REPUBLIC OF KENYA

MINISTRY OF AGRICULTURE AND LIVESTOCK DEVELOPMENT

LDD/IRRIGATION AND DRAINAGE BRANCH

SCHEME IDENTIFICATION AND EVALUATION

MANUAL FOR SENIOR STAFF
ON GRAVITY FED SCHEMES WITH
BASIN IRRIGATION OPERATED BY FARMERS

SECTION I

SOILS

1984

PREFACE

This Manual on soils is part of an Irrigation Manual on Scheme Identification and Evaluation of small-holder irrigation schemes characterised by gravity water supply, surface irrigation with basins and operated by the farmers themselves.

The Manual is aimed at Senior Land Development staff of the MoA either taking part in the identification themselves or advising decision makers at District, Provincial or National level.

The Manual on Scheme Identification and Evaluation will be published in different sections of which are in preparation:

1. Soils
2. Topography
3. Water Resources
4. Socio-economic Data
5. Evaluation of Existing Irrigation Schemes

Comments are invited and when received before September 1985 will be incorporated in a revised edition of this Manual.

This Manual (Section 1) is the first published and it is an edited version of courses given to senior staff at Provincial Irrigation Units in 1983 by the Kenya Soil Survey.

Contributions from the head of the KSS, Mr F N Muchena, and staff members W M Wamicha, P N Macharia, C K K Gachene, V M P van Engelen and A Weeda made this draft possible.

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T A B L E S

1. INTRODUCTION

Soil investigation forms an important part of the scheme-identification process. When the soils are unsuitable for irrigation, for example when having a site with saline and alkaline soils, shallow soils, soils with unfavourable structure or texture with low fertility, the idea of irrigation will be rejected. For decision-makers, this may be less obvious. Therefore, the irrigation officer should have sufficient knowledge to evaluate the soil for the purpose of irrigation and advice in this respect, to ensure that the right decisions and commitments are made.

In this part, a general review of existing bottom land soils in Kenya is given, as in most cases irrigation schemes are proposed on these types of soils. Attention is paid to those soil aspects which may cause problems when irrigating.

Regarding salinity and sodicity aspects, the methodology of measurements and the criteria for their evaluation are given. A method for measuring the hydraulic conductivity is dealt with. The conductivity is required to determine the need of a drainage system, for which the drain distance can be calculated.

All measurements given in this part of the Manual are in accordance with the measurements used by National Agricultural Laboratories and the Kenya Soil Survey.

Finally, a summary of aspects on soil site investigations is given, as well as a land classification in connection with surface irrigation of basins. Three maps, which indicate the occurrence of saline and sodic soils have beeen added. Because of the scale of these maps, a more detailed check on the proposed location may be required.

2. CHARACTERISTICS AND PROBLEMS OF BOTTOM LAND SOILS

Bottom lands are areas of varying shape and size with nearly level and often concave topography. They lack an outlet and as a result ground water and surface waters accumulate. This leads to subsequent accumulation of fine sediments and eventually soluble salts. Because of lack of an outlet the external and internal drainage condition is poor.

The bottom lands usually have slopes less than 1% and a relief intensity of less than 5 metres. Included in the category of bottom lands are "salt flats", valley bottoms, interfan depressions, and volcanic "sink holes".

The soil conditions in bottom lands vary greatly depending on the source and type of parent material, the prevailing drainage condition and the stage of development of the soil. The following soil types are commonly encountered in bottom land areas:

(1) Vertisols (black cotton soil)
(2) Planosols (vlei soils)
(3) Solonchaks (saline soils)
(4) Solonetz (sodic soils/alkaline soils)
(5) Fluvisols (alluvial soils)
(6) Histosols (bog and marsh soils)
(7) Gleysols (poorly drained soils)

2.1 VERTISOLS (BLACK COTTON SOILS)

Characteristics:

These are mainly dark, swelling and shrinking, and therefore cracking clays. The clay mineral is predominantly the swelling type, mainly montmorillonite. These soils are fine in texture and near alkaline in reaction. The texture is clay throughout the profile (more than 35% clay).

In the dry season, the soils develop large cracks, usually more than 1 cm wide at 50 cm depth. When the rains fall, the soil absorbs water and it swells, closing the cracks. When the cracks close, water intake by the soil becomes negligible; thus the soil becomes impervious. Because of their low hydraulic conductivity when wet, vertisols are usually poorly drained (seasonally)

On the basis of the structure of the top soil, two types of vertisols may be distinguished: the self-mulching vertisols which have granular or crumb structure and the crusty vertisols with a thin crust on the surface during the dry season. The self-mulching vertisols are more common in the drier parts of the country whereas the crust vertisols are more common in the higher rainfall areas.

Vertisols are predominant in Kano Plains, Mwea, Athi Plains, Yatta area, Bura East area, Nanyuki and Rumuruti area, among other places. Part of Njukini (road to Taveta) irrigation scheme has vertisols.

Problems:

When dry the soils have a very hard consistency. They are very sticky and plastic when wet. The optimum moisture range for tillage, characterized by friable consistency, is narrow and of short duration. For this reason, vertisols are not extensively cultivated using traditional methods (ox-ploughing). Only few patches are cultivated this way.

Because of their low hydraulic conductivity, vertisols are subject to flooding and water logging during the rainy season and this hampers growth of dry food crops.

Possibilities:

With mechanical tillage, the soils can be worked even during the dry season. This is common practice in the Nyanza Sugar Belt. Some provision of surface drainage is necessary. Some of the crops sensitive to water logging may be planted on ridges.

The soils are puddled after flooding for paddy rice either with oxen or tractor. These soils, however, require a drying out period before flooding in order to maintain a bearing capacity.

2.2 PLANOSOLS (VLEI SOILS)

These are soils with developed hard pans. They are, therefore, poorly drained. The top soil, which is relatively light textured and permeable, is abruptly underlain by a slowly permeable horizon (hard pan) within 125 cm of the surface. The soils are found on flat to nearly flat land either on the plateau or valley bottoms and bottom lands. Due to the flatness of the land once the top soil is saturated, water movement through the soil and also on the soil is restricted. The soils may thus be seasonally water-logged.

Problems:

The effective depth of planosols is the permeable top soil which may be as little as 30 cm. Root development is largely confined in this layer where fertility is low. The major problem of these soils is how to maintain a favourable soil moisture regime for the crops. The seasonal water-logging hampers root growth of most crops while the alternating drought conditions, depending on the seriousness of the drought, depresses yields. While provision of drainage might eliminate water-logging, that action alone may increase the severity of drought, particularly in years with rainfall below average.

Possibilities:

Drainage and loosening of the sub-soil has, in many countries, not resulted in notable improvements in productivity. Crop production may occur on slightly elevated or sloping areas, where drainage to surrounding lower elevated areas is possible. Where the drought period is not very severe (only short period), shallow rooted crops such as cabbages, beans, potatoes, etc can be cultivated with minimum drainage although there might be severe fertility problems. Otherwise the soils are better left with natural vegetation, mainly grasses and shrubs, and used for grazing.

These soils are less suitable for surface irrigation. If top soils are over 60 cm deep, overhead irrigation could provide a favourable moisture regime.

2.3 SOLONCHAKS (SALINE SOILS)

Characteristics:

These are soils which contain a lot of soluble salts. They are commonly light coloured and are low in organic matter. They form in depresssions in arid and semi-arid areas. As moisture evaporates, salts which have been dissolved in the water accumulate and salt efflorescence and crusts form.

These soils have an ECe greater than 4 mmhos/cm at 25°C; an ESP less than 15; and a pH generally below 8.5. Solonchaks usually occur in association with saline-sodic soils. Saline-sodic soils are characterized by an electrical conductivity of saturation extract (ECe) of more than 4 mmhos/cm (saline) in combination with an exchangeable sodium percentage (ESP) of more than 15 (sodic). Their pH may vary widely, but usually is between 8.0 and 8.5.

The clay disperses easily on wetting. Visual characteristics may be:

- white salt crystals (which can be seen precipitated on the sides of the profile pit or along cracks);
- clay is flocculated and gives a loose granular or blocky structure;
- a white salt crust covering the ground or a very loose fluffy surface caused by the growth of long needle-like crystals of sodium sulphate.

Problems:

From an engineering point of view, excessive contents of soluble salts in the soil causes structural problems. Water dissolves the salts, resulting in collapse of irrigation and drainage ditches.

The presence of much soluble salt in the soil solution creates a high osmotic pressure which subsequently reduces the availability of water to plants. Also, some ions may be present in the soil solution at toxic levels for plant growth.

Possibilities

The soluble salts have to be leached out. This requires good permeability of the soil, good quality irrigation water, and good drainage conditions.

2.4 SOLONETZ (SODIC/ALKALINE SOILS)

Characteristics:

These are soils which contain little soluble salt (ECe less than 4mmhos/cm) but much exchangeable sodium on the exchange complex that is harmful for the growth of agricultural crops (ESP more than 15). A high level of exchangeable sodium causes the clay to disperse. The dispersed clay subsequently moves from the top soil into the sub-soil and forms a natric horizon. Usually a characteristic columnar structure develops. Upon wetting, this natric horizon becomes virtually impermeable. These soils have a pH between 8.5 and 10 but the pH may be as low as 6 in lime-free soils, the low pH being attributed to exchangeable hydrogen.

Visual indications which may be present are:

-- a thin, coarse textured A horizon from which clay has been eluviated;

-- the A horizon overlies a compact, heavy textured B horizon (natric B horizon) as a result of clay illuviation from the top;

-- there is typically a columnar structure with rounded tops;

-- low permeability due to the natric B horizon;

-- dark colours (the organic matter present in the soil solution may be deposited on the soil surface by evaporation, thus causing darkening - a process which led these soils to be referred to as "black alkali").

If sodium is present and the salt concentration is low, on adding water, the soil structure may collapse after some time.

Problems:

High sodium contents in the soil result in poor soil structure, poor aeration and low permeability. Internal drainage becomes almost impossible. Sodic hard pans are also common. High sodium levels could also preclude uptake of some other necessary ions, and is toxic in itself for some crops.

Possibilities:

Solonetz soils are generally impossible to reclaim in an economic way. The leaching of sodium is almost impossible as permeability is poor due to the high sodium levels.

2.5 FLUVISOLS (ALLUVIAL SOILS)

Characteristics:

These are young soils which do not have horizon differentiation due to soil forming processes but they show strong stratification due to sedimentary deposition. Coarse soil layers (sandy) may alternate with fine layers (clay). They have an organic matter content that decreases irregularly with depth and they receive fresh sedimentary material at regular intervals if flooded.

Problems:

The layers with contrasting textures affect water movement through the soil. Water tends to stagnate in these layers. This results in a drainage/aeration problem. The layers may also offer mechanical impedance to root development.

Possibilities:

Some of these soils are well suited to agriculture. Some may require mechanical mixing to homegenize the profiles when stratification is prominent, if economically feasible, and drainage is provided for.

2.6 HISTOSOLS (BOG AND MARSH SOILS)

Characteristics:

These are poorly drained soils with a thick top soil containing a high percentage of fresh or partly decomposed organic matter (65% or more). The top soil is at least 40cm thick and is dark coloured (sometimes black).

The physical and chemical characteristics of these soils are strongly determined by the environment and type of plants that accumulated and raised the organic matter content. Most of the histosols are acidic (pH 3.5 - 5.5). They have a low bulk density and therefore high porosity. Fertility is in general low.

Problems:

Reclamation of these soils means removal of excess water by drainage. The drainage removes ground water buoyancy and is associated with compaction of the loose peat mass and decomposition of organic matter with considerable subsidence of the land surface after the initial crop(s) fertility problems may be severe. The low bulk density and the associated low bearing capacity coupled with the subsidence hampers construction works.

Sudden lowering of the ground water table may lead to strong drying up and shrinkage of the soil. Large and deep cracks may form, rendering the area a waste land, unsuitable for crops and dangerous for animals and even man.

Possibilities:

Drainage system investigations are necessary and should be more or less continuous, to determine the suitable water regime. Subsidence of these soils, which is gradual, necessitates this approach.

2.7 GLEYSOLS (POORLY DRAINED SOILS)

Characteristics:

These are poorly drained mineral soils which are periodically water-logged. Permanent or periodic saturation by ground water is reflected by greyish colours or prominent brown and yellow mottling. These soils have no clear textural differentiation. The pH of these soils may vary from acid to alkaline.

Problem:

Because of their periodic water logging, growth of dry food crops may be hampered. Workability of these soils may also be a problem during some time of the year.

Possibilities:

These soils can be drained and used for agriculture.

3. MEASUREMENT AND CRITERIA FOR SALINITY AND SODICITY IN SOIL AND IRRIGATION WATER

3.1 GENERAL

In order to assess the salinity and sodicity hazard of land and water for irrigation development, two quick measurements can be carried out on soil and water samples. These are the pH and electrical conductivity measurements which indicate the rate of sodicity and salinity.

Soil pH and electrical conductivity are characteristics which are determined in the soil solution. The latter is simply soil water in which the ionic forms of plant nutrients and other salts are dissolved.

Apart from the soil solution the characteristics of irrigation water have to be determined in order to assess the suitability of the land and the water for irrigation.

3.2 pH OF THE SOIL SOLUTION

An important property of the soil solution is its reaction - that is, whether it is acid, neutral or alkaline. Some soil solutions have more hydrogen (H^+) than hydroxyl (OH^-) ions and therefore are acid. Some show the reverse and are alkaline, while others which have an equal concentration of hydrogen and hydroxyl ions are neutral.

$H^+ > OH^-$	$H^+ = OH^-$	$H^+ < OH^-$
acid	neutral	alkaline

As the pH is the negative logarithm of the H^+ concentration, a difference of 1 unit in pH relates to a 10 times difference in H^+ ion concentration.

The concentration of the hydrogen ion (and consequently the pH) is related mathematically to the concentration of the hydroxyl ion. In any soltion in which water is the solvent, the product of the concentration of these two ions is constant (approximately

10^{-14} at 25°C).

$$H_2O \Longleftrightarrow H^+ + OH^-$$

$$(H^+) \times (OH^-) = 10^{-14}$$

Below are shown the ranges of soil pH encountered as well as the relationship between pH values and terms commonly used to describe the soil reaction.

TABLE 1: TERMS USED IN DESCRIBING SOILS ACCORDING TO pH VALUES

	pH
Extremely acid	below 4.5
Very strongly acid	4.5 - 5.0
Strongly acid	5.1 - 5.5
Medium acid	5.6 - 6.0
Slightly acid	6.1 - 6.5
Neutral	6.6 - 7.3
Mildly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 9.0
Very strongly alkaline	9.1 and over

For mineral soils the range in pH extends from near 3.5 to perhaps 10 or above. It is to be noted that certain peat soils or mangrove soils may show a pH of 3 or less. At the other extreme are alkali or sodic soils, some of which may reach a pH near 11.

However, the common range in pH of soils in humid and arid regions are sharply in contrast with the extremes just noted. The range for soils in humid regions extends roughly from somewhat below 5 to above 7. Also the latter figure overlaps the range common to soils of arid regions whose usual pH spread is from a little below 7 to approximately 9.

A pH value of about 7.5 or somewhat higher usually indicates the presence of some free carbonates of calcium, magnesium or both, but not necesssarily so.

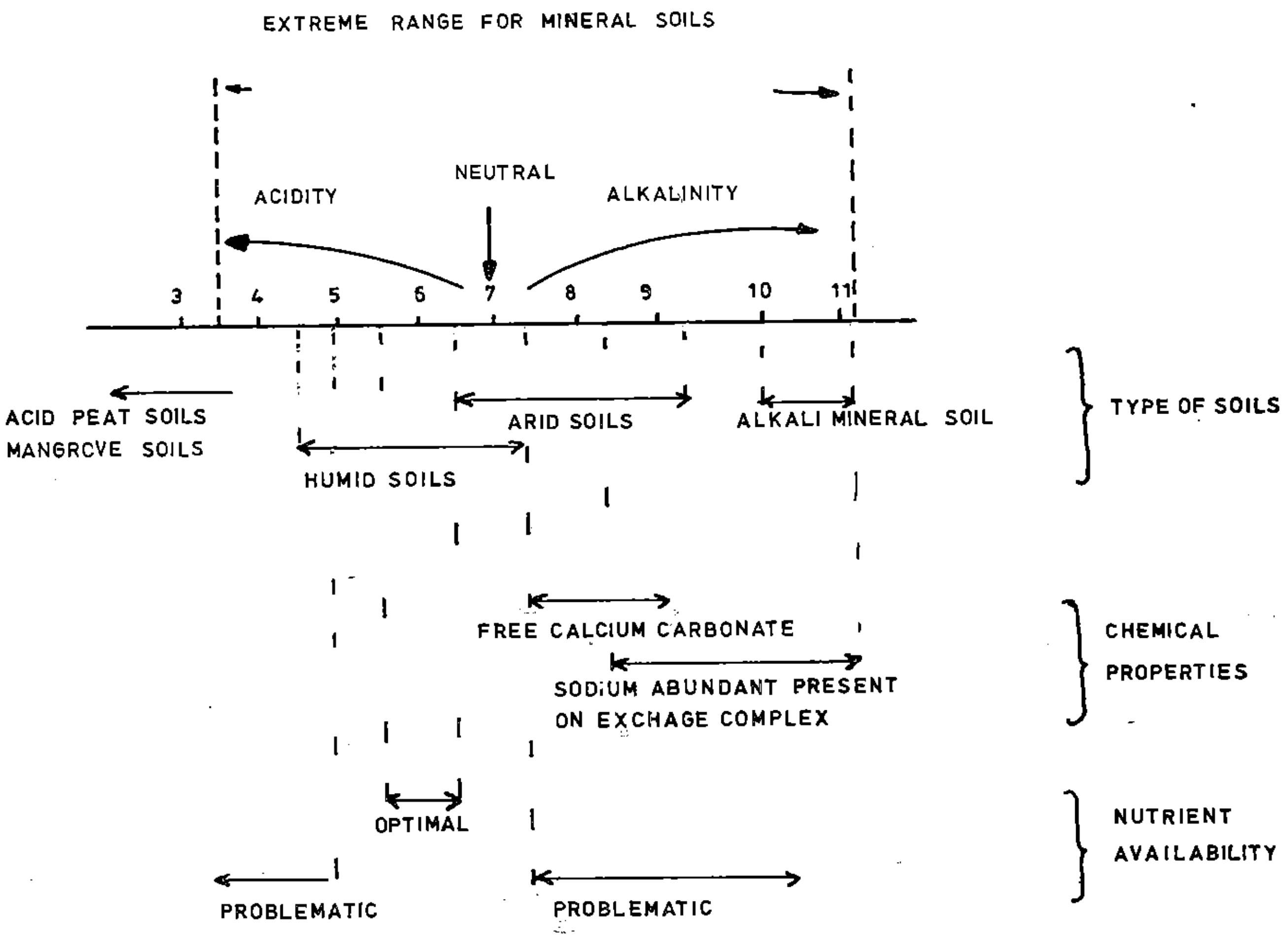


Fig. 1: Ranges of pH

The pH in the field is measured in a diluted suspension on the basis of 2.5 volume of water to 1 volume of soil. Therefore, a small plastic or glass container is filled with distilled water. The water level is marked and thereafter soil is added crumbwise unto the level is raised with 1/2.5 = $^2/5$ of the original marked water level. The field pH measurement is done with a portable pH-meter after callibration with buffer solutions (more accurate) or with pH-paper (rough indication).

3.3 EXCHANGEABLE SODIUM PERCENTAGE (ESP)

Soils having pH values higher than 8.5 nearly always contain significant amounts of exchangeable sodium. This high content of exchangeable sodium is also reflected in high ESP values. This Exchangeble Sodium Percentage, or the degree of saturation of the soil exchange complex with sodium, is defined as follows:

$$ESP = \frac{\text{exchangeable sodium (me/100g soil)}}{\text{cation exchange capacity (CEC) (me/100g soil)}} \times 100$$

Sodium ions have the tendency to envelop themselves with water molecules more than any other ion present in the soil solution. This is mainly due to their small diameter and therefore highly effective positive charge.

The sodium ions which are adsorbed on the surfaces of the clay particles will, upon wetting of the soil, form a water mantle around themselves. This will increase the distance between the clay particles and reduce the stability of the soil structure in soils with a high ESP (see Figure 2). Under moist conditions, these soils will disperse. This will have negative effects on aeration, infiltration, permeability, etc.

TABLE 2: CLASSIFICATION OF ESP VALUES

ESP	
0 - 6	non-sodic
6 - 10	slightly sodic
10 - 15	moderately sodic
above 15	strongly sodic

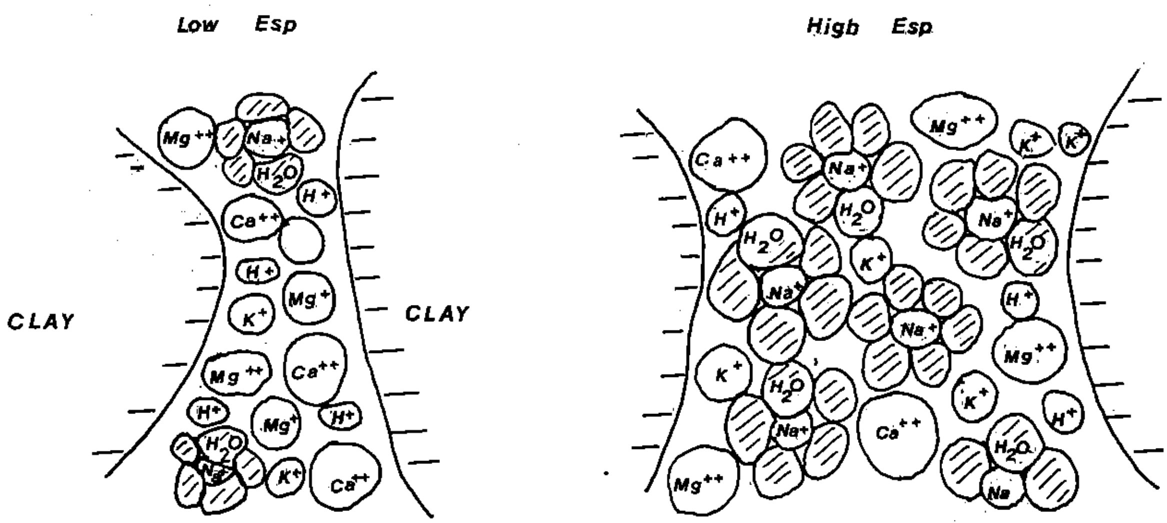


Fig. 2: Presence of sodium increases the distance between clay particles upon setting

3.4 ELECTRICAL CONDUCTIVITY OF THE SOIL SOLUTION

The electrical conductivity is the reciprocal of the electrical resistance and is expressed in mhos/cm. Recently the unit Siemens is being introduced (1 mS/cm = 1 millimho/cm). The salt content of the soil can be estimated roughly from an electrical conductivity measurement of a suspension of soil in distilled water (EC). Since the salt content of a soil-water suspension (even of a saline soil) is generally low, the conductivity may be expressed in millimhos/cm (mmhos/cm).

1 mho = 10^3 mmho = 10^6 micromho

In field analysis, a diluted suspension on the basis of 2.5 volumes of water to 1 volume of soil is used ($EC_{2.5}$). Assuming a specific gravity of soil of 2.5 m/cm^3 this results in a 1:1 weight/weight ratio. The classification of $EC_{2.5}$ values is given in Table 3.

TABLE 3: CLASSIFICATION OF FIELD MEASUREMENTS OF ELECTRICAL CONDUCTIVITY ($EC_{2.5}$ = mmhos/cm)

0 - 1.3	non-saline
1.3 - 2.7	slightly saline
2.7 - 5.3	moderately saline
over 5.3	strongly saline

In laboratory analysis, a saturated soil paste (ECe = Electrical Conductivity of Extract) is used, which resembles somewhat more the natural soil conditions. For chloride salts, the results will only be slightly affected by moisture content but for sulphates and carbonates, which have a low solubility, the amount of salt dissolved will depend on the soil:water ratio. The ECe values are roughly 3 times the $EC_{2.5}$ values.

For laboratory (ECe) results, the following classifications may be used:

TABLE 4: CLASSIFICATION OF ELECTRICAL CONDUCTIVITY (LABORATORY DATA) (ECe (mmhos/cm))

0 - 4	non-saline
4 - 8	slightly saline
8 - 15	moderately saline
over 15	strongly saline

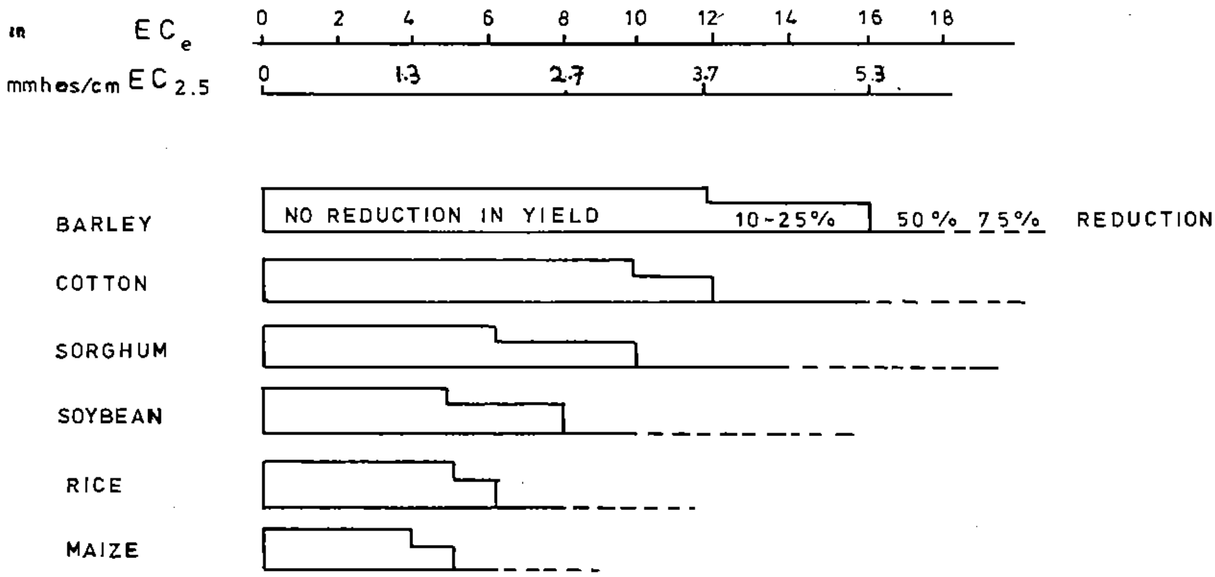


Fig. 3: Level of field reduction for various crops

3.5 INTERPRETATION OF SOIL pH WITH ECe

If we combine the various pH values and ECe data, the following picture can be drawn:

1) ECe less than 4mmhos/cm and pH 8.5 - 10: If ESP values are determined, they will be most likely greater than 15. This is a non-saline, sodic soil. These soils are unsuitable for irrigation development.

2) ECe greater than 4mmhos/cm and pH around 8.5: The ESP will exceed 15. This is saline, sodic soil unsuitable for irrigation, unless leaching also reduces the ESP to under 15.

3) ECe over 4mmhos/cm and pH less than 8.5: This is a saline soil. These soils may be reclaimed by leaching provided sufficient sub-surface drainage is present or provided for.

The influence on crop growth and yield of the sodicity and salinity soil data is summarized in Table 5 and Figure 3.

TABLE 5: THE INFLUENCE OF ECe, ESP AND pH ON CROP GROWTH AND YIELD

Influence on crop growth and yield	ECe mmhos/cm	ESP %	pH	Remarks
No injury	0-4	<6	<8.5	Suitable soil
Maize, rice, soya slightly affected	4-8	6-15	8.5	Moderately suitable soil
Moderately affected - no crops doing very well, only cotton & barley may still be grown	8-15	15-30	8.5-9.0	Suitability very limited
All crops strongly affected - only few species can survive	15-30	30-50	9.0-9.5	Very poor drainage Unsuitable soil

The data in Table 5 refer to measurements in laboratory conditions. In the field a rougher measurement is obtained. Therefore, the limits to be observed by using field data are lower. In the absence of a pH-meter, pH-paper may be used, for which still a lower limit has to be applied due to its slightly lower accuracy. If these limits are passed, a laboratory analysis combined with a soil expert's advice in the field (varying from a site investigation to a soil survey) is required. At very high levels the site may be assumed unsuitable for irrigation.

Field observations:

Suitable for irrigation	pH-paper	< 7.5
	pH-meter	< 8.0

May be suitable, but soil samples have to be analysed in laboratory (NAL) and soil expert advice (KSS) is needed:

pH-paper	> 7.5 but < 8.5
pH-meter	> 8.0 but < 8.5

Unsuitable for irrigation	pH-paper	> 8.5
	pH-meter	> 8.5

3.6 QUALITY OF IRRIGATION WATER

a) Electrical conductivity: The critical levels of EC in irrigation water are much lower than in soils; they are therefore expressed in micromhos/cm (1 micromho/cm = 1000 mmhos/cm). The EC level indicates the content of salts. The significance given to the conductivity groupings by the US Salinity Laboratory is shown in Table 6. These ratings may be considered rather severe by world standards. In Kenya, most surface waters have EC values of 250 micromhos/cm or lower. But in Tunisia and Algeria, water with values up to 2,000 micromhos/cm is used on well-drained and highly permeable soils (K above 10 m/day).

TABLE 6: QUALITY OF IRRIGATION WATER

EC irrigation water in micromhos/cm	Salt concentration in meq/l	Salinity hazard
100 - 150	0.10 - 0.25	Low
250 - 750	0.25 - 0.75	Medium
750 - 2,250	0.75 - 2.25	High
above 2,250	above 2.25	Very high

b) Sodium adsorption ratio (SAR): It provides a useful indication of the sodium hazard involved in the use of a particular irrigation water, since in the soil solution this ratio of cations has a simple relationship to the adsorption of sodium by the soil. The ratio is defined as follows:

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

where Na^{+}, Ca^{++} and Mg^{++} represent concentration in me/litre of the respective ions.

Hence the future exchangeable sodium value (ESP) is predicted by the SAR of the irrigation water. It may take some time (years) but in the end the ESP value will be reached.

TABLE 7: CLASSIFICATION OF SODIUM ADSORPTION RATIO (SAR) VALUES IN IRRIGATION WATER

Sodicity hazard	SAR
Low	0 - 10
Medium	10 - 18
High	18 - 26
Very high	over 26

A more elaborate classification is given in Table 8.

The interpretation of combined sodium hazard and salinity of irrigation water assigned by the US Salinity Laboratory is given in Figure 4.

c) Other hazards of irrigation water: Apart from toxic substances which can harm plant growth directly (Boron, Lithium, Chloride and Sulphate ions) the presence of carbonate and bicarbonate ions, although not toxic in themselves, can increase the sodium hazard of irrigation water since they bring about the precipitation of calcium and, to a lesser degree, magnesium in the soil, hence increasing the relative amount of sodium in the soil solution and therefore the ESP value. This risk is assessed by the residual sodium carbonate (RSC) expressed as follows (all ionic concentrations in me/litre):

$$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} \times Mg^{++})$$

The rating of the RSC is as follows:

RSC	Water suitability
Less than 1.25 me/l	Safe
1.25 - 2.5 me/l	Marginal
over 2.5 me/l	Unsuitable

3.7 INTERPRETATION OF COMBINED SOIL AND WATER SUITABILITY

Neither unsuitable soil nor unsuitable water will give problems in interpretation. The occurence of either one of them makes the site unsuitable for irrigation.

However, a suitable soil according to pH and EC data may still be unsuitable due to:

-- low or extremely low sub-surface drainage: The irrigation water may be of good quality. In the absence of leaching, salts will accumulate in the soil. See leaching requirements, Chapter 5.

However, a moderately suitable soil according to pH and EC data may still be unsuitable due to:

-- moderately suitable irrigation water: A combination of a moderate suitability in both soil and water often makes the site unsuitable for irrigation due to the combined effects.

TABLE 8: US SALINITY LABORATORY, 1954 CLASSIFICATION OF IRRIGATION WATERS IN TERMS OF SODIUM HAZARD (Richards et al. 1954)

Classification of water	Sodium hazard
Low sodium water (S1)	Can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.
Medium sodium water (S2)	Presents an appreciable sodium hazard in fine-textured soils having high cation exchange capacity, especially under low leaching conditons, unless gypsum is present in the soil. This water may be used in coarse-textured or organic soils with good permeability.
High sodium water (S3)	May produce harmful levels of exchangeable sodium in most soils and will require special soil management - good drainage, high leaching and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium except that amendments may not be feasible with waters of very high salinity.
Very high sodium water (S4)	Generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.
	Sometimes the irrigation water dissolves sufficient calcium from calcareous soils to decrease the sodium hazard appreciably, and this should be taken into account in the use of C1-S3 and C1-S4 waters. For calcareous soils with high pH values or for non-calcareous soils, the sodium status of waters in classes C1-S3, C1-S4 and C2-S4 may be improved by the addition of gypsum to the water. Similarly, it may be beneficial to add gypsum to the soil periodically when C2-S3 and C3-S2 waters are used.

Note: In the 1954 classification of the US Salinity Laboratory, the four classes of sodium hazard are separated by curves relating sodium adsorption ratio and electrical conductivity as shown in Figure 4.

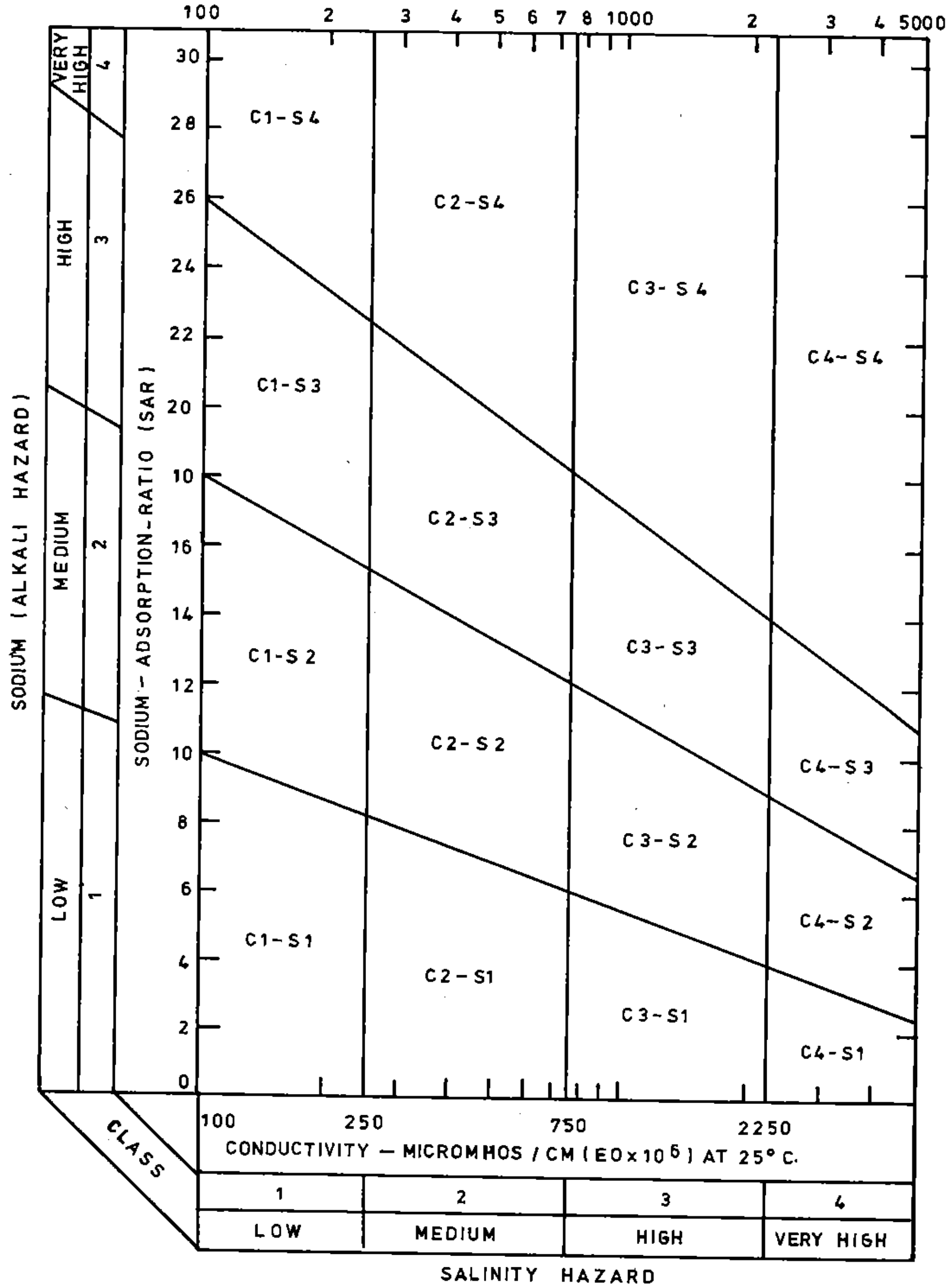


Fig. 4: US SALINITY LABORATORY CLASSIFICATION OF IRRIGATION WATER

4. MEASUREMENT OF HYDRAULIC CONDUCTIVITY

4.1 PRINCIPLE

Water moves through the soil due to the presence of a hydraulic gradient which is the driving force. According to Darcy's Law, the flow of water in the soil may be expressed as:

$$Q = K A \frac{H}{L}$$

where Q = discharge per unit time, for example cm^3/hr

K = hydraulic conductivity (cm/hr)

A = cross-section of flow area (cm^2)

$\frac{H}{L}$ = hydraulic gradient difference between hydraulic head at the inflow and outflow boundaries (dimensionless)

L = length of soil column (cm)

The hydraulic conductivity of soil is used for studies of water movement in the soil for various drainage purposes.

4.2 FIELD MEASUREMENT OF HYDRAULIC CONDUCTIVITY

Inversed auger hole method (in the absence of ground water)

The inverted auger hole method, which is also known as Pour-in method (USA) and Porchet method (France), has recently been adapted at NAL for field measurement of hydraulic conductivity. The method consists of augering a hole to a given depth, filling it with water and measuring the rate of fall of the water level.

Materials:

Measuring tape with float
Watch with second indicator (or stop watch)
8 cm auger (R = 4 cm) (Riverside or Edelman)
Bucket with water (or jerrycan)
Standard for reading level and tape house holder or iron with slot on surface

Procedure:

Make an 8 cm auger hole to the desired depth. Fix the measuring tape on the float. If a standard is used, measure its reading level above the surface (see Figure 5).

Pour water into the auger hole upto the relevant soil layer(s). Start looking at the watch or stop watch, and measure the fall of the water level at convenient time intervals. Lift the float slightly once in a while to check that it is not stuck. The tape should be stretched far enough outside its holder, to allow free downward movement of the float, without requiring the tape to move out of its holder during the measurement.

Readings:

The depth of the hole (and the reading level of the standard if used) gives the value for D.

The readings on the tape give values for Ht. To obtain the ht values, the Ht values are subtracted from the D value.

The time lapse of each interval may differ. The time intervals should be small at the start of the readings, varying from 10 - 150 seconds depending on the hydraulic conductivity. The intervals should be larger at the end, varying from 65 - 400 seconds. Preferably 6 - 8 intervals are required to obtain a value for K.

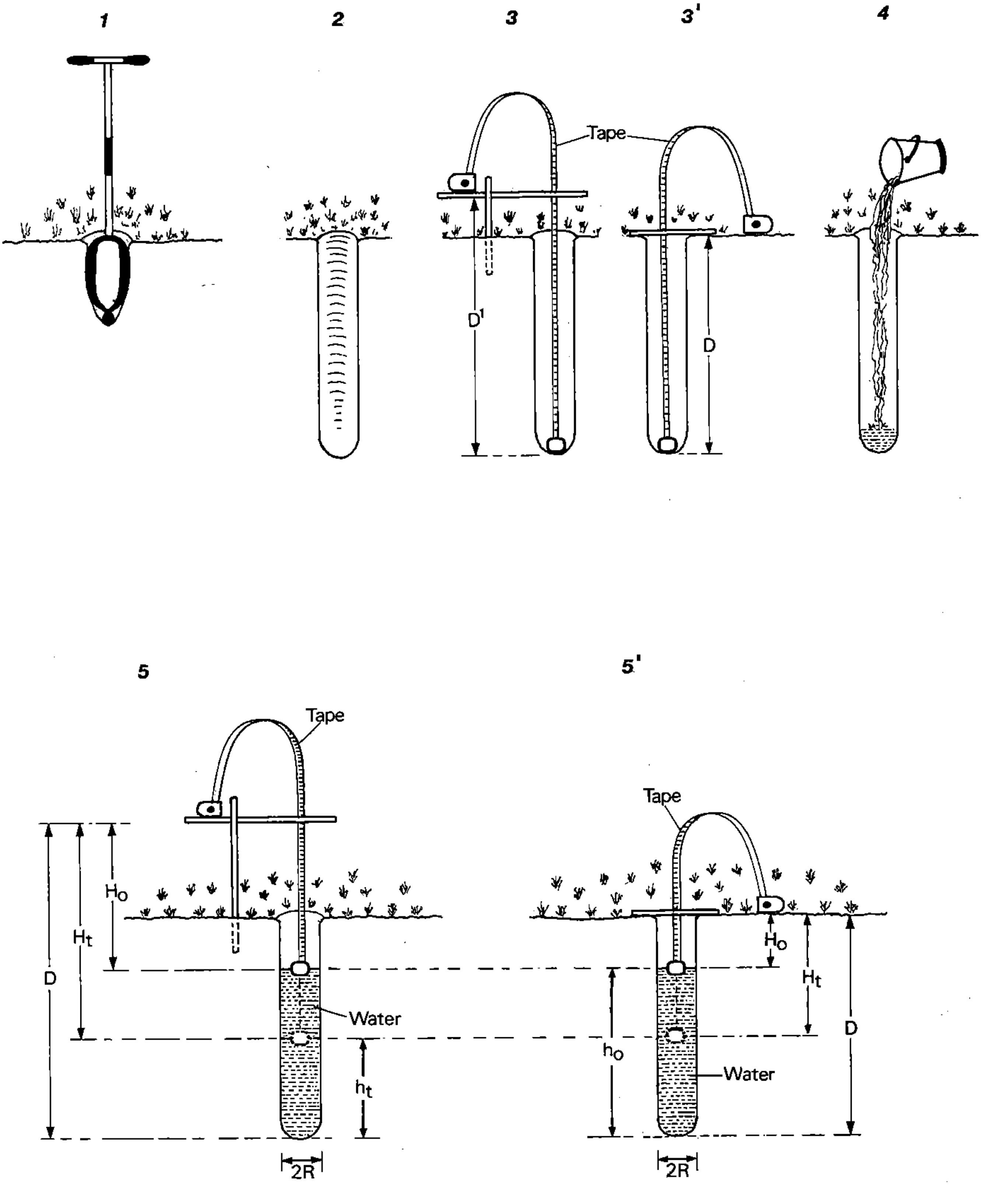


Fig. 5: The set up for the inverted auger hole method

CALCULATION

The permeability K may be expressed by the following equation:

$$K = 1.13R \quad \log (ht + R/2) - \log (ht + R/2) = 1.15R \tan \alpha$$

The values of (ht + R/2) in cm are plotted on a log scale against time in seconds on an ordinary scale. Half logarithmic graph paper is used. By making a copy of the given original or using transparent paper, it can be used again. (Figure 7).

Through the points on the graph a straight line is drawn. The points on the curved part of the line are not to be used for calculations as they represent the outflow from the hole while the soil is not yet saturated and are therefore not determined by its K value. Without calculating the log values, K can be found through tan α. Tan α is the length along the Y - axis in cm, divided by the length along the X - axis in sec.

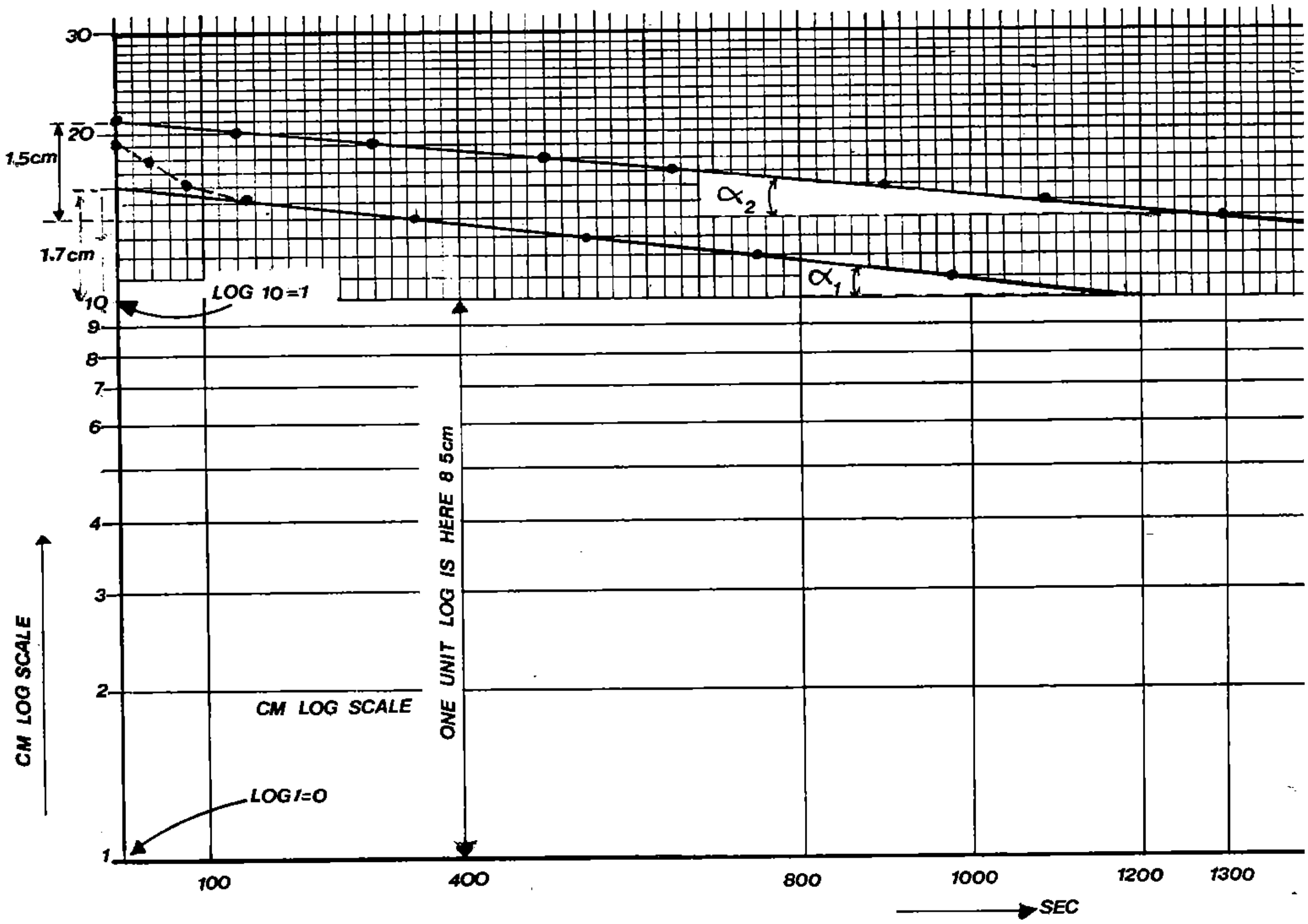


Fig. 6: The graphic solution for the value of tan α

The length along the Y - axis has to be corrected for the log sequence. The difference between 10 and 1 is in log scale (log 10 = 1) - (log 1 = 0) = 1. The distance on paper may be 10 or 8.5cm, depending on the type of paper used. Hence the measured length along the X - axis is divided by 10 or 8.5, whichever is relevant.

In the example given, the straight part of the curve is extended downwards until it reaches the (ht + R/2) level of 10, upwards until it crosses the Y - axis for α_1. For calculation of tan α. the whole line is considered straight. The line in between the Y - axis and the 13 line on the log is used. The latest measurement after 1520 sec is skipped to prevent contracting the sec scale too much.

R = 4cm
D' = 90cm

	t sec	Ht cm	ht cm	ht + R/2 cm	t sec	Ht cm	ht cm	ht + R/2 cm
1	0	73	17	19	0	71	19	21
2	40	74	16	18	140	72	18	20
3	80	75	15	17	300	73	17	19
4	150	76	14	16	500	74	16	18
5	250	77	13	15	650	75	15	17
6	350	78	12	14	900	76	14	16
7	550	79	11	13	1090	77	13	15
8	750	80	10	12	1300	78	12	14
9	975	81	9	11	1520	79	11	13

$$\tan\alpha = \frac{\quad}{8.5} \times \frac{1}{\quad}$$

(8.5cm is length of one log unit in cm on used one-sided log graph paper)

$$\tan\alpha_1 = \frac{1.7}{8.5} \times \frac{1}{1200}\ \text{sec}$$

= 0.000165 sec

= 0.000759 x 869 m/day

= 0.666 m/day

$$\tan\alpha_2 = \frac{1.5}{8.5} \times \frac{1}{1200}$$

= 0.000136 sec

= 0.000626 x 869 m/day

= 0.054 m/day

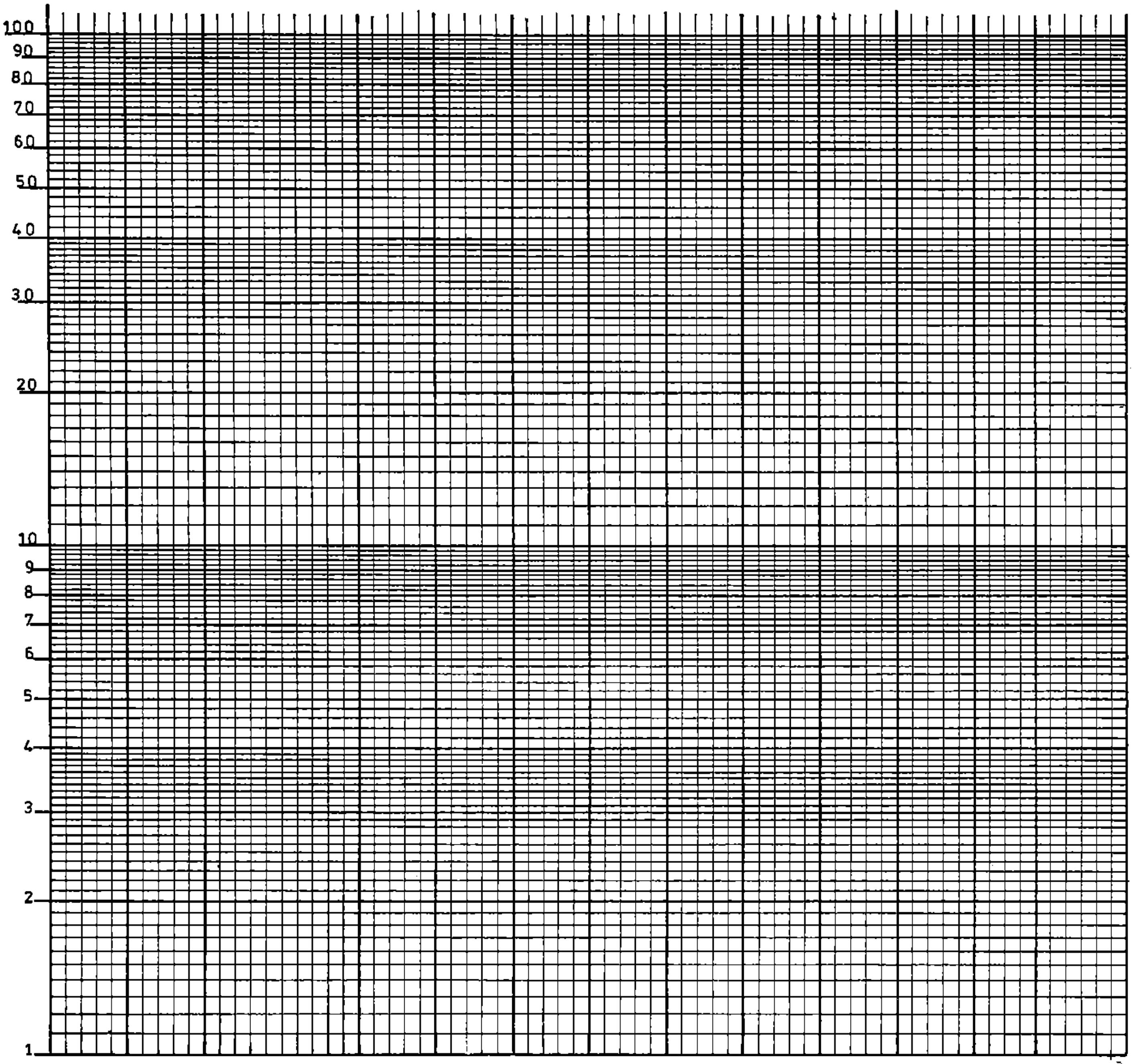


Fig. 7: The one-side log scale graph paper, to be used for making photocopies

4.4 APPLICATION

The K value is used in the calculation of drain spacings. For details reference is made to Chapter 5.5.

In using drains, excess water from the soil is drained by lateral ground water flow. As the root zone has to be aerated, ground water flow may only occur below the root zone. Hence for drain spacing calculations only the K values of the soil in between the lower bondary of the root zone and the impervious layer are used.

Most soils are not uniform. Hence K values may differ in subsequent layers or horizons. Analysing the soil while augering the hole indicates roughly the presence of different layers. In a soil pit a better view is obtained. The different layers can be measured separately. The hole is augered to 20 cm above the lower depth of that layer and filled with water not above its upper level.

A weighted average value is used, to calculate the permeability, if different layers are present. The weighting is done on the basis of the relative depth of the layer. For example:

K average =

K(layer 75-125cm) x 50/75 + K(layer 125-150cm) x 25/75

For more details, see Chapter 6.

5. LEACHING

5.1 SALT BALANCE

Salt accumulation in the soil should be prevented as saline soils are not or less suitable for agriculture (see Chapter 3). Therefore the amount of salt added by irrigation and ground water (input) should be removed by the drainage water (output).

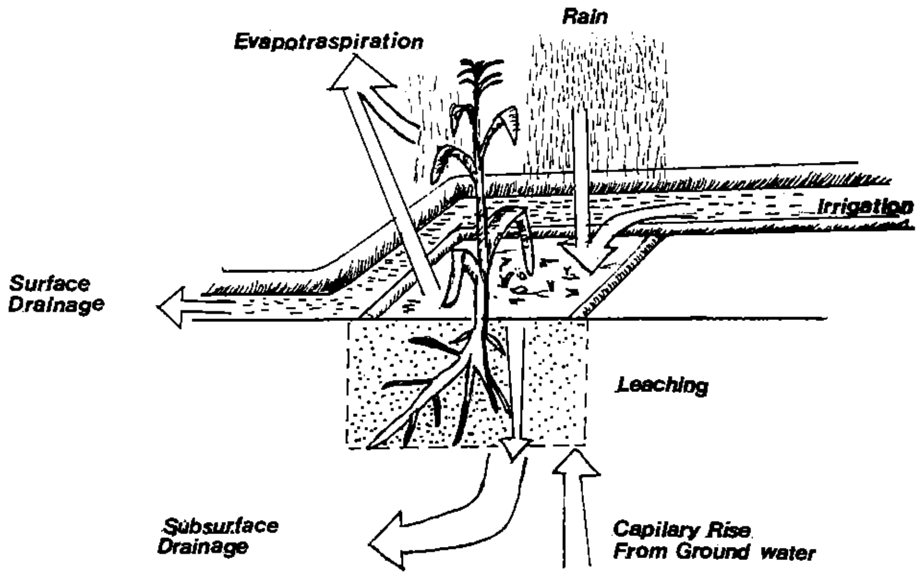


Fig. 8: The water balance

Drainage of salt from irrigation water

Every irrigation adds salt to the soil. Even water classified as having a low salinity hazard (100-250 micromho/cm) adds salts. For example, water with 200 micromho/cm contains salt in a concentration of 2 meq/1 (which equals 125 ppm = 0.0125 = .125 gr salt/1).

Assume irrigation adds 800 mm of water in one year (two crops a year with a 90 days growing period at 4.5 mm/day crop water requirement). An area of 10 x 10cm receives a column of water with a volume of 80cm high (800 mm). This volume is equal to 8000 cm^3 or 8 litres. The total amount of salt added to the soil below this area is therefore 8 X 2 meq = 16 meq or 1 gram.

The salt is added to the soil profile. Assume the added salt is concentrated in the upper 40 cm and evenly spread. The soil column below the top 100 cm^2 receives for every 10 cm depth in the top 40 cm, 16/4 = 4 meq.

In other words, a volume of 1 litre soil (base 100 cm^2, height 10 cm) receives 4 meq. In a soil/water mixture of 1:1, the concentration will then increase by 4 meq, as all values are related to meq per litre of water.

> In reality, the saturation extract is not a 1:1 mixture of soil and water, as the water is added to a grained soil while stirred to a paste. The moisture content may vary from 60-120 volume %. For our purpose, however, we may simplify this to 100% moisture content by volume.

The value of electrical conductivity for the saturation extract increases with 0.4 millimho/cm ($\approx$ 4 meq/l). This increase is due to one year of irrigation if removal of salts is absent. Each successive year will add the same amount.

Assume a non-saline soil (ECe 0.4 millimho/cm) with an ECe value of 2 millimho/cm before irrigation starts. After 5 years, 5 x 4 = 20 meq is added to a litre of soil, resulting in an increase of 2 millimho/cm. Together with the original salt concentration of 2 meq/l, a level of 4 meq/l is obtained, resulting in a slightly saline soil with an ECe value of 4 millimho/cm.

After 16 years of irrigation the soil becomes moderately saline with an ECe value of 2 + 16 x .4 = 2 + 6.4 = 8.4 millimho/cm, which is unsuitable for most crops.

Addition of salt from ground water

Ground water presence within 75-100 cm depth reduces crop growth and should be prevented. At these levels a maximum capacity of capillary rise is in the range of 0.5 - 1.0 mm/day. This value is 5-10 times smaller than the average crop water requirement of 4.5 mm/day.

Assuming non-saline ground water with 200 meq/l (EC = 200 millimho/cm), the increase in salt accumulation will take 5-10 times longer than with irrigation water of the same (low) salinity.

With higher salinity levels the contribution ground water makes to add salt to the root zone may be substantial. Saline sub-soils may therefore be dangerous if a high ground water table (within 75-100 cm) due to irrigation is established.

Addition of salts by rainfall

Rain water contains almost no salt, and addition of salts is negligible.

Rainfall occurring during the cropping season covers part of the crop water requirement. Hence the amount of irrigation applied (and therefore the salts) may be reduced.

5.2 LEACHING REQUIREMENTS

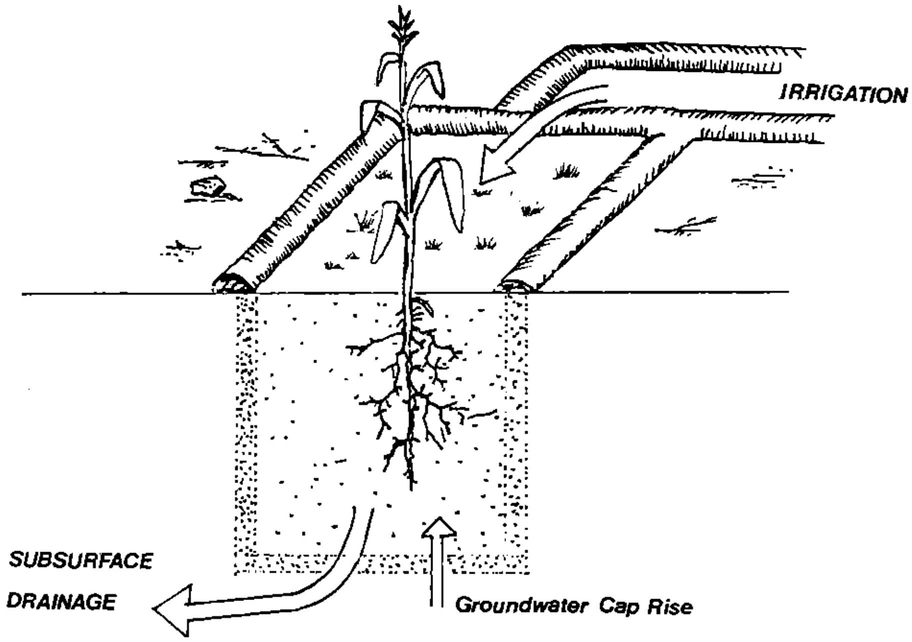


Fig. 9: The Salt Balance

To demonstrate the calculation of leaching requirements, a simple example is given. The input consists only of irrigation water (no contribution of ground water and no rainfall). There is equilibrium if the amount of salt added (volume of irrigation water applied x concentration) equals the amount of salt removed (volume of percolating drainage water x concentration).

$$Irr \times conc_{irr} = P \times conc_{per}$$

The volume of irrigation water equals the sum of the volumes of evapotranspiration (ET) and percolation (P).

$$Irr = ET + P$$

The salt balance equation re-written gives:

$$(ET + P) \times conc_{irr} = P \times conc_{per}$$

$$P = \frac{ET \times conc_{irr}}{conc_{per} - conc_{irr}}$$

The concentration in the percolation water is not equal to the average concentration of the soil moisture ($conc_{sm}$). This effect is called percolation efficiency. While percolating, the water passes through the larger pores mainly and does not contact, and therefor take up salt, from the smaller pores and between soil particles. Percolation efficiency measured in different soils amounts to about 50%.

$$Conc_{per} = 0.5\ conc_{sm}$$

The concentration of the soil moisture during percolation is that of a saturated soil, with for most soils about 50% of volume percent of water. The concentration of soil moisture in a saturated soil is about twice that in saturated soil extract (concEX)

$$conc_{sm} = 2\ conc_{ex}$$

Therefore: $$con_{per} = 0.5 \times 2 \times conc_{ex} = conc_{ex}$$

The percolation/leaching requirement is therefore:

$$P = \frac{ET \times conc_{irr}}{conc_{ex} - conc_{irr}}$$

In this equation the leaching requirement is given as a part of the crop water requirement. In Table 9, data are given for combinations of salinity levels occurring in irrigation water and acceptable salinity levels in the soil. These data refer to conditions where rainfall is absent, and no salt addition to the root zone is obtained from ground water.

TABLE 9: LEACHING REQUIREMENTS (Lr as a % of crop water requirement (CWR) to sustain different soil salinity levels in the absence of rainfall)

	Soil salinity levels (millmho/cm)			
Irrigation water quality	2	4	6	8
	LR as % of CWR			
Salinity hazard:				
High 1000 micromho/cm	100	33	20	14
Medium 500 micromho/cm	33	14	9	7
Low 200 micromho/cm	11	5	3	2

Leaching does not always require additional water application

A leaching requirement does not always require additional water application. In the field, water losses amount to 40-60% of the applied irrigation water. Over half of these losses occur due to excess water application, resulting in downward movement of water below the root zone. Leaching requirements up to 20% are in general already provided for.

TABLE 10: LEACHING REQUIREMENTS IN RELATION TO IRRIGATION WATER QUALITY

Quality of irrigation water	Leaching requirement above (percolation) irrigation losses
1000 micromho/cm	Substantial
500 micromho/cm	Low
200 micromho/cm	Absent

Local accumulation of salts

In the preceding pages, accumulated salt is assumed to be uniformly distributed over the irrigated area. This may be true for some methods of water application, but not for all (see Figure 10)

Water may be applied to:

a) the whole surface area, e.g. flat basins and sprinkler irrigation;

b) to only part of the surface area, e.g. ridged basins, level furrows, sloping furrows.

Water applied to the whole surface infiltrates and dissolves the salt accumulated in the top soil since the last irrigation and transports salts downwards. The salts are spread out over the root zone and tend to accumulate in the lower part of the soil.

With furrows and ridges, salt accumulates on the top of the ridges. With subsequent irrigation, these salts are not affected by the downward movement of the water. A continuous accumulation of salts will therefore occur on top of the ridges. In the furrow and on the lower sides of the ridges, accumulated salts from the last irrigation will be moved downward during irrigation.

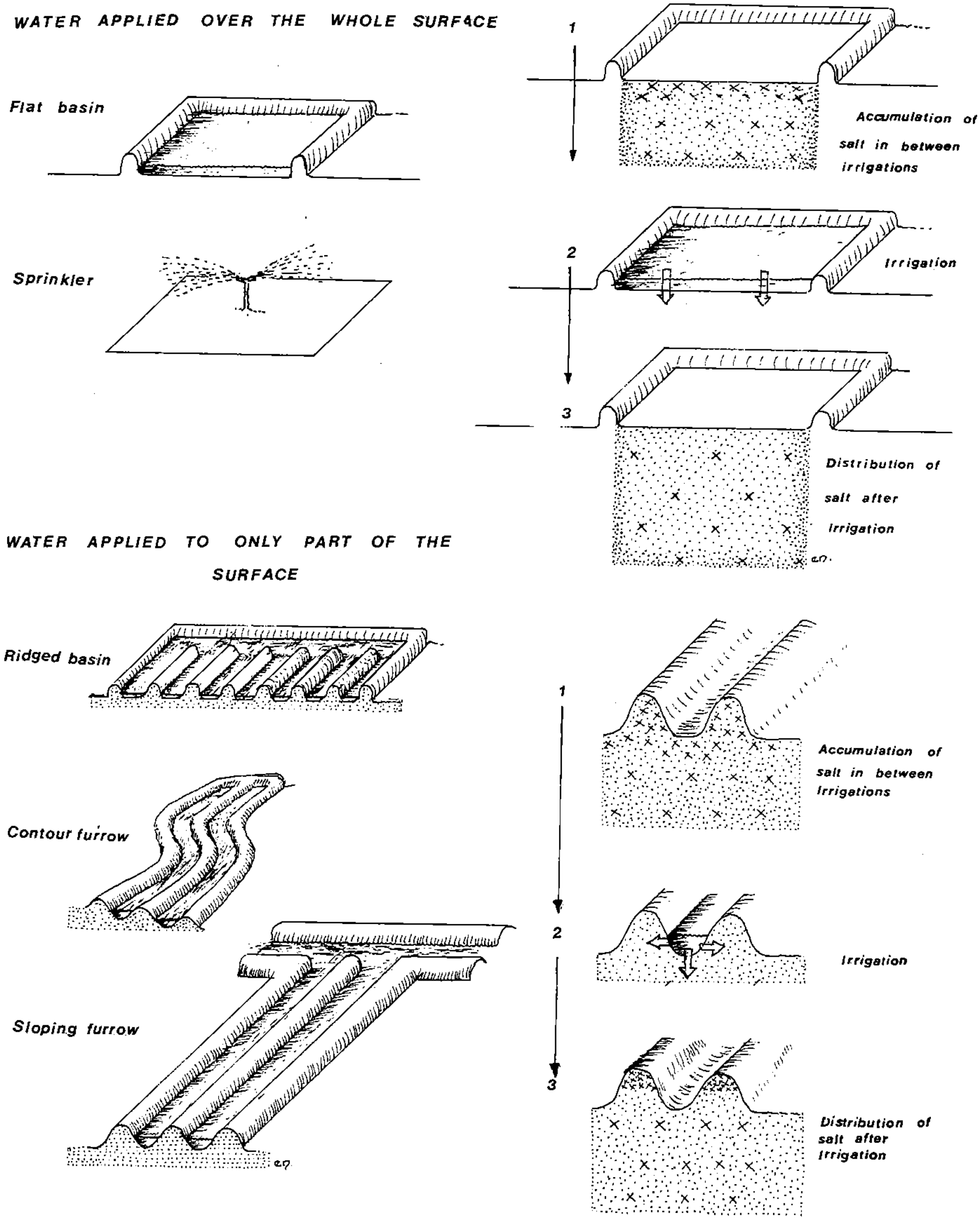


Fig. 10: Local accumulation of salt

In the absence of rain, salt as a crust or white spots may easily be observed on the tops of ridges. Planting on top of ridges with accumulated salts may result in poor yields. Most crops are sensitive to salt in the seedling stage, when all the roots are still concentrated on top of the ridges. Salt damage is prevented by planting on the side slopes. In very saline soils, crops are planted at the bottom of the furrow to provide low salinity levels in the seedling stage.

Leaching by surface run-off

In some very heavy clay soils water permeability may be very low (some mm/day). Percolation will then be absent. Removal of salts may occur by surface run-off of flood water as in low land rice production. The continuous layer of water on top of the surface prevents an accumulation of salts. Salts left in the soil after water uptake by the plants are constantly diluted by fresh water. Surface run-off due to rainfall or drainage of the surface for fertilizer application or pre-harvest drainage allows removal of these salts.

Timing of leaching

Periodic reclamation by leaching requires less water than proportional leaching with every irrigation. Post-harvest leaching removes the salts when most nutrients (nitrogen) have been removed from the soil by the plants. Lowering of the salt level and moistening may provide additional mineralized nitrogen for the next crop. Pre-sowing leaching removes available nitrogen.

Leaching when water is anyhow abundant outside the cropping season, for example at high river flows, reduces the requirements during cropping. The irrigated area could then be increased.

5.3 RECLAMATION OF SALINE SOILS

Reclamation of saline soils by leaching is difficult. It is only possible under certain conditions:

a) absence of sodicity either in the soil or in the irrigation water;

b) sub-surface drainage (vertical and lateral) needs to be sufficient to allow for sufficient percolation;

c) sufficient funds are available.

The effect of reclamation by successive leachings on a saline soil can be calculated by the following equation:

$$P = \frac{M}{f} . \ln \frac{fC_{smo} - C_i}{fC_{sm} - C_i}$$

in which:

P	=	Percolated amount of water (mm)
M	=	Amount of soil moisture (mm)
C_{smo}	=	Salt concentration before leaching (millimhos/cm)
C_{sm}	=	Salt concentration after leaching (millimhos/cm)
C_i	=	Concentration irrigation water
f	=	Leaching efficiency

With $f = 0.5$ and $C_{sm} = 2\ C_{ex}$, the equation may be written as:

$$P = 2M . \ln \frac{C_{exo} - C_i}{C_{ex} - C_i}$$

with C_{exo} and C_{ex} the concentration of the saturation extract before and after leaching.

If M = 150 mm (100 cm soil depth, storage capacity 15 mm/10 cm), C_{exo} = 16 mmho/cm, C_{ex} = 4 mmho/cm and C. = 500 micromho/cm, then the required amount of percolation water =

$$P = 2 \times 150 \times \ln \frac{16 - 0.25}{4 - 0.25} = 861\text{mm}$$

To reduce the salt concentration from 16 mmhos/cm to 8 mmhos/cm, only 426 mm of leaching is needed. If one would like to reduce the salt concentration to 2 mmhos/cm, an amount of nearly 1317 mm is required.

If irrigation water has a low to medium salinity hazard ($<$500 micromho/cm) the contribution of its salts may be neglected. The equation then can be approximated by:

$$P = 2M \ \ln \frac{C_{exo}}{C_{ex}}$$

which means that to reduce the salt concentration in the soil by half.

$$\ln \frac{C_{exo}}{C_{ex}} = \ln 2 = 0.7$$

the amount of leaching water is:

$$P = 2M \ 0.7 = 1.4M$$

Hence the amount of water required is 1.4 times the amount stored in the soil over which depth the salt concentration is to be halved.

6 SUB-SURFACE DRAINAGE

Sub-surface drainage will be needed to remove water which percolated through the root zone. This water can be excess irrigation, seepage from canals and rainfall. If the internal natural drainage capacity is not large enough, a sub-surface drainage system has to be constructed.

Natural internal drainage

Almost all soils have some natural internal drainage capacity. Natural drainage may be either deep vertical, lateral, or a combination of both.

Deep vertical drainage requires a deep permeable soil or rock. In most arid and semi-arid areas in Kenya, these soils are not common. They do occur in high potential and intermediate zones (volcanic soils, deep red soils). For irrigation purposes in most other soils the natural drainage will be lateral. It is difficult to assess whether the natural drainage will be sufficient for irrigation purposes by looking at the presence of a ground water table only. Rainfall in potential irrigation areas is low (300-600 mm/year) and largely lost by evapotranspiration and surface run-off. The contribution of rainfall to internal drainage amounts to 0.01 - 0.1 mm/day on average over a year, and is very low compared to the contribution of irrigation with 2 - 3 mm/day.

Depth of impermeable layers and permeability of the soil will give indications if additional drainage by drains is required. Measurement of the hydraulic conductivity (see Chapter 4) is an important requirement.

Sub-surface drainage system

If it appears that the natural drainage of the soil is not sufficient, a system of open or closed drains will have to be constructed to control the ground water table. For the design the drain depth and spacing will be needed.

Surface drainage

Provision for surface drainage will always be needed in an irrigation system. Excess water to be drained may be surface run-off from rainfall and field irrigation or may be tail-water from irrigation canals. Often irrigation canals can be used for surface drainage. The main canals and feeders leave the scheme as ditches, draining water to natural water ways or depressions.

Surface run-off inflow into the main canal in a scheme may be allowed, but the canal should be designed to carry the excess flow. Side weirs may be necessary to drain excess water into natural water ways. (See Manual on Structures)

Surface run-off inflow into the scheme area itself may be prevented by constructing cut-off drains.

6.1 DESIGN CRITERIA

Before calculating the depth and spacings of drains, design criteria have to be established, being the maximum permissible height of the ground water midway between the drains, the design discharge and the minimum depth of the ground water below the soil surface. The criteria will be discussed hereafter.

Design drainage rate

It is assumed that in Kenya the average net irrigation gift is 4.5 mm/day. The overall efficiency is assumed at 50% and the field efficiency at 70%. This will give a diversion from the river of 9 mm/day of which 6.5 mm/day is delivered to the field.

The percolation losses are 30% of 6.5 mm, thus approximately 2 mm/day. Including seepage losses, the rate may be a bit higher but in general a drainage design rate between 2.0 and 3.0 mm/day will be acceptable.

In determining the design sub-surface drainage rate, distinction has to be made between leaching and percolation from over-irrigation and non-uniform irrigation. The higher of the two may be chosen, but as has been indicated before (in Chapter 5.2) the over-irrigation is in general more than sufficient to avoid salinization.

Other losses as tail-water losses, surface run-off and direct evaporation do not have to be added to the drainage design rate.

Depth of ground water

The removal of excess water infiltrated into the soil is required to establish a sufficient deep root zone for the crop. This is an agronomic criterion.

For vegetables and field-crops, a root zone depth of respectively 0.75 and 1.00 m midway between the drains is recommended, while for tree crops this should be at least 1.50 m, but if irrigation practices are very deficient, the ground water depth may be increased by some 0.20 m to allow for fluctuation due to excess over-irrigation.

If the ground water is permanent in the area and there is a fallow season, salinization due to capillary upward movement should be avoided and the water table should be lowered during that season to a depth of at least 1.50 m.

Height of ground water above the drains

The ground water table in between the drains will be above the water level in the drain. The head which is thus established is the hydraulic head, which ensures water movement towards the drain. It is recommended to use values around 0.50m for the hydraulic head.

NOTE: It has been assumed that the collected water in the drain can be discharged to natural waterways. However, in a plain or basin or enclosed valley bottom this may not be the case. In the absence of an outlet of drained water the ground water may eventually rise to the surface. Hence, not only the soil profile but also the topographical drainage conditions have to be considered.

6.2 DEPTH AND SPACING OF OPEN DRAINS IN HOMOGENEOUS SOILS

The drain depth will be equal to the depth of the ground water table under the soil surface (root zone) and the required hydraulic head. A value of 1.25 - 1.50 m is thus recommended. If open drains are constructed, water will be standing in the drain (10 - 15 cm). Therefore, these drains will have to be dug slightly deeper, say from 1.35 - 1.60 m, but an over-excavation of another 0.20 to 1.50 - 1.80 cm is recommended. A summary of the assumed values of the different parameters is given in Figure 11.

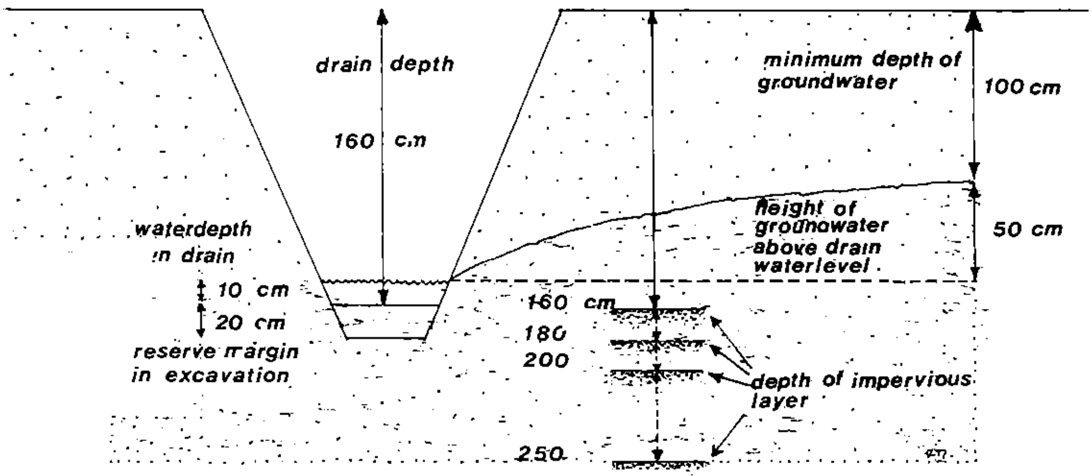


Fig. 11: Criteria used for the calculation of spacings open drains

Depth of an impervious layer between 1.60 - 3.50 m -- open drains

For a depth of an impermeable layer of between 1.60 and 3.50 m, examples have been worked out.

Drain spacings of open drains in homogeneous soil when an impermeable layer is at a shallow depth below the drain or at the level of the drain can simply be calculated because in general only the horizontal flow component need to be considered.

The equation which may be used is: $$L^2 = \frac{8KDh}{q}$$

in which (see Figure 12):

L = Drain spacing in metres

q = Drainage rate in metres/day (depth of water)

K = Hydraulic conductivity in metres/day

D = Do + 0.5h in metres

Do = Mean depth of the impermeable layer below the water level in the drain in metres

h = Height of the water table above the water level in the drain midway between drains

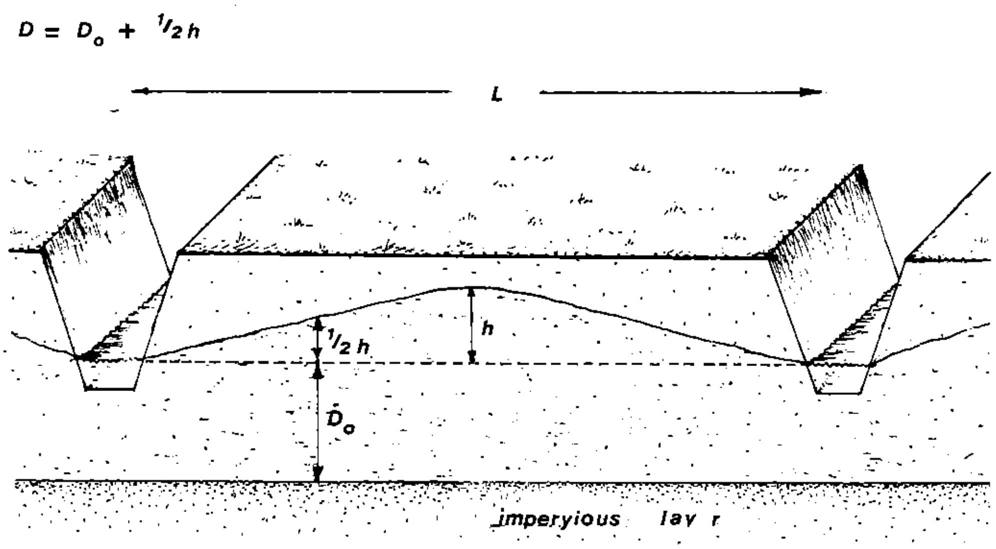


Fig. 12: The Parameters in the Horizontal flow equation

Drain spacings calculated with this equation for:

-- k values = from 0.1 - 5.0 m/day

-- q = 2.5 mm/day or 0.0025 m/day

-- Do = 0.1 - 2.0 m

-- h = 0.50 m

have been presented in Table 11.

In Table 11, the depth of the impermeable layer below the water level in the drain has been presented. In Table 12, the impermeable layer has been related to the soil surface, assuming that the water level in the drain is 1.0 m (field crops) + 0.50 m (hydraulic head) below the soil surface.

TABLE 11: REQUIRES DRAIN SPACINGS (IN METRES) FOR FIELD CROPS IN HOMOGENEOUS SOIL

Q = 2.5 mm/day)

Soil type	Permeability m/day	Depth of impermeable layer below water level in drain (cm)* 15	50	100	150	200
Clay	0.10	8	11	14	17	19
Clay loam	0.50	18	24	32	37	42
	0.25	13	17	22	26	30
Loam	1.00	25	35	45	53	60
	1.50	31	42	55	65	73
	2.00	36	49	63	75	85
Sandy loam	2.50	40	55	71	84	95
Sand	3.00	44	60	77	92	104
	5.00	57	77	100	118	134

* Ground water level between the drains is 50 cm above drain water level

TABLE 12: REQUIRED DRAIN SPACINGS (IN METRES) FOR FIELDCROPS IN HOMOGENEOUS SOILS (Q = 2.5 mm/day

Soil type	Permeability m/day	Depth impermeable layer below the surface (cm) drain depth = 160 cm* 160	180	200	250	300	350
Clay	0.10	-	-	11	14	17	19
Clay loam	0.50	17	21	24	32	37	42
	0.25	12	14	17	22	26	30
Loam	1.00	24	30	35	45	53	60
	1.50	29	36	42	55	65	73
	2.00	33	42	49	63	75	85
Sandy loam	2.50	37	47	55	71	84	95
Sand	3.00	41	51	60	77	92	104
	5.00	53	66	77	100	118	134

* Drain water level is 150 cm below the soil surface.

Shallow depth of impervious layer

In case an impermeable layer is located closer to the surface than 1.60 m, the criteria have to be changed. This may result in: (1) a decrease in the height of the ground water above the water level in the drains with consequently a reduction in drain spacing; or (2) a shallower ground water table; or (3) both.

Impervious layer deeper than 3.50 m

In case an impermeable layer is located more than 3.50 m below the soil surface, it is more than 2.0 m under the water level in the drain. It may then be necessary to correct the calculated drain spacing for radial resistance (see Figure 13). The equation would then be:

$$L = \frac{8KDh}{q} - D_0 \ln D_0/u$$

in which u = wetted perimeter of the drain in metres.

If the thickness of the layer between drain and impervious layer is more than 2.0 m but less than 3 m, the correction is only of importance if the permeability is very low (clay). In fact for a permeability of 0.1 m/day, a drain spacing of 20 m is recommended for any depth of impervious layer located more than 2.0 m under the level of the drain.

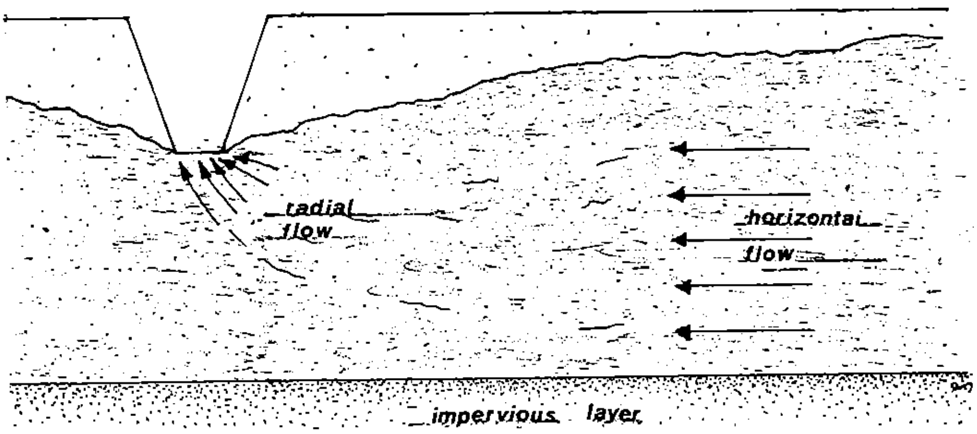


Fig. 13: Rasial resistance occuring near the drains

Permeability of the impervious layer

In those conditions where the seemingly 'impervious' layer is slightly permeable, drainage possibilities are likely to be better. Measurement of the permeability of the 'impervious' layer may be necessary and drainage conditions for percolated water through the 'impervious' layer have to be established.

6.3 SPACING OF OPEN DRAINS IN NON-HOMOGENEOUS SOILS

If there are two different soil layers with different permeabilities, K1 in the top layer and K2 in the lower layer and the water level in the drains coincides with the boundary of the two layers, then the equation presented before can be used (see Figure 14). Weighted averages are used as indicated in Chapter 4.4.

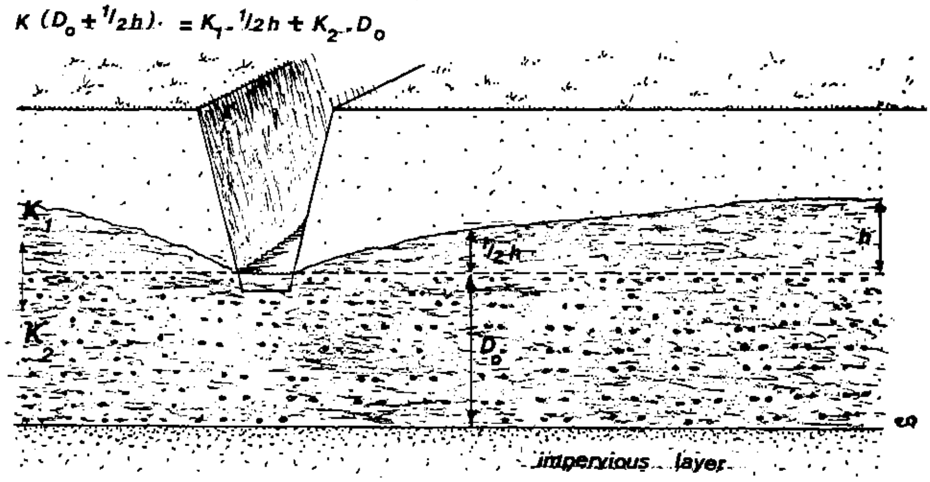


Fig. 14: The boundary of the two soil layers coincide, with the water level in the drain

If there are two soil layers and the drains are located entirely in the upper layer (see Figure 15) the same applies as for the general equation. If the impervious layer is deeper than 350 m the depth used for the correction for radial resistance is the depth of the layer between the water level in the drain and the boundary between the two layers and the correction is then:

Dr ln Dr/u.

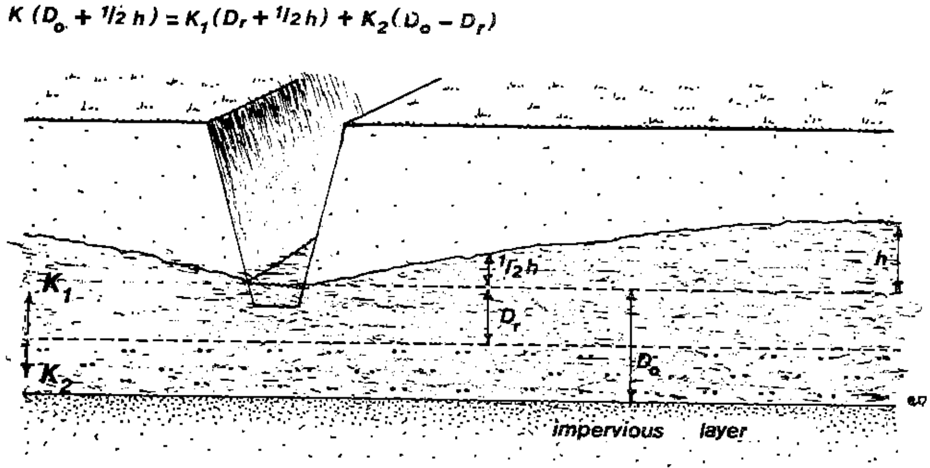


Fig. 15: The boundary of the two soil layers is below the drain depth

6.4 SUB-SURFACE DRAINS

When open drain spacings are too short, sub-surface drains may be preferred. They may either be perforated pipes, tiles or trenches refilled with porous material.

Perforated pipes and tubes: For these sub-surface drains, the same applies as for open drains but the radial resistance will be higher. It is, there-fore, recommended to correct the calculated drain spacings for radical resistance if the impervious layer is more than 2.50 m below the soil surface or more than 1.0 m under the level of the drain. This is very important for clay and clay loams.

Trenches refilled with porous material: When open drain spacings are too short, sub-soil drains may be preferred. A narrow trench is required in which water-bearing material is placed on the bottom. This may be stones or a layer of branches. A more expensive solution is tile drains. To provide for enough discharge the bottom of the trench requires a slope towards the open drain in which the water is discharged. The rest of the trench is filled back with soil (see Figure 17).

In Ishiara scheme, Embu District, sub-soil drains filled with stones are used. The trenches there penetrate the shallow impervious layer, draining the water below this level. The sub-soil drains at 16m distance are 100m long and 120cm deep. They make up half the implementation costs of the scheme (providing the stones and their transport). After a few years, some drains got blocked and are at the moment changed to open drains to prevent further blockages.

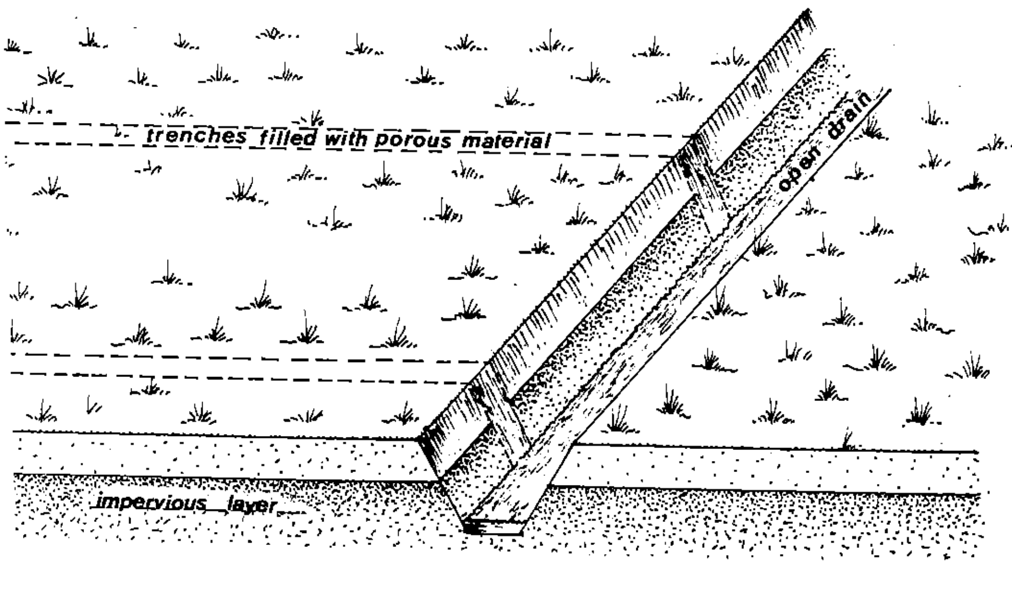
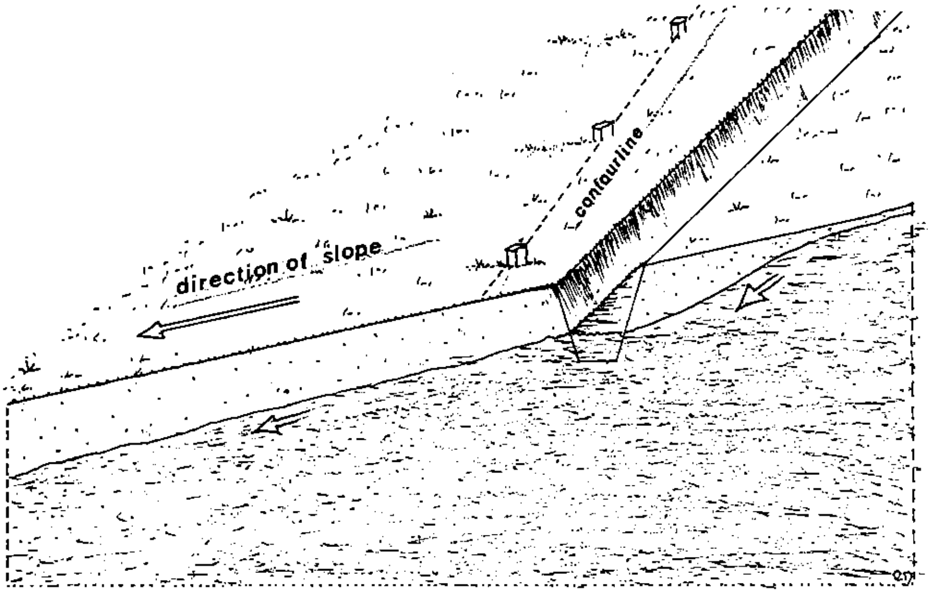


Fig. 16: Trenches filled with porous material

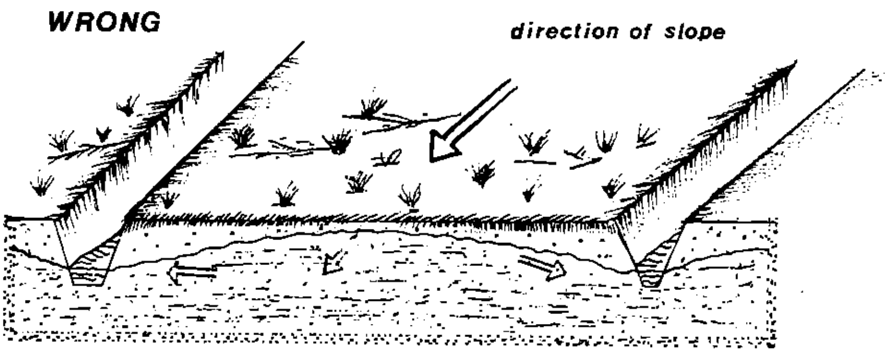
6.6 REMOVAL OF GROUND WATER INFLOW FROM ADJACENT AREAS

To collect the inflow the drains have to be on the contours, with a slight angle to provide sufficient slope for discharge of the drain (see Figure 17a). One drain also called cut-off drain will then be sufficient.

If the drains are down the slope, ground water in between the drains continues to enter the area and is only partially removed (see Figure 17b).



a. Drains in a slight angle to the contour



b. Drains down the slope

Fig. 17: Interception of ground water inflow

7. SUMMARY OF SOIL SITE INVESTIGATION ASPECTS — FOR SURFACE IRRIGATION

7.1 TEXTURE

Determination by hand: When soil is dry, add water to moisten it.

Sand: A sandy soil is loose. The individual sand grains can be seen easily. Squeezed in the hand when dry, sand falls apart when hand is opened again. Squeezed when moist, it forms a cast but crumbles when touched.

Sandy loam: The individual sand grains make up most of the soil and can be readily seen and felt, but are mixed with some fine material. This mixture makes the soil somewhat cohesive if squeezed when dry, forming a cast that falls apart easily. Squeezed when moist, a cast is formed that needs careful handling to prevent breakages.

Loam: Sand grains and fine material are evenly mixed. It is mellow but slightly plastic. Squeezed when dry, it forms a cast that needs careful handling to prevent breakage. Squeezed when moist, the cast can be handled freely without breakage.

Silt loam: When dry, appears cloddy but the lumps can be easily broken. When pulverised, it feels soft and floury. When wet, the soil runs together readily and puddles. Either dry or moist, it forms a cast that can be handled freely without breaking.

Clay loam: When dry, breaks into clods or lumps that are hard. When moist, the soil pinched between the thumb and forefinger forms a thin ribbon that breaks easily.

Clay: Very hard lumps or clods when dry, and very plastic and sticky when wet. When moist, the soil pinched between the thumb and forefinger forms a thin ribbon that does not break easily.

Rough indication for water storage capacity

Texture	Readily available moisture: half of water storage between field capacity and wilting point (mm/10cm soil depth)	
Clay	10 - 15	suitable for irrigation
Clay loam	8 - 10	suitable for irrigation
Loam	7 - 9	suitable for irrigation
Sandy loam	4 - 7	moderately suitable
Sand	3 - 5	unsuitable

Rough indication for infiltration capacity

Soil texture	Infiltration rate (mm/hr)	
Clay	1 - 15	moderately suitable
Clay loam	5 - 15	suitable
Loam	15 - 25	suitable
Sandy loam	15 - 75	suitable
Sand	25 - 250	unsuitable

Limitation: If less than 2 - 4 mm/hr, infiltration will take 24 hours (with an application of 50 - 100 mm) and roots may die off due to lack of air in the soil over an even longer period due to drainage of excess water (48 hours).

Limitation (black cotton soils): If large cracks are present, earthen feeder canals and in-field canals may lose their water by seepage totally, leaving no water to irrigate.

Rough indication for workability

Texture	Workability
Very heavy clay	Very sticky when moist, very hard when dry; workable when wet for rice growing
Heavy clay	Moderately workable
Clay loam	Workable
Loam	Workable
Sandy loam	Workable
Sand	Workable

Rough soil data

	Bulk density weight/volume of dry soil
1 dm^3 = 1 l of soil	= 1.2 - 1.3 kg of clay 1.3 - 1.5 kg of loam 1.5 - 1.8 kg of sand
1 dm^3 of soil has	pore volume of 0.5 dm^3 = 50% porosity (range 10 - 60%)
Saturated soil	1 dm^3 contains roughly 0.5 dm^3 of water (range 30 - 55%)
Soil at field capacity:	1 dm^3 contains roughly 0.25 dm^3 of water = 25 mm/10 cm soil depth (range - 10 - 50%)

Rough indication for hydraulic conductivity

Texture	K : cm/day
Clay	< 25
Clay loam	25 - 50
Loam	50 - 200
Sandy loam	200 - 300
Sand	>300

7.2 SLOPE

Determination: Line level, water hose level, e.o. instruments.

Classification:

Slopes 0 - 2%	No limiation to irrigation.
2 - 5%	Basins (flat or ridged) are small (width less than 1.5 m). Level furrows can still be used. Sloping furrows diagonal to the slope are possible, but require careful management to avoid erosion.
over 5%	Only sprinkler irrigation is possible.

7.3 SOIL DEPTH/POTENTIAL ROOTING DEPTH

Determination: Soil pit or soil auger hole.

Restrictions to rooting depth:

-- mechanical	bed rock compacted layers layers of alternate clay and sand columnar structure
-- chemical	saline or sodic layers
-- ground water	natural fluctuations rise and fluctuation due to irrigation

(Easily) available moisture

Texture	Required minimum soil depth to store 32 mm readily available moisture (7 x 4.5 mm/day)	Required minimum soil depth to store 18 mm readily available moisture (4 x 4.5 mm/day)
Clay	30 cm	20 cm
Clay loam	35	20
Loam	40	25
Sandy loam	60	30
Sand	80	50

With moderately deep and deep rooting crops (over 60 cm root depth) irrigation is given when the easily available moisture is taken up by the plants. For the whole root zone depth, this amounts roughly to 50% of the total available moisture (storage capacity) between field capacity and wilting point.

For shallow rooting crops (e.g. onions, 30 cm), the root intensity is higher (all over the rooting zone), allowing the plants to extract up to 75% of the total available moisture.

Classication:

Sand	Unsuitable for all soil depths and crops	
Other soils	Over 90 cm	- no severe limitations
	60 - 90 cm	- less suitable for deep rooting crops such as maize, cotton
	45 - 60 cm	- only suitable for shallow rooting crops on all soils except sandy loam
	Below 45 cm	- only suitable for very shallow rooting crops (less than 35 cm) e.g. onions, on clay, clay loam and silt loam.

The root depth may be reduced by the occurrence of ground water and its capillary rise (Section 7.4 - Ground water and permeability).

7.4 GROUND WATER

Determination: In pit or soil auger hole. Fluctuations in level might be indicated by soil mottle colours.

Red	No ground water fluctuation, constantly well drained.
Yellow/brown Grey/dark colours	Flunctuations during part of the year; ground water up to these colours.
Concretions	Fluctuations of ground water table either due to present fluctuations or a relic from the past.

Future level: With irrigation a rise in ground water level may be expected, depending on hydraulic permeability of the soil, depth to impermeable layer, and slope.

Yield reduction to crops will occur at ground water levels due to root depth limitation within:

75cm for shallow rooting crops (beans, vegetables)
100cm for deep rooting crops (maize, cotton, sorghum)

Capillary rise will be substantial at high ground water levels. The maximum discharge from ground water by capillary rise to dry soil (wilting point) is given in Table 12. The distance from the ground water can be either to the root zone where the water is taken up by the plants or to the soil surface where the water evaporates.

Contribution to crop water requirement by capillary rise is substantial at a discharge of 2mm/day or more.

TABLE 13: MAXIMUM DISCHARGE OF CAPILLARY RISE IN MM/DAY FROM GROUND WATER

Soil	Distance to ground water level (cm) 50	75	100	150
Clay	1.0	0.5	0.2	0
Clay loam	>5.0	4.0	3.0	1.0
Loam	>5.0	>5.0	>5.0	4.0
Sandy loam	>5.0	1.0	0.3	0
Sand	>5.0	3.0	1.0	0.2

Salt accumulation

The salt contribution to the root zone depth depends on the salinity of the ground water. With saline ground water the discharge should be preferably less than 0.5 mm/day, as otherwise leaching of accumulated salts by rainfall or excessive irrigation is required.

Sodicity of the ground water combined with the capillary rise will destroy the structure of the soil, and reduce the permeability, making the soil totally unsuitable for crops.

7.5 PERMEABILITY (HYDRAULIC CONDUCTIVITY) AND DEPTH IMPERVIOUS LAYER

Determination:
- texture determination by hand
- visual observation in a pit
- reversed auger hole method

Classification of K values in mm/day:

1.0 m/day and over	-	low drainage hazard
1.0 - 0.1 m/day	-	drainage hazard depends on depth of impermeable layer
less than 0.1 m/day	-	high drainage hazard, only suitable for rice irrigation

A rough indication of drainage possibilities of flat land (slope 1% or less) is given below:

TABLE 14: REQUIRED DRAIN SPACING IN HOMOGENEOUS SOILS (IN METRES) FOR SHALLOW ROOTING VEGETABLES (Drainage rate = 2.5 mm/day)

Soil type	Permeability m/day	Depth impervious layer (= Imp.L) below the surface (cm): Drain depth = depth Imp.L			Drain depth = 135 cm			
		100	120	140	160	180	200	250
Clay	0.10	-	-	-	10	12	13	16
Clay loam	0.25	-	10	13	16	18	20	25
	0.50	-	14	19	22	26	29	35
Loam	1.00	-	20	27	32	37	41	50
	1.50	11	24	33	39	45	50	61
	2.00	14	28	38	45	52	58	70
Sandy loam	2.50	16	31	42	51	58	65	79
Sand	3.00	20	34	46	56	63	71	86
	5.00	25	44	60	72	82	92	111

REMARKS: Ground water 75 cm below soil surface
Hydraulic head 50 cm above water level in drain
Drain water level below soil surface is:
125 cm for impervious layer of 160 cm and over
130 cm for impervious layer of 140 cm
110 cm for impervious layer of 120 cm
90 cm for impervious layer of 100 cm

TABLE 15: REQUIRED DRAIN SPACING IN HOMOGENEOUS SOILS (IN METRES) FOR FIELD CROPS (Drainage rate = 2.5 mm/day)

Soil type	Permeability m/day	Depth impervious layer (= Imp.L) below the surface (cm): drain depth = depth Imp.L: 120	140	Drain depth = 160 cm: 160	180	200	250	300	350
Clay	0.10	-	-	-	-	11	14	17	19
Clay loam	0.05	-	11	17	21	24	32	37	42
	0.25	-	-	12	14	17	22	26	30
Loam	1.00	-	16	24	30	35	45	53	60
	1.50	-	19	29	36	42	55	65	73
	2.00	-	22	33	42	49	63	75	85
Sandy loam	2.50	-	24	37	47	55	71	84	95
Sand	3.00	-	27	41	51	60	77	92	104
	5.00	(5)	35	53	66	77	100	118	134

REMARKS: Ground water = 100 cm below the soil surface

Hydraulic head = 50 cm above water level in drain

Drain water level below soil surface is:

150 cm for impervious layer at 160 cm depth and over
130 cm for impervious layer at 140 cm depth
110 cm for impervious layer at 120 cm depth

Slopes of over 1% contribute positively to the drainage possibilities. The hydraulic head contribution to the water flow (ground water, open drains) is then substantial.

7.6 SODICITY

Determination: pH meter in 1:2.5 soil/water solution.

pH lower than 8.0	-	No danger of sodicity in non-saline soils In saline soils, determination of sodium in the laboratory is necessary
		ESP % $<$ 6 no sodicity problem 6-16 sodicity problems $>$ 16 unsuitable for all crops - no reclamation possible.
pH 8.0 - 8.5	-	Danger of sodicity. A check of the pH measurement in the laboratory is required.
pH above 8.5	-	sodicity problems. Soil unsuitable for all crops, no reclamation possible.

7.7 SALINITY

Determination: EC meter in 1:2.5 soil/water solution.

EC in millimho/cm

0 - 1.2	Non-saline soil
1.2 - 2.5	Saline soil
2.5 - 5.0	Moderately saline
5.0+	Strongly saline

Reclamation is possible if sufficient water for leaching is available and drainage possibilities are present. Minimum drainage requirements are: K above 1 m/24 hours and impermeable layer deeper than 150 cm.

COTTON

The same as for commonly grown crops with the exception of:

	Highly suitable	Moderately suitable	Marginally suitable	Unsuitable
ECe	<4.0	4.0-8.0	8.0-12.0	>12.0
$EC_{2.5}$	<1.3	1.3-2.7	2.7-4.0	>4.0

RICE

The same as for commonly grown crops with the exception of:

Effective rooting depth (cm)	>80	50-80	30-50	<30
Depth (cm) to impervious layer	<120	120	120	>120
Slopes for basins	<1%	1%	1-2%	>2%

SHALLOW ROOTING CROPS (onions, cabbage, cauliflower)

The same as for commonly grown crops with the exception of:

Effective rooting depth (cm)	>50	40-50	30-40	<30
Drainage depth to impervious layer or ground water table (cm)	>120	100-120	100-120	<100