egypt, Iran, Iraq and Jordan

5 December Wednesday

5. Water Management

   a. Reduction in conveyance losses in sandy soils

   b. Irrigation of sandy soils

   c. Drainage of sandy soils

   d. Country Reports - Kuwait, Lebanon, Libya, Morocco, Oman, Pakistan and Qatar

6 December Thursday

6. Applied Research

   a. Reclamation and management of sandy soils in Cyprus

   b. Country Reports - Saudi Arabia, Somalia, Sudan, Syria, Tunisia, Yemen Arab Republic, Yemen People's Dem. Rep.

   c. Regional applied research on sandy soils

7 December Friday	7.	<u>Excursion</u>
8 December Saturday	8.	Presentation of the final draft report
		Closing session

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APPENDIX 3

ARAB CENTRE FOR THE STUDIES OF ARID ZONES AND DRY LANDS (ACSAD)
Damascus, Syria

Activities of the Soil-Water Division

by

Jamal S. Dougrameji
Head, Soil-Water Division

INTRODUCTION

Farmers have tended to over exploit natural resources up to the present in the absence of scientific and technological help and social and financial aid. The balance between the human population and the natural resources has been upset, either because of climatic fluctuations or man's intervention or due to a complex interaction of these two factors. Where this has continued unchecked, it has led to the loss of valuable plant species, lower soil fertility and, ultimately, their replacement by large areas of unproductive lands, salt affected soil and barren sand dunes.

With the above background in mind, ACSAD was established in September 1971 in order to find some solution to these problems in the Arab countries. As indicated by the title, its studies will cover the arid zones and dry land regions where soils and environmental conditions are almost similar. Therefore, soil and water management and conservation, soil reclamation, irrigation, drainage, soil fertility, groundwater resources, field crops, animal resources, range management and climatology are given the highest consideration.

OBJECTIVES

The main objectives of the Soil-Water Division are:

1. Reclamation of salt affected soils in pilot areas through:

   a. determination of critical depth and spacing of drainage systems;

   b. testing of different methods of leaching and leaching requirements for different soil types;

   c. testing of drainage materials;

   d. crop rotation and fertilization;

e. study of salt and water balance;

f. economical feasibility of soil reclamation.

2. Reclamation of sandy soils and sand dunes by means of biological, mechanical and chemical methods in selected pilot areas.

3. Studies on fertilizer requirements of the farm crops and fruit trees.

4. Studies on the problems of gypsic and calcic soils and their management.

5. Studies on water requirements of the important farm crops in selected climatological regions.

6. Studies on the use of saline water in soil reclamation and irrigation.

7. Studies on methods of soil and water analysis.

8. Soil and water conservation in dry farming regions.

The accomplishment of these objectives will be carried on through:

i. research studies in relation to the development of agriculture in the arid zones of the Arab countries;

ii. cooperation with local regional and international scientific organizations concerned;

iii. training technicians and specialists in methods of survey, conservation and utilization of natural resources in arid zones;

iv. publication of important findings as well as documentation of scientific information.

PRESENT PROGRAMME 1972 - 1974

The present programme of ACSAD includes:

1. Reclamation and management of salt affected soils in the Euphrates basin at Der El Zor pilot project to:

a. find the best drain spacing;

b. find the best drain depth;

c. study leaching methods and requirements;

d. select the best crop rotations for reclaimed soils.

2. Study of the water requirements of cotton and wheat in the Euphrates basin at Der El Zor pilot project using lysimeters and field plots.

3. Study of the relationships between water use efficiency and fertilization of wheat and cotton at Der El Zor pilot project.

4. Studies of the response of some fruit trees to different levels of fertilizers.

5. Studies on soil conservation in high rainfall areas through cultural practices in the Lattakia region.