AN EVALUATION OF THE INFLUENCE OF WATER QUALITY AND IRRIGATION MANAGEMENT ON SOIL PROPERTIES OF SOME SELECTED IRRIGATION FARMS IN KIBOKO AND MAKINDU

BY

DAVID KIPLANG'AT TONUI

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FACULTY OF AGRICULTURE
UNIVERSITY OF NAIROBI

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signed ---------------------------- 29-7-92. --------------
David K. Tonui Date

This thesis has been submitted for examination with our approval as University Supervisors.

Signed ---------------------------- 06/8/1992 --------------
S.M. Kinyali Date

Signed ---------------------------- 15/8/92 --------------
Dr. J.P. Mbuvi Date

DEDICATION

This thesis is dedicated to my loving parents, wife and children

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LIST OF ABBREVIATIONS AND SYMBOLS

CEC	Cation Exchange Capacity
cm	Centimetre
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
g	Gram
g/cm^3	Gram per cubic centimetre
hr	Hour
Ksat	Saturated hydraulic conductivity
kg	Kilogram
l	Litre
m.e	Milliequivalent
ml	millilitre
mm	Millimetre
ds/m	decisiemen/metre
mmhos/cm	Millimhos per centimeter
ppm	Parts per million
r	Correlation coefficient
RSC	Residual Sodium Carbonate
SAR	Sodium Adsorption Ratio
SSP	Soluble Sodium Percentage
USDA	United States Department of Agriculture
USSL	United States Salinity Laboratory
P_p	Particle density
SARadj	Adjusted Sodium adsorption ratio
Pb	Bulk Density
$p^{H^*}c$	Calculated value based on total cations, Ca + mg and $CO_3 + HCO_3$ in the water

List of Abbreviations and Symbols Cont'd

LS	Loamy Sand
C	Clay
Sc	Sandy Clay Loam
SL	Sandy Loam
Cl	Clay Loam

ABSTRACT

Three irrigation farms were studied. Two in Makindu and one in Kiboko. Representative soil sampling sites were selected to represent irrigated and non-irrigated soils. The physical and chemical properties were determined in the laboratory. This was done to study the influence of water quality and management on soil properties.

Water samples used for irrigation were analysed to determine their chemical characteristics and their suitability for irrigation. From irrigation point of view, all the waters may be regarded as being unsafe for irrigation particularly on heavy textured soils, unless sufficient drainage is provided and the necessary soil amendments are adopted or salt tolerant crops are grown.

This study has indicated that poor quality irrigation water have little impact on light textured soils. The criteria used to classify soils as well as irrigation waters as having high salinity hazard are not tenable for well drained light textured soils and therefore need modification. Due consideration should be given to soil type, drainage characteristics, topography and irrigation management when judging the suitability of irrigation water.

Sufficient drainage should be provided to lower Muhindi farm in order to reduce the groundwater level to below the zone of root penetration.

The waterlogging condition experienced in Makwatta farm is attributable to the dispersed clay colloids brought about by high

ESP of the soils. The dispersed colloids moved and blocked the pores through which water flows thus diminishing the hydraulic conductivity of these soils. The pH of these soils is more then 8.5 due to the hydrolysis of adsorbed sodium. Soil amendments would be of doubtful value in correcting the high exchangeable sodium status of the subsoils due to their extremely low permeabilities. Ploughing under of farmyard manure or green-manuring crops might help improve drainage.

The irrigated surface soils of Musengya farm in Makindu are well drained and no appreciable increase in salt accumulation has been experienced despite the use of high salinity water of Makindu river for irrigation. Sufficient drainage should be provided to the fine textured soils of Museng'ya farm in order to reduce the groundwater level to below the root zone and prevent the occurrence of waterlogging condition.

Single correlations between irrigation water and soil characteristics were not significant to be of any prediction value suggesting that the soil solution is not in equilibrium with irrigation water.

CHAPTER ONE

INTRODUCTION

All irrigation waters contain dissolved salts. The effects of these salts upon the chemical and physical characteristics of irrigated soils is of utmost importance to the continued soil productivity and perhaps to the permanence of irrigated agriculture.

During the last eighty years or so, considerable progress has been made in the study of problems developing from soluble salts. In most cases salinity and sodicity problems developed after the land had been put under irrigation, and in such instances salinity of the irrigation water was undoubtedly a contributing factor. Other factors which influence salinity effects are concentration and composition of salts in the irrigation water, adequacy of soil permeability and drainage, management practices, and inherent soil characteristics such as clay mineralogy, soil texture and topography.

Although irrigation has been practised in the world for several millenium, it is only in this century that the importance of the quality of irrigation water has been recognized. The use of saline water may result in reduction of crop yields, while sodic water may cause deterioration in the physical properties of soils, again with consequent reduction in yields.

Considerable attention is at present being given to the environmental aspects of water quality, including the possible presence of minute amounts of potentially harmful substances. Quality of irrigation water is of particular importance in arid climates.

Salts formed in situ by weathering of soil minerals or by salt deposition from applied water tend to accumulate in the soil profile.

Development of soil salinity and sodicity conditions may be due to high water table and accumulation of salts on the surface by capillary movement of salts along with water and their deposition after evaporation of water. It may also be due to continuous use of saline irrigation water, especially in arid and semi-arid regions where rainfall is limited and no other sources of irrigation water is available (secondary salinisation). It could also be due to salts formed in situ by weathering of soil minerals. All secondary salinity problems have their origins in man's disturbance of the natural environment.

The continuous prosperity of a country dependent on Agriculture and without adequate rainfall is dependent on its irrigated lands. In areas where irrigation is practised, the economic importance of salt problems, though generally recognised, have not been fully understood and that could be why many practical problems have not been solved. Although soils of the irrigated areas may not be saline, the extent of soil salinity and alkalinity is expected to increase with the increase of irrigation.

As water resources become limited, increased use will be made of inferior irrigation water with a high sodium or total salt content or both. Without proper irrigation water management based on the knowledge of the possible harmful effects, continued application of such water will not be possible.

Besides soil texture, hydraulic conductivity and cation exchange capacity modify the rate of leaching and composition of accumulated salts, and their effect in modifying salinity and/or sodium hazards of irrigation water are important. It is therefore important to have detailed information on the physical as well as chemical properties of irrigated soils. Such information is essential when irrigating with poor quality water where several interactions between soil and water characteristics take place simultaneously.

OBJECTIVES

1) To study the chemical characteristics of the irrigation waters and their suitability for irrigation.

2) To study the influence of irrigation management and water quality on the soil properties.

3) To establish relationships, if any, between irrigation water characteristics and soil properties.

THE STUDY AREA

The farms under study are in Kiboko and Makindu. Makindu falls in the boundary between ecological zone IV and V while Kiboko falls in ecological zone V (Michieka and Van der Pouw, 1977).

The average annual rainfall, evaporation and temperature are in the order of 600mm, 200mm and 23^{o}C respectively. The rainfall distribution is bimodal with rainy seasons from end of March to mid May and from end of October to mid December.

Part of the area belongs to the erosional Plain of undifferentiated Basement System gneisses which are of Pre-Cambrian age. The rest of the area is almost entirely built up of recent lava flows. Bottomlands only occupy minor portions (Michieka and Van der Pouw, 1977).

The soils of the Kiboko and Makindu area show strong variation in most of their properties. The soils of the lava flows are shallow or very shallow, extremely stony to bouldery and rocky; they are highly permeable. The soils of the floodplain and bottomlands range from non-calcareous and non-saline to extremely calcareous and saline (Michieka and Van der Pouw, 1977).

gure 1: The approximate location of the study areas o Kiboko and Makindu on the map of Kenya.

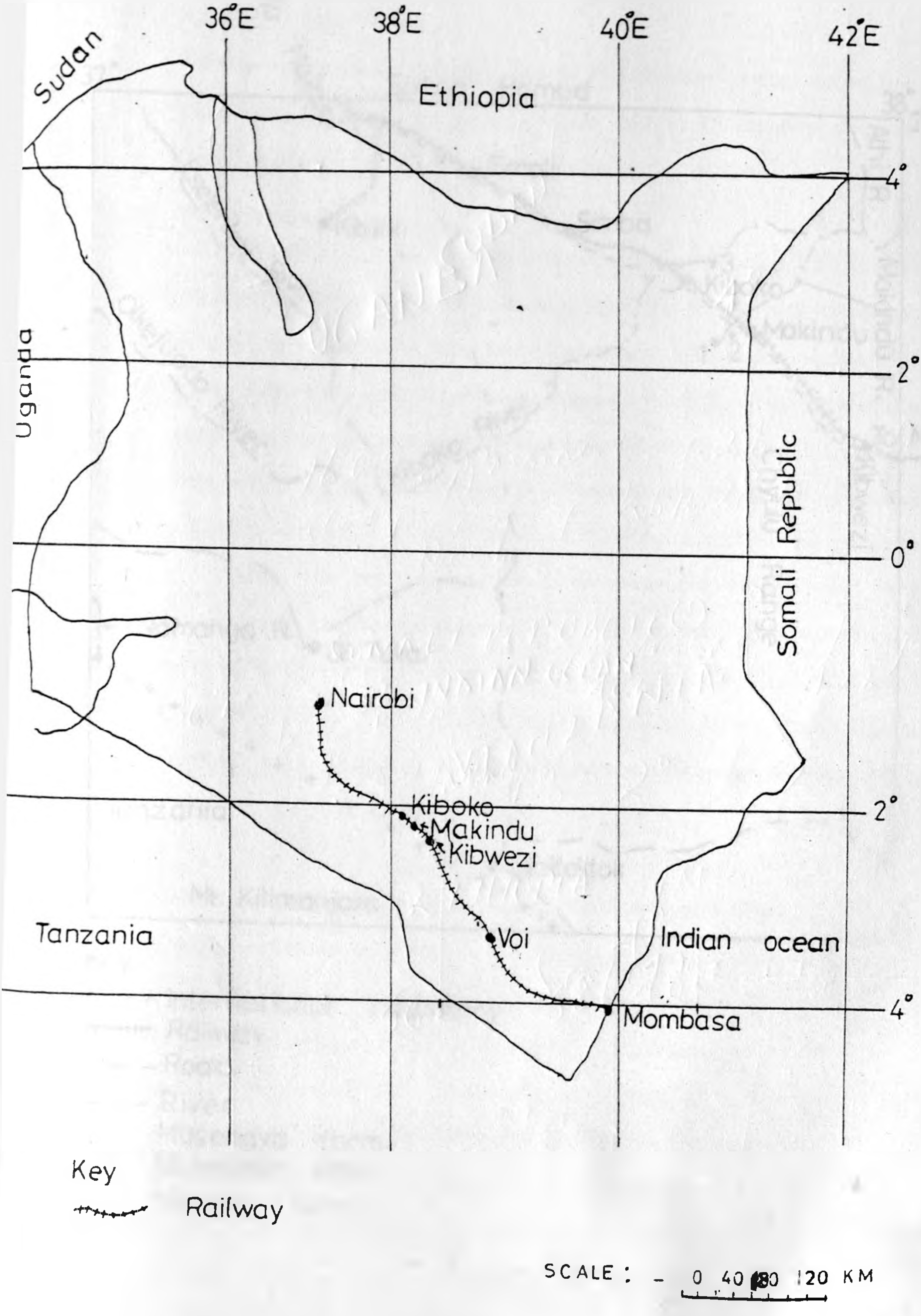
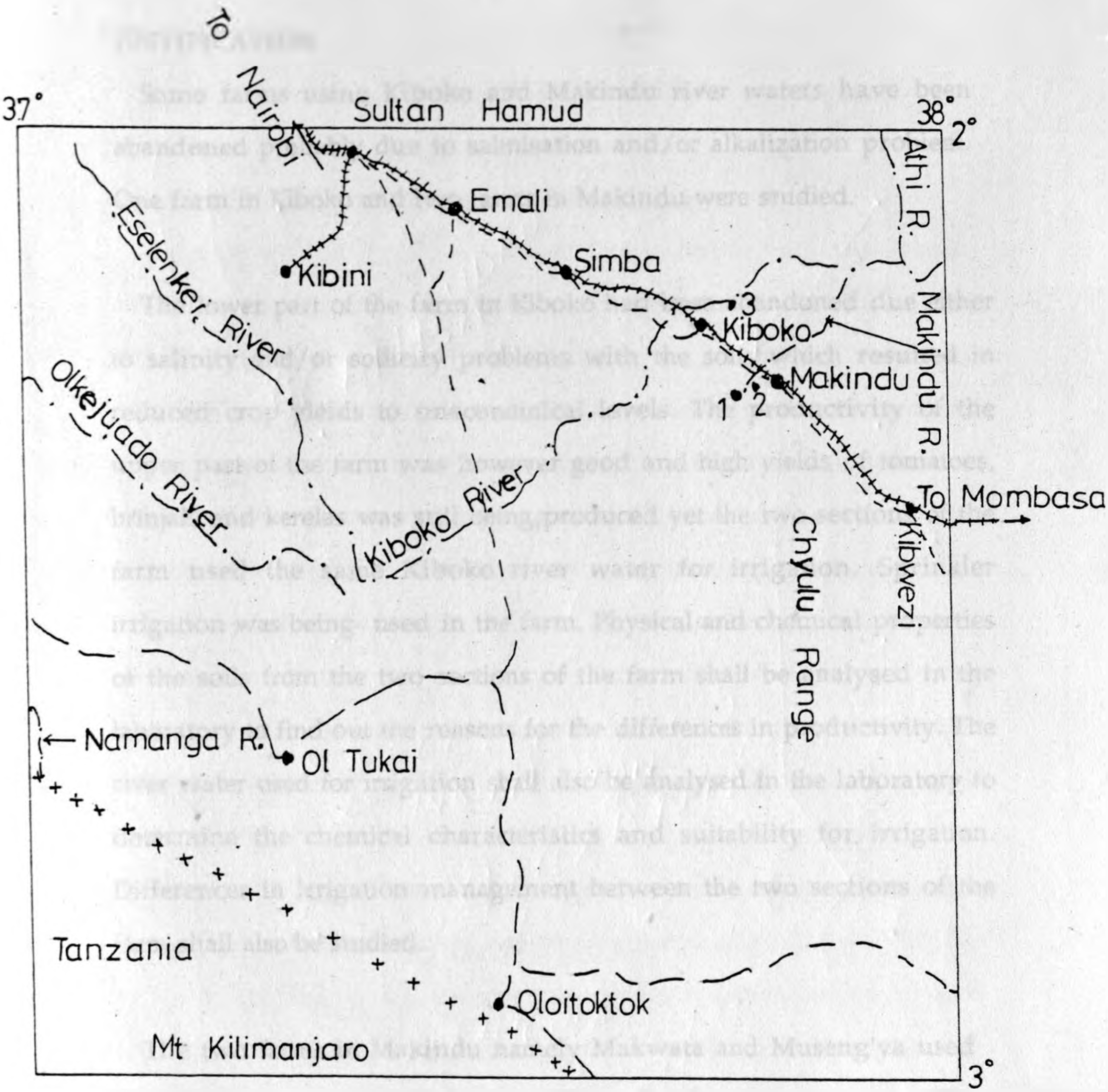


Figure 2: Map showing the approximate location of the farms studied.



Key
× × × × International baundary
Railway.
– – – Road.
—·— River.
1 Musengya farm.
2 Makwatta farm
3 Muhindi farm.

Not to scale.

JUSTIFICATION

Some farms using Kiboko and Makindu river waters have been abandoned probably due to salinisation and/or alkalization problem. One farm in Kiboko and two farms in Makindu were studied.

The lower part of the farm in Kiboko had been abandoned due either to salinity and/or sodicity problems with the soils which resulted in reduced crop yields to uneconomical levels. The productivity of the upper part of the farm was however good and high yields of tomatoes, brinjals and kerelas was still being produced yet the two sections of the farm used the same Kiboko river water for irrigation. Sprinkler irrigation was being used in the farm. Physical and chemical properties of the soils from the two sections of the farm shall be analysed in the laboratory to find out the reasons for the differences in productivity. The river water used for irrigation shall also be analysed in the laboratory to determine the chemical characteristics and suitability for irrigation. Differences in irrigation management between the two sections of the farm shall also be studied.

The two farms in Makindu namely Makwata and Museng'ya used Makindu river water for irrigation. Museng'ya farm is upstream while Makwata farm is downstream. Makwata farm has been abandoned due to poor yields either as a result of salinity, sodicity and/or waterlogging problem of the soil. The productivity of Museng'ya farm is high and good yield of tomatoes is still being realized. In this study an attempt shall be made to find out whether the difference could be in the soil physical and chemical properties or in the chemical characteristics of irrigation water as it flows downstream.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Origin and Occurrence of Salt Affected Soils.

Saline and alkali soils are formed due to certain natural and man-made causes in which undesirable concentrations of salts accumulate in the layers of the soils. These salts are mainly chlorides, sulphates, bicarbonates and carbonates (and sometimes nitrates) of sodium, calcium and magnesium (and potassium). Heavily salinized soils may show efflorescence or complete salt crusts. Rao and Govinda (1971), showed that the origin of these salts could be due to one of the following: (a) Either these salts are formed in situ by a process of gradual weathering of parent materials which are rich in these elements and have not moved elsewhere, or (b) they have been transported from other places through surface and subsurface drainage and deposited at these places. Under humid conditions, the salts are either washed down into the lower layers where they get mixed with the groundwater and carried away into streams and ultimately to the ocean or washed through surface run-off into waterways, streams and rivers. Under arid and semi-arid conditions however, leaching and transportation is not complete and the salts tend to concentrate either on the surface of the soil or at certain depths because soil moisture is not sufficient to carry them very far.

Other ways through which saline soils came into being is through flooding by seawater, by windborne salt sprays or dust, by irrigation with water that contained salt or that was contaminated by saline industrial waste waters. The majority of saline soils have developed as a result of upward capillary flow of water exceeding its downward movement (Verhoeven, 1979). It has been reported that the primary cause of salinity problems in agriculture is salt accumulation through evapo-transpiration (Carter, 1975; Carter et al , 1971).

As the demand for irrigation water increases, the tendency to develop groundwater increases. This results in using more medium and highly saline groundwaters, and thus intensifying the salinity problem (Carter, 1975). A considerable capillary transport of groundwater to the surface only occurs when water tables are high for prolonged periods of time. This is often the case in irrigated areas without adequate drainage. Verhoeven (1979) pointed out that the extent of capillary salinization and the depth at which salts accumulate are governed by the rate of capillary rise and the salinity of the groundwater, counteracted by the leaching intensity (by rain or irrigation water). He has also showed that the rate of water transport to the soil surface depends on the depth of the groundwater table, on the hydraulic potential gradient between groundwater and soil surface, and on the capillary conductivity of the soil in relation to the moisture content. The reduction of the salt content in the soil brought about by irrigation water depends on the quantity and quality of water percolating through the soil, on the physical characteristics of the soil, and on its moisture content.

It has been reported that drainage water that has passed through the soil has a higher salt concentration than irrigation water. Most of this drainage water returns to the natural stream or river channel, downstream from the point where the irrigation water is diverted. As a result, the salt concentration in rivers and streams in arid and semi-arid regions generally increases from the head waters downstream.

This, in itself, creates a salinity problem for agriculture because the salt concentration in the stream can become so high that the water cannot be used for irrigation (Wilcox and Resch, 1963; Carter et al , 1971).

2.2 <u>Classification of Salt Affected Soils.</u>

Salt affected soils are those which contain excessive concentrations of soluble salts and/or exchangeable sodium. Soluble salts produce harmful effects on plants by increasing both the salt content of the soil solution and the degree of saturation of the exchange complex of the soil with exchangeable sodium. Based on these two factors, the U.S Salinity Laboratory Staff (1954) classified salt affected soils into three categories:

2.2.1. Saline Soils

This group of soils includes those containing soluble salts in quantities sufficient to interfere with the growth of most crop plants but not containing enough exchangeable sodium to alter soil characteristics appreciably. The amount of salt in a soil above which plant growth is affected depends upon the species of the plant, the texture and water holding capacity of the soil and the composition of the salt. Thus, according to Shainberg (1975), the critical concentration of the salt in the soil for distinguishing saline from non-saline soil is arbitrary.

Kearney and Schofied (1936) suggested that saline soils are those which contain more than 0.1% salt. The disadvantage of this definition is that it is independent of the soil properties, mainly its water capacity. In sandy soils with low water capacity, the above percentage of salt when dissolved in the soil solution will cause very high osmotic pressure. Conversely, the above concentration of salt in a heavy-textured soil with large water capacity, will cause only a moderate osmotic pressure. Thus, the U.S Salinity Laboratory (1954) defined a saline soil as one having an electrical conductivity of the saturation extract (ECe) greater than 4.0 mmhos/cm and an exchangeable sodium percentage (ESP) less than 15. Owing to the presence of excess salts and the absence of significant amounts of exchangeable sodium, saline soils generally are flocculated as compared to similar non-saline soils (Shainberg, 1975).

When Harper and Stout (1950) studied the relation of soil texture to soluble salt accumulation in irrigated soils of Oklahoma, they found that as the salt content of the water and the clay content of the soils increased. There was more salt in the soil profile.

2.2.2 Non-Saline Alkali Soils (Sodic Soils)

This group includes soils containing exchangeable sodium in quantities sufficient to interfere with the growth of most crop plants and not containing appreciable quantities of soluble salts.

Shainberg (1975) has pointed out that the decision as to the level of exchangeable sodium in the soil which constitutes to an excessive degree of saturation is complicated by the lack of sharp change in soil properties as the degree of saturation with exchangeable sodium is increased. He defined a sodic soil as one whose ESP is greater than 15 and in which the conductivity of the saturation extract is less than 4.0mmhos/cm. This he cautioned is an arbitrary and tentative definition. Lewis and Juve (1955) pointed out that alkalinity is a secondary effect of removal of excess soluble salts leaving the soil colloids saturated with respect to sodium ions.

Lewis and Juve (1955) also observed that the exchangeable sodium present in sodic soils may have a marked influence on the physical and chemical properties of these soils. As the proportion of exchangeable sodium increases, the clay particles in the soil tend to disperse. The dispersed colloids may then move and block the pores through which the water flows, thus diminishing the hydraulic conductivity of the soil and causing poor aeration. The pH of these soils usually ranges between 8.5 and 10.0. This high pH is due to hydrolysis of adsorbed sodium in the absence of electrolytes in the soil solution.

2.2.3 Saline -Alkali Soils

This term is applied to soils for which the conductivity of the saturation extract is greater than 4.0 mmhos/cm and the ESP is greater than 15.0. As long as the concentration of the salt in the soil solution is high; the properties of these soils are similar to saline soils; the particles are flocculated and the permeability for water is high. It has been reported that in the presence of excess salt, adsorbed sodium does not hydrolyse and that the pH of these soils is usually less than 8.5 (Kamil and Shainberg, 1968).

As the concentration of the salts in the soil solution is lowered, for example, due to leaching the properties of these soils may change markedly and become similar to sodic soils: exchangeable sodium hydrolyzes and the pH increases to values above 8.5, the particles disperse, and the permeability, drainage and aeration become poor (Shainberg, 1975).

2.3 Water Suitability for Irrigation

Regardless of its source, irrigation water always contains impurities in the form of dissolved, or sometimes suspended materials. The amount and nature of these materials under given environmental, climatic, soil, and plant conditions determine the usefulness and relative quality of the water. The quality of irrigation water is defined with respect to its effect on plant growth, soil properties, soil biological equilibrium, and irrigation technology. In the past two decades, problems of irrigation water quality have been viewed primarily from the standpoint of salinity (U.S Salinity Laboratory, 1954; Rhoades and Berenstein, 1971).

Highly saline water may be suitable for irrigation of well drained, light textured, fertile soils while less saline water may be more harmful for the same crop grown on heavy textured soils with impeded drainage. It is the actual salt concentration near the root zone which determines the suitability of irrigation water rather than the chemical properties of irrigation water alone (Michael, 1978).

2.3.1 Constituents of Irrigation Water

All river waters contain suspended materials. The composition of river salts depends on the mineralogy and chemistry of the transported particles. Rainwater contains the lowest salt concentration of all types of water used for irrigation. It includes dissolved gases and dissolved salts originating from terrestrial and marine sources.

The ratios of Mg/Ca, K/Na and $\frac{(Cl-(Na+K))}{Cl}$

in milliequivalents/litre for rainwater are similar to those for sea water in the vicinity of the sea, but differ as the distance from the sea increases (Scholler, 1962). The salt concentration of rainwater in arid zones has a significant influence on the salt content of surface and groundwater. The salt content of surface water is a function of the rocks prevalent at the water source, of the climatic zone, and of the nature of the soil over which the water must flow (Yaron, et al, 1973).

The lack of rainfall and a high evaporation rate during the dry seasons contributes to an increase in the salt concentration of lakes. The salt content of groundwater depends on the source of water and on the course over which it flows (Brysine, 1961).

Not all of the minor elements are found in any one source of irrigation water. They appear sporadically, singly or in groups, in different water sources. One particular micronutrient that is found in irrigation water and having a strong effect on plant growth is boron. Man-made pollutants that may be found in irrigation water come from Municipal, Industrial and agricultural wastes. Generally, the composition is affected by the presence of man-made pollutants when irrigation return flow is used again for irrigation (Yaron, 1973).

2.3.2 Classification of Irrigation Water.

A number of criteria have been devised for the classification of water quality for irrigation. These schemes vary from general to detailed classifications for a particular crop or region. In addition to the chemical analysis of the water, many other factors require evaluation, such as soil properties, irrigation management, climate and crops, before determining its suitability for irrigation (Yaron, 1973).

Research on the quality of irrigation water dates back only a few decades. However, during the latter part of the nineteenth century Hilgard's pioneering work on water quality showed the importance of composition and he rated water by the anion content as well as by the total salt concentration (Hilgard, 1906). Based on Hilgard's work, Stabler (1911) rated sodium carbonate as being twice as undesirable as sodium chloride and ten times as undesirable as Sodium Sulphate for irrigation waters, which indicated the importance of the bicarbonate ion in evaluating water quality for irrigation.

Wilcox (1958) published a diagram showing five classes of water. Wilcox's classification appears to be a forerunner to the U.S salinity classification as many waters fall in the same general class for both criteria. The U.S salinity laboratory water classification has received worldwide distribution by handbook No. 60 (U.S.S.L, 1954). The essence of the salinity laboratory's classification is based on the interaction of total salt concentration and sodium concentration which is expressed as the sodium adsorption ratio (SAR) and is defined as

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

ions in m.e/l

At equilibrium the SAR is closely related to the exchangeable sodium of the soil.

Among the qualities considered when judging the suitability of water for irrigation are salinity, sodium carbonate, chloride, boron and suspended material. Yaron (1973) has pointed out that it is not possible to develop a universal classification system that is suitable for all purposes. A comparative analysis of some of the classifications commonly used in different countries is presented below.

(a) Salinity Hazards

The total salt content of irrigation water is one of the factors that indicate whether there is a danger that salt will accumulate in the soil. It can be determined by measuring the electrical conductivity (EC) of the water.

Badhe and Kadwe (1977) reported that waters having EC below 0.25 mmhos/cm are suitable for crops, those having EC between 0.25 and 0.75 mmhos/cm are less suitable for crops and that those having EC above 0.75mmhos/cm should be used cautiously.

Currently, the classification proposed by the U.S Salinity Laboratory (1954) and modified by Thorne and Peterson (1954) is the most widely used. In this system, the limits between different classes of electric conductivities are (in micromhos/cm): < 250- low salinity; 250-750 - moderate salinity; 750-2250 - medium salinity; 2250-4000- high salinity;, 4000-6000 - very high salinity; and > 6000- excessively high salinity.

It has been reported that in Algeria, a relatively large percentage of the water fall above 2250 micromhos/cm yet it is extensively used for irrigation. And that in India (Rajasthan area), 40% of the water is classed as being highly and very highly saline, a definition that does not fit the particular conditions prevalent in India. In Israel however, 60% of the water is considered to be moderately saline according to the above classification, although this is not really so.

Thus Yaron (1973) has indicated that the salinity ranges chosen to characterize irrigation water in a given area must be modified according to the local environmental conditions. And that the total salt content of irrigation water only serves as a general qualitative assessment of its quality.

(b) Sodium Hazards

Sodium is considered one of the major factors governing water quality mainly because of its effect on the soil and on the plant. Several methods have been proposed for expressing sodium hazard. Previously, water quality was defined on the basis of its sodium percentage (SP) alone, the sodium percentage being the ratio of the total sodium content to the total cations held in solution, multiplied by 100 (Yaron,1973).

Water with an SP of 60% or more was considered by Scotfied (1935) and Magistad and Christiansen (1944) to be harmful. The sodium hazard, as determined by the SP of irrigation water, must be reflected in the exchangeable sodium percentage (ESP) of the soil. However, in research conducted in Western Texas, no correlation was found between the SP of the water and the ESP of the soil (Longenecker and Lyerly, 1959).

Eaton (1950) and the U.S Salinity laboratory staff (1954) proposed procedures for rating the quality of irrigation waters based on total salt concentration in the water, and on the proportion of sodium to other cations. A value that has come into wide use in predicting the sodium hazard is the sodium adsorption ratio (SAR) proposed by the U.S Salinity Laboratory (1954):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad \text{.....................} \quad (2.2)$$

The classification of water according to SAR is related to the total salt content of the water, and the range is divided into four categories:- low, medium, high and very high. For an electrical conductivity of 100 micromhos/cm, the dividing points are at SAR values of 10, 18 and 26, and with an increase in salinity to 750 micromhos/cm, the dividing points are at SAR values of 6,10 and 18. This relationship presents the relative activity of the sodium ion in the cation exchange reactions with the soil and is derived from classical Gapon equation. The validity of the sodium hazard prediction may be confirmed by examining the relationship between the SAR and the ESP of the soil (Yaron, 1973).

A refinement of the SAR called the "Adjusted SAR" (SARadj) has been developed (Ayers, 1976). It includes the added effects of precipitation and mineralization of calcium in soils as related to CO_3 + HCO_3 concentrations. To evaluate the sodium or permeability hazard:

$$SARadj. = SAR[1 + (8.4 - pH^*c)] \quad \ldots\ldots\ldots\ldots\ldots (2.3)$$

Where pH^*c is a calculated value based on total cations, Ca + Mg and $CO_3 + HCO_3$ in the water. There should not be any problems expected with sodium or permeability for SARadj values less than 6.0. In the range of 6.0 to 9.0 increasing problems should be expected. If the SARadj is greater than 9.0, severe problems should be expected.

Recent studies have indicated that soil permeability, as affected by long-term irrigation will be influenced by the total salt concentration of the water and by the sodium and bicarbonate content. These three items are incorporated into a formula termed the "Permeability Index". This index has been empirically developed from a series of experiments conducted in the laboratory and a series of Lysimeter studies using a large number of irrigation waters varying in ionic relationships and concentration. In addition, it has been tested under field conditions. It has been formulated as follows (Doneen,1961):-

$$\text{Permeability Index (PI)} = \frac{\sqrt{Na + HCO_3} \times 100}{Ca + Mg + Na} \quad \ldots\ldots\ldots (2.4)$$

ions in m.e/l

An empirical relationship between the SAR of the irrigation water and the ESP of the irrigated soil was established by U.S.S.L. staff (1954). It has been reported that a good correlation between the ESP, as calculated from the SAR value and the ESP as determined experimentally has been found (Yaron, 1973).

Using a modified Langelier Index together with SAR in evaluating the sodium hazard for water with high carbonate and without residual sodium bicarbonate, Bower (1961, 1963) proposed the empirical equation:

$$ESP = 2\ SAR + 2\ SAR\ (8.4 - pH^{*}c) \ .... \ (2.5)$$

In using the SAR value, Handra (1964) took account of the fact that water with a high sodium content is usually applied with gypsum. He therefore proposed that gypsum should be included in the calculation of SAR, thereby reducing the SAR values of the irrigation water.

Fireman and Bodman (1939) and Fireman (1944) have shown a wide difference in infiltration rates between waters of high and low salt concentrations. Working independently and utilizing different techniques, Quirk and Schofield (1955) and Henderson (1958) came to the same conclusion, that increasing the salt concentration (in the range for irrigation waters) and holding the SAR constant increased the infiltration rate.

Generally, there is a linear relationship between SAR and exchangeable sodium percentage (ESP) of the soil upto moderate ESP levels, and at high ESP levels the relationship tends to be curvilinear (Michael, 1978). Wilcox *et al* (1954) showed that waters high in bicarbonate can increase the exchangeable sodium content of soils by precipitation of calcium and magnesium as carbonates.

(c) Bicarbonate Hazard.

The Bicarbonate anion is important in irrigation due to its tendency to precipitate calcium and magnesium from the soil in the form of calcium and magnesium carbonates. This brings a change in the ratio between Na and the total amount of cations, thereby accentuating the effect of the sodium hazard of the irrigation water (Yaron, 1973).

Eaton (1950) introduced the term "Residual Sodium Carbonate" (RSC) as a means of characterising the bicarbonate hazards, where RSC = $(CO_3^{2-} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$ .... (2.6), the concentrations being expressed in me/l. Studies by Wilcox (1958) indicate that waters > 2.5 me/l RSC are probably not suitable for irrigation purposes. And that water containing 1.25 to 2.5 me/l RSC are marginal, and those containing < 1.25 me/l RSC are probably safe. He indicated that good management practices and proper use of amendments, particularly gypsum, might make it possible for some marginal waters to be used. Arany (1956) indicated that in evaluating the effect of residual sodium carbonate (RSC), the soil type must be considered. Water with a given RSC may be dangerous for soil with an alkaline pH, but may have an ameliorating effect on soils with an acid pH (Yaron, 1973).

(d) Chloride Hazard.

Although the chloride ion has no effect on the physical properties of the soil and is not adsorbed by the soil complex and generally not included in modern classification systems, it is a factor to be considered in some regional water classifications (Grillot, 1954).

Fireman and Kraus (1965) recommended that water be divided into groups according to chloride content, with limits at 2,5 and 8 me/l. Dutt and Doneen (1963) introduced the term "potential salinity of irrigation water" which is equal to Cl + 1/2 SO_4, in me/l. For soils having good, medium, and low permeability, he recommended that the chloride limits be 5-20, 3-15, and 3-7 me/l, respectively. Yaron (1973) has, however, cautioned that prediction of the chloride hazard is not general but can be made only for a specific area and for a specific crop.

With Sprinklers, chloride concentrations in the irrigation water critical of 3 me/l have caused leaf burn levels (in % by weight) quoted by ILACO (1981) are as follows: slightly affected 0 to 0.05; moderately affected 0.05 to 0.1; strongly affected > 0.1.

(e) Boron Hazard

The occurrence of boron in toxic concentrations in certain irrigation waters makes it necessary to consider this constituent when assessing the quality of water. The boron content of irrigation water is classified on the basis of plant tolerance to this element.

Plant sensitivity to boron is influenced by the amount of boron in the soil solution and not by the boron adsorbed by the soil. The adsorption of boron in the soil varies with the soil texture (Shah Singh, 1964), and is higher in fine textured soils. When boron concentration in the soil solution is equal to its concentration in the irrigation water, it is possible to predict the boron hazard on the basis of the boron in the water (Hatcher *et al*, 1959). Wilcox (1960) has reported the relative boron tolerance of a number of crops as determined by Eaton (1935), with only minor modifications based on field observations.

In the localized nonirrigation low rainfall areas boron may be in toxic concentrations in the surface layers of soil and their reclamation by leaching is reported by Doneen (1968).

Boron does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant (Michael, 1978).

(f) Suspended Solid Hazard.

The suspended solids are responsible for the adverse effects on irrigation technology and soil permeability. When large quantities of suspended material are present in irrigation water, the ability of sprinkler and trickle irrigation systems to carry and distribute water is reduced.

In Sprinkler irrigation systems, the suspended material may accumulate on the leaves and cause biological disturbance. Some of the nozzles in the trickle irrigation system may be blocked, resulting in nonuniform water distribution in the field. When flooding and furrow irrigation are used and the water continues to have a high or relatively high amount of suspended material, the permeability of the soil may be affected, especially if the irrigated area is characterized by fine-textured soil. Under these conditions the suspended material can also cause crust, which may reduce seedling germination apart from adversely affecting infiltration (Yaron, 1973).

2.4 Relationships between Irrigation Waters and Soil Properties

The relationships between chemical properties of irrigation waters and irrigated soils not only reveal the effect of saline water on soil properties but also indicate the possibility of utilizing them for a quick appraisal of the saline sodic condition of the soil (Paliwal, 1972). Some of the main relationships obtained on the field soils of practical importance are as follows:-

2.4.1 EC and Total Cations:-

EC both of irrigation water and the saturation extract of soils correlated well with the total soluble salts expressed either in ppm or in me/l, with varying multiplication factors (Paliwal and Maliwal, 1968; Mehta and Paliwal, 1969). Paliwal (1972) indicated that the proportion of various cations and anions having different specific electrical conductivity in a wide range of salinity seem to be responsible for this variation. A multiplication factor of 10 x EC (mmhos/cm) gives an approximate concentration of salts in me/l upto an EC value of about 5.0 mmhos/cm. Paliwal (1972) pointed out that such a factor would show more variation in the higher salinity range and for solutions containing significant amounts of carbonates and bicarbonates.

2.4.2 EC of Irrigation Water and Soil solution

The EC of the saturation extract regularly increases with that of irrigation water used and a significant correlation exists between these properties but the degree of validity in most cases is about 40% (Paliwal and Gandhi, 1969).

Paliwal (1972) reported a slightly lower correlation for the subsoils than for the surface soils probably due to lack of equilibrium between these properties. The EC of the irrigation waters was found by Vyas et al (1982) to be significantly related to the EC for the saturation extracts of soils in all pedons. Thorne and Thorne (1954) reported a similar relationship. Singh and Mahnot (1976) however reported a non-significant positive correlation (+.02058) between EC of irrigation waters and EC of soil extracts. Gupta et al (1969) showed that EC of soil/water suspension in 1:2.5 ratio can be successfully used to estimate EC and total cations of the saturation extract. Paliwal (1972) however, pointed out that the relationship between EC of irrigation water and saturation extract of soil cannot be used for prediction purposes because of influence by other factors such as soil type, moisture fluctuations, irrigation management, topography and drainage characteristics.

2.4.3. <u>SAR of Irrigation Water and Soil Solution</u>.

These variables have been found to correlate significantly between themselves. The degree of determination (r^2) has been reported to be so low as to be of any prediction value (Paliwal, 1972). This is quite reasonable because SAR of the saturation extract is the reflection of the adsorption characteristics of the cations on the soil applied through irrigation water and as such may not be in the same proportion as applied in irrigation water.

Vyas *et al* (1982) reported a highly significant and positive correlation between SAR of Irrigation waters and that of saturation extract of soil. Jain (1978) however, reported a non-significant positive correlation.

2.4.4. ESP and SAR.

A significant correlation between ESP and SAR of soil solution was observed for 110 surface soils (Paliwal and Maliwal, 1967). A significant correlation between ESP of soil and SAR of irrigation water has also been reported by Hausenbuiller *et al* (1960). While Vyas *et al* (1982) found no such relationship, Singh and Mahnot (1976) only found a weak correlation (r = + 0.1796) which they attributed to the sandy nature of the soils. ESP was found to be correlated with the soluble sodium percentage both of irrigation water and soil solution but the correlation was lower than that obtained by SAR (Paliwal and Maliwal, 1967).

SAR of soil solution was found to correlate well with ESR (Banerjee, 1959). Paliwal (1972) has indicated that a low prediction value, with the help of SAR, for exchangeable sodium status of the soil either on the basis of ESR or ESP, could be due to the limited applicability of these types of ion exchange relationships in soils under field conditions.

Waters rich in bicarbonate ions lower SAR - ESP correlation by virtue of precipitation of Ca and Mg as their carbonates. Maliwal (1968) observed a better SAR-ESP correlation by excluding arbitrarily waters having residual sodium carbonate of 2 m.e/l and above and pointed out that RSC value should be given due consideration while predicting ESP on the basis of SAR only.

2.4.5. ESP and pH

The relation between pH and ESP of soils of the Western United States of America was extensively analyzed statistically by Fireman and Wadleigh (1951). They also studied the effects of various factors, such as moisture content, salinity level, and presence of alkaline earth carbonates and gypsum upon this relationship. They indicated that ESP could be predicated from pH values, although the exact exchangeable sodium content of the soils had no such relations. Chang (1953) found the coefficient of correlation (r= + 0.728) between ESP and pH to be statistically significant. The coefficient of determination (r^2 = 0.52) indicated that 52% of the pH could be accounted for by ESP and about 48% by other factors. Agarwal and Yadav (1956), working with the saline and sodic soils of the Indian Gangetic alluvium in Uttar Pradesh, also found a good correlation between pH and ESP which was significant at 1% level. Banerjee (1959), while studying the salt affected soils of West Bengal, India found a correlation coefficient (r = 0.372) between pH and ESP which was significant at 10% level. The coefficient of determination (r^2 = 0.138) indicated that only 14% of the pH could be accounted for by exchangeable sodium, the remaining 86% of the pH could be accounted for by other factors.

Fireman and Reeve (1948) observed that the relationship between pH and ESP is not sufficiently close or consistent to be of much diagnostic value in assessing the degree of sodium saturation from the pH value alone.

The pH of soils increases with the SAR and ESP of soils and significant correlation has been observed between themselves but the relation is not much of practical utility for prediction purposes (Paliwal, 1972). Banerjee (1959) also reported that the prediction of ESP values from pH determinations was not feasible. U.S salinity laboratory staff (1954), however, emphasised the necessity of testing fully the reliability of the relationship between pH and ESP before applying it for any given group of soil samples.

2.4.6. ESP and RSC.

A positive correlation between RSC and SAR of Irrigation water and soil solution has been reported (Paliwal, 1972). The accumulation of sodium on the soil surface seems to increase with the RSC of water as evident by the positive correlation between these variables (Singh and Bhumbla, 1968). Hausenbuiller *et al* (1960) reported a significant correlation between ESP and RSC of irrigation water. Singh and Mahnot (1976) have however reported a negative correlation between RSC of the water and ESP of the soils. Their studies have revealed that poor quality waters have little impact on light textured soils.

2.4.7. pH and Soluble Carbonate and Bicarbonate.

The pH values of irrigation water and soil solution are mostly governed by the amount and proportion of carbonate and bicarbonate ions. Mehta (1970) observed a significant correlation (r = 0.60) between pH of irrigation water and soil. The soluble carbonate and bicarbonate of soils correlated with the pH of soils (Kanwar *et al*, 1963; Kanwar and Mehta, 1970). The pH of irrigation water correlated with its carbonate and bicarbonate contents, but the degree of validity was low (Kanwar and Mehta, 1970). The soil pH correlated with the RSC of irrigation water, and also with SAR of soil solution (Paliwal and Maliwal, 1968).

Paliwal (1972) pointed out that all these correlations except that of EC and total cations though significant, are of low degree of validity and thus are of little practical utility for prediction purposes due to lack of equilibrium and interaction of several soil factors operating simultaneously under field conditions.

2.5 Effect of salts on soil.

The physical and chemical properties of irrigated soils depend largely on the chemical composition of the irrigation water, soil type, drainage characteristics and climatic conditions (Michael, 1978). A knowledge of the chemical and physical characteristics of several salt-affected soils is essential to serve as a basis for their diagnosis, treatment, and management (Richards and Hayward, 1957).

2.5.1 Effect on the soil Chemical Properties

The main process occurring in soils while irrigating with poor quality water are:

(i) Ionic exchange between cations in irrigation water and those present on the soil exchange complex;

(ii) Dissolution and precipitation of Calcium Carbonates;

(iii) Weathering of the primary minerals in the exposed rocks of the earth's crust;

(iv) Hydration and dehydration of the soil as a result of fluctuation in soil moisture;

(v) Leaching down of ions;

(vi) Upward movement of ions through capillary activity, and;

(vii) Mineral nutritional characteristics of the crop.

Among these processes, cation exchange is the most important process governing the accumulation of excessive sodium during irrigation with saline water (Michael, 1978).

(1) <u>Salinization</u>

In saline water irrigated areas, particulary in the arid regions, salt concentration is maximum on the surface and decreases with the increase in depth. Verhoeven (1979) pointed out that a high salt concentration in the soil solution compresses the layer of adsorbed cations resulting in good physical properties of the soil. He explained that these effects can be predicted from the Gouy-Chapman diffuse double layer theory for exchangeable cations. This theory describes the thickness of the mantle of bound water in which the adsorbed exchangeable ions are distributed around the clay particles.

Restricted drainage is a factor that contributes to salinization of irrigated soils. This may involve the presence of a high groundwater table, or low permeability of the soil, or both. Where a high water table exists within 1.0 or 1.5 metres of the soil surface, upward movement of saline ground water, combined with the evaporation of applied irrigation water, may result in the formation of a saline soil (Allison, 1964).

In a well drained light textured soil immediately after irrigation, the soil salinity, as measured on the basis of saturation extract of the soil sample, would be less at surface layers and more at deeper layers. On the contrary, in heavy soils accumulation of salts would be more on the surface due to impeded drainage. Thus it has been reported that under similar soil-water conditions, more salinity would be observed in arid than in humid regions and in heavy textured soils than in light soils (Michael, 1978).

Shainberg and Oster (1978) reported that the electrical attraction of the surface for counter ions (e.g Na) is constant, irrespective of the bulk concentration. However, with the increase in electrolyte concentration in the bulk solution, the tendency of the counter-ions to diffuse away from the surface has been reported to diminish. This has been found to result in the diffuse double layer getting compressed toward the surface when salt concentration in the bulk solution is increased.

(2) Alkalinization.

This is the process whereby the exchangeable sodium content of a soil is increased, leading to the formation of a sodic soil. It involves both salinization and change in composition of the accumulated salts. (Allison, 1964).

Calcium and Magnesium are the dominant cations found in normal soils in arid regions. However, as soluble salts accumulate from irrigation waters and become more concentrated in the soil owing to consumptive use and to the lack of leaching, certain compositional changes occur. The solubility limits of calcium sulphate, calcium carbonate, and magnesium carbonate are exceeded, causing calcium and magnesium to precipitate. This has been reported to cause a corresponding increase in the relative proportion of sodium in the soil solution, i.e soluble - sodium percentage (SSP) increases. Due to the dynamic equilibrium between soluble and adsorbed ions, It has been reported that half or more of the soluble cations must be sodium (SSP >50) before appreciable amounts of this ion are adsorbed by the cation exchange complex (Allison, 1964). As long as soluble salts are present in the soil solution in appreciable quantities, the soil (Saline-Sodic) remains flocculated and permeable, and the pH is less than 8.5. If the soluble salts are removed by leaching, the soil (sodic) may become very impermeable because of the dispersing effect of the adsorbed sodium ion on the exchange complex (Allison, 1964). Arany (1956) pointed out the importance of the anions associated with sodium in the formation of sodic soils. He indicated that the rate of alkalinization is more rapid for the basic than for the neutral salts.

2.5.2 Soil Physical Properties.

The physical properties of soils may be improved or deteriorated in the presence of salts, depending on the nature and amount of salts, the reaction product and the initial physical and chemical conditions of the soil.The main physical properties influencing the air-water relationships in irrigated agriculture are dispersibility of the clay particles and permeability of the soil (Michael, 1978). These properties are markedly influenced by the nature and amount of exchangeable cations and swelling characteristics of the soil.

(i) Dispersibility

The degree of dispersion (DD) was defined by Paliwal (1972) as:

$$DD = \frac{\text{Amount of clay dispersed}}{\text{Total Clay}} \times 100 \quad \text{.... (2.7)}$$

The degree of dispersion (DD) increases with the increase of easily dispersible clay contents and highly hydrated mono-valent cations

The degree of dispersion (DD) increases with the increase of easily dispersible clay contents and highly hydrated mono-valent cations such as sodium on the exchange phase and decreases with the presence of cementing agents (Paliwal 1972).

Light textured soils need a higher degree of sodium saturation for the same degree of adverse effect than heavy soils. It has been reported that the degree of dispersion of soil is controlled by the actual salt concentration in contact with the soil phase, that a saline-sodic soil irrigated with good quality water or less saline water may show a higher degree of dispersion. Michael (1978) indicated that these factors were of great practical significance in the management of sodic soils. He observed that the degree of dispersion of a calcium soil increased with the amount of sodium carbonate or oxalate added, and that the relative increase was different for different types of soil.

Irrigation with highly saline water, particulary having divalent cations is recommended to decrease the dispersibility of the soil and improve its physical conditions, though the salinity of such soils may slightly increase (Michael 1978).

At any salinity level, the degree of dispersion (DD), ESP and pH, has been found to increase with the SAR of the Irrigation water (Paliwal, 1972). He also reported a close correlation between the degree of dispersion and ESP for some deep medium black clay loam desert soil, non-calcic loamy sand and yellowish brown loam, both in Na-Ca and Na-Ca - Mg systems.

In the presence of salts, the diffuse double layer is compressed even at the same level of ESP (Paliwal, 1972). He also observed that although the degree of dispersion increases with the degree of sodium saturation, defining a critical limit of ESP beyond which the soil physical properties are deteriorated is difficult because there is no sharp change in the soil dispersibility with the increase of ESP. Thus he concluded that for the same degree of dispersibility of different textured soils a higher ESP would be necessary in case of light textured soils as compared to heavy soils.

(ii) Permeability.

Permeability of a soil refers to the readiness with which the soil transmits fluids. This property is of great practical importance in the management of saline and sodic soils (Michael, 1978).

Until recently the effect of the salt concentration of the irrigation water as affecting soil permeability has received little attention. This has been the case even though it has been known for a long time that saline - alkali soils have extremely low permeabilities after the salts are removed by leaching (Doneen, 1968). Doneen (1968) has indicated that waters having sodium as the predominant cation tend to disperse i.e, puddle easily when wet and form hard surface clods when dry, resulting in a reduced rate of infiltration. That with an extremely high sodium content in either the water or soil, the irrigation water may remain on the surface for days or weeks, and its disappearance may be due more to evaporation than percolation into the soil.

The permeability of a soil is closely related to its dispersibility and exchangeable sodium status. The movement of water through a highly sodic soil is quite slow due to the dispersion of clay and the increase of zeta-potential. Hydraulic conductivity has been found to decrease with the increase of ESP. It has also been reported that if the applied water contains sufficient salts to suppress the thickness of the diffuse double layer, then the soil permeability is bound to increase (Paliwal, 1972). Abrol (1962) studied dispersion of bentonite clay equilibrated to varying levels of ESP in presence of salts. He reported that a minimum amount of Ca+Mg in milliequivalents, equal to the CEC of the mineral, is required for coagulating the clay, irrespective of the amount of exchangeable sodium. That if soluble plus exchangeable (Ca+Mg) fall below this value the clay remains dispersed (Paliwal, 1972).

Paliwal (1972) pointed out the practical importance of finding the ESP limits and the relative salt concentration with which the soil is completely dispersed and permeability significantly reduced.

CHAPTER THREE

MATERIALS AND METHODS

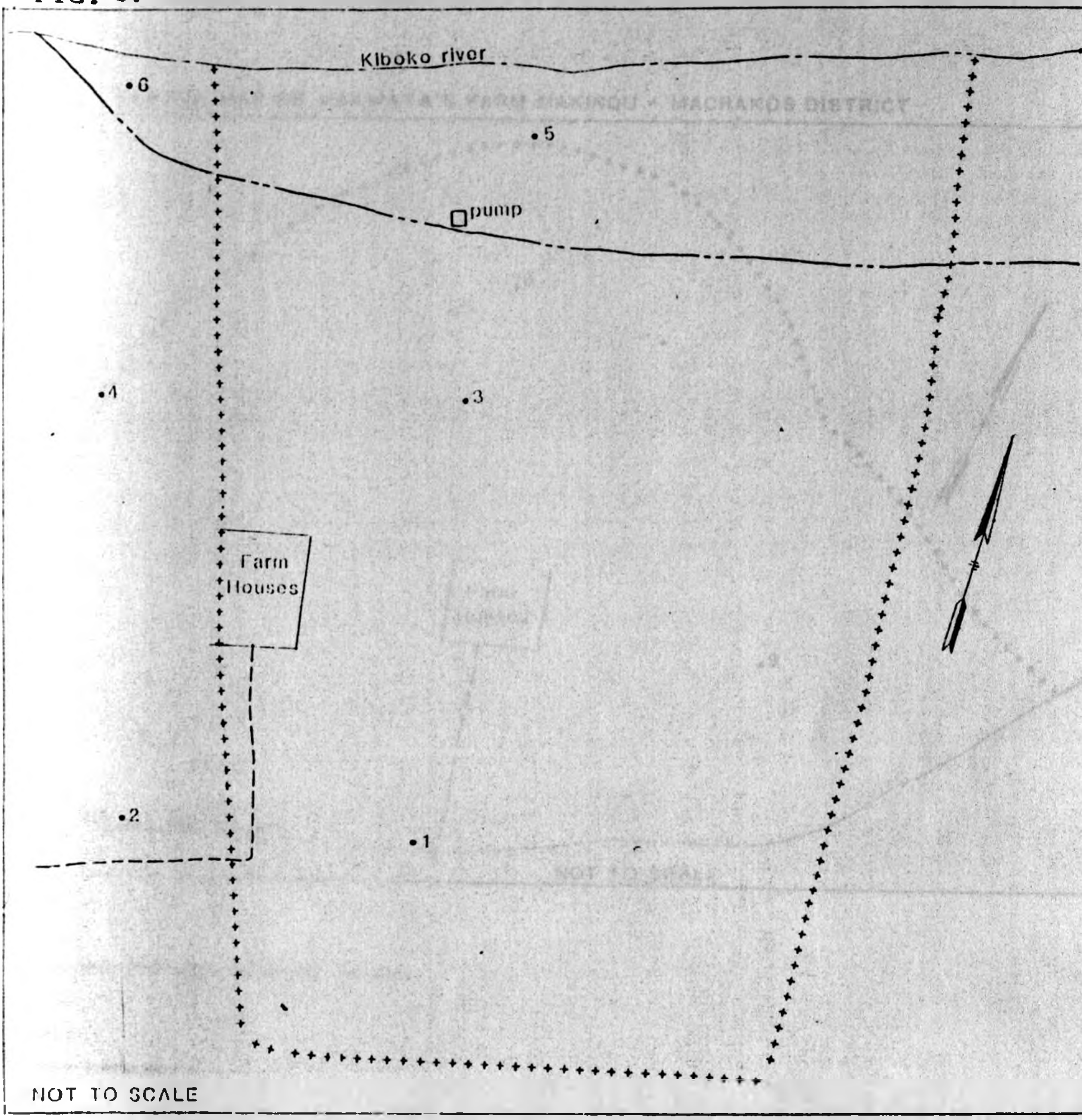
In the study area representative soil sampling sites were selected to represent irrigated and non-irrigated soils. Non-irrigated sites were selected such that they were adjacent to the irrigated sites. This was done so as to see the effect of irrigation water on the soil properties. The properties of the non-irrigated soils are supposed to be the starting point while the properties of the irrigated soils are assumed to give a picture of a soil having been affected by the irrigation water quality.

Soil profiles on representative sites were dug. Three farms were studied; One farm in Kiboko, Muhindi farm and two in Makindu namely Makwata and Museng'ya farms.

Water samples from the rivers from whose water is used for irrigation in each of the three farms was collected for analysis in the laboratory. The objective was to determine their chemical properties and hence their suitability for irrigation on each of the farms concerned. Soil samples were taken from each horizon for all the profiles dug for both physical and chemical analysis in the Laboratory.

The disturbed soil samples were placed in polythene bags. About 5kg of soils were taken from each horizon for all the profiles dug. Six profiles were dug in Muhindi farm, three in Makwatta farm and four in Musengya farm.

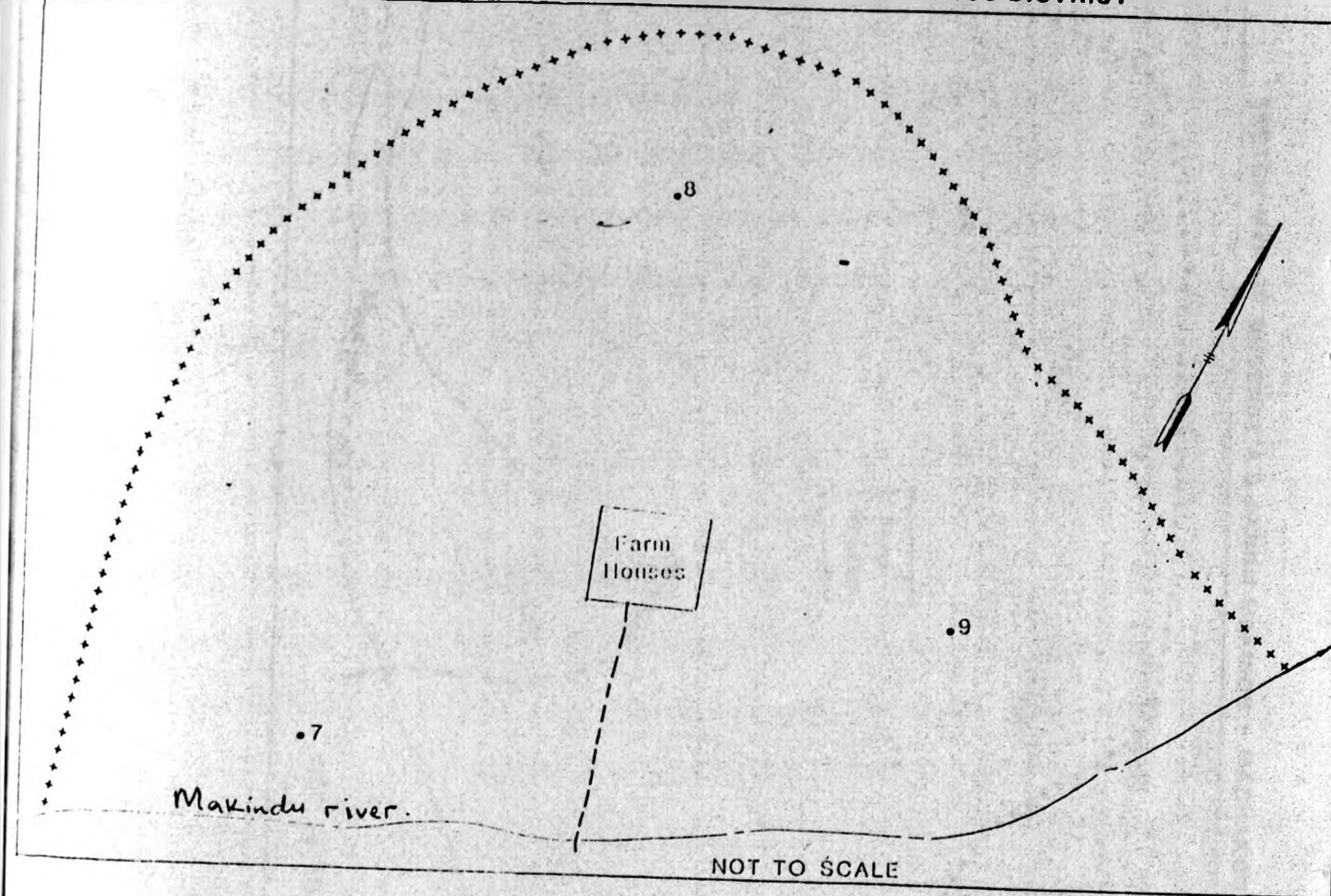
FIG. 3: SKETCH MAP OF MUHINDI'S FARM KIBOKO - MACHAKOS DISTRICT



KEY

•4	sampling site with reference number
- - -	river
—-- —	canal
— — —	track
+ + + +	farm boundary

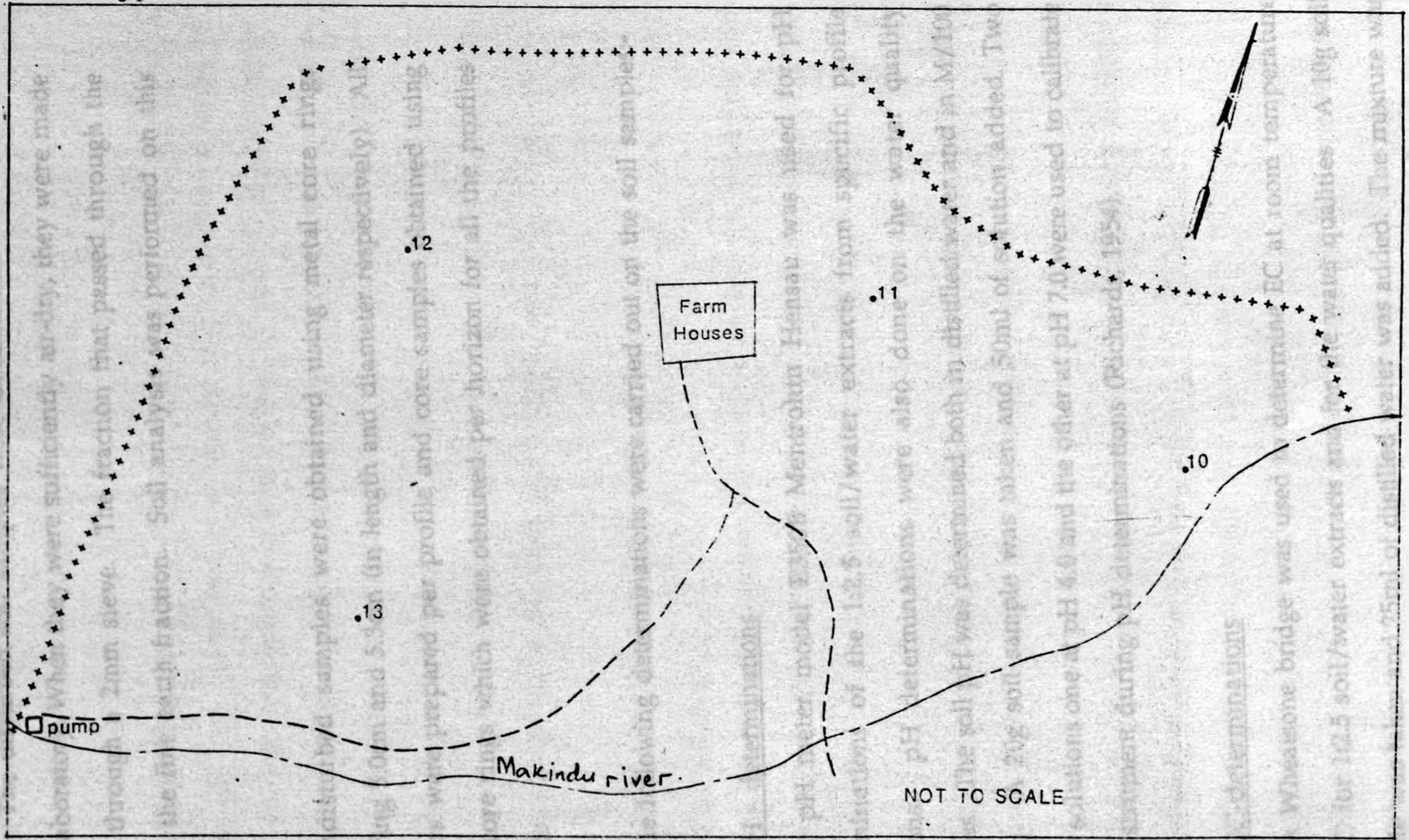
FIG. 4: SKETCH MAP OF MAKWATA'S FARM MAKINDU - MACHAKOS DISTRICT



KEY

- • 7 sampling site with reference number
- - - - river
- — — track
- + + + + farm boundary

FIG. 5: SKETCH MAP OF MUSENGY'A'S FARNM MAKINDU - MACHAKOS DISTRICT



KEY

- •12 sampling site with reference number
- — - — river
- — — — track
- + + + + farm boundary

The disturbed soil samples were documented and air-dried in the Laboratory. When they were sufficiently air-dry, they were made to pass through a 2mm sieve. The fraction that passed through the sieve is the fine earth fraction. Soil analysis was performed on this fraction.

Undisturbed samples were obtained using metal core rings measuring 5.0cm and 5.3cm (in length and diameter respectively). All horizons were prepared per profile and core samples obtained using metal core rings which were obtained per horizon for all the profiles studied.

The following determinations were carried out on the soil samples:-

(a) pH - determinations

A pH meter model E350B Mentrohm Hensau was used for pH determinations of the 1:2.5 soil/water extracts from specific profile horizons. pH determinations were also done on the water quality samples. The soil pH was determined both in distilled water and in M/100 $CaCl_2$. A 20g soil sample was taken and 50ml of solution added. Two buffer solutions one at pH 4.0 and the other at pH 7.0 were used to calibrate the Instrument during pH determinations (Richards, 1954).

(b) EC-determinations

A Wheatsone bridge was used to determine EC at room temperature (22^{o}C) for 1:2.5 soil/water extracts and for the water qualities. A 10g soil sample was taken and 25ml of distilled water was added. The mixture was shaken for one hour. The suspension was left to stand for half hour. The EC readings obtained at 22^{o}C were corrected by correction factors as given by Richards (1954) so as to give the EC values at 25^{o}C. The method followed is similar to the one given by Loveday (1974).

(c) CEC-determination

The CEC was determined by successive shaking and centrifuging of 5.0g of soil with four portions of 33ml each of 1N NaOAC of pH8.2, three portions of 33ml each of 95% ethanol and three portions each of 33ml of IN NH_4OAC of pH 7.0. Determination of Na in the last extract was done using EEL-Flame Photometer. The procedure followed is similar to the one detailed by Black (1965) and United States Department of Agriculture Handbook No.60 (Richards, 1954).

(d) Exchangeable and Soluble Cations and Anion Determinations:

The EEL-Flame Photometer was used to analyse for potassium and sodium in 1:2.5 soil/water extracts and also in the water quality samples as detailed in the U.S.D.A. Handbook No.60 by Richards (1954).

Calcium and magnesium determinations were done on 1:2.5 soil/water extracts and also on the water quality samples by the Versenate titration method using N/100 EDTA as titre and calcon and EBT-Eriochrome Black T. as calcium and calcium plus magnesium indicators respectively. Magnesium titre was obtained by subtraction of calcium titre from the calcium plus magnesium titre upon using 10 ml aliquot.

Exchangeable Na and K were analysed using EEL-flame photometer. Exchangeable Ca and magnesium were analysed by the Versenate titration method using N/100 EDTA as titre. 10ml aliquot were used. Soil samples whose EC (1:2.5 soil/water) were above 0.8 mmhos/cm were first prewashed with 95% Ethanol until free of soluble salts as tested using 2% $BaCl_2$ and 2% $AgN0_3$. The method followed is similar to the one given by Richards (1954) and Metson (1971).

(e) Carbonate, Bicarbonate, Hydroxide and Chloride Determinations:

1:2.5 soil/water extracts were used for the analyses of carbonate, bicarbonate, hydroxide and chloride anions. A 50ml aliquot was used for all the anions determined. It involved titrating the soil/water extracts or the water quality sample with 0.050N H_2SO_4 using Phenolphthalein as indicator. To the same sample 1ml of 2% $K_2Cr_20_7$ was added and the mixture titrated with 0.050N $AgNo_3$.

Hydroxide and carbonate titration were obtained from the first titration with sulphuric acid and Phenophthalein indicator whereas bicarbonate was obtained by the same titration but using methyl orange as indicator. The final titration with 0.050N $AgNo_3$ gave the chloride content. The procedure is as described by Richards (1954) and Black (1965).

(f) Organic carbon determination

Soil samples passing through a 2mm sieve were made to pass through 0.50 mm sieve and used for organic carbon determination.

Organic carbon determination was done using the Walkley and Black method (Black, 1965).

(g) Particle Size Analysis

Soil samples which had been previously made to pass through a 2 mm sieve were used for particle size analysis. Using Boyoncous Hydrometer method (Ahn, 1973). This gave the percentages of sand (0.02-0.2mm), silt (0.02-0.002mm) and clay (< 0.002mm). The particle size analysis involved the initial destruction of the soil organic matter using hydrogen peroxide, dispersion with sodium hexametaphosphate and mechanical stirring, and then analysis of the various size classes by the hydrometer method. Soil textural classes were determined from the standard U.S.D.A. textural triangle (Richards, 1954).

(h) Saturated Hydraulic Conductivity (Ksat)

The constant head method as outlined by Klute (1965) was used. For each horizon from the various profile pits made, core samples were replicated three times. Each core sample was trimmed at the edges to the ring volume and a cheese cloth used to cap the bottom before connecting a second empty ring on the other side using a water-proof adhesive tape. The samples were then saturated using water in a basin by allowing them to stand half-submerged for at least 24 hours at room temperature. Samples from irrigated sites were saturated using irrigation water while samples from non-irrigated sites were saturated using distilled water and so was the experiment also.

The fully saturated samples were mounted on constant head hydraulic conductivity apparatus. Water was introduced into each by siphon tubes supplied from a constant level reservoir tube. A shallow column of water was maintained over the soil surface and all air bubbles excluded from the system to ensure constant and consistent flow. After allowing about 10 minutes for stabilization, water flowing through each core was collected while timing. The water height above the soil core was measured using a glass-slide. At durations varying from 1 hour to 6 hours depending on the rate of conductivity, volumes of water were collected and measured using graduated measuring cylinders. Saturated hydraulic conductivity Ksat was calculated according to Darcy's equation as follows:-

$$K_{sat} = \frac{Q}{A_t} \times \frac{L}{H} \quad \text{.................} \quad (3.1)$$

where

Ksat = Saturated hydraulic conductivity

Q = Quantity of water collected in cm^3,

A = Cross-sectional area of soil core in cm^2

t = Time in hours

L = Length of soil core in cm.

H = Hydraulic Head gradient which is equal to (L+h),

where h is the height of the water column above the soil core surface.

(i) <u>Bulk Density</u>

The method followed is described by Richards (1954). Soil core samples, in triplicates, were placed in the oven at 105°C for at least 24 hours to dry to constant weight. The volume was that of the sample as taken from the field (i.e. volume was calculated from the core-ring dimensions). Bulk density was then calculated as follows:-

$$P_b = \frac{M_s}{Vt} \quad \text{.....................} \quad (3.2)$$

where

M_s = Weight in grams of the oven dry soil sample,

V_t = Total volume of soil at field conditions in cm^3.

(j) Calcium Carbonate Equivalent

Calcium carbonate equivalent was determined by the gravimetric loss of carbon dioxide upon adding 3N hydrochloric acid to a known weight of soil in an Erlenmeyer flask. A torsion-type balance capable of detecting weight differences of 2 to 3 mg was used. The method followed is as detailed by Richards (1954).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Water Analyses

From the data (Table 1) it is observed that electrical conductivity of the irrigation waters ranges from 0.88 to 2.71 dS/m. According to the classification suggested by Richards (1954), all the irrigation waters studied fall in the high to very high salinity classes.

Water containing more than 6 me/l chloride is reported to be unsatisfactory for irrigation by Eaton (1942). In the present study chloride content is less than 6 me/l in all the waters. Such waters may be considered as suitable for irrigation. According to the FAO guidelines for evaluating irrigation water quality (FAO, 1979), the critical limits for surface type of irrigation are as follows: less than 4 me/l Cl^-, no problem expected; 4-10 me/l Cl^-, increasing problem expected; more than 10 me/l Cl^-, severe problems expected if such water is used. For sprinkler irrigation the limits are: less than 3 me/l Cl^-, no problems expected; more than 3 me/l Cl^-, increasing problems expected if such water is used; severe problems are likely to be encountered if water of 10 me/l Cl^- is used. Thus according to the FAO (1979) guidelines, it is only Muhindi farm irrigation water which may be regarded as satisfactory for irrigation. Sprinkler irrigation is used at Muhindi farm in Kiboko. Makwatta and Musengya farms irrigation water may be regarded as suitable for irrigation on the basis of chloride concentration. The concentrations for the two farms are 1.00 me/l and 0.85 me/l Cl^- respectively.

Soluble sodium percentage (SSP), sodium adsorption ratio (SAR) and RSC which govern the quality of irrigation water are presented in Table 1.

The soluble sodium percentages (SSP) of Irrigation waters of Muhindi farm in Kiboko, Makwatta and Musengya farms in Makindu are 36.9, 38.8 and 42.0 respectively. All these waters are in safe limits of solube sodium. According to Richards et al (1957) there is no likelihood of hazard from sodium, provided values of soluble sodium percentage are less than 60 and that in cases where the soils have naturally good structure the limits can be extended to 75. Considering these limits all the waters under study may be regarded as in safe limits of soluble sodium.

The sodium adsorption ratios (SAR) for the Irrigation waters are 3.28, 2.42 and 2.34 while SARad; values are 9.18, 6.29 and 5.85 for Muhindi, Makwatta and Musengya farms respectively. As per the quality classification suggested by Richards (1954), all the waters fall in the low Sodium group.

According to Eaton (1950) Carbonates and Bicarbonates in irrigation water are not desirable as they tend to increase the soil alkalinity. All the irrigation waters analysed do not contain titratable quantities of carbonates. The irrigation waters analysed contain medium concentration of bicarbonates. A major factor affecting the final SAR value of soil water is the change in calcium and magnesium concentration due to precipitation or dissolution of alkaline earth carbonates. In irrigation water containing high concentration of bicarbonate ions, there is a tendency for calcium and, to a lesser extent, magnesium to precipitate in the form of carbonate as the soil solution becomes more concentrated, thus leading to an increase in the SAR of the soil solution and consequently to an increase in the ESP of the soil. On the basis of Residual Sodium Carbonate Concept of Eaton (1950) water with RSC higher than 2.50 me/l is not suitable for irrigation purposes. He defined the range of RSC between 1.25 and 2.50 me/l as marginal and under 1.25 me/l as safe. Thus Muhindi farm irrigation water whose RSC is -11.85 me/l may be considered suitable for irrigation while Makwatta and Museng'ya farms irrigation water with RSC values of 4.05 and 4.20 me/l respectively may be regarded as unsatisfactory for irrigation.

Quality class based on electrical conductivity and sodium adsorption ratio show that Muhindi farm irrigation water fall in the very high salinity and low sodium class, while both Makwatta and Musengya irrigation water fall in the high salinity and low sodium class. On the basis of SARadj it is only Musengya farm irrigation water which is not likely to bring about a sodium or permeability problem. Increasing permeability problems would be expected if Makwatta farm irrigation water is used. Severe permeability problem would result if Muhindi farm irrigation water is used. Upward capillary rise of both Musengya and Muhindi farms groundwaters would give rise to severe sodium or permeability problems.

Thus irrigation waters for the three farms contain high to very high concentration of total soluble salts and low concentration of sodium. From irrigation point of view all the waters studied may be considered as unsatisfactory because their salt concentration is high. However, while judging the quality class of irrigation water, soil texture and soil permeability must also be taken into consideration.

Table 1: Characteristics of Irrigation and Ground Waters

Location	pH	EC (dS/m) at 25°C	Cations (m.e/l) Ca+Mg	Na	K	pH*c	SAR	SARadj	SSP	Anions (m.e/l) CO_3	HCO_3	Cl	RSC
Muhindi Farm Irrigation Water	7.80	2.71	18.6	10.0	1.0	6.6	3.28	9.18	36.9	-	6.75	4.15	-11.85
Muhindi Farm Goundwater (56-120mm)	7.90	17.40	75.5	120.0	5.8	5.8	19.53	70.3	69.0	-	13.00	23.0	-62.5
Makwata Farm Irrigation Water	7.20	1.16	6.9	4.5	1.0	6.8	2.42	6.29	38.8	-	10.95	1.00	4.05
Makwata Farm Groundwater	9.0	53.0	16.0	50.25	31.2	5.7	17.76	65.71	94.7	36.0	180.0	21.0	200.0
Musengya Farm Irrigation Water	7.30	0.88	5.0	3.7	1.00	6.9	2.34	5.85	42.0	-	9.20	0.85	4.20
Musengya Farm Groundwater	7.90	2.40	7.7	14.0	2.2	6.6	7.14	20.0	58.3	-	14.60	1.60	6.9

4.2 Soil Analyses

(i) Soil Chemical properties

Analytical data of the soil samples from all the three farms are presented in Tables 2, 3 and 4. The EC values of 1:2.5 soil/water extracts of soils range from 0.11 to 7.00 dS/m (Table 2). There is a general tendency for these values to increase with depth.

The surface soils for all the profiles dug in Muhindi farm except profile 3 have very low EC values compared to that of irrigation water. This may be due to the light texture of these soils which vary from loamy sand to sandy clay; this allowed free percolation of water. The EC value for the surface soils of profile 3 is somewhat higher probably due to the heavy texture of these soils. The soils of the whole of profile 3 have predominantly clay texture; the clay content increased with depth giving the subsoils high EC values due to increased salt accumulation. The EC values for the lower horizons of profiles 5 and 6 are quite high probably due to the influence of the groundwater whose EC at 25^{0}C was 17.40dS/m. The groundwater in this section of the farm was encountered at a depth of about 90cm from soil surface. The other explanation is the increased clay content down the profile which favoured salt accumulation. According to the U.S.S.L. classification (Richards, 1954) the groundwater belong to very high salinity and high sodium hazard class.

Due to the non-accumulation of salt on the surface of the light textured soils on the upper part of Muhindi farm, tomatoes, brinjals and chillies have been grown without any detrimental effect. The abandonment of the lower part of Muhindi farm in 1982, where profiles 5 and 6 are situated, probably was because the farmer had applied excess water. This raised the water table and led to increased accumulation of salts on the soil surface by capillary movement of salts along with water and their deposition after evaporation of water. During this time , Pawpaws, Watermelons and Pepper had been grown. A poor crop stand and consequent crop failure was experienced.

Sufficient drainage should be provided to the lower part of Muhindi farm in order to reduce the groundwater level to well below the zone of root penetration. It seems probable that continued use of the water for irrigation in the upper part of Muhindi farm, with coarse textured soils, may not result in harmful accumulation of either soluble salts or sodium if good water management practices are followed and salt-tolerant crops grown. The texture of Makwatta farm soils are predominantly clay. The chemical status of these soils (Table 2) show progressive increase in soil salinity with depth in the profiles of both irrigated and non-irrigated soils. This undoubtedly could be attributed to the very high salinity of the groundwater whose EC at $25^{o}C$ was 53.0 dS/m coupled with the fine texture of these soils (See Table 1). Muhindi Farm groundwater was encountered at a depth of 120cm from soil surface and rose to a depth of 56cm from the surface overnight. Makwata and Museng;ya farms groundwaters were encoutered at a depth of 150cm and 100cm respectively and rose overnight to 80cm and 58cm from the soil surface respectively. The groundwater belong to very high salinity and very high sodium class. Based on SARadj the groundwater may be the cause of the observed severe permeability problem. The hydraulic conductivity values of these soils ranged from slow to moderately slow corresponding to

Table 2: **Soil reaction, calcium carbonate equivalent salinity, SAR, and SSP of soil extracts**

1. MUHINDI FARM IN KIBOKO

Profile Number	Soil depth (cm)	pH-H_2O	$CaCO_3$ eq %	EC (dS/m)	SAR	SSP
Irrigated						
	0 - 20	7.6	0.8	0.14	0.58	35.71
1	20 - 34	7.8	0.3	0.11	0.58	45.45
	34 - 87	5.6	0.0	0.25	0.50	20.00
	87 - 108	5.0	0.0	0.22	0.50	22.75
Non-Irrigated						
	0 - 28	6.3	0.6	0.54	0.32	9.26
2	28 - 62	6.1	0.6	0.35	0.24	7.14
Irrigated						
	0 - 10	7.8	0.4	0.83	2.47	42.17
3	10 - 28	7.6	0.5	0.72	2.12	41.67
	28 - 51	7.3	0.3	1.75	0.71	11.43
	51 - 118	7.1	0.2	2.68	0.51	7.46
Non-Irrigated						
	0 - 14	7.0	0.1	0.13	0.71	38.46
4	14 - 41	7.0	0.2	0.72	0.14	3.47
	41 - 66	7.5	0.0	0.77	0.13	3.28
	66 - 106	7.0	0.2	1.39	0.88	14.39
Irrigated before (Abandoned)						
	0 - 28	7.3	0.5	0.15	0.40	16.67
5	28 - 45	6.8	4.5	3.51	5.97	39.89
	45 - 83	8.0	0.1	6.40	6.21	39.06
	83 - 130	8.1	1.8	5.57	5.79	40.39
Non-Irrigated (Salt affected) due to see page						
	0 - 12	6.9	0.4	0.26	0.53	19.23
6	23 - 49	7.9	0.1	7.00	10.83	60.71
	49 - 110	8.1	1.1	6.83	8.39	52.71

Table 2 Continued

2. MAKWATTA FARM IN MAKINDU

Profile Number	Soil depth (cm)	pH-H_2O	$CaCO_3$ eq %	EC (dS/m)	SAR	SSP
	Non-Irrigated					
	0 - 15	8.1	5.5	0.21	0.23	9.52
7	15 - 40	8.6	17.7	0.25	0.50	20.00
	40 - 56	9.3	15.8	0.64	4.62	62.50
	Irrigated					
	0 - 10	8.0	34.2	0.41	0.41	12.20
	10 - 21	8.4	49.4	0.3	0.77	25.64
8	21 - 50	8.8	20.4	2.89	7.16	44.98
	50 - 80	9.1	29.1	3.92	20.79	70.15
	80 - 124	9.2	31.7	1.13	5.70	57.52
	Irrigated					
	0 - 27	8.2	10.3	0.23	0.65	21.74
	27 - 48	8.6	27.6	0.35	0.71	14.29
9	48 - 74	8.9	46.9	3.30	12.33	59.09
	74 - 102	8.8	38.2	5.98	12.85	56.86

Table 2 Continued

3. MUSENGYA FARM IN MAKINDU

Profile Number	Soil depth (cm)	pH-H_2O	$CaCO_3$ eq %	EC (dS/m)	SAR	SSP
	Non-Irrigated					
	0 - 40	8.3	12.9	0.25	0.22	8.00
10	40 - 72	8.6	19.8	0.29	0.29	9.68
	72 - 102	8.6	28.7	0.16	0.16	5.56
	Irrigated					
	0 - 20	8.2	0.05	0.19	0.79	26.32
	10 - 21	8.4	0.70	0.33	1.58	30.30
11	21 - 50	8.8	2.00	0.14	1.58	71.43
	50 - 80	9.1	2.40	0.55	2.12	27.27
	80 - 124	9.2	3.50	0.31	1.94	48.39
	Irrigated					
	0 - 28	8.0	0.6	0.17	0.57	23.53
	28 - 42	8.4	2.7	0.25	1.58	40.00
12	42 - 82	8.6	17.8	3.27	2.12	55.56
	82 - 115	8.5	14.5	0.33	4.53	15.15
	Irrigated					
	0 - 23	8.6	2.5	0.99	9.56	80.80
13	23 - 58	8.9	26.4	0.72	5.59	69.44
	58 +	8.8	39.0	0.84	1.00	20.83

0.004 to 0.69 cm^3/hr. The non-accumulation of salts on the surface soils of Makwatta farm was observed despite the low permeability of these soils. This could be attributed to the high organic matter content and large amount of free Carbonates which may have aided in maintaining some degree of amelioration.

Makwatta farm was first cultivated in 1977 and abandoned in 1978 after the farmer experienced salt problem and waterlogging condition. Before cultivation of the land the soils were already sodic due to the high sodium hazard of the groundwater (SARadj = 65.71) The farmer could have applied excess irrigation water which then raised the water table. This led to increased accumulation of salt in the lower layers of the soil. The salt concentration of the surface soils was lowered through leaching with irrigation water. The sodium in the exchange complex was hydrolysed and clay particles were dispersed permeability reduced and as a result drainage and root aeration became poor. The yield of Karela, Brinjals and Okra were adversely affected. The waterlogging condition experienced by the farmer is attributable to the heavy texture of the soils and restricted soil permeability as a result of the high exchangeable status of the soils. The observed low productivity was because of poor internal drainage of these soils Lack of root aeration and high sodium status of the subsoils prevented deeper root penetration in the farm. These soils are not saline on the surface layers and should produce good yields of shallow-rooted crops such as chillies and other vegetables possessing some degree of salt tolerance.

The reclamation of Makwatta farm soils would be a slow process even after ample drainage has been provided because of dense clay subsoils. The presence of dense clay layers makes it difficult to remove salts. Ploughing under of farmyard manure or green-manuring crops might help improve drainage. Soil amendments such as gysum ($CaSO_4$) alone would probabily be of doubtful value in correcting the high exchangeable Na status of the subsoils due to their extremely low permeabilities.

Irrigated surface soils of Musengya farm in Makindu whose texture range from sandy clay loam to clay loam are well drained (the section of the farm where profiles 11 and 12 were sited). Chemical analysis (Table 2) indicate that there has been no appreciable increase in soil salinity with depth despite the use of high salinity water for irrigation (Table 1). The reason for this could be because the farmer incorporated farmyard manure into the soil in bulk. The farmyard manure that the farmer applied periodically aided in improving drainage. It also prevented the deterioration of the physical condition of the soil by interacting with the inorganic cation exchange material. Farmyard manure also counteracts the effect of exchangeable sodium in the because of their high cation exchange capacity. soil and allows free percolation of water.

The soils of the section of Musengya farm where profile 13 was sited had a texture which was predominantly clay. The EC value of soil/water extracts for surface soils was found to be higher than for the water used for irrigation. The heavy texture of the soil facilitated the accumulation of salts on the soil surface due to impeded drainage. Although groundwater whose EC value at 25^{o}C was 2.40 dS/m was encountered within 90 cm of the soil surface in this section of the farm, this did not result in higher EC values for soil/water extracts of subsurface horizons. This was probably due to clay accumulation making these soils to have low permeability.

The cation exchange capacity for the soils of Muhindi farm vary from 5.4 to 19.0 me/100g which is considered low because of the light textural character and the low organic matter content of these soils. The CEC for the soils of Makwata farm vary from 8.5 to 34.0 me/100g which may be regarded as ranging from low to high. The surface soils have high CEC values probably due to the high organic matter content and high clay content. The CEC values for Musengya farm soils range from 13.0 to 46.0 me/100g which is considered to belong to the categories of medium to very high due to the high clay content and high organic matter content (See Table 3).

According to FAO (1979), soils with CEC values of more than 40 me/100g clay are considered to be good agricultural soils. CEC values in the range of 25 - 40 me/100g are rated as high and require only small quantities of lime and potassium fertilizer for good productivity. Those soils with CEC values between 15 and 25 me/100g fall in the medium category and are considered satifactory for agriculture given fertilizers. The FAO (1979) quote CEC value of 8.0 to 10.0 me/100g of soils as indicative minimum values in the top 30cm of soil for satisfatory production under irrigation, provided other factors are favourable. A highly significant positive correlation ($r = 0.7162$) between organic carbon content and CEC was obtained in this study . The coefficient of determination ($r^2 = 0.51$) indicate that 51 per cent of the CEC could be accounted for by the organic carbon content of the soils and the remaining 49 per cent by other factors.

The ESP values for the upper layers of soils are comparatively lower than for the lower layers which suggests that equilibrium condition had been attained in the upper layer. The higher ESP values for the lower layers may be ascribed to the incomplete equilibrium conditions. The mechanism governing the equilibrium conditions seem to be that the irrigation water first passed through the top layers and exchanged most of the calcium and magnesium for sodium, leaving very little to be exchanged in the lower layers.

Table 3: Organic Carbon, Cation Exchange Capacity, Exchangeable Cations and ESP of Soils

1. MUHINDI FARM IN KIBORO

Profile Number	Soil Depth (cm)	Organic Carbon %	Exchangeable Cations (m.e/100g) Na	K	Ca	Mg	CEC (m.e/100g)	ESP
	Irrigated							
	0 - 20	0.51	0.8	0.8	2.0	0.5	6.1	13.11
1	20 - 34	0.27	0.9	0.7	1.8	0.5	5.8	15.51
	34 - 87	0.19	0.9	0.7	1.8	0.4	5.6	16.07
	87 - 108	0.09	1.0	0.7	1.9	0.5	5.4	18.51
	Non-Irrigated							
2	0 - 28	0.74	0.8	0.6	2.9	0.7	7.6	10.53
	28 - 62	0.34	0.8	1.1	1.5	1.4	8.0	10.00
	Irrigated							
	0 - 10	1.80	2.5	2.5	9.5	4.1	19.0	13.16
3	10 - 28	0.62	2.0	2.4	7.5	1.8	17.0	11.76
	28 - 51	0.3	2.0	1.8	10.0	2.2	16.3	12.27
	52 - 118	2.19	2.1	2.2	4.8	4.8	14.0	15.00
	Non-Irrigated							
	0 - 14	1.75	0.8	1.2	6.3	1.6	14.0	5.71
4	14 - 41	0.40	0.7	1.4	5.0	2.0	13.4	5.22
	41 - 66	0.23	0.8	1.1	5.0	1.9	13.4	5.97
	66 - 106	0.07	1.1	1.3	9.5	1.3	15.0	7.33
	Irrigated before (Abandoned)							
	0 - 28	1.71	1.0	2.6	11.2	2.8	18.3	5.66
5	28 - 45	0.40	1.1	2.6	4.3	4.8	15.8	6.96
	45 - 83	0.34	1.5	3.1	8.2	6.0	18.8	7.98
	83 - 130	0.08	1.5	2.4	6.8	5.1	15.8	9.49

Table 2 Continued

2. MAKWATA FARM IN MAKINDU

Profile Number	Soil Depth (cm)	Organic Carbon %	Exchangeable Cations (m.e/100g) Na	K	Ca	Mg	CEC (m.e/100g)	ESP
	Non-Irrigated (salt affected) due to see page							
	0 - 12	2.07	1.0	1.8	10.0	3.4	16.3	6.13
6	23 - 49	0.38	4.0	3.0	8.7	3.0	18.3	21.86
	49 - 110	0.25	3.0	2.8	9.0	2.6	17.5	17.14
	Non-Irrigated							
	0 - 15	0.97	1.3	6.4	18.0	3.8	34.0	3.82
7	15 - 40	0.69	1.4	6.2	1.7	7.7	18.0	7.78
	40 - 56	0.35	1.5	1.3	5.0	5.1	16.5	9.09
	56 - 100	0.08	6.6	1.5	1.3	0.8	15.0	44.00
	Irrigated							
	0 - 10	3.53	1.5	2.2	13.5	2.4	27.0	5.56
8	10 - 21	1.44	1.6	2.1	10.4	4.9	24.0	6.67
	21 - 50	0.30	2.6	2.0	9.0	7.0	22.0	11.82
	50 - 80	0.13	5.0	1.8	6.4	3.6	18.0	27.78
	80 - 124	0.14	2.1	1.4	6.4	1.6	12.5	16.80
	Irrigated							
	0 - 27	2.67	1.2	3.9	16.6	4.4	30.0	4.00
9	27 - 48	0.80	1.8	5.4	5.2	5.5	18.0	10.00
	48 - 74	0.17	0.8	1.0	2.4	3.8	8.5	9.41
	74 - 102	0.09	0.5	4.5	2.0	2.8	9.5	5.26

Table 3 Continued

3. MUSENGYA FARM IN MAKINDU

Profile Number	Soil Depth (cm)	Organic Carbon %	Exchangeable Cations (m.e/100g) Na	K	Ca	Mg	CEC (m.e/100g)	ESP
	Non-Irrigated							
	0 - 40	5.48	1.6	5.0	10.8	6.4	46.0	3.48
10	40 - 72	1.64	1.2	3.1	9.6	12.8	32.0	3.75
	72 - 106	0.86	1.2	3.2	5.6	16.0	17.0	7.06
	Irrigated							
	0 - 20	1.32	1.4	2.1	7.6	3.5	15.0	9.33
	20 - 52	0.55	1.6	2.0	8.6	3.4	18.0	8.89
11	52 - 88	0.35	1.8	2.3	4.0	3.2	17.0	10.59
	88 - 115	0.16	1.9	2.8	7.1	3.5	15.5	12.26
	115 - 165	0.05	1.5	1.9	6.0	2.8	13.0	11.53
	Irrigated							
	0 - 28	2.10	1.4	3.6	14.8	4.8	24.0	5.60
12	28 - 42	0.40	1.2	3.8	10.4	3.2	23.0	5.22
	42 - 82	0.29	1.1	3.2	8.4	3.1	19.0	5.79
	82 - 115	0.10	0.5	4.0	5.2	8.3	20.0	2.50
	Irrigated							
	0 - 28	3.46	4.0	3.4	20.4	2.4	44.0	9.09
13	23 - 58	0.75	1.2	2.2	11.6	2.4	28.0	4.29
	58+	0.42	0.2	1.0	7.6	2.8	14.0	1.41

In Musengya and Makwata farms, the pH of soils are higher than for their respective irrigation waters probably due to the heavy texture of these soils. The pH of the soils of Muhindi farm are however lower than the pH of irrigation water due to the light textural character of these soils.

The principal soluble cations in the soil/water extract are the alkali earth ions and more particularly sodium ions especially in the lower depths (Table 4) . Among the anions, chlorides and bicarbonates dominated over carbonates. The presence of greater amounts of soluble sodium in soil/water extracts of Makindu soils have provided higher sodium saturation percentages to these soils compared to Kiboko soils (Table 2). This is also reflected in the soil reaction which is distinctly alkaline with pH values of 8.1 and more. The pH values for the subsoils of profiles 5 and 6 are higher than for the irrigation water probably due to the influence of the groundwater.

The calcium carbonate equivalent of Muhindi farm soils range from 0.0% to 4.5%. These soils may be regarded as non-calcareous except one pedon of Profile 5 of 28-45cm depth which is calcareous. All the Pedons of the two farms in Makindu range from calcareous to extremely calcareous.

Table 4: Ionic Composition of 1:2.5 Soil/Water Extract of Soils

1. MUHINDI FARM IN KIBOKO

Profile Number	Soil Depth (cm)	Cations (me/100g.) Na	K	Ca+Mg	Anions M.e/l) CO_3	HCO_3	CL
	Irrigated						
1	0-20	0.50	0.25	1.50	-	1.00	0.70
	20-34	0.50	0.25	1.50	-	1.00	0.50
	34-87	0.50	0.25	2.00	-	0.50	1.00
	87-108	0.50	0.25	2.00	-	0.40	1.50
	Non-Irrigated						
2	0-28	0.50	0.25	5.00	-	3.00	1.00
	28-62	0.25	0.25	2.20	-	3.00	0.00
	Irrigated						
3	0-10	3.50	1.00	4.00	-	3.00	1.00
	10-28	3.00	0.50	4.00	-	3.00	1.00
	28-51	2.00	1.00	16.00	-	1.00	1.00
	51-118	2.00	1.00	31.00	-	3.00	2.00
	Non-Irrigated						
4	0-14	0.50	0.50	0.25	-	1.50	0.40
	14-41	0.25	0.50	6.60	-	4.50	2.00
	41-66	0.25	0.25	7.00	-	4.50	2.00
	66-106	2.00	0.50	10.40	-	4.00	4.00
	Irrigated before (Abandoned)						
5	0-28	0.25	1.00	0.80	-	0.00	1.0
	28-45	14.00	2.30	11.00	-	0.40	13.00
	45-83	25.00	4.50	32.40	-	6.90	18.00
	83-130	22.50	4.00	30.20	-	4.70	17.40

Table 4 Continued

2. MAKWATTA FARM IN MAKINDU.

Profile Number	Soil Depth (cm)	Cations (m.e/l)			Anions (m.e/l)		
		Na	K	Ca+Mg	CO_3	HCO_3	CL
	Non-Irrigated (salt affected) due to see page						
	0-12	0.50	1.00	1.80	-	1.00	2.00
6	23-49	42.50	6.50	30.80	-	3.00	14.00
	49-110	36.00	5.00	36.80	-	3.00	17.40
	Non-Irrigated						
	0-40	0.20	1.00	1.50	-	1.50	1.20
7	15-40	0.50	0.50	2.00	-	2.00	1.00
	40-56	4.00	1.00	1.50	2.50	1.70	3.00
	56-100	8.00	1.00	1.00	4.00	1.30	7.50
	Irrigated						
	0-10	0.50	1.00	3.00	-	2.00	1.00
	10-21	1.00	1.00	3.40	-	2.50	1.60
8	21-50	13.00	4.00	6.60	1.00	7.00	12.90
	50-80	27.50	4.50	3.50	3.00	5.00	16.00
	80-124	6.50	3.50	2.60	2.50	3.00	4.00
	Irrigated						
	0-27	0.50	0.50	1.20	-	1.00	1.20
9	27-48	0.50	1.50	1.00	-	2.00	1.00
	48-74	19.50	4.50	5.00	3.00	13.00	9.90
	74-102	34.00	6.50	14.00	1.00	16.00	30.00

Table 4 Continued

3. MUSENGYA FARM IN MAKINDU

Profile Number	Soil Depth (cm)	Cations (m.e/l) Na	K	Ca+Mg	Anions (m.e/l) CO_3	NCO_3	CL
	Non-Irrigated						
	0-40	0.20	1.00	1.70	-	1.00	1.20
10	40-72	0.30	1.00	2.10	-	1.50	1.00
	72-106	0.20	1.00	3.20	-	2.40	1.00
	Irrigated						
	0-20	0.50	0.50	0.80	-	0.80	0.00
	20-52	1.00	0.50	0.80	-	1.00	0.20
11	52-88	1.00	0.50	0.80	-	1.50	0.10
	88-115	1.50	0.50	1.00	-	4.00	0.00
	115-165	1.50	0.50	1.20	-	2.00	0.00
	Irrigated						
	0-28	0.40	0.50	0.50	-	0.00	2.00
12	28-42	1.00	0.50	0.50	-	2.00	1.00
	42-82	1.50	0.50	0.50	-	3.00	0.00
	82-115	0.50	1.00	1.00	-	2.00	1.00
	Irrigated						
	0-23	8.00	1.50	1.40	-	4.00	2.00
13	23-58	5.00	1.00	1.60	-	5.00	1.00
	58+	1.00	0.50	2.00	-	2.00	1.00

Alkaline-earth carbonates are important for they constitute a potential source of soluble calcium and magnesium for the replacement of exchangeable sodium in alkali soils. The choice of chemical amendments for the replacement of exchangeable sodium is directly related to the presence or absence of alkaline-earth carbonates. The free carbonates present in the soils of Makindu were derived from carbonate-rich rocks of sedimentary origin (Michieka and Van der Pouw, 1977).

(ii) Soil Physical Properties

Data on the soil physical properties determined for the three farms studied are presented in Table 5. It can be seen that texture for irrigated surface soils vary from Sandy Loam to Clay for Muhindi farm, and Sandy Clay Loam to Clay for both Makwata and Museng'ya farms. The texture of the non-Irrigated surface soils for the three farms studied vary from Sandy Clay Loam to clay. It can be observed that clay content increased with depth for all the soil profiles studied. The soil texture for Makwata and Museng'ya farms are mainly clay. The formation of clay may be as a result of hydrolytic decomposition in presence of high moisture status prevailing in the profiles and their subsequent accumulation favour the genesis of heavy textured subsoils.

Table 5: Soil Physical Properties

1. MUHINDI FARM IN KIBOKO

Profile Number	Depth (cm)	Bulk density (g/cm)	Porosity	Sand	Silt	Clay	Textural Class	Hydraulic conductivity (cm^3/hr)
	Irrigated							
	0 - 20	-	-	82	6	12	-	-
1	20 - 34	1.59	40	80	6	14	SL/LS	6.30
	34 - 87	1.55	42	76	6	18	SL	2.50
	87 - 108	1.55	42	78	4	18	SL	0.84
	Non-Irrigated							
	0 - 28	1.44	46	78	6	16	SL	3.93
2	28 - 62	1.46	45	68	6	26	SCL	1.65
	Irrigated							
	0 - 10	-	-	32	24	44	C	-
3	10 - 28	1.47	45	44	12	44	C	0.53
	28 - 51	1.43	46	38	6	56	C	0.92
	51 - 118	1.45	45	40	12	48	C	0.07
	Non-Irrigated							
	0 - 14	1.57	41	60	12	28	SCL	0.35
4	14 - 41	1.52	43	14	38	38	CL	0.22
	41 - 46	1.49	44	50	8	42	SC	0.48
	66 - 106	1.43	46	46	16	38	SC	0.17
	Irrigated before (Abandoned)							
	0 - 28	1.48	44	58	14	28	SCL	0.91
5	28 - 45	1.43	46	50	8	42	SC	0.07
	45 - 83	1.39	48	44	8	48	C	0.05
	83 - 130	1.46	45	48	6	46	SC	0.02

Table 5 Contined

2. MAKWATA FARM IN MAKINDU

Profile Number	Depth (cm)	Bulk density (g/cm)	Porosity	Sand	Silt	Clay	Textural Class (cm^3/hr)	Hydraulic conductivity
	Non-Irrigated (salt affected) due to see page							
	0 - 23	1.37	48	60	14	26	SCL	0.97
6	23 - 49	1.44	46	46	6	48	C	0.05
	49 - 110	1.40	47	48	6	46	SC	0.02
	Non-Irrigated							
	0 - 15	0.99	66	26	30	44	C	0.48
7	15 - 40	1.03	61	26	8	66	C	0.22
	40 - 56	1.17	56	24	8	68	C	0.17
	56 - 100	1.18	55	24	10	66	C	0.004
	Irrigated							
	0 - 10	0.99	63	46	20	34	SCL	18.19
	10 - 21	-	-	42	18	40	C/CL	-
8	21 - 50	1.16	56	24	8	68	C	0.69
	50 - 80	1.14	57	26	6	68	C	0.18
	80 - 124	1.05	60	32	8	60	C	0.10
	Irrigated							
	0 - 27	0.88	67	28	28	44	C	0.33
	27 - 48	1.00	62	20	12	68	C	0.15
9	48 - 74	0.98	63	16	12	72	C	0.25
	74 - 102	-	-	24	16	60	C	-

Table 5 Continued

3. MUSENGYA FARM IN MAKINDU

Profile Number	Depth (cm)	Bulk density (g/cm)	Porosity	Sand	Silt	Clay	Textural Class	Hydraulic conductivity (cm^3/hr)
	Non-Irrigated							
	0 - 40	0.94	65	32	30	38	CL	0.72
10	40 - 72	1.01	62	28	16	56	C	0.63
	72 - 106	1.18	55	22	12	66	C	0.26
	Irrigated							
	0 - 20	1.28	52	56	12	32	SCL	7.28
	52 - 88	1.44	46	48	6	46	SC	0.24
11	88 - 115	-	-	50	8	42	C	0.34
	115 - 165	-	-	46	16	38	C	-
	Irrigated							
	0 - 28	1.15	57	50	12	38	SC	2.04
	28 - 42	1.15	57	38	8	54	C	0.43
12	42 - 82	1.26	52	34	12	54	C	0.12
	82 - 110	-	-	34	14	52	C	-
	Irrigated							
	0 - 23	0.89	66	32	20	48	C	0.42
	28 - 58	0.95	64	24	12	64	C	1.76
12	58+	0.98	63	24	18	58	C	0.11

The total porosity (f), or total pore space, of the soils were calculated from dry bulk density Values and the average particle density of $2.65 g/cm^3$ according to the equation:

$$\text{Total porosity (f)} = (1 - \rho_b/\rho_p) \times 100 \quad \text{--------------} \quad (4.1)$$

$$\text{Total Porosity (Volume \%)} = 1 - \frac{\text{(Dry bulk density)}}{\text{(particle density)}} \times 100 \; \ldots \; (4.1)$$

where f = Total porosity (volume %)
ρ_b = Dry bulk density,
and ρ_p = Particle density.

Values of total Porosity of soils are of interest because they determine how much soil space is occupied jointly by water and air. The values also indicate the degree of soil campaction in the same way as bulk density is used. It will be noted that there is a gradual decrease in total porosity values with depth. The values range from 40 - 67 Per cent. The low porosity of surface soils in Muhindi farm may be a reflection of the poor structural condition and lack of stability of the aggregates which may lead to compaction. Lutz (1952) stated that the reduction in total porosity that accompanies compaction is usually at the expense of the larger pores. The other possible reason might be the deflocculation of the soil as a result of the dispersing effect of soluble sodium present in the irrigation water.

The desiccation of the surface soil especially in Makwata and Musengya farms during prolonged dry season would be expected to result in pronounced compaction but this is not the case. Soil porosity values for the two farms are quite high probably due to the cracks that these soils develop during the dry season which tend to increase pore spaces. These soils are difficult to cultivate during the dry season as well as during the wet season. They tend to be sticky when wet and hard when dry because of the high clay content. Total pore space for the coarse textured soils is low, a large proportion of it being composed of large pores which are very efficient in the movement of water and air. The percentage of the volume occupied by small pores in the sandy soils is low. This accounts for their low water-holding capacity. In contrast, the fine-textured surface soils have more total pore space and a relatively large proportion is composed of small pores. That is why they have a higher water-holding capacity. Water and air will move through the soil with difficulty because there are few large pores. Thus the amount of pore spaces in the soil may be as important as the total amount of pore space.

The soil bulk density refers to the density of the soil in its natural state. It is the weight per unit volume of an undisturbed soil. The soils that have high total porosity values have low bulk densities. Likewise, the soils that have low total porosity values have high bulk densities. Although both soil porosity and bulk density give a measure of pore space, they do not tell how fast water will move through the soil. The bulk density values for irrigated soils in Muhindi farm decreased with depth while for non-irrigated soils they generally increased with depth. This probably could be because clay content increased with depth and also the effect of cultivation and organic matter content decrease with depth. It can be observed that where bulk density is high, total soil porosity is low. The lowest and highest bulk density values are 0.88 and 1.57g/cm^3 and correspond to the highest and lowest total soil Porosity values of 67 and 41 percent respectively.

It can be observed that the coarse textured soils have high bulk densities (1.78 to 1.59 g/cm^3), low pore space (40 to 46 per cent) but are quite permeable (the observed hyraulic conductivity values are high) because the pores that are present are large and continuous. Conversely, heavy textured soils have low bulk densities (0.88 to 1.47 g/cm^3), high pore space values (45 to 67 per cent), but are slowly permeable (0.07 to 0.33 cm^3/hr) because the pores are small and often discontinuous.

The hydraulic conductivity values for the soil surface for the irrigated soils in Muhindi farm vary from 0.53 to 6.30 cm^3/hr and then may be classified as moderately slow to moderate. The surface soils for the irrigated sites in Makwata farm have hydraulic conductivities varying from moderately slow to rapid (0.33 cm^3/hr to 18.19cm^3/hr) while those of Museng'ya farm vary from moderately slow to moderate (0.42cm^3/hr to 7.28cm^3/hr). The reasons for extremely low values of hydraulic conductivity in subsoils may be the high moisture regime (wetness of soil was observed to increase with depth) and sodium saturation, which causes the swelling and dispersion of clays, thus reducing the effective size of the pores. Soil permeability is related to pore size and pore continuity which in turn is related to soil texture and structure. To change the permeability of a soil one can either change the texture or improve structure. Textural changes only apply to small areas and therefore improved soil structure is the only economical way of changing large areas.

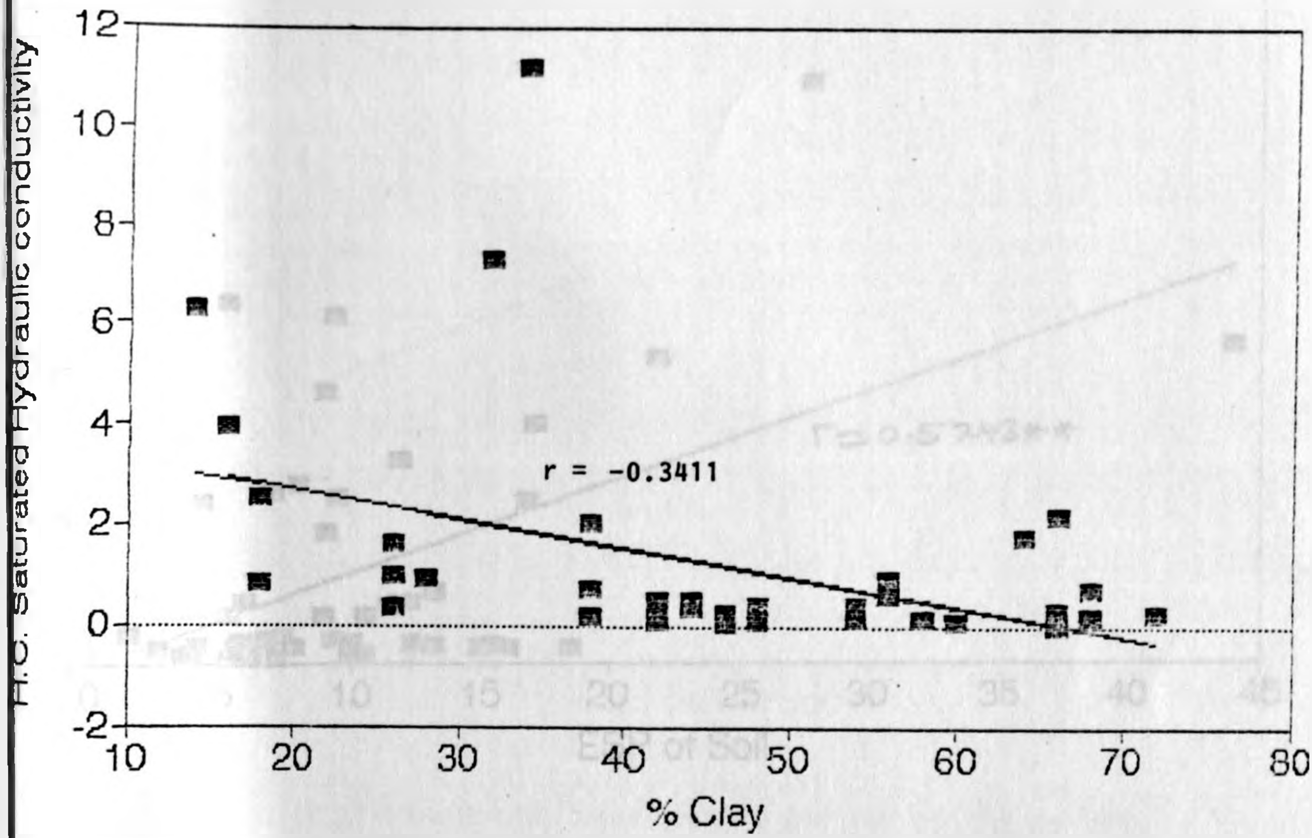


Figure 6 (a): Relationship between % clay and saturated hydraulic conductivity

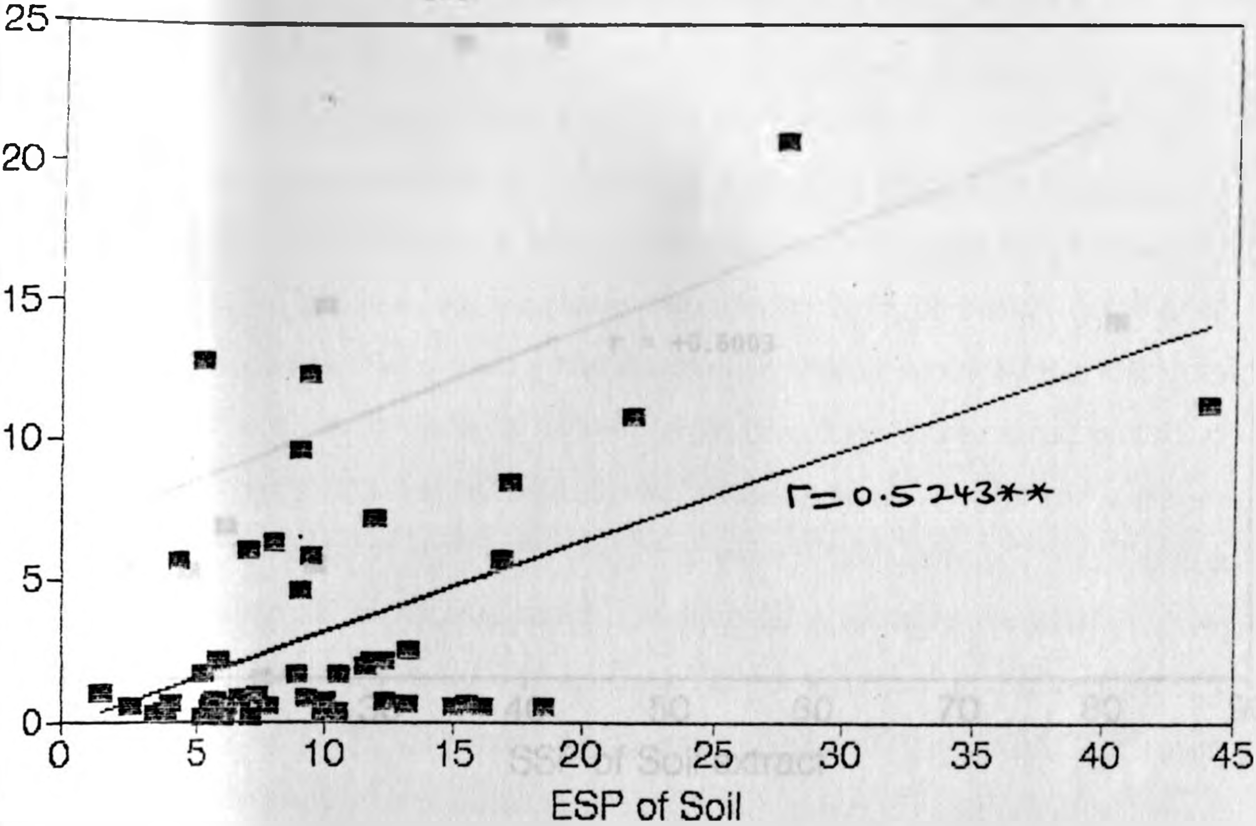


Figure 6 (b): Relationship between ESP and SAR of soil extract (for both surface and sub-surface horizons)

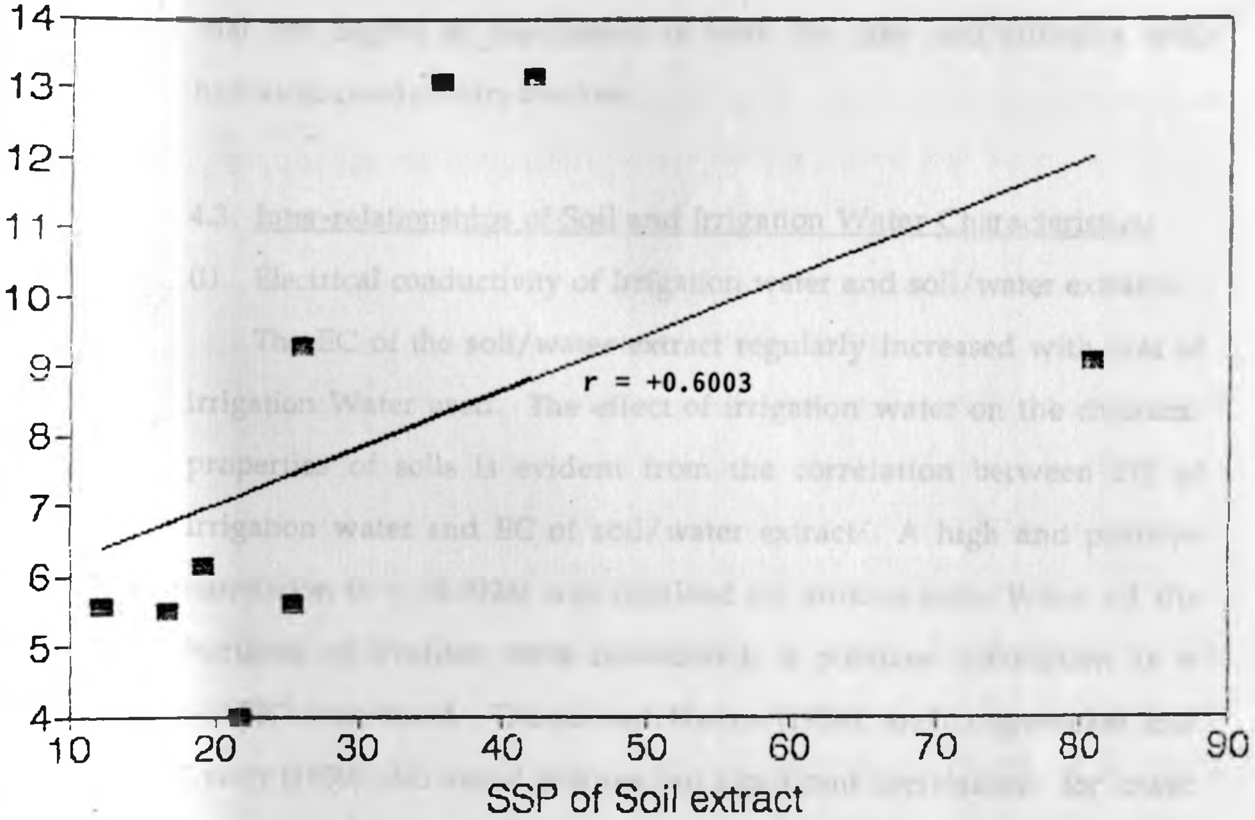


Figure 6 (c): Relationship between SSP and ESP of soil extracts (for surface horizons)

A low but negative correlation (r = -0.3411) between per cent clay and saturated hydraulic conductivity has been obtained (Fig. 6a) correlation between percent silt plus clay and hydraulic productivity has also been found to be low and negative (r = -0.2859). This indicates that the degree of association of both the clay and silt+clay with hydraulic conductivity are low.

4.3 <u>Inter-relationships of Soil and Irrigation Water Characteristics:</u>

(i) Electrical conductivity of Irrigation water and soil/water extract:-

The EC of the soil/water extract regularly increased with that of irrigation Water used. The effect of irrigation water on the chemical properties of soils is evident from the correlation between EC of Irrigation water and EC of soil/water extract. A high and positive correlation (r = +0.9926) was obtained for surface soils. When all the horizons of Profiles were considered, a positive correlation (r = +0.5237) was found. Thorne and Thorne (1954), and Longenecker and Lyerly (1959) also found positive but significant correlations for lower horizons. Hausenbuiller et al (1960) however, did not find such relationships. The coefficient of determination (r^2 = 0.98) indicate that 98% of the EC of soil/water extract for surface soils could be accounted for by the EC of irrigation water.

(ii) SAR of Irrigation water and ESP of soil:-

A fairly high and positive correlation (r = +0.7574) was obtained between SAR of irrigation water and ESP of soil when entire Profile depths were considered. When surface soils were considered, a high and positive correlation (r = +0.7863) was also obtained. A significant relationship has also been noted by Thorne and Thorne (1954); Longenecker and Lyerly (1959); Hausenbuiller et al (1960) and Paliwal

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(iii) Soluble sodium of Water and ESP of Soil:-

In the present study the correlation,for both surface and subsurface horizons between soluble sodium percentage of irrigation water and ESP was very high but negative (r = -0.9930); a low and negative correlation (r = -0.3068) was obtained for surface horizons . Soluble sodium percentage of soil/water extract however gave a fairly high correlation (r = +0.6003) for surface soils (Fig 6c). These results are in line with what Lewis and Juve (1955), Hausenbuiller et. al (1960) and Change Fig. 6b (1961) got but differ from those obtained by Longenecker and Lyerly (1959); they observed a better relationship with equilibrated soils.

(iv) SAR of Irrigation water and soil/water extract:-

Insignificant negative correlations have been obtained for surface horizons (r = -0.3995) and for both surface and subsurface horizons considered together (r = -0.4680). The degree of determination (r^2) is fairly low to be of any prediction value. This may be due to the fact that SAR of the soil/water extract is the reflection of the adsorption characteristics of the cations on the soil applied through irrigation water and as such may not be in the same proportion as applied in irrigation water. Jain (1978) however, reported a non-significant but positive correlation between the two variables.

(v) RSC of water and ESP of soil:-

A negative correlation between RSC of Irrigation water and ESP of soil has been obtained in this particular study both when surface soil and entire profile depths were considered. A correlation coefficient of ($r = -0.8268$) was obtained for surface horizons and ($r = -0.7108$) was obtained when surface and subsurface horizons were considered together. Singh and Mahnot (1976) have also reported a negative but insignicant correlation between RSC of the water and ESP of soil. Hausenbuiller et al (1960) have however reported a significant but positive correlation between ESP and RSC of irrigation water.

CHAPTER FIVE

CONCLUSION

(i) Water quality class based on electrical conductivity and SAR indicate that Kiboko river water contain a very high concentration of salts and a low concentration of sodium. Makindu river waters on the other hand have high concentration of salts and low concentration of sodium.On the basis of SARadj, however it is only Musengya farm irrigation water that is not likely to bring about a sodium or permeability problem.

(ii) The limits given by Richards et al (1947) with respect to soluble sodium percentages indicate that all irrigation waters considered in this study are in safe limits of soluble sodium and no likelihood of hazard from sodium should expected. According to RSC concept of Eaton (1950) only kiboko river water may be considered as suitable for irrigation. From irrigation point of view however, all irrigation waters studied may be regarded unsatisfactory for irrigation on the basis of their high salt concentrations.

(iii) The use of highly saline Kiboko river water on the light textured soils of the upper part of Muhindi farm may not result in harmful effects on crop growth due to the non-accumulation of salts on the surface horizons. The magnitude of the effect of the quality of irrigation water is not the same on different types of soil but rather is dependent upon the textural class of the soil, drainage characteristics, topography, soil permeability, and other soil characteristics.

(iv) The abandonement of the lower part of Muhindi farm could probably be due to high groundwater table whose groundwater had an electrical conductivity value of 17.40 dS/m at 25^{o}C. The texture of the first horizons is sandy clay loam and may be regarded as of medium texture. The second and subsequent horizons have become highly impregnated with salts that only shallow rooted and salt-tolerant crops will grow. The salinity level of the soil in this section of the farm may have been higher at the time it was abandoned in 1982. During that time pawpaws were grown under irrigation. A poor crop stand and consequent total crop failure was experienced in the second year. The farmer could have applied excess water which raised the water table and led to increased salt accumulation in the soil rather than correcting the saline condition. Sufficient drainage should be provided to this imperfectly drained section of the farm in order to lower the groundwater level to well below the zone of root penetration and also to prevent waterlogging condition from occurring. The observed low EC values for soil/water extracts of surface soils could be due to the lowering of groundwater table as a result of not irrigating since 1982.

(v) The texture of Makwata farm soils is predominantly clay. The waterlogging condition, alkalinity and salinity are the reasons for the abandoning of the farm in 1978 which was first cultivated in 1977. The waterlogging condition is attributable to the heavy texture of these soils. Restricted soil permeability is brought about by the high ESP of soil which resulted in the dispersion of clay collinds. The dispersed colluids moved and blocked the pores through which water flows as evidenced by the low hydraulic conductivity of these soils. The observed low productivity of okra,karela and brinjals vegetables in

1977 and 1978 was because of poor internal drainage of these soils. Lack of root aeration due to the high sodium status of the subsoils would be sufficient to prevent deeper root penetration. The reclamation of these soils are underlain by dense clay subsoils. The presence of thick clay subsoils makes it difficult to remove salts. Ploughing under farmyard manure or green-manuring crops would not help improve drainage. Soil amendments alone would not correct the exchangeable sodium status of the subsoils because of their low permeabilities. Salt accumulation on the surface horizons were not excessive although soil permeability was limited. The high organic matter content and large amounts of free carbonates may have aided in bringing about some degree of amelioration. Organic matter aided in improving and preventing the deterioration of the physical condition of soil by interacting with the inorganic cation exchange material. The presence of a high organic matter content counteracted the effect of the high exchangeable sodium in the soil. In these soils good yields of shallow-rooted vegetable crops possessing some degree of salt tolerance can be produced. Cumbered-beds could be made on the farm as a means of dealing with waterlogging and poor drainage conditions.

(vi) Irrigated surface soils of Musengya farm in Makindu whose sandy clay loam to clay loam are well drained (the section of the farm where profiles 11 and 12 were sited). Chemical analysis indicate that there was no appreciable increase in soil salinity with depth despite the use of water with high salt content for irrigation. The fine texture of the soil in the section of the farm where profile 13 was exposed coupled with very high salinity level of the groundwater, explains why EC values of soil extracts are somewhat higher than elsewhere on the farm. Salt accumulation was however not excessive even though soil permeability is limited because the large amounts of free carbonates may have aided in maintaining some degree of amelioration. Good drainage is necessary for the reclamation of this near saline soils and prevent possible occurrence of waterlogging. During the reclamation process, excess salts should be removed from the root zone. The furrow irrigation being practised requires that the vegetable crops be planted in the ridges such that two rows of crop are planted per ridge. This has been shown to reduce salt accumulation near the root zone (Ayers, 1976). Planting on the ridges also lowers the groundwater table.

(vii) From the interrelationships between soil and irrigation water characteristics, only the correlation between EC of irrigation water and EC of soil/water extract and that between SAR of irrigation water and ESP were fairly high and positive. They were however not significant to be of any prediction value. The rest of the correlations are negative and also not significant. This suggests that the soil solution does not seem to be in equilibrium with irrigation water and is probably influenced by other factors such as soil type, moisture fluctuation, irrigation management, topography and drainage characteristics.

(viii) The interrelationships between soil indices, indicate that E.C. was highly correlated with total soluble cations of soil/water extract (r=0.9949 **) for surface horizons. The coefficient of determination is quite high such that one factor may be used to predict the other. Correlations between the other factors were either low and not significant or significant but of low order to be of any value in predicting one factor for the other.

(ix) The results for the present study suggest that high salinity water may be preferably used on light textured soils without much increase in salinity level of the soil. Because salts move with water, salinity depends directly on water management, that is irrigation, leaching, and drainage. These three aspects of water management should be considered collectively in the overall plan for an irrigated area in order to obtain maximum efficiency.

RECOMMENDATIONS

1. High salinity water could preferably be used on light textured soils without much increase in salinity level of the soil as long as water management practices (Irrigation, leaching and drainage) are followed and salt-tolerant crops grown.

2. The ploughing under of farmyard manure or green manuring crops might help improve drainage of Makwata farm soils which are predominantly heavy textured and underlain by dense clay subsoils.

3. Sufficient drainage should be provided to lower Muhindi farm in order to reduce the groundwater level to well below the zone of root penetration. Excessive application of irrigation water should be avoided as this raises the water table and leads to increased salt accumulation on the soil surface by capillary movement.

4. Farmyard manure improves drainage and prevents the deterioration of the physical condition of the soil by interacting with the inorganic cation exchange material. It also counteracts the effects of exchangeable Sodium in the soil and allows free percolation of water.

5. Cumbered beds should be constructed in the sections of Museng'ya farm with poor drainage as a means of dealing with the water lossing condition and the poor internal drainage of these soils.

REFERENCES

Abrol, I.P. (1962). Studies on the Soil factors affecting the safe utilization of Irrigation Waters as regards their alkali-hazards. Ph.D. Thesis, I.A.R.I., New Delhi. Quoted by Paliwal (1972).

Ayers, R.S. (1976). Water quality for Agriculture. FAO, Irrigation and Drainage Paper 29.

Allison, E.L. (1964). Salinity in relation to Irrigation. Adv. Agron. 16: 139-180.

Agarwal, R.R. and Yadav, J.S.P. (1956). Diagnostic techniques for saline and alkali soils of the Indian Gangetic alluvium in uttar Pradesh. J. Soil Sci. 7: 109-121.

Ahn, P.M. (1973). Analytical methods used in the development of soil Soil Science. Technical Communication No. I.

Arany, S. (1956) VI Congress Int. Soil Sci. Soc. VI, 615-619. Quoted by Allison (1964).

Badhe, N.N. and Kadwe, R.S. (1977) : Quality of well waters and their suitability for Irrigation in Deep Black Soils. J. Soil and Water conserv. in India. 27, 89-94.

Banerjee, S. (1959). Some aspects of Salt- affected soils of West Bengal. Soil Sci.88,45-50.

Black, C.A. (1965) (ed.). Methods of Soil Analysis. Agronomy Number 9, Amer. Soc. Agron. Madison, Wisconsin.

Bower, C.A. (1961). Salinity Problems in the arid Zones UNESCO, PP.215-222. Quoted by Yaron (1973).

Bower, C.A. and Mausland, M.(1963). Symp. Waterlogging and Salinity W. Pakistan, pp.49-61. Quoted by Yaron (1973).

Brysine, G. (1961). Salinity Problems in the Arid Zones. UNESCO, pp. 245-249.

Carter, D.L. and Bondurant, J.A. (1971). Water-soluble NO_3 -Nitrogen, PO4 -Phosphorus, and total salt balances on a large Irrigation tract. Soil Sci. Soc. Am. Proc. 35, pp.331-335.

Carter, D.L. (1975). Problems of Salinity in Agriculture. In: Plants in Saline Environments. Poljakoff-Mayber, A. and Gale, J. (ed.) pp.25-34, (1975).

Chang, C.W. (1953). Chemical Properties of alkali soils in Mesilla Valley, New Mexico. Soil Sci. 75, 233-242.

Change, C.W. (1961). Effect of saline irrigation water and exchangeable sodium on soil properties and growth of alfalfa. Soil Sci. 91 : 29-37.

Doneen, L.D .(1961) In: The influence of crop and soil on Percolating Waters. Proc. Biennial Conference on Ground water Recharge. Schiff, L. (ed.).(1961).

Doneen, L.D. (ed.) (1968). Agricultural Development of new Lands West side of San Joaquin Valley. In Plants in Saline Environments. Poljakoff-mayber, A. and Gale, J.(ed.) (1975) Springer- Verlag Berlin Heidelberg. New York.

Dutt, G.R. and Doneen, L.D. (1963). Predicting the Solute Composition of the Saturation extract from soil undergoing Salinization. Proc. Am. Soil Sci. Soc. 27, 627-630.

Eaton, F.M. (1942). J. Agric. Res. 64.357-399. Quoted by Kadwe and Badhe (1977).

Eaton, F.M. (1950). Significence of carbonates in irrigation waters. Soil Sci. 69, 123-133.

Eaton, F.M. (1935). Boron in soils and Irrigation Waters and its effect on Plants. U.S. Dept. Agr. Tech. Bul. 448, 1-132.

FAO. (1979). Soil Survey Investigations for Irrigation. Soils Bull. No.31. FAO, Rome. In: Tropical Soil Manual. Landon, J.R. (Ed). (1984).

Fireman, M. and Bodman, G.B. (1939). The effect of Saline Irrigation Water upon the Permeability and base status of soils. Proc. Am. Soil Sci. Soc. 4, 71-77.

Fireman, M. (1944). Permeability Measurements on disturbed Soil Samples. Soil Sci. 58,337-353.

Fireman, M. and Reeve, R.C. (1948). Some characteristics of Saline and alkali soils in Gem County Idaho. Soil Sci. Soc. Amer. Proc. 13, 494-498.

Fireman, M. and Wadleigh, C.H. (1951). A Statistical Study of Relations between pH and the exchangeable Na Percentage of Western Soils. Soil Sci. 71, 273-285.

Fireman, M. and Kraus, Y. (1965). Salinity Control in Irrigated agriculture, P.46. Israel: Tahal.

Grillot, G. (1954). Utilisation des Eaux Salines. UNESCO, pp.11-39. Quoted by Yaron (1973).

Gupta, I.C., Bohra, R.K. and Abichandani, C.T. (1969). Relationships between certain Indices of Saline Water Irrigated soils of Western Rajasthan. Annals of Arid Zone, 8,27-32

Govinda Rajan, S.V. and Gapala Rao, H.G. (ed). (1971). Soil and Crop productivity. Asia publishing house, London.

Harper, H.J. and Stout, O.E. (1950). The relation of soil texture to soluble salt accumulation in 29 Irrigated soils in Oklahoma. Okla. Agr. Expt. Sta. Techn. Bull. T-39. Quoted by Lewis, G.C. and Juve, R.L. (1955): Some effects of Irrigation Water quality on Soil characteristics. Soil Sci. 81:125-138.

Hatcher, J.T., Blair, G.Y., C.A. (1959). Soil Sci. 88, 98-100.

Handra, B.K. (1964). Modified Classification Procedure for rating Irrigation Waters. Soil Sci. 98: 264-270.

Hausenbuiller, R.L., Haque, M.A. and Wahab, A. (1960). Some effects of Irrigation Waters of differing quality on Soil properties. Soil Sci. 90, 357-364.

Henderson, D.W. (1958). Influence on soil permeability of total concentration and sodium in irrigation water. Univ. of California Water Resources Center, Contribution 14, 153-157.

Hilgard, E.W. (1906), Soils, their formation, Properties, Composition and relations to climate and plant growth. New York: MacMillan.

ILACO, B.V. (1981). Agricultural Compendium for Rural Development in the Tropics and subtropics. Elsevier, Amsterdam.

Jain, B.L. (1978). Soil Characteristics and Irrigation Water hazards. Annals of Arid Zone 17(4), 337-342.

Kamil, J. and Shainberg, I. (1968). Hydrolysis of Sodium Montmorillonite in Nacl solutions. Soil Sci. 106, 193-199.

Kanwar, J.S. and Mehta, K.K. (1970). Quality of Well Waters and its effect on Soil Properties. Indian J. Agr. Sci. 40, 251-258.

Kanwar, J.S. Sehgal, J.L. and Bhumbla, D.R. (1963). Relationship between some Indices of Saline-Sodic soils. J. Indian Soc. soil sci. 11, 198-208.

Kearney, J.H. and Schofield, C.S. (1936). The choice of crops for saline Land. U.S. Dept. Agr. Circ. 404.

Kelly, W.P. (1951). Alkali soils, their formation, properties and Reclamation. Reinhold, New York. Quoted by Allison (1964).

Klute, A. (1965). Laboratory Measurement of hydraulic Conductivity of Saturated Soil. In: Black (1965). Methods of Soil Analysis. Agronomy No.9. Amer. Soc. Agron. Madison. pp.210-221.

Lewis G.C. and Juve, R.L. (1955). Some effects of irrigation quality on soil characteristics. Soil Sci. 81 : 125-138.

Longenecker, D.E. and Lyerly, P.J. (1959). Chemical characteristics of soils of West Texas as affected by Irrigation water quality. Soil Sci. 8, 207-216.

Loveday, J. (ed.) (1974). Methods of Analysis of Irrigated Soils. Techn. Comm. No.54 of the Common Bureau of soils.

Lutz, J.F. (1952). Mechanical Impendence and Plant growth. Soil Physical Conditions and Plant growth. Agronomy Monographs. Academic press, New York.

Magistad, O.C. and Christiansen, J.E. (1944). Saline Soils, their nature and Management. U.S. Dept. Agr. Circ. 707.

Maliwal, G.L. (1968). Effect of Irrigation Waters of different qualities on soils and crops. Ph.D. Thesis, Udaipur University, Udaipur. Quoted by Paliwal (1972).

Mehta, K.K. and Paliwal, K. V. (1969). Quality of Well waters of Bhilwara district. Paper presented at 35th Annual Session of Indian Soc. Soil Sci. held at Udaipur. Quoted by Paliwal (1972).

Mehta, K.K. (1970). Studies on the effect of Irrigation Water on soil properties and crop growth with special reference to Boron. Ph.D. Thesis Udaipur University, Udaipur. Quoted by paliwal (1972).

Metson, A.J. (1971). Methods of Chemical Analysis for soil Survey Samples. New Zealand department of Scientific and Industrial Research. Soil Bureau Bulletiri 12.

Michael,, A.M. (1978). Irrigation: Theory and Practice. Chapter 9: Salt Problems in Irrigated Agriculture, pp.686-740.

Michieka, D.O. and Van der Pouw, B.J.A. (ed.) (1977). Soils and Vegetation of the Kiboko Range Research Station, Kenya Soil Survey.

O'Neal, A.M. (1952). Soil Sci. Soc. Am. Proc. 16, 312-315.

Paliwal, K.V. and Maliwal, G.L. (1967). Some relationships between constituents of Irrigation waters and Properties of Irrigated soils of Western Rajasthan, Paper Presented at the ICAR's Northern Zonal Workshop on soils held at Punjab Agric. Univ. Hissar, Feb. 1967. Quoted by Paliwal (1972).

Paliwal, K.V. and Maliwal, G.L. (1968). A Statistical Study of Some Indices of Saline Water Irrigated Soils of Rajasthan. Annals of Arid Zone 7:127-131.

Paliwal, K.V. (1972). Irrigation with Saline Water. I.A.R.I., Monograph No. 2, Water Technology Centre, New Delhi, pp. 1-190.

Paliwal, K.V. and Gandhi, A.P. (1969). Quality of Irrigation Waters of Nagaur district. Techn Bull NO. 2, Agr. Expt. Station, University of Udaipur, Udaipur. Quoted by Paliwal (1972).

Poljakoff-Mayber, A. and Gale, J. (1975). Plants in Saline Environments. Springer Verlag, Berlin, New York, 213 pp.

Quirk, J.D. and Schofield, R.K. (1955). The effect of electrolyte Concentrations on Soil Permeability. Soil Sci. 6, 163-178.

Rhoades, J.D. and Berestein, L. (1971). Chemical, Physical and Biological Characteristics of Irrigation and soil water. In: Water and Water Pollution Handbook, CIACCIO, L.L. Ed. Marcell Dekker. Inc. New York. (1971).

Richards, L.A. and Hayward, H.E. (1957). Proc. Ist Intersoc. Conf. Irrigation Drainage, San Francisco, Calif. 1957 pp. 93-96.

Richards, L.A. (ed). (1954). Diagnosis and Improvement of Saline and Alkali soils. U.S. Dept. of Agric. Handbook NO.60.

Scholler, M. (1962). Les Eaux Souterraines, 642 pp. Paris: Masson et cie. Quoted by Yaron (1973).

Scotfield, C.S. (1935). The Salinity of Irrigation Water. Smithsoman Inst. Ann. Rep., pp. 275-287. Quoted by Yaron (1973).

Shah and Singh, S. (1964). Boron adsorption equilibrium in soils. 98, 383-388.

Shainberg, I. (1975). Salinity of Soils-Effects of Salinity on the Physics and Chemistry of soils. In: Plants in Saline Environments. Poljakoff-mayber, A. and Gale, J. (eds.) (1975).

Shainberg, I. and Oster, J.D. (1978). Quality of Irrigation Water. IIIc publication No.2.

Singh, B. and Bhumbla, D.R. (1968). Effect of Quality of Irrigation Water on soil properties. J. Research 5:166-171.

Singh, K.S. and Mahnot, S.C. (1976). Survey of Well
Waters located in the Arid Zone of Rajasthan and their influence on soil properties with special reference to salinity. J. Soil and Water Conserv. in India. 26,103.

Stabler, H. (1911). Some stream Waters of the Western United States. U.S. Geol. Survey Water-Supply paper 274,188. Quoted by Poljakoff-Mayber, A. and Gale, J. (1975).

Thorne, O.W. and Peterson, H.G. (1954). Irrigated Soils, their fertility and Management (2nd Ed.), 483 pp. N.Y. Blofiston.

Thorne, D.W. and Thorne, J.P. (1954). Changes in Compund of Irrigation Water. Proc. Soil Sci. Soc. Amer., 18 : 92-97.

Verhoeven, B. (1979). Salty Soils. In: Drainage Principles and applications. Pub.16.Vol.1, ILRI. Netherlands. pp.75-79.

Vyas, K.K., Khurana, G.P. and Vyas, B.M. (1982). Soil Properties as affected by Saline Irrigation waters of Bilara (Jodhpur district). Annals of Arid Zone, 21(4), 225-233.

Wilcox, L.V., Blair, G.Y., and Bower, C.A. (1954). Effect of bicarbonates on Suitability of Water for Irrigation. Soil Sci. 77,259-266.

Wilcox, L.V. (1958). Determining the quality of Irrigation water Agr. Inf. Bull. 194, 7pp. Quoted by Yaron (1973).

Wilcox, L.V. (1960). Boron Injury to Plants. U.S. Dept. Agr. Inform. Bull., 21.

Wilcox, L.V. and Resch, W.F. (1963). Salt balance and leaching Requirements in irrigated lands. U.S.D.A. Techn. Bul. 1290.

Yaron, B., Danfors, E. and Vaadia, Y. (1973). Arid Zone Irrigation, Ecological Studies. Vol.5.

APPENDICES

Appendix 1(a).

PROFILE DESCRIPTION NO.1

General site information

Survey area/district	: KIBOKO / MACHAKOS
Observation No./date	: Mu1 / 18/10/90
Soil classification	: Cambic ARENOSOL, sodic phase
Geological formation	: Basement System Rocks
Parent Materia!	: Gneisses rich in quartz
Physiography	: Upland
Relief, Macro	: Gently undulating
Relief, Micro	: Nil
Slope	: 3-4%
Vegetation /Land use	: Shamba / Cultivation
General ground water	: deep (not observed)
Rainage class	: well drained

Profile description8

Ap 0-20 cm dark brown (7.5 YR 3/4 moist, 10 YR 4/6dry); Sandy loam / loamy sand; disturbed (single grain) Structure; non-sticky and non plastic when wet; clear and smooth transition to:

AB 20-34 cm Dark brown (7.5YR 3/4 moist, 7.5YR 4/4 dry); sandy loam; weak medium subangular blocky; slightly hard when dry, loose when moist, non sticky and non plastic when wet; many medium and coarse pores; clear and smooth transition to :

Bw1 34-87 cm Dark reddish brown (%YR 3/6 moist, 5YR 4/8 dry); sandy loam' moderate, coarse subangular blocky; slightly hard, loose when moist, non sticky and non plastic; many medium coarse pores; clear and wavy transition to:

Bw2 87-108 cm Reddish brown (5YR 4/6 moist, 5YR 6/8 dry); sandy loam; moderate, fine subangular blocky; slightly hard when dry, loose when moist, non sticky and non plastic when wet; many medium and coarse pores; abrupt and wavy transition to:

C108 cm+ Quartz gravels

Appendix 1(b).

PROFILE DESCRIPTION NO 2

General site information

Survey area / district	: Kiboko/ Machakos
Observation No. /date	: Mu 2 / 18/10/90
Soil Classification	: Cambic ARENOSOL, sodic phase
Geological formation	: Basement System rocks
Parent material	: Gneisses rich in quartz
Physiography	: Upland
Relief, Macro	: Gently undulating
Relief, Micro	: termite mounds
Slope	: 2-3%
Vegetation/ Land use	: Bushland/ grazing
General ground water	: deep (not observed)
Drainage class	: well drained

Profile description

Au 0-28 cm	dark reddish brown (2.5YR 3/6 moist, 5YR 4/8 dry); sandy loam; weak, medium subangular blocky; slightly hard when dry, loose when moist, non sticky and non plastic when wet; many medium and coarse pores; common, very fine, fine and medium, few coarse roots; clear and smooth transition to:
Bw28-62 cm	reddish brown (2.5YR 4/6 moist, 5 YR 5/8 dry); sandy clay loam; moderate, medium subangular blocky; slightly hard when dry, loose when moist, non sticky and non plastic when wet; many medium and coarse pores; common, very fine few fine medium roots; abrupt and wavy transition to:
C 62 cm+	Parent material

Appendix 1(c).

PROFILE DESCRIPTION NO.3

General site information

Survey area / district	: Kiboko /Machakos
Observation No. /date	: Mu 3/ 18/10/90
Soil classification	: Chromic LUVISOL, sodic phase
Geological formation	: Basement System Rocks
Parent material	: Gneisses
Physiography	: Upland (lower part)
Relief, Macro	: Gently undulating
Relief, Micro	: Nil
Slope	: 2-3%
Vegetation /Land use	: Shamba /Cultivation
General ground water	: deep (not observed)
Drainage class	: well drained

Profile description

Ap 0-10 cm dark reddish brown (5YR 3/4 moist, 5YR 5/6 dry); clay; disturbed structure; sticky and plastic when wet; common very fine and few fine roots; clear and smooth transition to:

Bt1 10-28cm dark reddish brown (5 YR 3/6 moist, 5 YR 5/8 dry); lay; moderate, coarse subangular blocky; hard when dry, friable when moist, sticky and plastic when wet; common very fine, fine and medium pores; few very fine and fine roots; clear and smooth transition to:

Bt2 28-51 cm dark reddish brown (5YR 3/6 moist, 5YR 5/6 dry); clay; moderate, medium subangular blocky; hard when dry, friable when moist, sticky and plastic when wet; many, very fine and fine, common medium roots; clear and smooth transition to:

Bt3 51-118 cm reddish brown (2.5YR 4/6 moist); clay; moderate, fine subangular blocky, friable when moist, sticky and plastic when wet; many very fine and fine, common medium pores; few very fine dead roots; abrupt and smooth transition to:

C 118cm+ Weathering parent material

Remarks:
- Observation in an irrigated tomato field
- Salt crusts observed on the surface.

Appendix 1(d).

PROFILE DESCRIPTION NO. 4

General site information

Survey area / district	: Kiboko / Machakos
Observation No / date	: Mu 4 / 18/10/90
Soil classification	: Chromic LUVISOL
Geological formation	: Basement System Locks
Parent material	: Gneisses
Physiography	: Upland (lower part)
Relief, Macro	: gently undulating
Relief, Micro	: scattered termite mounds
Slope	: 2-3%
Vegetation /land use	: Bushland/ Grazing
General ground water	: Deep (not observed)
Drainage class	: Well drained

Profile description

Au 0-14cm Very dark reddish brown (5YR 2/3 moist, 5YR 3/3 dry); sandy clay loam; weak, medium subangular blocky; hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common very fine and fine, few medium pores; few very fine, fine and medium roots; clear and smooth transition to:

Bt1 14-41cm dark reddish brown (2.5YR 3/4 moist, 5YR 3/6 dry); clay loam; moderate, medium subangular blocky; hard when dry, friable when moist, sticky and plastic when wet; common very fine and fine, few medium pores; few very fine and fine roots; clear and wavy transition to:

Bt241.66cm dark reddish brown (2.5YR 3/4 moist, 2.5YR 4/6 dry); sandy clay; moderate, fine subangular blocky; hard when dry, friable when moist, sticky and plastic when wet; many, very fine and fine, few medium pores; clear and wavy transition to:

Bt3 66-106cm dark reddish brown (2.5YR 3/6 moist); sandy clay; moderate to strong, medium subangular blocky; friable when moist, sticky and plastic when wet; many, very fine and fine, few medium pores; 2%, soft manganese concretions; clear and smooth transition to:

C 106 cm+ weathering parent material.

Appendix 1(e).

PROFILE DESCRIPTION NO.5

General site information

Survey area / district	: Kiboko / Machakos
observation No. /date	: Mu 5 / 22/10/90
Soil classification	: Chromic LUVISOL, sodic phase
Geological formation	: Basement System Rocks
Parent	: Gneisses
Physiography	: Plain
Relief, Macro	: Flat
Relief, Micro	: Few scattered termite mounds
Slope	: 0-1%
Vegetation /Land use	: Grassland /grazing (fallow)
General ground water	: deep (not observed)
Drainage class	: Imperfectly drained

Profile description

Au 0-28cm black (7.5YR 2/1 moist, 7.5YR 2/3 dry); sandy clay loam: moderate, medium subangular blocky; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many, very fine and fine, common medium pores; many very fine and few fine roots; abrupt and transition to:

Bt1 28-45cm brownish black (5YR 2/2 moist); sandy clay; moderate, medium to coarse subangular blocky; friable when moist, sticky and plastic when wet; common very fine, few fine and medium pores; common, very fine and few fine roots; clear and broken transition to:

Bt2 45-83cm very dark reddish brown(2.5YR 2/3 moist); clay; moderate, medium subangular blocky; friable when moist, sticky and plastic when wet; many very fine, common fine and few medium pores; few, very fine and fine roots; gradual and smooth transition to:

Bt3 83-130cm+ dark reddish brown (2.5YR 3/4 moist); sandy clay; moderate, coarse subangular blocky; friable when moist, sticky and plastic when wet; many very fine, common fine, few medium and coarse pores; few, very fine dead roots.

Remarks:

- The second horizon (28-45 cm) is a hard pan.
- The profile is in a formerly irrigated area but now abandoned.

Appendix 1(f).

PROFILE DESCRIPTION NO 6

General site information

Survey area / district	: Kiboko / Machakos
Observation No. /date	: Mu 6 / 19/10/90
Soil classification	: Haplic SOLONETZ
Geological formatio	: Basement System Rocks
Parent material	: Gneisses
Physiography	: Plain
Relief, Macro	: Flat
Relief, Micro	: Nil
Slope	: 0-1%
Vegetation/ land use	: Bushland/ grazing
General ground water	: deep (not observed)
Drainage class	: Imperfectly drained

Profile description

Au 0-12cm brownish black (7.5YR 2/2 moist); sandy clay loam; moderate, medium, subangular blocky; hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common very fine and fine, few medium pores; common very fine and few fine roots; abrupt and smooth transition to:

Bt1 12-23cm A layer of hard pan with clear and smooth transition to:

Btn2 23-49cm very dark reddish brown (5YR 2/4 moist); clay; moderate coarse subangular blocky; friable when moist, sticky and plastic when wet; many very fine, common fine and few medium pores; few, very fine and fine roots; gradual and smooth transition to:

Btn3 49-110cm very dark reddish brown (2.5 YR 2/3 moist); sandy clay; moderate, medium to coarse subangular blocky; friable when moist, sticky and plastic when wet; many, very fine, common fine and few medium pores; clear and smooth transition to:

C 100 cm+ Weathering parent material

Remarks: - Second horizon is cemented hard-pan.

Appendix 1(g).

PROFILE DESCRIPTION NO 7

General site information

Survey area / district	: Makindu / Machakos
Observation No. /date	: MA 1 /19/10/90
Soil classification	: Vertic LUVISOL
Geological formation	: Basement System rocks
Parent material	: Alluvium
Physiography	: Alluvial plain
Relief, Macro	: Flat
Relief, Micro	: Old irrigation channels
Slope	: 0-1%
Vegetation	: Grassland / grazing
General ground water	: deep (not observed)
Drainage class	: Moderate to Imperfectly drained

Profile description

Au 0-15cm black (10YR 1.7/1 moist, 10YR 4/.1 dry); clay; moderate, fine to medium crumbs; slightly hard when dry, friable when moist, sticky and plastic when wet; many, very fine and fine pores; many, very fine, common fine and medium roots; clear and smooth transition to:

Bt1 15-40cm brownish grey (10YR 5/1 moist, 10YR 6/1 dry); clay; moderate, medium subangular blocky; hard when dry, friable when moist, sticky and plastic when wet, many, very fine and fine, common medium pores; common, very fine and fine, few medium roots; gradual and smooth transition to:

Bt2 40-56cm black (10YR 1.7/1 moist, 10YR 8/1 dry) clay; moderate, coarse subangular and moderate medium angular blocky; hard when dry, friable when moist, sticky and plastic when wet; common, very fine and fine, few medium pores; common, fine to medium $caco_3$ concretions; few, very fine and fine roots; gradual and smooth transition to:

Bt3 56-100cm+ greyish yellow (2.5Y 7/1 moist); clay; moderate, medium angular blocky; hard when dry, friable when moist sticky and plastic when wet; common, very fine and few medium pores; very few, very fine roots.

Remarks: - Area formerly not irrigated and presently being used for grazing

Appendix 1(h).

PROFILE DESCRIPTION N0 8.

General site information

Survey area / district	: Makindu / Machakos
Observation No. /date	: MA 2 / 19/10/90
Soil classification	: Vertic LUVISOL
Geological formation	: Basement System rocks
Parent material	: Old alluvium
Physiography	: Alluvial plain
Relief, Macro	: Flat
Relief, Micro	: Scattered termite mounds
Slope	: 0-1%
Vegetation/Land use	: Open grassland / Grazing
Ground water table	: deep (not observed)
Drainage class	: Imperfectly drained

Profile description

Au1 0-10cm black (10YR 2/1 moist, 10YR 7/1 dry); sandy clay loam; moderate, medium subangular blocky; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many, very fine and fine, common medium and few coarse pores; clear and smooth transition to:

Au2 10-21cm brownish black (10YR 2/2 moist, 10 YR 5/2 dry); clay /clay loam; weak, fine subangular blocky; slightly hard when dry, friable when moist, sticky and plastic when wet; many, very fine and fine, common medium pores; clear and smooth transition to:

Bt1 21-50cm black (10YR 2/1 moist, 10YR 4/2 dry); clay; moderate, medium subangular blocky; hard when dry, friable when moist, sticky and plastic when wet; many very fine and fine, few medium pores; clear and wavy transition to:

Bt2 50-80cm greyish yellow (2.5Y 7/2 moist); clay; strong, medium angular blocky; very hard when dry, friable when moist, sticky and plastic when wet; common very fine and fine pores; gradual and smooth transition to:

Bt3 80-124cm+ light grey (2.5Y 8/2 moist); clay; moderate, fine to medium subangular blocky; friable when moist, sticky and plastic when wet; common very fine, few fine and medium pores.

Appendix 1(i).

PROFILE DESCRIPTION NO.9

General site information

Survey area / district	: Makindu / Machakos
Observation No. /Date	: MA 3 / 19/10/90
Soil classification	: Luvic CHERNOZEM
Geological formation	: Basement System Rocks
Parent material	: Alluvium
Relief, Macro	: Flat
Relief, Micro	: Old irrigation ridges
Slope	: 0-1%
Vegetation /land use	: Grassland/Grazing (formerly Cultivated)
General ground water	: deep (not observed)
Drainage class	: Moderately well drained

Profile description

Au 0-27cm black (10YR 1.7/1 moist, 10YR 4/2 dry); clay; moderate fine crumbs; soft when dry, friable when moist, sticky and plastic when wet; many very fine and fine, common medium pores; clear and smooth transition to:

Bt1 27-48cm brownish black (10YR 2/2 Moist, 10YR dry); clay; moderate, medium subangular blocky; slightly hard when dry, friable when moist, sticky and plastic when wet; many very fine and fine, common medium pores; gradual and smooth transition to:

Bt2	48-74cm	brownish black (10YR 3/2 moist, 10YR 6/2 dry); clay; moderate, medium subangular blocky; hard when dry, friable when moist, sticky and plastic when wet; common, very fine and fine pores; clear and smooth transition to:
Bt3	74-102cm+	light grey (10YR 7/1 moist, 10YR 8/1 dry); gravelly clay; weak, medium subangular blocky; hard when dry, friable when moist, sticky and plastic when wet; common very fine and few fine pores.

Remarks:
- A layer of salt in the last horizon.
- Area formerly irrigated but now abandoned and used for grazing only.

Appendix 1(j).

PROFILE DESCRIPTION NO 10

Profile site information

Survey area / district	: Makindu / Machakos
Observation No. /date	: Mus 1 /21/10/90
Soil classification	: Luvic CHERNOZEM
Geological formation	: Basement system rocks
Parent material	: Alluvium
Physiography	: River Terrace
Relief, Macro	: Flat
Relief, Micro	: Nil
Slope	: 0-1%
Vegetation /Land use	: Shamba edge/cultivation
Ground water table	: deep (not observed)
Drainage	: Moderately well drained

Profile description

Ah 0-40cm black (10YR 1.7/1 moist, 10YR 2/2 dry); dry loam; weak fine to medium subangular blocky; soft when dry, very friable when moist, slightly sticky and slightly plastic when wet; many, very fine and fine, common medium pores; common, very fine, fine and medium roots; clear and smooth transition to:

AB 40-72cm black (10YR 1.7/1 moist, 10YR 3/2 dry); clay; moderate, medium subangular and strong, fine to medium angular blocky; hard when dry, very friable when moist, sticky and plastic when wet; many very fine common fine and medium pores; few medium $CaCO_3$ concretions; common very fine and fine, few medium roots; gradual and smooth transition to:

Bt 72-106cm brownish grey (10YR 4/1 moist); clay; strong, fine subangular blocky; very hard when dry, friable when moist, sticky and plastic when wet; common very fine and fine, few medium pores; common very fine and fine roots.

R 106cm+ Coherent rock.

Appendix 1(k).

PROFILE DESCRIPTION No 11

General site information

Survey area /district	: Makindu / Machakos
Observation No. / date	: Mus 2 / 17/10/90
Soil classification	: Chromic CAMBISOL
Parent materia	: Lava flow
Geological formation	: Basement System rocks
Physiography	: Piedmont plain
Relief, Macro	: Very gently undulating
Relief, Micro	: Furrow ridges
Vegetation /Land use	: Shamba / Cultivation
Ground water	: Deep (not observed)
Drainage class	: Moderately well drained

Profile description

Au 0-20cm Very dark reddish brown (5YR 2/3 moist, 5YR 3/4 dry); sandy clay loam; weak to moderate, medium subangular blocky; hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; many very fine and fine, common medium pores; very few, very fine roots; clear and smooth transition to:

Bwm 20-52cm dark reddish brown (2.5YR 3/4 moist, 5YR 3/6 dry); sandy clay; massive; very hard when dry, very friable to loose when moist, sticky and plastic when wet; few very fine and fine, common medium pores; common medium quartz gravel; very few fine dead roots; clear and wavy transition to:

Bw1 52-88cm dark reddish (5YR 3/6 moist; gravelly sandy clay; weak, fine subangular blocky; very hard when dry, very friable when moist, sticky and plastic when wet; few very fine and fine, pores; very few dead roots; clear and wavy transition to

Bw2 88-115cm dark reddish brown (2.5YR 3/6 moist, 2.5YR 4/6 dry); clay; moderate, medium angular blocky; friable when moist, sticky and plastic when wet; common very fine and fine, few medium pores; a lot of animal activity; very few, very fine dead roots; clear and smooth transition to:

Bw3 115-165cm+ reddish brown (2.5YR 4/8 moist, 2.5YR 4/8 dry); clay; moderate, medium angular blocky; friable when moist, sticky and plastic when wet; many very fine and fine, common medium pores; a lot of animal activity; very few, very fine dead roots.

Remarks: The second and third horizons are very compacted and the soil material looks like burnt volcanic material.

Appendix 1(l).

PROFILE DESCRIPTION NO 12.

General site information

Survey area/ district	: Makindu / Machakos
Observation No / date	: Mus 3 / 17/10/90
Soil classification	: Luvic CHERNOZEM
Geological formation	: Basement System rocks
Parent material	: Alluvium
Physiography	: Alluvial plain
Relief, Macro	: Very gently undulating
Relief, Micro	: Nil
Slope	: 1-2%
Vegetation /land use	: Grassland /grazing (formerly cultivated)
Ground water	: deep (not observed)
Drainage class	: well drained

Profile description

Ah 0-28cm Black (10YR 1.7/1 moist, 10YR 4/2 dry); sandy clay; moderate, fine subangular blocky; slightly hard when dry, friable when moist, sticky and plastic when wet; many, very fine and fine, common medium and few coarse pores; common very fine and fine roots; clear and smooth transition to:

Bt1	28-42cm	brownish black (10YR 2/2 moist, 10YR 3/3 dry); clay; strong medium subangular and moderate, medium angular blocky; very hard when dry, friable when moist, sticky and plastic when wet; common, very fine, fine and dead roots; clear and smooth transition to:
Btck	42-82cm	brownish black (10YR 3/3 moist, 10YR 5/3 dry); clay; moderate, medium subangular blocky; hard when dry, firm when moist, sticky and plastic when wet; many, very fine and fine, common medium pores; common, fine $caco_3$ concretions; gradual and smooth transition to:
Bt2	82-110cm	dark greyish yellow (2.5Y 4/2 moist,2.5Y 5/3 dry); clay; weak, medium subangular blocky; hard when dry, firm when moist, sticky and plastic when wet; many, very fine and fine, few common pores; abrupt and smooth transition to:
R	100cm+	Parent rock.

Appendix 1(m).

PROFILE DESCRIPTION NO 13

General site information

Survey area / district	: Makindu / Machakos
Observation No / date	: Mus 4 / 17/10/90
Soil classification	: Luvic CHERNOZEM
Geological formation	: Basement System rocks
Parent material	: Alluvium
Physiography	: River Terrace
Relief, Macro	: Flat
Relief, Micro	: Basin irrigation ridges
Slope	: 0-1%
Vegetation /land use	: Shamba /Cultivation of tomatoes
Ground water table	: Perched groundwater table at 58 cm
Drainage class	: Imperfect to moderately well drained

Profile description

Al 0-23cm Black (N1.5/0, moist); clay; strong, medium subangular blocky; friable when moist, sticky and plastic when wet;many very fine, fine and medium, few coarse pores; few , very fine and fine roots;clear and smooth transition to:

Bt 23-58cm brownish black (10YR 2/2 moist); clay; moderate, medium subangular and strong medium angular blocky; firm when moist, sticky and plastic when wet; many, very fine and fine, common medium pores; very few, very fine roots; clear and smooth transition to:

Btck	58cm+	dull yellowish orange (10YR 7/2 moist); clay; firm when moist, sticky and plastic when wet; common soft $CaCO_3$

Remarks:

1. Perched ground water table was encountered at 90 cm but the level rose to 58 cm overnight.
2. Horizon below 58 cm was submerged in water
3. Salt crusts observed in the surrounding

Appendix 2: Relationship between Irrigation Water and soil properties

Relationship between	Surface and Sub-surface horizons	Surface horizons
1. ECiw and EC of soil extract	+0.5237	+0.9926
2. SAR of water and ESP of soil	+0.7574	+0.7863
3. SAR of soil extract and SAR of water	-0.4680	-0.3995
4. SSP of water and ESP of soil	-0.9930	-0.3068
5. RSC of water and ESP of Soil	-0.7108	-0.8268

Appendix 3: Coefficient of correlation for some soil indices

Correlation between	Surface Horizons	Surface + Subsurface Horizons
EC x T.S.C (me/l)	+0.9949**	+0.9963**
pH x ESP	+0.0563	+0.064
pH x SAR	+0.5615	+0.4366**
SSP x ESP	+0.6002	+0.3768*
SAR x ESP	+0.2595	+0.5243
pH x CO_3 + HCO_3	+0.0154	+0.3396*
CEC x Organic Carbon	-	0.7162*

* Significant at 1%

** Significant at 0.1%

Appendix 4: Relationship between soil properties

X	Y	R	Regression Equation
Per cent clay	Hydraulic conductivity	0.3411	Y = 4.3683 - 0.6568x
Per cent silt + clay	"	0.2859	Y = 4.24852 - 0.04961x
ESP	"	0.0953	Y = 176051 - 0.38716x
Percent Total Porosity	"	0.0943	Y = 0.4527 - 0.03469x