EVALUATION OF THE EFFECTS OF FILTERMUD ON SOIL SALINITY AT TANGANYIKA PLANTING COMPANY SUGARCANE PLANTATION, TANZANIA

BY

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BSc. AGRICULTURE (SUA)

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE LAND AND WATER MANAGEMENT FACULTY OF AGRICULTURE, UNIVERSITY OF NAIROBI

AUGUST 2004

DECLARATION

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

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This thesis has been submitted for examination with my approval as university supervisor

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DEDICATION

This thesis is dedicated to my late loving mother, Madam Mariam S. Mwenduwa, my beloved father, Mr. H.I Mwenduwa who sacrificed so much to educate me, my lovely husband, Yusuph my precious children Hassan, Ismail and Naulah.

ACKNOWLEDGEMENT

My sincere thanks go to Mr. R. K. Muni, and the late Mr. S. M. Kinyali, who were my former supervisors, for their guidance, encouragement and constructive suggestions throughout my research programme. I am also thankful to my substitute supervisor Dr. Mohammed A. Hassan who oversaw the thesis corrections.

Also I am thankful to the African Academy of Sciences (AAS) who, through the University of Nairobi under soil and water Management project (SWMP) fully financed my postgraduate programme (MSc. Land and water management).

My sincere appreciation to the entire technical staff of the Soil Physics, Soil Chemistry, Soil and Water Management Project (SWMP) laboratories, University of Nairobi for assisting me in soil and water analysis. Notably is the contribution of Mr. G. Mukolwe & J. O. Agullo for formatting editing and printing this manuscript.

I also take this opportunity to thank the authority of Tanganyika Planting Company (TPC Ltd) - Moshi, Tanzania for allowing me to carry out my field studies in their farm to investigate the factors accelerating the development of secondary salinity and the effects of local amendment (filtermud) as an ameliorating agent for the salt affected soils as well as other possible management solutions to the problems.

Finally I express sincere thanks and appreciation to my husband Yusuph, son Hassan and Mwenduwas' family for their patience, encouragement and understanding during the entire period of the programme.

ABSTRACT

This study was undertaken to evaluate the effect of filtermud on selected chemical and physical properties of an irrigated salt-affected soils under field conditions. Three fields (O4, 10A and control) were selected for this study at Tanganyika Planting Company Ltd, (Tanzania). Representative soil sampling sites were selected to represent irrigated salt affected soil from abandoned field 10A, irrigated salt affected soil reclaimed with filtermud from field O4 and non irrigated soil from control field. The effect of water quality management on soil properties was also evaluated.

Mean infiltration rate, saturated hydraulic conductivity and moisture retention varied significantly within fields ($P < 0.05$). The initial infiltration rates were 180, 120 and 60 cm/hr, for control, 04 and 10A fields respectively while the corresponding steady-state infiltration rates were 36, 9 and 5 cm/hr. Saturated hydraulic conductivity values for top soils were 27.3cm/hr for control; 4.3cm/hr for field O4; and 2.0 cm/hr for field 10A while the volumetric water content retained at 300 and 1500 KPa, were 0.21, 0.25 and 0.30 cm^3/cm^3 and 0.91, 0.21 and 0.24 cm^3/cm^3 for control, O4 and 10A fields respectively.

Electrical conductivity values for topsoil from field O4 were significantly low ($P<0.05$) as compared to that of field 10A with mean values of 0.6 dsm^{-1}, 0.8 dsm^{-1} and 3.7 dsm^{-1} for control, reclaimed and abandoned fields respectively. The pH of the topsoil from field O4 was low compared to that of soils from field 10A with mean values of 7.5, 8.0 and 8.9 for control, O4 and 10A fields respectively. Calcium ion content was high in soils from the filtermud-applied field as compared to the abandoned salt affected field. Exchangeable sodium percentage (ESP) mean values for the topsoils were 4.1, 12.8 and 40.0 for control, O4 and 10A fields respectively. Similarly the sodium adsorption ratio (SAR) values for topsoils were 1.0, 3.8 and 10.5 for control, O4 and 10A fields respectively.

Vertical K_{sat} correlated positively and significantly (r = 0.8) with sand fraction. Moisture retention correlated positively and significantly with clay and silt fraction, with correlation coefficient of 0.8 and 0.6 at 700 and 1000 KPa respectively. Also the moisture retention correlated negatively with sand fraction at 700, 1000 and 1500 KPa with correlation coefficient of 0.9. Finally, percentage base saturation was higher than 100 percent and significantly correlated with exchangeable sodium content of the soil.

The water samples analyzed were regarded as being unsatisfactory for irrigation except water from Weruweru River particularly on heavy textured soils, unless sufficient drainage is provided and the necessary soil and water amendments are adopted. Therefore slightly poor quality irrigation water, when used without sufficient drainage and management practice under semi arid conditions has a adverse effect on light textured soils in the long run and may turn the formerly fertile land into salt affected waste land. Filtermud provided significant improvement for some soil properties especially the surface soils. Therefore the main beneficial effect of this organic amendment is an increased infiltration rate and thereby facilitating movement of chemical agents to deeper soil layer by the irrigation waters more efficiently.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS AND SYMBOLS

CEC	Cation exchange capacity
cm	centimetre
Ctrl	control plot
dsm^{-1}	decisiemen/metre
EC	Electrical conductivity
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization
FM	filtermud
g	gram
g/cm^3	gram/cubic centimetre
hr	hour
K_{sat}	saturated hydraulic conductivity
kg	kilogram
L	Litre
me	milliequivalent
OM	organic matter
Pb	bulk density
pH	hydrogen ion concentration
pHc	calculated value based on total cations, Ca + Mg and CO_3^{-2} + HCO_3^{-2} in water
PR	profile
RSC	Residual sodium carbonate
SA	Stable Aggregate
SAR	Sodium adsorption ratio
SAR_{adj}	Adjusted Sodium adsorption ratio
SUA	Sokoine University of Agriculture-Tanzania
TPC	Tanganyika planting Company
USDA	United States Department of Agriculture
O4	treated plot
10A	untreated plot (abandoned)

1. INTRODUCTION

1.1 Background Information

The Tanganyika Planting Company Ltd (TPC Ltd) is an irrigated sugarcane estate in a dry area where rain fed smallholder cane cannot perform well (Acland, 1971). The area is in Kilimanjaro region 20 km South of Moshi town (Figure 1). The estate is located at latitude 3° 32"South of the Equator, and longitude 37°20" East of Greenwich, and its altitude is 701 m above sea level (TPC, 1996). The range of irrigated cane yield was 119-300 tonnes/ha declined further to 82 tonnes/ha (Sloot, 1987,Sadiki, 1997 personal communication). Irrigation is essential at TPC since the area is within a semi-arid zone with an average annual rainfall ranging between 500-550 mm, with mean evaporation rate of 8.4 mm per year.

The area receives short rains from October to December, which are exceptionally low, and ranges between 32.2-64.9 mm (TPC, 1996). Monthly and yearly temperature variations are quite small. The coolest months are June, July and August with mean sunshine hours of 6.8 hours per day (TPC, 1996). According to weather report, average wind speed is 4.75 km per hour for the month of December. Negative moisture balance was recorded in 1996. Therefore it is apparent those non-irrigated sugar canes suffer from moisture stress. Thus cane growth would depend entirely on the availability of irrigation water. The major varieties of sugarcane grown at TPC Ltd are 7097 EA, B52113 and 1001 (Sadiki, 1997 personal communication). Most of the cane is watered through overhead irrigation using water from rivers Kikuletwa and Weruweru. Water from Kikuletwa River is saline compared to that of Weruweru (Waiyaki, 1971 and Sloot, 1987).

The two rivers meet at Kikuletwa pump station and form the Pangani river whereby its water results in a slightly acceptable level of salinity and alkalinity, SAR_{adj} = 1.90; EC 0.88 dsm^{-1} (Sloot, 1987), (Figure 2). There are open drains bordering the sides of few blocks for surface water collection. They are exceptionally deep from 2.5 - 4 metres and usually 1 - 2 m wide at the bottom. Slopes are in the order of 1:300 to 1:1000 (Sloot, 1987).

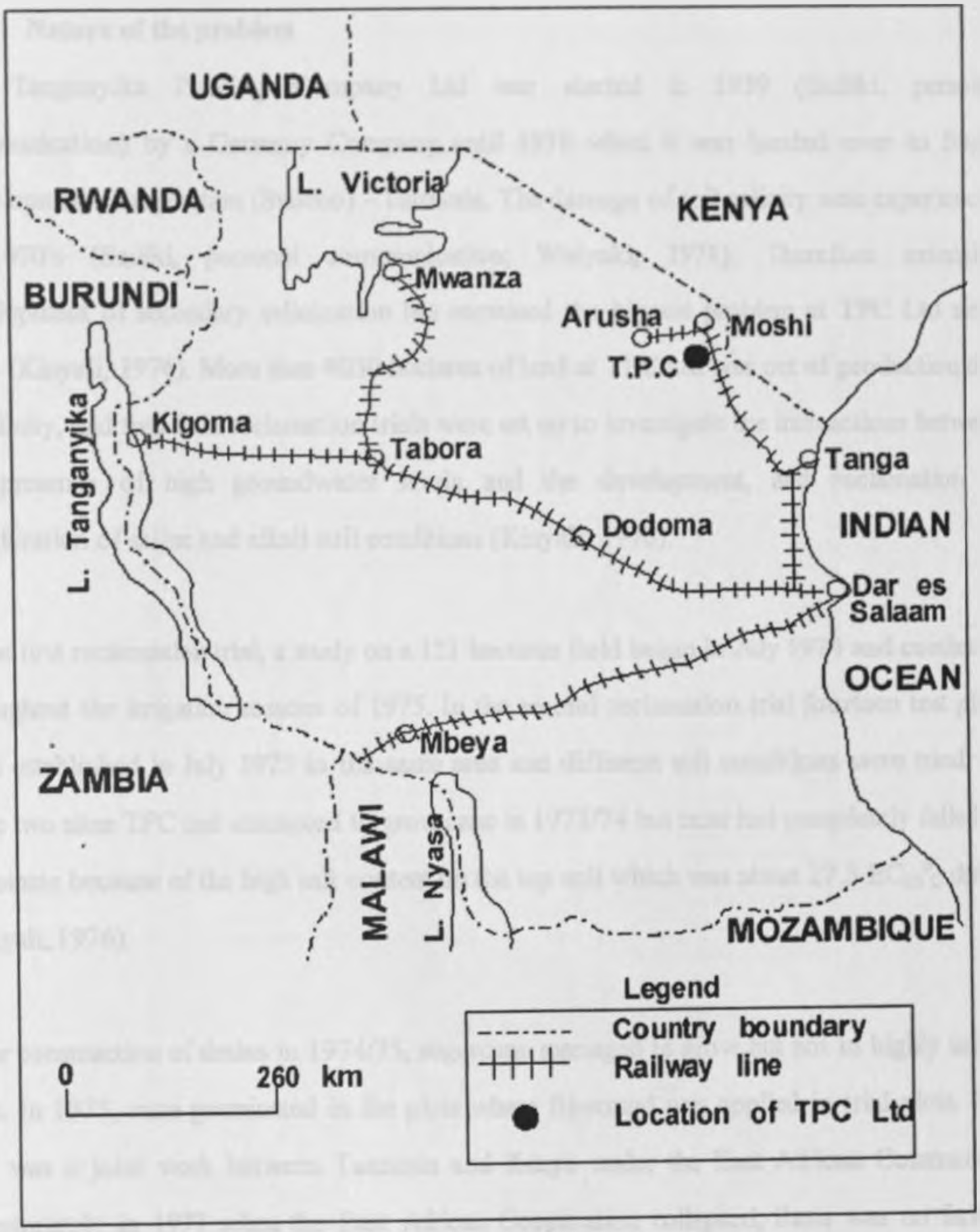

Figure 1: Location of Tanganyika Planting Company (TPC Ltd), Tanzania

Most drains lead south towards to **Nyumba ya Mungu** dam or back to the river (Figure 2). There might be an appreciable upward water movement in the soil as it has been the case in some fields for example field R8, where the water table was very near the surface (less than 1 m deep) during the field study.

1.2 Nature of the problem

The Tanganyika Planting Company Ltd was started in 1939 (Sadiki, personal communication) by a Germany Company until 1978 when it was handed over to Sugar Development Cooperation (Sudeco) - Tanzania. The damage of soil salinity was experienced in 1970's (Sadiki, personal communication; Waiyaki, 1971). Therefore extensive development of secondary salinization has remained the biggest problem at TPC Ltd since 1976 (Kinyali, 1976). More than 4050 hectares of land at TPC Ltd was out of production due to salinity, and two field reclamation trials were set up to investigate the interactions between the presence of high groundwater levels and the development, and reclamation or amelioration of saline and alkali soil conditions (Kinyali, 1976).

In the first reclamation trial, a study on a 121 hectares field began in July 1974 and continued throughout the irrigation seasons of 1975. In the second reclamation trial fourteen test plots were established in July 1975 in the same area and different soil conditions were tried. At these two sites TPC had attempted to grow cane in 1973/74 but cane had completely failed to germinate because of the high salt content on the top soil which was about 27.3 $EC_{25}{}^{\circ}C$ dsm^{-1} (Kinyali,.1976).

After construction of drains in 1974/75, sugarcane managed to grow but not in highly saline soils. In 1975, cane germinated in the plots where filtermud was applied in trial plots. The trial was a joint work between Tanzania and Kenya under the East African Community, unfortunately in 1977 when the East African Cooperation collapsed, there was no further monitoring of the experimental trial.

In 1977 a sharp decline in yield per unit area harvested was experienced under salt affected fields. Yield dropped to 13 tonnes/ha in some fields (TPC Ltd, 1996). Therefore the company decided to abandon the severely salt affected fields completely, for example block 18X as seen in Figure 2. Recently the company has abandoned several blocks, namely 18, 19, 20 and 21 (Figure 2). About 30% of the total 7000 ha under cultivation are salt affected with different degree of salinity. However, the area currently under cane production is 6400 ha.

Since the area under wasteland was increasing with time due to the Silty nature of the soil itself (Waiyaki, 1971), and the slightly saline irrigation water used, (Sloot, 1987), the company realised that it was absolutely essential to find ways of cultivating the salt affected

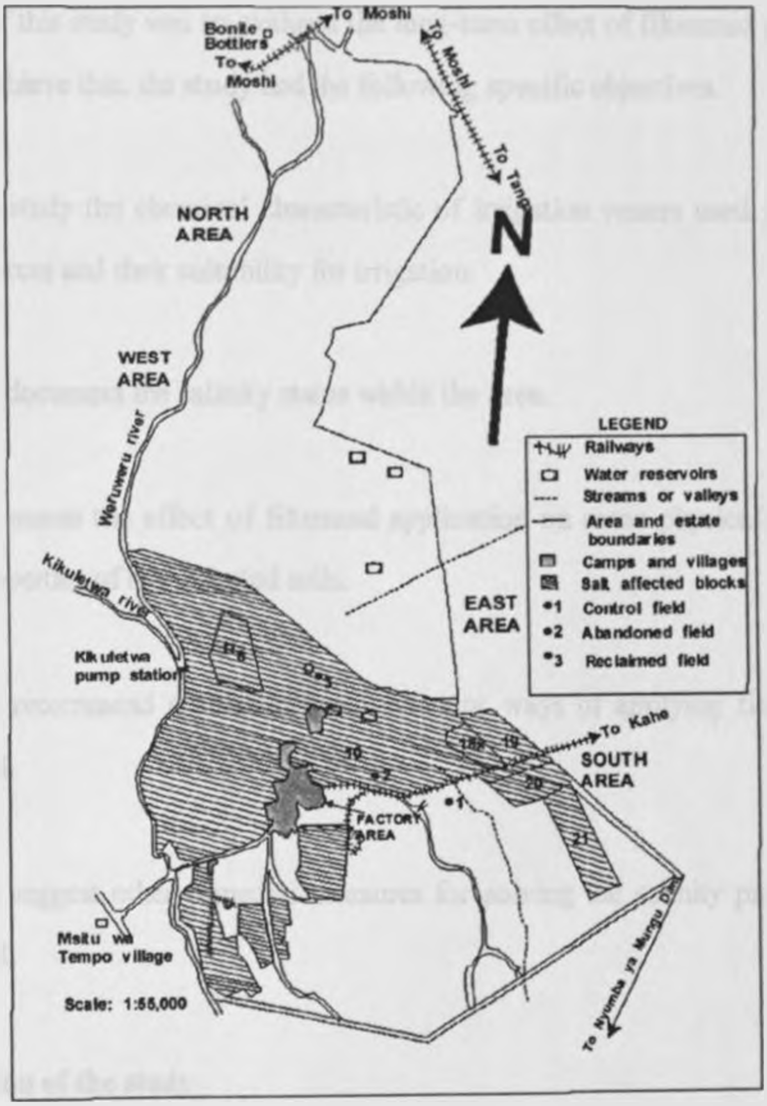

Figure 2: Map of Arusha Chini indicating the study area (TPC Ltd)

soils. However, reclamation of salt affected soil is expensive, especially the use of inorganic amendments like gypsum, sulphuric acid and others. In 1992/93, the company started trials using locally available filtermud. Application of filtermud on the abandoned Field O4 was carried out to investigate whether filtermud may offer the possibility of soil improvement. Filtermud at the rate of 50 tonnes/ha was applied on Field O4 in 1992/93.

1.3 Objectives of the study

The overall aim of this study was to evaluate the long-term effect of filtermud application on soil salinity. To achieve this, the study had the following specific objectives.

1. To study the chemical characteristic of irrigation waters used from different sources and their suitability for irrigation.

2. To document the salinity status within the area.

3. To assess the effect of filtermud application on some physical and chemical properties of salt affected soils.

4. To recommend appropriate and efficient ways of applying filtermud to the soil.

5. To suggest other remedial measures for solving the salinity problem at TPC Ltd.

1.4 Justification of the study

Filtermud as an amendment when tried in 1992/93 in Field 04 showed that the general vegetative growth of cane improved in that particular season, but neither chemical or physical analysis of the treated field soils was carried out, nor was a statistical analysis carried out to confirm the findings. So far no results have been published.

Therefore the study will provide information about the use of organic amendment (filtermud) to improve soil productivity/fertility of the salt affected soils. Also the information can be used by the company as a management tool for planners and decision makers for measures to be undertaken in order to minimize salinity and prevent further development of secondary salinity at TPC Ltd.

2. LITERATURE REVIEW

2.1 Distribution of Salt Affected Soils

Salinization and alkalization problems are wide spread in the world, both in regions with humid climate for example Holland, Sweden, and U.S.S.R; in arid or semi arid regions for example Southern United States, Australia, India, Middle East and Africa (Chapman, 1975; Dregne, 1976; 1983, and Worthington, 1977).

Soil salinity is both an old and modern pollution problem, which presents us with most recent challenges in soil management. The problem is mostly associated with the arid and semi arid regions of the world where there is insufficient rain to leach away soluble salts (Shainberg, 1975 and Rowel, 1974). These salts occur naturally in the soil and are added by irrigation water, rain and wind blown dust and by groundwater (Shainberg, 1975; Szabolcs, 1992 and Rowel, 1994).

Szabolcs (1991) stated that 10% of the World's land surface is estimated to produce nothing or negative productivity each year in addition to that already affected by salinity. The seriousness of the land degradation problem is exacerbated by the distribution of degraded land relative to land shortages. In Africa, it has been estimated that 47 countries will be critically short of land for agriculture production by the year 2000 (Malcolm, 1993). He further estimated that there would be 43.6 million hectares of salt affected land in the African region. The situation is not only being made worse by further deterioration but also by population increase. Worldwide, it is projected that by the year 2000, 50-65% currently irrigated cropland will suffer reduced productivity due to excess soil salinity (Buras, 1992). Consequently the sustainability of irrigated lands is sometimes questioned (Porta and Herero, 1996).

Agricultural expansion programmes have often encompassed marginal land in many parts of the world. Therefore wise management of the environment requires an ability to forecast, monitor, measure and analyze environmental trends and assess the quality of land and water at different levels ranging from a small irrigated plot to catchments (Dougherty and Hall, 1995). In their study the emphasis was placed on how to get the best out of the potential benefits of irrigation and to ensure their permanence, as well as how to overcome the detrimental effects of soil salinity.

2.2 Sources of Salinity

Saline soils occur in arid regions not only because there is less rainfall available to leach and transport the salts, but also because of the high evaporation rates characteristic of arid climates, which tend to further concentrate the salts in soils and in surface water (Shainberg, 1975 and Rowel, 1994).

However, 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 is undoubtedly a contributing factor (Shainberg, 1975; Macharia & Muriuki, 1987 and Rowel, 1994). Other factors, which influence salinity effects, are concentration and composition of salts in the underground water, inadequate soil permeability and drainage management practices, climate and inherent characteristic such as clay mineralogy, soil texture and topography (Carter, 1975; Michael, 1978; Ayers and Westcot, 1985; Rowel, 1994 and Dougherty and Hall, 1995).

In flood plains, coastal belts and in areas of high water table, the salt concentration is usually high. In such situations surface runoff is low and the drainage water evaporates, leaving the salts on the surface (Carter, 1975 and Michael, 1978). In areas of high water table, salts move up under thermal gradient (capillary action) and are deposited on the surface (Hillel, 1982).

Therefore all the above-mentioned factors either singly or in association with other factors are responsible for the development of saline and alkali soils in different parts of the world. Thus according to Ghassemi et al. (1995), land and water resources can be salinised by natural, physical and chemical processes or by human activities (secondary salinisation).

2.3 Classification of Salt Affected Soils

Salt affected soils are classified into three groups, depending on the kinds and amounts of the various salts present: i.e. Saline, sodic and saline-sodic (Follet et al., 1981; Rowel, 1994 and Ghassemi et al, 1995). The principal criteria used to classify them are salinity of the saturated soil extract as determined by the electrical conductivity (Ce in dsm^{-1}) at 25°C, soil pH, exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR) (Table 1).

Table 1: Summary of Classification of Salt-affected Soils

Classification	Electrical Conductivity (dsm^{-1})	Soil pH	Exchangeable sodium percentage	Soil physical condition
Saline	> 4.0	< 8.5	< 15	Normal
Sodic	< 4.0	> 8.5	> 15	Poor
Saline-sodic	> 4.0	< 8.5	> 15	Normal

Source: Follett et al. (1981)

Exchangeable Sodium Percentage (ESP) of a soil is the percentage of exchangeable sodium ions to the total exchangeable cations in the soil sample (Richards, 1954; Rachel, 1984; Kenya Soil Survey staff, 1987; Landon, 1991; Rowel, 1994 and Ghassemi *et al.*, 1995). It is expressed as:

$$ESP = \frac{exchangeable \;\; sodium \;\; ions}{soil \;\; cation \;\; exchange \;\; capacity} \;\; X \;\; 100 \qquad (1)$$

Where the ions are expressed in milliequivalent per 100 g of soil.

The sodium adsorption ratio (SAR) is the relation between sodium and divalent cation (calcium + Magnesium) of irrigation water or saturated soil extract. It is used to express the relative activity of sodium in exchange reactions with soils. It is expressed as:

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

Where the cations are expressed in milliequivalent per litre (Rachel, 1984; Kenya Soil Survey staff, 1987, Landon, 1991; Rowel, 1994 and Ghassemi *et al.*, 1995).

However if bicarbonates and carbonates are present, then part of the Ca and Mg may be precipitated as salts. In this case the relative amounts of Na^{+} as compared to Ca^{2+} and Mg^{2+} will increase. To account for this possibility the SAR value has to be adjusted before it is meaningful with regard to the exchangeable sodium in the soil (Rachel, 1984; Kenya Soil Survey staff, 1987, Landon, 1991). The adjusted SAR is computed as follows:

$$SAR_{adj} \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}}[1 + (8.4 - PHC)] \qquad (3)$$

In which Na^{+}, Ca^{2+} and mg^{2+} are obtained through analysis of water or soil extract and expressed as milliequivalent per litre of sample.

The PHc is a theoretical, calculated PH of the irrigation water (extract) in contact with lime and in equilibrium with soil Carbon dioxide. Values of PHc below 8.4 indicate a tendency to dissolve lime from a soil through which the water moves, more than pH 8.4 there is a tendency to precipitate lime from the water applied (Kenya Soil Survey Staff, 1987 and Landon, 1991).

The pH is calculated by the equation

$$PHC = (Ca^{2+} + Mg^{2+} + Na^{+}) + P(Ca^{2+} + Mg^{2+}) + P(Alk) \quad (4)$$

Where

$P(Ca^{2+} + Mg^{2+} + Na^{+}) = (Ca^{2+} + Mg^{2+} + Na^{+})$ in me/l

$P(Ca^{2+} + Mg^{2+}) = (Ca^{2+} + Mg^{2+})$ in me/l

$P(Alk) = (CO^{2+}_3 + HCO^{-}_3)$ in me/l

All values are obtained by analysis. For further details of the calculations, see Appendix 4b.

2.3.1 Saline Soils

Saline soils are defined by the presence of excess soluble salts. Soil is usually considered saline when the electrical conductivity of an extract from saturated soil (EC) exceeds 4dsm^{-1} (Follet *et al.*, 1981, Landon, 1991 and Rowel, 1994). This value is generally used world wide, although the Soil Science Society of America has recommended that this limit be reduced to 2.5 dsm^{-1} because many crops can be damaged in the range of 2-4dsm^{-1} (Abrol *et al*, 1988). The ESP value of these soils is less than 15, which is equivalent to SAR value of 13. Saline soils have a pH value of 8.5. The physical properties of saline soils are normally good. Chiefly the osmotic effects of excess soluble salts impair plant growth in saline soils.

The dominant soluble salts in saline soil mostly comprise chloride, sulphate and bicarbonates of sodium, calcium and magnesium. Saline soils are the most common and are usually the easiest to reclaim (Follet *et al.*, 1981). Their structure is generally good and their permeability to water and tillage characteristics are like those of non-saline soils, (Follet *et al.*, 1981).

Saline soils are recognised by spotty growth of crops and when dry often by white crusts of salts on the soil surface.

2.3.2 Sodic or alkaline soils

Sodic soils are relatively low in soluble salts but are high in exchangeable sodium (Follet *et al.*, 1981). These soils have an electrical conductivity of saturated soil extract of less than 4dsm^{-1}, ESP of 15 or more, SAR of 13 or more and pH value of 8.5 to 10 (Follet *et al.*, 1981; Landon, 1991; Rowel, 1994 and Ghassemi *et al.*, 1995). In contrast to saline soils, alkaline soils are those, which adversely affect plant growth due to an excessive amount of sodium on the exchange soil complex. The adverse effect of exchangeable sodium on plant growth is mainly associated with changes in the physical properties of the soil. High ESP causes dispersion of soil colloids, which in turn results in blocking of soil pores (Ghassemi, *et al.*, 1995). Consequently air and water movement is impeded. Thus creating unfavourable conditions for plant roots in getting air and absorb water and nutrients. Sodic soils are of poor tilth and prone to form hard clods and crust upon drying (Follet *et al.*, 1981). When wet they have a characteristic smooth, slick look caused by the dispersed condition of clay and humus (Follet *et al.*, 1981)

2.3.3 Saline-sodic soils

Saline-sodic soils contain large amounts of total salts as well as more than 15% of exchangeable sodium (Follet *et al.*, 1981 and Rowel, 1994). The pH is less than 8.5 as long as an excess of soluble salts is present; the physical properties of these soils are generally good and similar to those of saline and non-saline soils (Follet *et al.*, 1981).

When rains occur or after irrigation with good quality water, most of the soluble calcium and magnesium are leached out of the surface soil and the sodium remains attached to the clay and humus. The pH rises above 8.5, the soil becomes dispersed, and permeability to water virtually ceases. Such soils require amendments and leaching to remove the excess sodium.

2.4 Effects of Salts on Sugarcane Growth

Sugarcane (*Saccharum officinarum L.*) is moderately tolerant to salt in low concentration in soils and irrigated water when the drainage is good, particularly if occasional rainfall is experienced (Barnes, 1974 and Frenkel & Meiri 1985). Excessive quantities of salts seriously affect the growth and appearances of the plant. Barnes (1974) stated that, crops, which grow to maturity under saline conditions, the processing of the juice becomes troublesome; sugar recovery is reduced and yields of molasses increased. Salts cause poor germination of canes, many of which may fail completely, Young shoots do not develop normally and few plants may be left in a row. If a full stand is obtained, the colour of the leaves is abnormal and may vary from pale green to clear yellow, with a generated yellowish tinge. In extreme cases, the leaves become white with black patches of dead tissues (Barnes, 1974). Barnes explains that the cane will display an irregular, ill grown habit with stunted growth, short, thin canes with short internodes and an absence of well developed stalks having large healthy leaves. In more severely affected cases the plants may survive with difficulty for some months, and the stool can be easily pulled up as a decaying mass with short dead roots (Barnes, 1974).

Blackburn (1984) stated that, the tolerance of sugarcane to saline conditions depends on varieties. For example B-42231 proved highly tolerant in Jamaica and is widely planted in saline areas. The symptoms of salts damage on the leaves, which become pale green or yellowish, similar to those suffering from nitrogen deficiency, but also, have scorched tips and margins. The roots are deformed and it is widely accepted that the damage is caused by the accumulation of chloride in the soil rather than sodium ion. Similar damage was reported in Venezuela, which was caused by high concentration of potassium sulphate (Blackburn, 1984). The effects of SAR and pH values on sugarcane growth is summarised in Table 2 according to Blackburn (1984).

Table 2: Summary of the effects of SAR and pH on cane growth

Parameter	Cane healthy	Cane slightly affected	Cane severely affected	Cane dead
SAR	13	18	35	41
PH	8.2	8.3	9.5	9.6

Source: Blackburn (1984)

2.4.1 Yield Potential of Sugarcane as Influenced by Salinity

A number of research workers have measured the effects of salinity on sugarcane yield and they came up with different critical levels of salinity, which obviously depend on cane varieties. Blackburn (1984) suggested that yields are virtually unaffected where $EC_{25°C}$ values are less than 2-3 dsm^{-1}, and 50% yield reduction is likely to occur at values of about 7 dsm^{-1} and that total growth failure is likely to occur at values of 11-12 dsm^{-1}. He added that SAR of about 20 is likely to cause a 50% yield reduction.

Valdivia and Pinna (1974) pointed out that cane yields were affected by soil physical factors as well as salinity. They calculated that the critical levels for salinity would be 3.5 dsm^{-1} on a silty-clay loam and 2.2 dsm^{-1} on a clay loam and that tolerance levels could be increased by cultivation, which would relieve compaction.

It is obvious that clear-cut definitions of critical levels cannot be derived from the literature. According to FAO (1979), the critical levels for soil and water salinity, are recorded as follows:

	$EC_{25°C}$ dsm^{-1}
Noticeable yield reductions (10%)	2-3
Severe yield reduction (50%)	5-9

Total growth failure	11-12

Dougherty & Hall (1995) indicated the effect of salinity on sugarcane yield and gave the critical levels of $EC_{25°C}$ approximately above 15 dsm^{-1} when the yield will decline. Data on critical levels of ESP and SAR in cane are too few to be of any great value. The limited data available suggest that values in excess of 20 are likely to be noticeably harmful to cane (Booker, 1979,FAO, 1979).

For the free draining soils acceptable water quality was calculated as 3.7 dsm-1 with traditional furrow type of irrigation. However with permanent trickle irrigation on coarse freely draining, aerated soil, the limit of water salinity before inducing any reduction in yield is about 4.0 dsm^{-1} (Blackburn, 1984). The author explained that SAR of about 20 is likely to cause a 50% yield reduction.

2.5 Effects of Salinity and Sodicity on Soil Properties

The presence of sodium ion in irrigation water and/or in soil solution presents a potential hazard to soils and crops through the following: A high sodium concentration may be toxic to certain plants, the destructive effect of excessive sodium on the soil structure. The effect of adsorbed sodium on the physical properties of soil is manifested in low infiltration rate of water, low permeability of the soil to water and gases and poor structural quality of the soil because sodium disperses soil particles (Shainberg, 1975, Frenkel & Meiri, 1985, Hillel 1980a, Follet et al, 1981, Landon 1991; Rowel, 1994). High salt content in irrigation water may also alter the pH to an extent that plant nutrients become unavailable or insoluble (Hillel, 1980a; Rachel, 1984; Landon, 1991; Rowel, 1994). Therefore, salinity limits soil fertility and hinders agricultural development (Worthington, 1977).

2.5.1 Infiltration Rate

Infiltration is one of the most important process in both irrigated and rain fed agriculture. The rate of infiltration relative to the rate of water supply determines how much water will enter the root zone and how much, if any will runoff (Hillel, 1980a). Hillel defined infiltration as the time rate at which water penetrate into the soil through its soil-atmosphere interphase. He described infiltration as the process of water entry into the soil, normally by downward movement through all or part of the soil surface. According to Hillel (1982), infiltration rate is the volume flux of water flowing into the profile per unit of soil surface area and it is generally expressed in cm/hr.

Measurement of infiltration rate is essential in studies concerning hydrology, runoff, erosion, irrigation, and water conservation. Several researchers have distinguished four categories of methods for the determination of the infiltration rate of soil (Klute, 1986). These methods are watershed hydrograph, rainfall simulators, and cylinder infiltrometer and basin methods. Infiltration rate measurement is one of the parameters under investigation in this study.
The cylinder infiltrometer has been used extensively in infiltration tests for irrigation system. The cylinder infiltrometers in principle are simple devices and because of its portability and ease of use, may be a good choice. Necessary measurements can be taken with great precision in this method (Bouwer 1986). It involves little sampling error compared to the sprinklers which are more complex, involve more assumptions, have greater probability of sampling error and are logistically more difficult (Julander & Jackson, 1983).

Generally infiltration rate is high in the early stages of infiltration, particularly when the soil is initially dry, but tends to decrease and eventually to approach asymptotic constant rate or steady-state infiltration rate (Hillel 1980a). The decrease of infiltration from initial, high rate to final steady-state rates result from gradual deterioration of the surface soil structure, from swelling of clay or from entrapped air bubbles (Hillel, 1980a & Bouwer, 1986).

Primarily, however, the decrease in infiltration rate results from the inevitable decrease in the metric suction gradient, which occurs as infiltration, proceeds (Hillel, 1982 and Marshall & Holmes, 1988). Many researchers have elucidated the factors, which affects the rate at which water percolates into the soil. In summary, soil infiltrability depends on the following factors:

(1) Time from the onset of rain or irrigation. The infiltration rates is relatively high at first, then decrease, and eventually approach a constant rate that is characteristic of the soil profile (Hillel, 1982, and Marshall & Holmes, 1988).

(2) Initial water content: The wetter the soil initially, the lower will be the initial infiltrability and the quicker will be the attainment of the constant rate.

(3) Hydraulic conductivity. The higher the saturated hydraulic conductivity of the soil, the higher the infiltrability.

(4) Soil surface conditions. When the soil is highly porous and of open structure the initial infiltrability is greater than that of a uniform soil but the final infiltrability remains unchanged as it is limited by the lower conductivity of the transmission zone beneath. When the soil surface is compacted and profile covered by a surface crust of lower soil, the surface crust act as hydraulic barrier, or bottleneck impeding infiltration. This effect reduces both the initial infiltrability and eventually attained steady infiltrability. A soil of stable structure tends to form such a crust during infiltration, especially as a result of the slaking action of beating raindrops. In such a soil, a plant cover or a surface mulch of plant residues can save to intercept and break the impact of the raindrops and thus help to prevent surface sealing.

(5) The presence of impending layers inside the profile. This may retard water movement during infiltration. Therefore factors that influence the surface entry, profile transmission and storage capacity have a greater influence on infiltration rate.

With regard to the above factors, infiltration rate can be classified as indicated in Table 3

2.5.2 Effects of Salinity on Water Infiltration

Saline irrigation water usually contains a mixture of sodium and calcium ions. Thus positively charged ions (cations) in the soil water, such as calcium, sodium and magnesium attach to the clay particles in the soil. The clay portion of the soil consists of stacked clay particles that have a negative charge and attract these positively charged ions. If the sodium becomes excessive and dominates the clay surface, the clay can swell, making the soil less permeable.

Table 3: Classification of infiltration rate values

Infiltration rate (cm/hr)	Interpretation or classification
< 0.1	Very slow
0.1-0.5	Slow
0.5-2.0	Moderately slow
2.0-6.0	Moderate
6.0-12.5	Moderately rapid
12.5-25.0	Rapid
> 25.0	Very rapid

Source: Landon (1991)

This prevents salt leaching and reduces the solubility of the inherent soil calcium and magnesium. If sodium ions are excessive in root zone, calcium and magnesium are trapped and hence become less available to the plants (Oster & Frenkel, 1980; Ayers and Westcot, 1985).

2.5.3 Saturated Hydraulic Conductivity and Salinity

The most severe effect of sodium ions on the physical properties of field soil is seen in the change in hydraulic conductivity of the soil. Hydraulic conductivity is the effective flow velocity or discharge velocity of water in the soil at unit hydraulic gradient (Hillel, 1980b). Nevertheless, the relation between infiltration rate and hydraulic conductivity is highly complex.

Fine, textured, soils or low bulk density soils have small pore size for conductivity; therefore clay will only move short distances before clogging the soil pores (Frenkel & Meiri, 1985). Increasing amounts of exchangeable sodium promote structural changes of the soil matrix by two main mechanisms, which are clay swelling and soil particle dispersion. As the proportion of exchangeable sodium increases, the clay particles in the soil tend to disperse. The dispersed colloids may move and block the pores through which the water flows, thus diminishing the hydraulic conductivity of the soil and causing poor aeration (Shainberg, 1975; Rowel, 1994).

It may be deduced from the double layer theory that both swelling and particle dispersion increases as the concentration of salts in the soil solution increases (Oster & Frenkel, 1980; Macharia & Muriuki 1987; and Landon, 1991) have classified the hydraulic conductivity values as shown in Table 4.

Table 4: Classification of hydraulic conductivity values

Hydraulic conductivity (K) (cm/hr)	Interpretation or classification
< 0.8	very slow
0.8-2.0	Slow
2.0-6.0	moderate

6.0-8.0	moderately rapid
8.0-12.5	Rapid
> 12.5	very rapid

Source: Landon (1991)

Dispersion is strongly dependent on soil texture and mineralogy. Felhendler et al. (1974) found that clay dispersion in soils with low silt content was more pronounced than in soils with similar ESP and clay mineralogy but with higher silt content. Normally hydraulic conductivity, soil structure and texture are related phenomena (Table 5).

2.6 Soil Water Retention and Release Curves

The soil moisture retention and release curves are used to illustrate the retention and moisture release at corresponding suctions, usually over the range of 0.0 to 1500 KPa (Kinyali, 1973; Sessanga, 1982). As water is released from the matrix, the adsorptive forces holding soil moisture into the surfaces of colloids build up such that successive moisture release requires higher and higher desorption forces as suction rises (Hillel, 1980a; Hillel, 1980b). The soil moisture retention curve is used to evaluate the phenomenon of soil moisture-energy relationship.

The soil moisture release curve illustrates the cumulative volumetric moisture release of the soil matrix of over 0.0 to a specified range of 1500 KPa. However, the cumulative moisture release could be evaluated up to a selected KPa or suction along the release curve in accordance with the purposes of the evaluation, especially in application of irrigation water to either potted or field soil (Greenland, 1981).

Soil water retention and release curves or soil moisture characteristic is strongly affected by soil texture (Hillel, 1980b). Generally, the greater the clay content, the greater the water retention at any particular suction, and the more gradual the slope of the curve.

In sandy soil, most of the pores are relatively large, and once these large pores are emptied at a given suction, only a small amount of water remains. In a clay soil, the pore size distribution is more uniform, and more water is adsorbed, so that increasing the matrix suction causes a more gradual decrease in water content.

The amount of water retained at relatively low values of matrix suction (1-3 bars of suction) depends primarily upon the capillary effect and the pore size distribution and thus is strongly affected by the structure of the soil (Hillel, 1980b; Rowel, 1994).

Table 5: Approximate relationships between texture, structure and hydraulic conductivity

Texture	Structure	Indicated hydraulic conductivity cm/hr
Coarse sand gravel	single grain	≥ 50
Medium sand	single grain	25-50
Loamy sand, fine sand	medium crumb grain	12-25
Fine sandy,loam,sandy loam	coarse, subangular blocky and granular fine crumb	6-12
Light clay loam, silty, silt loam, very fine sandy loam, loam	medium prismatic and subangular blocky	2-6

Clay, silty clay, sandy clay, silty clay loam, silty loam, silty, sandy clay loam	fine and medium prismatic angular blocky, platy	0.5-2
Clay, clay loam, silty clay	very fine or fine prismatic angular blocky, platy	0.25-0.5
Clay, heavy clay	massive, very fine or fine columnar	< 0.25

Source: Adapted form Landon (1991)

However, the retention in the higher suction range is due to adsorption force and is therefore influenced less by the structure and more by the texture and specific surface of the soil material.

Since accumulation of salts in the soil adversely affect structural component of the soil then indirectly it has effects on soil moisture retention and release as well. Water availability to crops in the salt affected soils will be affected by the osmotic pressure and will not be available to crops (Follet *et al.*, 1981 and Ayers & Westcot, 1985). Therefore anything, which can modify soil structure, can consequently change soil water retention, as pointed out by Rasiah et al. (1990), when they used oily waste application in the modification of soil water retention and hydraulic conductivity. They found that oily waste reduced the water retention by approximately 30% at the suctions of -200 to -10 KPa.

2.7 Management of Salinity

Salinity management is a problem of multiple dimensions and includes different aspects of agriculture, engineering and economics. Broadly salinity management can be considered a two-stage problem (Porta & Herero, 1996).

- Root zone salinity management
- Regional or project level salinity management.

2.7.1 Root Zone Salinity Management

The engineering and agronomic practices for management of saline or sodic soils and water at field level are as follows

- Using chemical amendments to improve soil physical and chemical properties,
- Land preparation methods that provide uniform infiltration of water
- Following irrigation procedures that maintain sufficient soil moisture and cause periodic leaching,
- Adopting irrigation methods that permit frequent uniform and efficient water application with little runoff loss as possible without curtailing essential leaching requirements,
- Using planting procedures that minimize salt accumulation around seeds,
- Avoiding saline or sodic waters at sensitive stages of the plant growth,
- Providing leaching and drainage to take care of excess salt water.

In this study, only root zone salinity management was considered

2.7.2 Common amendments

Materials, that directly or indirectly through chemical or microbial action supply the soluble calcium for replacement of exchangeable sodium are called amendments (Porta & Herero, 1996; Gupta & Abrol, 1990; Gill & Abrol, 1993 and Aslam *et al*, 1993). The choice of an amendment and the quality required for reclamation depends on the physical-chemical properties of the soil. The amount of exchangeable sodium to be replaced will depend on the desired rate of improvement, the quantity and quality of water available for leaching and the cost of the amendment. The usual inorganic amendments are:

- Gypsum ($CaSO_42H_20$)

- Sulphur (S)
- Sulphuric acid (H_2SO_4)
- Lime Sulphur (24%S)
- Calcium Carbonate ($CaCO_3$)
- Calcium Chloride ($CaCl_2.2H_20$)
- Ferrous Sulphate ($FeSO_4.7H_20$)
- Aluminium Sulphate ($Al_2(SO_4)_3.18H_20$)
- Iron Pyrite ($FeSO_2$.30%S)

The quantity of amendment needed to reclaim an alkali soil is determined as product of gypsum requirement (the equivalent amount of exchangeable sodium to be replaced in the soil), which is multiplied by a factor (1.2 - 1.3) to compensate inefficiencies (Porta & Herero, 1996). The assessment of gypsum requirement is based on cation exchange capacity (CEC) of the soil. Reclamation of alkali soils requires removal of part or most of the exchangeable sodium and its replacement by the more favourable calcium ions in the root zone (Gupta and Abrol, 1990). The process can be accomplished in many ways best dictated by local conditions, available resources and the kind of crops to be grown during reclamation. If the farmers can spend little for reclamation and are willing to wait for many years for good crop yields, reclamation can be accomplished, simply by long continued irrigation/cropping and incorporation of large quantities of organic manures.

2.7.3 Effects of Organic Amendments in soil Properties

Organic amendments are known to have favourable effects on soil physical and chemical properties. One of the effects most commonly cited is the improvement of the soil structure. Chen & Amvimen (1986) explained that, different soil parameters combined under the term structure affects processes such as infiltration, wind and water erosion, root growth, distribution of air and water filled pores, energy consumption for soil cultivation, seed germination etc.

One of the measurable functions of soil structure is the bulk density of the soil. Havez (1974) stated that continuous cultivation tends to raise the bulk density i.e. to compact the soil and thus reduce infiltration, aeration or root growth. Khaleel *et al*, (1981) surveyed results of 42 field experiments dealing with the effects of manures and composts on soil properties. A highly significant correlation was found between the increase in soil organic carbon induced by manure application and the lowering in percents of bulk density of the soil.

Gupta and Abrol (1990) explained that incorporating organic materials such as husks and cereal straw has helped in increasing the water intake rates of alkali soils. They also said that, for quick results, however, cropping must be preceded by the application of chemical amendment followed by leaching for removal of soluble salts and other toxins.

2.8 Filtermud (FM)

Filtermud is a by-product of white sugar processing factories. It is obtained after filtering the sugarcane juice to separate out the insoluble substances at the filtering station (Paturau, 1969;Philpotts1976; Acland, 1971). Filtermud is mainly composed of numerous specks of bagasse, sugarcane roots, waxes and other extraneous material (Paturau, 1969 and Paul, 1974).

Abu-Idris et al. (1979) reported the physical composition of filtermud as having moisture content of 73% with a particle size analysis of coarse fibres 7%, fine fibres 17% and non-fibrous 76%. Philpotts (1976) described filtermud as having a very high moisture holding capacity (400% moisture at field capacity), the pH value is usually close to 7.

Acland (1971) explained filter cake as having high calcium content and has approximately the same concentration of nitrogen and phosphate as farmyard manure, and it is sometimes applied to the cane fields. Paturau (1969) reported that filtermud could simply be spread in the cane field as fertilizers about six weeks before planting.

Ssali and Keya (1985) found that, filtermud obtained from Kenya sugar growing areas contain organic carbon range from 20-34%, with organic matter content of 35-60%. The calcium content was the highest compared to other exchangeable bases (Table 6). Basis of the above observations it seems that filtermud can be used to reclaim salt affected soils (alkali soils) because it contains high concentrations of calcium which can replace exchange complex of the alkali (sodic) soils as shown in the chemical reaction below.

$$Na - clay + Ca^{2+} (in \quad solution) \rightarrow Ca - clay + Na^{+} \quad (in \quad solution) \qquad (5)$$

Therefore filtermud can be used as organic manure, fertilizer, incorporated into the soil as well as an amendment for sodic soils (Paturau, 1969; Acland, 1971; Weber *et al.*, 1971; Kinyali, 1976; Van Rooyen, 1977; Abu-Idris *et al.*, 1979 Cooper and Abu Idris, 1980 and Songambele, 1982).

2.8.1 Influence of Filtermud on Soil Physical Properties

From Table 6, it can be seen that filtermud contains substantial amounts of organic matter. It may therefore be reasonable to expect filtermud to act as a binding material to soil particles, improving soil structure, porosity and bulk density.

Table 6: Chemical characteristics of filtermud from sugar Factories in Kenya

Source of filtermud	pH		Organic C (%)	Organic matter (%)	Exchangeable bases (me/100g)			
	1:5 H_2O	1:5 0.01M $CaCl_2$			K	Na	Ca	Mg
Ramisi	7.4	7.3	34.54	59.72	9.75	1.52	166.7	4.63
Miwani	7.9	7.6	22.95	39.68	10.42	1.04	127.0	5.0
Muhoroni	7.3	7.2	20.46	35.38	14.65	0.71	126.0	4.0
Mumias	6.7	6.4	24.29	41.99	2.22	0.78	107.0	5.6
Nzoia	7.0	6.9	21.99	38.02	5.77	0.70	64.0	11.0

Source: Ssali and Keya (1985)

2.8.1.1 Bulk density

Paul (1974) while studying the effects of filtermud on the soil physical properties of a loamy sand soil at sugar estates in Guyana reported that there was a significant decrease in soil bulk density with an application of 30.2 tonnes of filtermud per hectare. The bulk density dropped from 1.6 g/cm^3 to 1.24-g/cm^3. However, when he used 15.1 tons/hectare of filtermud the bulk density decreased to only 1.21 g/cm^3 and was not significantly different from the control. Paul attributed this fall in bulk density not only to the specific organic matter being lower than that of the sandy soil, but also to an increase in the total porosity of the soil. This decrease in bulk density resulted to an improved sugarcane root growth compared with plots that were not treated with filtermud.

Abu-Idris et al (1979) investigated the effects of 100 tonnes/ha of filtermud - bagasse mixture on soil physical conditions of clay soil in Trinidad and reported a significant decrease in soil bulk density at two sites from 1.37 g/cm^3 to 1.30 g/cm^3 and from 1.47 g/cm^3 to 1.35 g/cm^3. Songambele (1982) while studying the effects of filtermud and factory ash application on physical and thermodynamics properties of molted soils of Kilombero estate, Tanzania, reported a beneficial effect on many soil properties after the application of 30 and 60 tonnes per hectare of filtermud in the green house. Bulk density values were significantly reduced.

. Weber & Van Rooyen (1971) reported that molasses significantly reduced the bulk density of the soil compared to that of the control after 5 months of presence in the soil.

2.8.1.2 Saturated hydraulic conductivity

Paul (1974) investigated the effect of filtermud on the saturated hydraulic conductivity of some loamy sand soils at Bookers Sugar Estate, Guyana and reported a significant ($P \leq 0.05$) improvement in permeability compared to the untreated soils, ie from 7.4 to 16.2 cm/hr, from the application of 15.1 tonnes/ha of filtermud. When he doubled the rate to 30.2 tons/ha of filtermud the permeability increased to 49.7 cm/hr ($P \leq 0.001$). Even when he compared the effect of 30.2 tonnes/ha of filtermud to that of 15.1-tonnes/ha filtermud the improvement was still significant at the 0.1% level. Paul attributed this increase in saturated hydraulic conductivity to increased continuity of the transmission pore system rather than creating large channels.

Songambele (1982) reported a very marked increase in saturated hydraulic conductivity of the soil by a general mean factor of 8 to 10 after the application of 30 to 60 tonnes/ha of filtermud in the greenhouse. Van Rooyen *et al.*, (1977) demonstrated that molasses was the most effective amendment compared to the others in terms of improved infiltration rate. He reported that, after one year of application of molasses meal, infiltration rate increased to 104% above that of the control plots, while the other ameliorant did not achieve any significant improvement in this respect. Songambele (1982) also reported an increase in the minimum infiltration rates by general mean factor of 4 to 8 after the application of 30 to 60 tonnes/ha of filtermud in the greenhouse.

2.8.1.3 Aggregate stability

Aggregate stability is a measure of the degree to which the soils are vulnerable to externally imposed destructive forces (Hillel, 1980b). More specifically, it expresses the resistance of aggregates to breakdown when subjected to potentially disruptive processes. To test aggregate stability, soil aggregates are subjected to artificially induced forces designated to simulate phenomena which are likely to occur in the field, like intermittent rainfall causing slaking, swelling, shrinkage erosion, repeated traffic particularly by heavy machinery (Hillel, 1980b). Most frequently, however the concept of aggregate stability is applied in relation to the destructive action of water. The classical and still most prevalent procedure for testing the water stability of soil aggregates is the wet sieving method (Kemper, 1965; Hillel, 1980a).

Weber & Van Rooyen (1971) while investigating polysaccharides in molasses meal as an ameliorant for saline-sodic soils compared to other reclamation agents, demonstrated that molasses meal brought about highly significant increases of aggregate stability percent over other amendments used in the reclamation process. They added that percent aggregate stability in the molasses meal plots increased more than 33% compared to the control plots.

2.8.2 Influence of Filtermud on Crop Yield

Cooper and Abu-Idris (1980) investigated the effects of 100 tonnes/ha of filtermud -bagasse mixture on soil physical conditions of a clay soil in Trinidad they reported a significant increase in sugarcane yield from 65 tonnes to 124 tonnes/ha. Van Rooyen (1977) showed a constant increase in tobacco yield over control after the application of molasses.

2.8.3 Influence of Filtermud on Soil Chemical Properties

2.8.3.1 Soil pH

Tsai et al (1964) Kan-Tien clay reported that 58.5 tons/ha of filtermud substantially raised the soil pH of Kan-Tien clay soil in Taiwan. No actual figures were given. Prasad (1974) reported that filtermud raised the soil pH of both a clay soil and a loamy sand soil, but the pH increments were much more pronounced in sandy soil. Weber *et al.*, (1971) reported that molasses meal brought about no change in soil pH.

2.8.3.2 Exchangeable bases (Ca, Mg)

Prasad (1974) reported that the exchangeable calcium and magnesium increased in the clay soils of Talparo at varying moisture status. For instance calcium increased from 400 ppm to 1003 ppm to 1120 ppm at 0, 134 and 268 tons/ha of filtermud respectively. All these increases were significant at the 1% level. Prasad (1976a) reported significant increases in exchangeable calcium and magnesium. He showed that 33 metric tons of filtermud per hectare on a dry weight basis could supply approximately 160 kg potassium, 650 kg of calcium and 230 kg of magnesium. Ssali & Keya (1985) stated that filtermud has been observed by many researchers as a potential and an economic source of plant nutrients.

2.9 Water Quality for Irrigation

Quality of irrigation water should be the most important factor to consider in the development of irrigated agriculture. Irrigation even with good quality water may turn a good soil into saline or sodic conditions under poor in waterlogged and poor drained soils. Water quality has effects on both the physical and chemical properties of soil and these may lead to reduction in yield (FAO, 1976,Ayers & Westcot 1985). The suitability of water for irrigation depends on (i) how it is managed (ii) the nature of the soil (ii) crop tolerance to salinity of irrigation water.

Water quality criteria must be interpreted in the context of overall salt balances and toxicities and the effects on soil. The problems that result from using poor quality water vary both in kind and degree but the most common are salinity, infiltration, toxicity and miscellaneous problems (Ayers and Westcot, 1985).

Therefore in order to accomplish objective one in the study, the chemical characteristic of irrigation waters used from different sources within the estate should be analyzed in order to determine their suitability for irrigation, by using the guidelines for interpretation of water quality for irrigation as shown in Table 7 (Ayers and Westcot, 1985).

2.9.1 Residual Sodium Carbonate (RSC) for Irrigation Water

Residual sodium carbonate is one of the salinity indices used in evaluation of water quality. Eaton (1950) stated that, if water supply contains more carbonate and bicarbonate than calcium and magnesium, then after evaporation resulted in precipitation of the calcium and magnesium as carbonate salts. The residue of carbonate is paired with sodium. This sodium carbonate is primarily alkaline. As the concentration of sodium carbonate increases, so also does the pH of the soil. Thus RSC is another criteria used to classify irrigation water. It is expressed as:

RSC < 1.25 Water probably safe for irrigation.

RSC 1.25-2.5 Water marginally suitable for irrigation.

RSC > 2.5 Water unsuitable for irrigation.

With concentration in me/l. The values were quoted from Landon (1991)

From Table 7

ECw = electrical conductivity, a measure of water salinity, reported in deciSiemens per metre at 25 °C (dS/m).

TDS means total dissolved solids, reported in milligrams per litre (mg/l).

SAR = sodium adsorption ratio. At a given SAR, infiltration rate increases as water salinity increases.

NO_3-N = nitrate nitrogen reported in terms of elemental nitrogen (NH_4-N and organic -N should be included when wastewater is being tested).

Table 7: Guidelines for interpretation of water quality for irrigation

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to moderate	Severe
Salinity (affects crop water availability)[2]				
EC_w	dS/m	< 0.7	0.7-3.0	> 3.0
(or)				
TDS	mg/l	< 450	450-2000	> 2000
Infiltration (affects infiltration rate of water into the soil). Evaluate using EC_w and SAR together[3]				
SAR = 3-3 and EC_w =		> 0.7	0.7-0.2	< 0.2
= 3-6 =		> 1.2	1.2-0.3	< 0.3
= 6-12 =		> 1.9	1.9-0.5	< 0.5
= 12-20 =		> 2.9	2.9-1.3	< 1.3
=20-40 =		> 5.0	5.0-2.9	< 2.9
Specific Ion Exchange (affects sensitive crops)				
Sodium (Na)[4]				
surface irrigation	SAR	< 3	3-9	> 9
sprinkler irrigation	me/l	< 3	> 3	
Chloride (Cl)[4]				
surface irrigation	me/l	< 4	4-10	> 10
sprinkler irrigation	me/l	< 3	> 3	
Boron (B)	me/l	< 0.7	0.7-3.0	> 3.0
Miscellaneous Effects (affects susceptible crops)				
Nitrogen (NO_3-N)[5]	mg/l	< 5	5-30	> 30
Bicarbonate (HCO_3^-) (overhead sprinkling only)	me/l	< 1.5	1.5-8.5	> 8.5
PH			Normal range (6.5-8.4)	

Source: Ayers & Westcot, 1985

3. MATERIALS AND METHODS

3.1 The Study area

The study area was located at the southeast of the Tanganyika Planting Company (TPC) Ltd (Figure 3). The soils are silty to fine sand and alkaline in reaction, (Waiyaki, 1971). From Figure 3, it can be seen that the salt affected area is almost under depression, and therefore subsurface drainage system is needed for efficient drainage (FAO, 1973). However there is no adequate drainage system existing in all blocks. There are open drains bordering the sides of few blocks, for surface water collection. They are exceptionally deep, from 2.5-4 metres and usually 1-2 metres wide at the bottom; slopes are in the order of 1:300 to 1:1000 (Sloot, 1987). Most drains lead southwards towards "Nyumba ya Mungu" dam or back to the river (Figure 3). Because of the silty nature of soils and absence of sufficient drainage system, which caused an upward water movement in the soil as it has been the case in some fields (Field R8) where the water table was very near, less than 1 m deep.

3.2 Site Selection

Three study sites were chosen as shown in Figure 4. These sites were selected according to the procedure recommended by Steel and Torrie (1980). In the study area representative soil sampling sites were selected and represented a virgin field as the control treatment; salt affected and reclaimed with filtermud (Field O4) and salt affected unreclaimed and abandoned (Field 10A). The selected fields were adjacent to each other and had the same history, tillage, irrigation water used and the method of irrigation.

- Virgin field (control)
- Salt affected field, later applied with 50 tons/ha of filtermud in 1993 (Field 04)
- Salt affected field with no amendments (Field 10A).

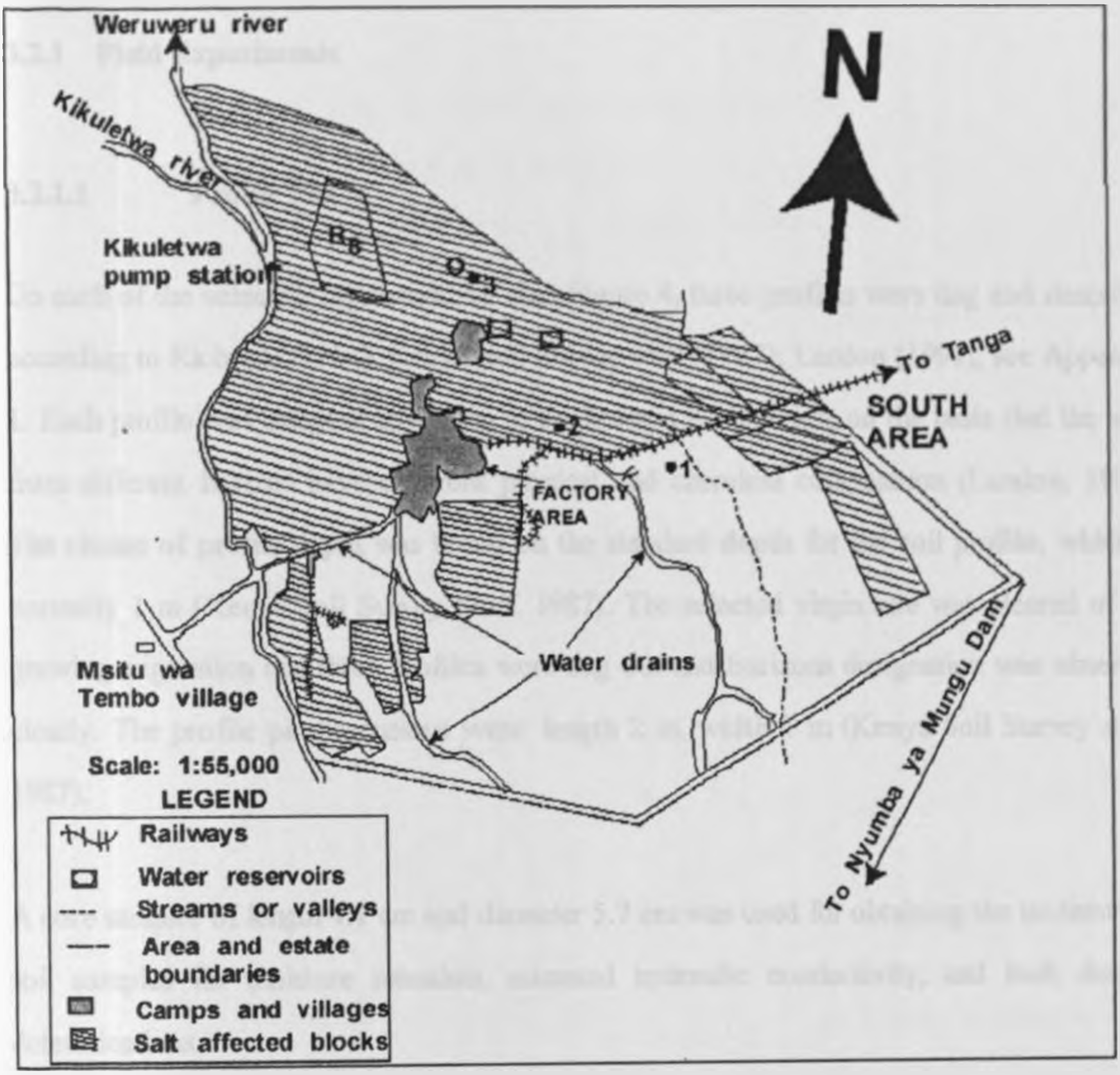

Figure 3: Map of the Southern part of Arusha Chini indicating the study area

Fieldwork involved selection of three sites to represent each treatment. Representative and consistence in sites selection per treatment were further improved by limiting of slopes for the sites within the 2-3-metres range. The precaution was intended to minimize local variations attributable to slope factor. Field O4 was selected on the basis that maize crop was grown and was doing well bearing in mind that maize crop is sensitive to salinity, so the amendment seem to be effective. Virgin area was selected on the basis of being relatively less disturbed, uncultivated and not affected by irrigation water. Field 10A was selected on the basis of being mostly affected having a total failure of sugarcane crop.

3.2.1 Field Experiments

3.2.1.1 Profile Pits

On each of the selected, representative sites Figure 4, three profiles were dug and described according to Richards (1954), Kenya Soil Survey staff (1987); Landon (1991), see Appendix 1. Each profile was sampled according to the horizon designation, on the basis that the soils from different horizon have different physical and chemical composition (Landon, 1991). The choice of profile depth was based on the standard depth for the soil profile, which is normally 1 m (Kenya Soil Survey Staff, 1987). The selected virgin site was cleared of the growing vegetation and three profiles were dug out and horizons designation was observed clearly. The profile pit dimensions were: length 2 m, width 1 m (Kenya Soil Survey staff, 1987).

A core sampler of length 4.1 cm and diameter 5.7 cm was used for obtaining the undisturbed soil samples for moisture retention, saturated hydraulic conductivity, and bulk density determinations.

3.2.1.2 Infiltration Test

The double-ring with a constant head was used as recommended by Landon (1991) and Bouwer (1986). At each site a single infiltration test was carried out within 30m radius from a representative profile pit. Uniform and vertical penetration of the cylinders was ensured in all cases by driving them into the soil carefully and steadily to about 10 cm depth. The soil surface from both cylinders was protected from splash by placing, in each piece of nylon papers. This was done to ensure that there is no water movement between both cylinders occur After 180 minutes the experiment was discontinued and infiltration rate calculated as follows:

$$Infiltration\ rate = \frac{V}{At} cm/hr \tag{7}$$

where

A = cross sectional area of inner cylinder (cm^2)

t = time interval in hours.

V = change in volume in aspirator reading (cm^3)

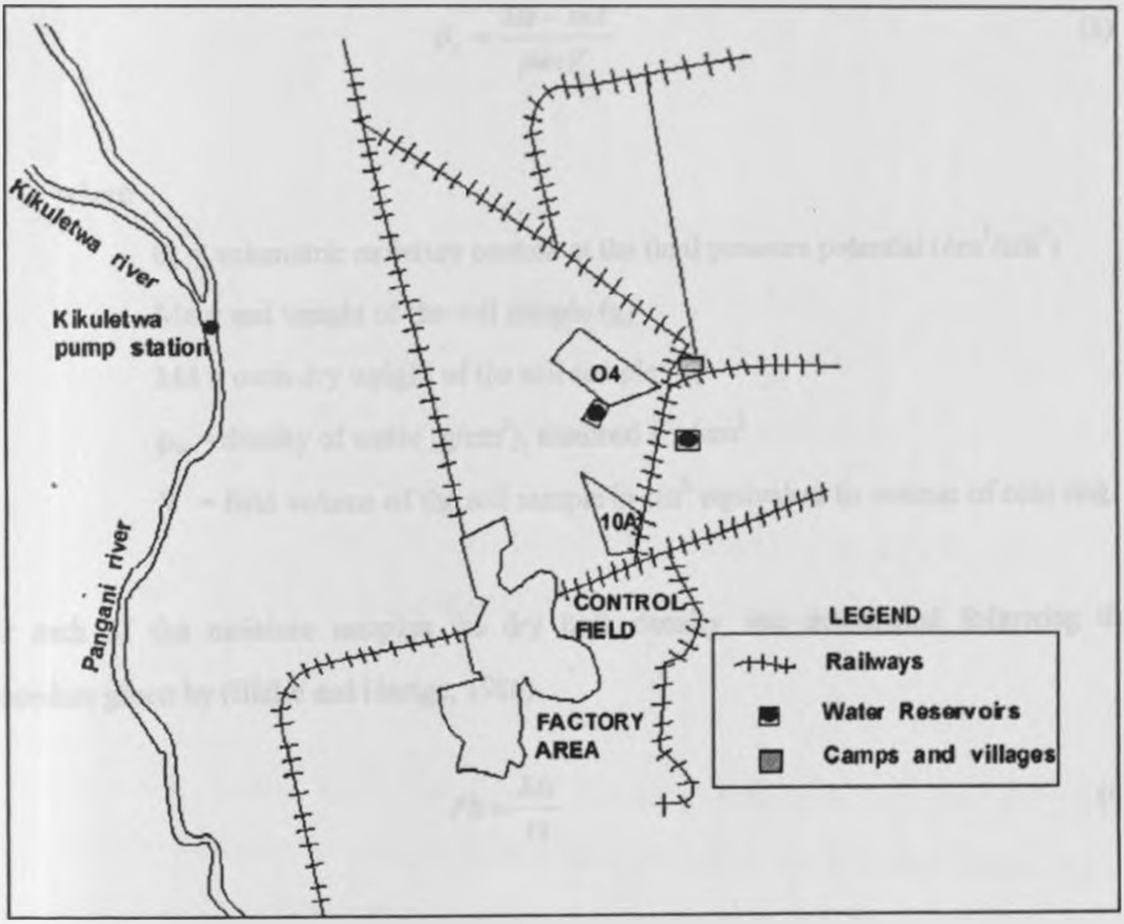

Figure 4: A sketch of the experimental layout

3.2.2 Laboratory Tests

3.2.2.1 Water Retention

The pressure chamber method as described by Klute (1986); Keith & Mullins (1991); Woperreis *et al.*, (1994) was used to determine soil water retention within 10 to 1500 KPa range. Core samples were taken in triplicate and subjected to 10-1500 KPa. Depending on the soil type, equilibrium was attained after 2 to 4 days for the low pressures and 6-10 days for the high pressures (Kinyali, 1973). Samples were prepared as recommended by Klute (1986) and weighing done at each test pressure. After the 1500 KPa equilibrium samples were oven dried at 105°C, for 24 hours. The soil water retention was then computed as

$$\theta_e = \frac{Me - md}{\rho wx V} \tag{8}$$

where

θ_e = volumetric moisture content at the final pressure potential (cm^3/cm^3)

Me = end weight of the soil sample (g)

Md = oven dry weight of the soil sample (g)

ρ_w = density of water (g/cm^3), assumed 1 g/cm^3

V = field volume of the soil sample in cm^3 equivalent to volume of core ring.

For each of the moisture samples the dry bulk density was determined following the procedure given by (Blake and Hartge, 1986).

$$Pb = \frac{Ms}{Vt} \tag{9}$$

where

Pb	=	bulk density in g/cm^3
Ms	=	oven dry weight of the soil sample (g)
Vt	=	field volume of the soil sample in cm^3 equivalent to volume of core ring = $100cm^3$

3.2.2.2 Saturated Hydraulic Conductivity (Ksat)

The constant head method as outlined by Klute and Dirkensen (1986) was used in the saturated hydraulic conductivity determination. Undisturbed soil samples in core ring of 4.1 cm length and 5.7 cm diameter were used. The saturated hydraulic conductivity (K_{sat}) in cm/hr was calculated according to Darcy's Law (Hillel, 1980b).

$$K_{sat} = \frac{Q}{At} \cdot \frac{L}{\Delta H} \qquad (10)$$

where

K_{sat}	=	hydraulic conductivity permeability cm/h
Q	=	quantity of water collected after time t in cm^3
A	=	cross-sectional area of the soil core ring (cm^2)
t	=	time used in the experiment (1 hour)
L	=	length of soil in the core through which water travelled (cm)
ΔH	=	hydraulic head difference or gradient across the soil core
ΔH	=	L + h

where h is the water column level over the soil surface. Nine samples were used per soil treatment material. For each core sample dry bulk density in g/cm^3 was determined after oven drying for at least 48 hours at 105 °C as described by Blake and Hartge (1986)

3.2.2.3 Aggregate Stability

The aggregate stability was determined by the procedure outlined by Kemper (1965) using wet sieving method. With sieves of dimension 2 mm, 1 mm, 0.5 mm, 0.25 mm and 63 µmm. Finally, the percentage stable aggregate was calculated using the equation given by Hillel (1980b).

$$\%SA = 100x \frac{(weight \quad retained) - (weight \quad of \quad sand)}{(total \quad sample \quad weight) - (weight \quad of \quad sand)} \tag{11}$$

Where %SA is the percentage stable aggregate

3.2.2.4 Texture

This involved analysis of the soil for the % sand, % silt, and % clay; using Boyoncous hydrometer method as described by Gee and Bauder (1986). The process involves the initial destruction of organic matter using hydrogen peroxide, dispersion with sodium hexametaphosphate, shaking, mechanical stirring and then analysis of the various size classes by hydrometer method. Later soil textural classes were determined from textural triangle as in Appendix .3

3.2.2.5 pH Determination

This was done according to the procedure given by Loveday (1974). A pH meter model E 350B Mentrohm Herisan was used for pH determination of 1:2.5 soils: 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 0.01M $CaCl_2$. A 20 g soil sample was taken and 50 mls of solution added. Then the mixture shaken for 15 minutes, allowed to rest for 1 hour and shaken again for 2 hours. The readings were taken after the instrument had been calibrated using buffer solutions, one at pH 4.0 and the other at pH 7.0 (Richards, 1954).

3.2.2.6 Electrical Conductivity Determination

This was done using the procedure described by Loveday (1974). The electrical conductivity (EC) was measured using a conductivity meter Bridge. A soil suspension of 1:2.5 (soil: water ratio) was prepared and readings taken after shaking the mixture for 15 minutes, then settled for 1 hour and shaken again for 2 hours, allowed to settle for at least 15 minutes. The reading obtained was recorded and the room temperature noted, (18°C). The EC value was then corrected to the standard temperature of 25C by a correction factor as recommended by USDA, (1954) and Hinga *et al.*, (1980).

3.2.2.7 Organic Matter Determination

The Walkey Black method as described by Nelson and Sommers (1986) was followed in the organic matter determination.

3.2.2.8 Cation Exchange Capacity Determination

The cation exchange capacity (CEC) was determined according to the method described by Rhoades (1982). The CEC of the soils was determined by leaching of 5 g soil samples with 100 ml of 1N Sodium acetate at pH 8.2 as recommended by Richards (1954). During the leaching process exchangeable cations were replaced by sodium ions.

A second leaching with 100 ml of 96% ethyl alcohol in order to leach out excess sodium ions from the soil followed initial leaching. Finally the soil was leached with 100 ml of 1N ammonium acetate at pH 7.0 during which the sodium ion in the final leachate was then determined using the same Atomic Absorption Spectrophotometer (AAS) machine as for exchangeable cations.

3.2.2.9 Exchangeable Cations Determination

Exchangeable cations (Ca^{2+}; Mg^{2+}; K^+; and Na^+) were analyzed using the methods described by Loveday (1974). K^+ and Na^+ were determined using the EEL- flame photometer, while Ca^{2+} and Mg^{2+} were analyzed using Atomic Absorption. Spectrophotometer Samples weighing 2g were leached with 100 ml of ammonium acetate at pH 7.0 in stages of 25 ml each (4 leachings of 25 mls). A 100 ml of soil leachate was then taken for the analysis.

3.2.2.10 Carbonates, bicarbonates, hydroxide and chloride ions determination

Soluble anions were determined using the method given by Richard (1954), and Black (1965). Samples of 1:2.5 soil/water extracts were used for the analysis of CO_3^{-2}; HCO_3^{-2}; OH^- and Cl^- ions. A 50 ml aliquot was used for all anions determined. It involved titrating the soil/water extracts or the water quality sample with 0.050N sulphuric acid using phenolphthalein as indicator. The same sample 1 ml of 2% $Kr_2Cr_2O_7$ (Potassium dichromate) was added and the mixture titrated with 0.050N $AgNO_3$ (Silver nitrate).
Hydroxide and carbonate titration were obtained from the first, titration with sulphuric acid and phenolphthalein indicator where by 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. Finally, salinity indices for soil samples were calculated from the result i.e (ESP), (SAR) as described by (Hinga *et al.*, 1980; Landon, 1991; Rowel, 1994

3.3 Water Sample Collection

Tanganyika Planting Company (TPC) had two main sources of water used for irrigation, which were: water from the two rivers namely Kikuletwa and Weruweru; water from reservoirs, pumped to several boreholes. Therefore, in order to accomplish objective one in the study, the chemical characteristic of irrigation waters used from different sources within the estate were analysed in order to determine their suitability for irrigation,using the guidelines for interpretation of water quality for irrigation as shown in Table 7 (Ayers & Westcot 1985).

Water samples from both rivers before and after the two rivers met and some boreholes whose water is used for irrigation in the estate were collected for their chemical analysis in the laboratory. Water from Q and BO pumps only, were sampled because the other pumps was out of order by the time the field work was undertaken. Q pump feeds Q1-Q5 boreholes while B0 pump feeds BO1-B05 borehole. Drainage and stagnant water from R8 field (completely abandoned field in 1977) were sampled at different places in order to observe changes in salinity over time.The water samples were put in1 litre clean plastic containers for PH; EC, SAR, SAR_{adj} and RSC determinations.

Water samples from the completely abandoned field (R8) were also collected at different places for laboratory analysis. A total of 15 samples of water from different water sources were analyzed for pH; EC (dsm^{-1}), exchangeable cations (Ca^{2+}; Mg^{2+}; K^{+}; Na^{+}) and anions (HCO^{-2}_{3}; CO^{-2}_{3}; SO_{3}^{-2}; Cl^{-}). The methods followed were those described by Richard (1954). Finally the salinity indices for soil samples and water samples (SAR, SAR_{adj}, RSC) were calculated using equations given by Landon (1991); Rowel (1994).

3.3 Method of data Analysis

The data obtained were analyzed statistically using procedures laid down in Steel and Torrie (1980). Means were separated using Duncans New Multiple Range test (DNMR). Simple linear correlation analysis was used to determine the relationship between saturated hydraulic conductivity, moisture release/retention with the selected soil physical parameters.

SPSS/PC+ programme was used to analyze the data using oneway (single way) ANOVA method and means separation as summarized in Appendix 2.

4. RESULTS AND DISCUSSIONS

4.1 Soil Analysis

The results of the various soil parameters investigated are given in Tables 8, 9, 10 and 11 for some soil physical properties, mean infiltration rate, soil moisture retention and some chemical properties, respectively.

4.1.1 Observation on Soil Physical Properties

4.1.1.1 Bulk Density

The results in Table 8 indicate that there was no much difference in soils bulk density between the reclaimed field and the abandoned field. The bulk density from the three fields: reclaimed field (04), abandoned field (Field 10A), and control field (virgin field) were almost the same. The dry bulk density values for top soils were 1.00, 1.10 and 1.20 g/cm^3 for soils from the control field, reclaimed field and abandoned field respectively, may be due the 1year fallowing period for Field 10A which has similar bulk density to that of control. The bulk densities for sub-soils (second horizon) were 1.20, 1.30 and 1.30 g/cm^3 for the control field, reclaimed field and abandoned field respectively. Probably the effect of filtermud was not felt at this depth (30-45cm). The third horizon had the values of 1.40, 1.40 and 1.20 g/cm^3 for the control field, reclaimed field and abandoned field respectively. Thus Field 04 had the higher value of bulk density compared to Field 10A and this may be because of high clay and silt contents observed in the subsoil of Field 04.

When the bulk density values were analyzed according to soil depth, it was found that, the values of the topsoils were significantly lower than the subsoil values at 5% level of significance, (Appendix 2a). Thus the bulk density values increased with depth except in field 10A. (Table 8). The Duncan multiple range test showed that the bulk density values ranged from 1.09 to 1.26 g/cm^3 for top soils and subsoils respectively, (Appendix 2a). This could be because of the high organic matter content observed in the topsoils in all the three fields.

4.1.1.2 Texture

According to USDA system, of classification as given by Hinga *et al* (1980), the textural class observed in the control field was sandy loam, loamy sand, and sand for topsoil, second horizon and third horizon respectively. The percentage of sand increased with depth while the clay percentage decreased with depth, and the silt percentage was almost constant throughout the profile depth. The gravel concentration was high in the subsoil especially in the third horizon. Percentage sand were 78, 84 and 88 for first, second and third horizon respectively. Nutrients release and water retention in such soils are low while natural biological activity is also low in sandy soils accentuating their infertility (Pitty, 1978).

Similar trend was observed in the abandoned field, whereby, the percentage of sand increased with depth. But the quantity of sand was lower than that found in the control field. The silt and clay percentages varied with profile depth, with higher values of silt percent than clay percent. The textural class observed in this particular field was loam throughout the profile. The dominant particles were very fine sand and silt with constant clay percentage (16%) throughout the profile. These proportions of very fine sand, silt and clay in Table 8 favoured the accumulation of salts, consequently having slow water movement with higher moisture retention and a very low moisture release for sugarcane growth.

In the reclaimed field (Field O4) the textural class was loam for both first and second horizons, and silt loam class for the third horizon. The percentage of sand decreased with soil depth. Silt and clay contents followed the opposite trend by increasing with depth. The dominant particles found in this plot were very fine sand and silt. The last horizon had a higher clay content compared to the other horizons in the other field as well.

4.1.1.3 Saturated Hydraulic Conductivity (K_{sat})

Regarding K_{sat} measurements, Table 8 indicates that, K_{sat} for soils from the abandoned field (Field 10A) was significantly lower than the K_{sat} for soils from the reclaimed field (Field O4). The mean values for the topsoils were 27.3, 4.3 and 2.0 cm/hr for the control, reclaimed and abandoned plots respectively. So the control field had the highest K_{sat} (very rapid K_{sat}), which implies that the soils in that particular field had a large number of macropores, characteristic of sandy soils, which are responsible for water transmission. Also the very rapid K_{sat} observed in the control field throughout the profile depth may have been influenced by the effects of forest vegetation with its enormous rooting network as well as accumulated litter and favourable conditions for soil organisms (micro and macro) activity, together with gravel/stony soil structure.

The observed values of hydraulic conductivity from the reclaimed field (O4) were 4.3, 0.6, and 0.4cm/hr for the topsoils, second and third horizons respectively, while hydraulic conductivity values from the abandoned field (10A) were 2.0, 0.2 and 1.4 for topsoils, second and third horizons respectively. Meaning that reclaimed field had moderate hydraulic conductivity for the topsoil decreasing with soil depth. The hydraulic conductivity of the abandoned field was slow for the topsoil, decreasing with depth up to the second horizon and then increasing downward. This implies that, the effect of exchangeable sodium present in the abandoned field (ESP = 40.0,31.3 & 20.1) together with high electrical conductivity values (3.7,3.1 & 2.7) Table 11caused clay swelling and soil particle dispersion consequently blocking the soil pores through which water flows, hence diminishing the hydraulic conductivity of the soil (Shainberg, 1975; Rowel 1994). Furthermore, the positive effect of 50 tonnes/ha of filtermud on field O4 was reflected by low values of both, Exchangeable Sodium Percentage (ESP =12.8,25.0 & 43.3), and electrical conductivity (0.8, 0.6 &0.6) this implies that organic matter and calcium content contained in the filtermud was substantial to reclaim the affected soils of filed O4 effectively up to 45cm deep

The K_{sat} of soils from the reclaimed field was significantly lower than that of soils from the control field; meaning that water movement through saturated soil in the reclaimed field was slow compared to the control field. However, this does not indicate that filtermud was not effective in improving the structure of the affected soils. The reason behind this may be that the rate of filtermud applied (50 tonnes/ha) was not enough to bring a significant improvement in soil structure in relation to sodium levels present in the soil during the reclamation process. The slow saturated hydraulic conductivity observed in the slight saline sodic soils from abandoned field were due to high ESP which increased dispersion and swelling of clay which led to structural damage hence reduction of hydraulic conductivity. The slow saturated hydraulic conductivity may also be caused by physical disruption of aggregates leading to seal formation on the soil surface, which resulted in low water permeability. However, the K_{sat} for the topsoils from the reclaimed field was two times the K_{sat} of the abandoned field. Therefore filtermud was still effective at that moment.

4.1.1.4 Relationship between texture, and hydraulic conductivity

Basing on the hydraulic conductivity (K_{sat}) values observed; soils from the control field were 27.3, 30.2 & 35.3cm/hr (Table 8). These values imply that, soils are of single grain structure with medium sand texture (Table5). Similar observation was observed in the textural class that, is soils from the control field had high sand and silt contents increased with soil depth (78, 84 & 88%) and (9,10,8%). Soils from the reclaimed field (O4) had Ksat values of (4.3, 0.6 &0.4cm/hr) decreasing with soil depth. These values imply that, the topsoil could be medium prismatic or sub angular blocky structure with light clay loam, silty, silt loam, very fine sandy loam or loam texture (Table 5), which is similar to the textural class observed loam (Table 8). According to Table 5, soils from second horizon could be fine and medium prismatic angular blocky, platy structure with clay, silt clay, sandy clay, silty clay loam, silty loam, silty, and sandy clay loam however the observed structural class was loam. Similar trend was observed in the subsoil whereby the textural class observed was silty loam, but with regard to Table 5 the soil texture could be clay, clay loam or silty clay with very fine or fine prismatic angular blocky or platy structure. This is due to the effect of Exchangeable Sodium Percentage (ESP= 25.0, 43.3) being high caused poor structural quality of the soil because sodium disperses soil particles hence low permeability. (Shainberg, 1975, Hillel, 1980b, Frenkel & Meiri, 1985, Landon, 1991, Rowel, 1994).

Soils from the abandoned field (10A) was loam textured (Table 8), the Ksat values (2.0, 0.2, 1.4cm/hr) which reflects similar texture (loam) for top soil (Table 5). This means fallowing period of 1 year was effective and improved soil structure. However in the second and third horizons, the soil texture observed was different with regard to Ksat values observed and that of Table 5 this is probably due to high sodium content (ESP = 40.0, 31.3 &20.1) and high salt content which was reflected by high values of electrical conductivity (3.7, 3.1 &2.7dSml) Table 11. High concentration of sodium causes soil particle dispersion and clay swelling which block the soil pores through which water flows, causing low soil permeability (Shainberg, 1975, Hillel, 1980b Hillel,1982; Frenkel & Meiri 1985, Landon,1991, Rowel, 1994)

4.1.1.5 Effect of filtermud on aggregate stability

Table 8 shows that soils from the reclaimed field had percent stable aggregate (%SA) ranged from 40, 45 and 47 for the first, second and third horizons respectively. Soils from the abandoned field had their percent stable aggregate as 43, 41 and 40 for the first, second and third horizons respectively, while the soils from the control field have %SA of 50, 48 and 46 for the first, second and third horizons respectively. Therefore soils from the control field had the highest percent of stable aggregate, followed by soils from the reclaimed field. This is because of the gravel/stony soil structure of the soil from the control field. In the control field the percent SA decreased with depth, and this is due to field sand fraction, which was increasing with depth. Similar trend was observed for the abandoned field. However, in the reclaimed field, the percent SA increased with depth and this is probably because of the silt and clay content being high in the subsoil. Moreover, the percent SA for the topsoil from the reclaimed field was low compared to that from the abandoned field, this is because the abandoned field was under fallow period of one year that improved soil structure and increased aggregate stability. The reclaimed field was recently, cultivated and also the filtermud applied was susceptible to further microbial decomposition like other organic manures, therefore it decomposed and left the top soil with porous structure hence less stable aggregates. In this particular case filtermud could be replenished and supplied continually if aggregate stability was to be maintained (Hillel, 1980a; Hillel, 1980b).

That is why in this particular case filtermud brought no significant improvement of percent stable aggregate over control as well as abandoned fields.

4.1.1.6 Mean Infiltration Rate

The mean infiltration rate values are presented in Table 9 and in Figure 6. It was found that infiltration rates varied significantly ($p < 0.05$) with time particularly at intervals of 1; 2; 60; 120 and 180 minutes among the fields (Appendix .2d).

Table 8: Mean Values of Some Soil Physical Properties

Site	%SA Soil depth (cm)	Bulk density (g/cm^3)	Saturated Hydraulic conductivity (cm/hr)	%SA	Texture			Textural class
					% sand	% silt	% clay	
Non Irrigated	0-30	1.00	27.3	50	78	9	13	Sandy Loam
	30-68	1.20	30.2	48	84	10	6	Loamy Sand
	68-100	1.40	35.3	46	88	8	4	Sandy
Irrigated Field O4	0-30	1.10	4.3	40	58	28	14	Loam
	30-45	1.30	0.6	45	52	33	15	Loam
	45-100	1.40	0.4	47	44	38	18	Silty Loam
Irrigated Field 10 A	0-35	1.20	2.0	43	58	26	16	Loam
	35-78	1.30	0.2	41	60	25	15	Loam
	78-100	1.20	1.4	40	64	20	16	Loam

Results are means of (3) three profile

Virgin field had the highest initial infiltration rate (180 cm/hr), probably because of the correspondingly high organic matter 9.2% (Table 11) in the surface horizon, accumulation of litter, forest vegetation, grass and the conducive environment for soil organisms that might have led to a relatively porous structure at the surface. Furthermore a very rapid infiltration rate observed at the time could be due to the high percentage of sand 78% by weight, found on topsoil (Table 9). Sandy loam with few stones and gravel associated with soil macro-pores, which are responsible for water transmission (Pitty, 1978).

Initial mean infiltration rate of Field O4 was 120 cm/hr, two times compared to that of field 10A 60 cm/hr. The initial infiltration rates for all the three fields are of very rapid class according to Landon (1991). (Table 3 & 9). For the first 15 minutes the infiltration rate was very rapid in field O4 and then decreased to rapid class for one hour, and finally changed to moderately rapid. This trend was apparently due to the effect of filtermud, which improved soil structure, provided a water stable structure, which resulted in a good trend mean infiltration rate. Similar findings are reported by Van-Rooyen and Weber (1977).

Field 10A had the lowest value of the initial infiltration rate of 60 cm/hr. However, the rate was very rapid for the first seven minutes. The trend decreased to rapid for 23 minutes and then to moderately rapid class for one and a half hours. The steady infiltration rate was moderately slow, and this may be attributed to low aggregate stability and the collapse of the soil structure, surface sealing, swelling and clay dispersion due to the exceedingly high ESP 40 (Table 11). Equilibrium infiltration rates for fields O4 and 10A was attained after one and a half hours while in virgin field the final stable infiltration rate was attained after two and a half hours.

The sharp increase of the mean infiltration rate in the second minute for all fields indicated a change to another phase of wet run after the dry run. The curve for control field was not smooth especially after 10 minutes up to 60 minutes and this could be due to entrapped air bubbles in the aspirator tube, as well as lateral divergence of flow below the cylinder infiltrometer (Hillel, 1980a; Hillel, 1980b; Bouwer, 1986; Landon, 1991).

4.1.1.7 Moisture Retention

Regarding moisture retention measurements, Table 10 shows that application of 50 tonnes/ha of filtermud reduced the water retention for topsoil by approximately 4-7% at each pressure potential from -1500 to -10 KPa, as compared to the soils from the abandoned field, (Figure 6). Furthermore, the volumetric water content retained by the second horizon, from the control field was the lowest followed by the reclaimed and then abandoned soils (Figure 6). This is due to high number of macropores characteristic of sandy soil. While the reclaimed and abandoned soils retained high volumetric moisture content due to their texture, (loamy) as compared to the soils from the control field (sandy). In sandy soil most of the pores are relatively large, and once these large pores are emptied at a given suction, only small amount of water remains (Hillel, 1980a, Hillel, 1980b). Figure 7 indicates that the volumetric water content retained by the reclaimed soil from the third horizon was the highest at each pressure potential. This is because of high clay and silt content having large number of micropores responsible for moisture retention. Also in clayed soil, the pore-size distribution is more uniform, and more water is adsorbed, so that increasing suction causes a more gradual decrease in water content (Hillel, 1980a).

Table 9: Mean Infiltration Rates (cm/hr) of the soils in the Three Studied Fields

Time (min)	Mean infiltration rate (cm/hr)		
	O4	10A	Control
1	120.0	60.0	180.0
2	75.0	54.0	120.0
3	60.0	40.0	94.0
4	49.5	36.0	85.5
5	42.0	32.4	74.4
6	38.0	28.0	69.0
7	34.3	24.9	65.1
8	32.3	23.3	61.5
9	29.3	21.3	60.0
10	27.0	19.8	58.2
12	28.9	26.4	62.6
14	26.6	22.6	61.0
16	24.8	20.3	59.7
18	23.5	18.5	61.6
20	22.0	17.1	59.6
25	19.6	14.7	57.9
30	17.5	12.5	58.4
35	16.0	12.0	57.8
40	15.0	10.9	54.4
45	14.3	10.1	52.1
60	12.6	8.7	47.6
75	11.5	7.6	47.8
90	10.8	6.9	47.9
120	9.7	6.0	43.4
150	9.1	5.5	39.6
180	8.7	5.2	36.1

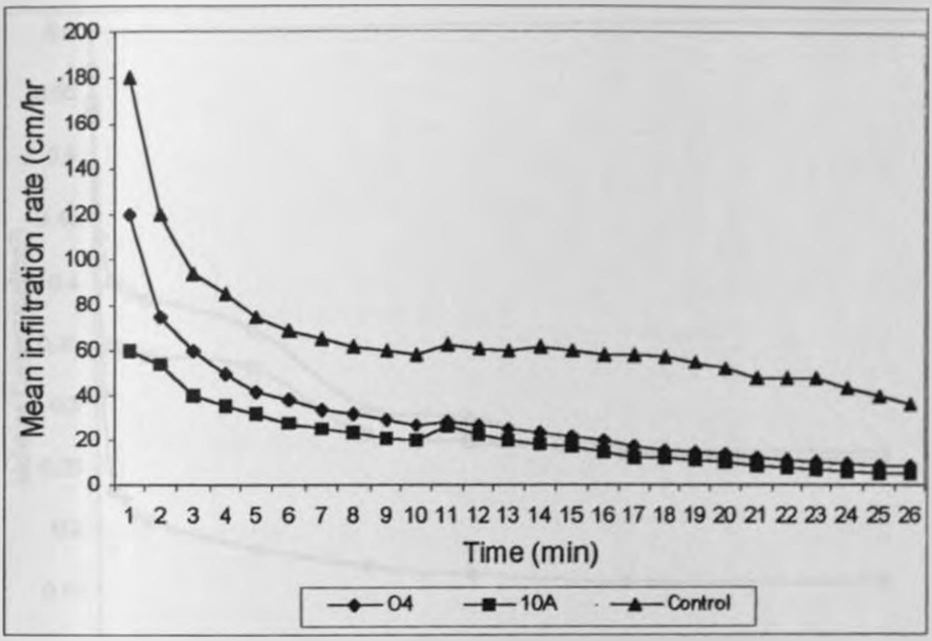

Figure 5: Mean Infiltration rate of the control, reclaimed and abandoned fields

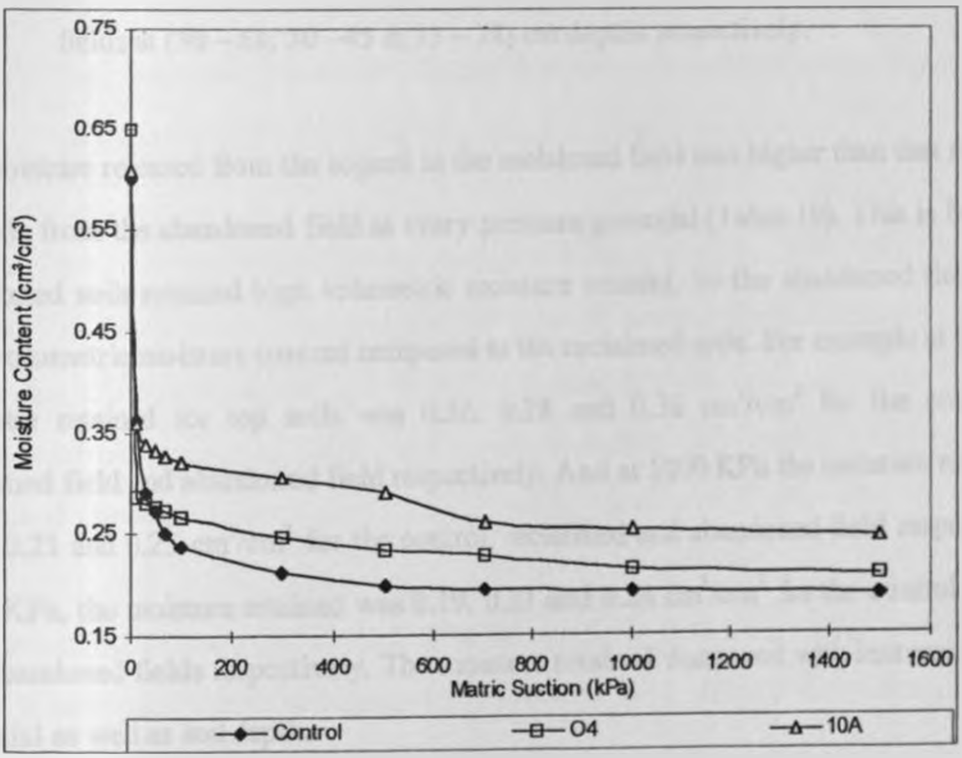

Figure 6: Soil water retention for first horizon for the reclaimed, abandoned and control fields at (30, 35, 30) cm depths respectively.

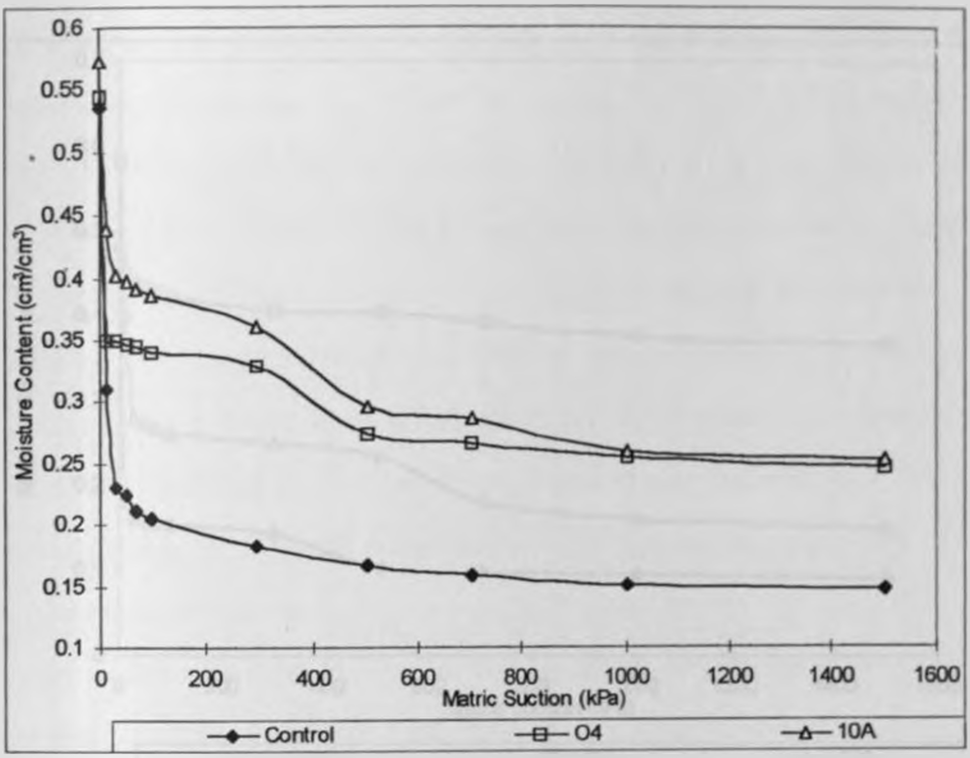

Figure 7: Soil water retention for second horizon for the control, reclaimed and abandoned fields at (30 – 68; 30 –45 & 35 – 78) cm depths respectively.

The moisture released from the topsoil in the reclaimed field was higher than that released by the soils from the abandoned field at every pressure potential (Table 10). This is because the abandoned soils retained high volumetric moisture content. So the abandoned field released little volumetric moisture content compared to the reclaimed soils. For example at 10 KPa the moisture retained for top soils was 0.36, 0.28 and 0.36 cm^3/cm^3 for the control field, reclaimed field and abandoned field respectively. And at 1000 KPa the moisture retained was 0.19, 0.21 and 0.25 cm^3/cm^3 for the control, reclaimed and abandoned field respectively. At 1500 KPa, the moisture retained was 0.19, 0.21 and 0.24 cm^3/cm^3 for the control, reclaimed and abandoned fields respectively. The moisture retained decreased with increasing pressure potential as well as soil depth.

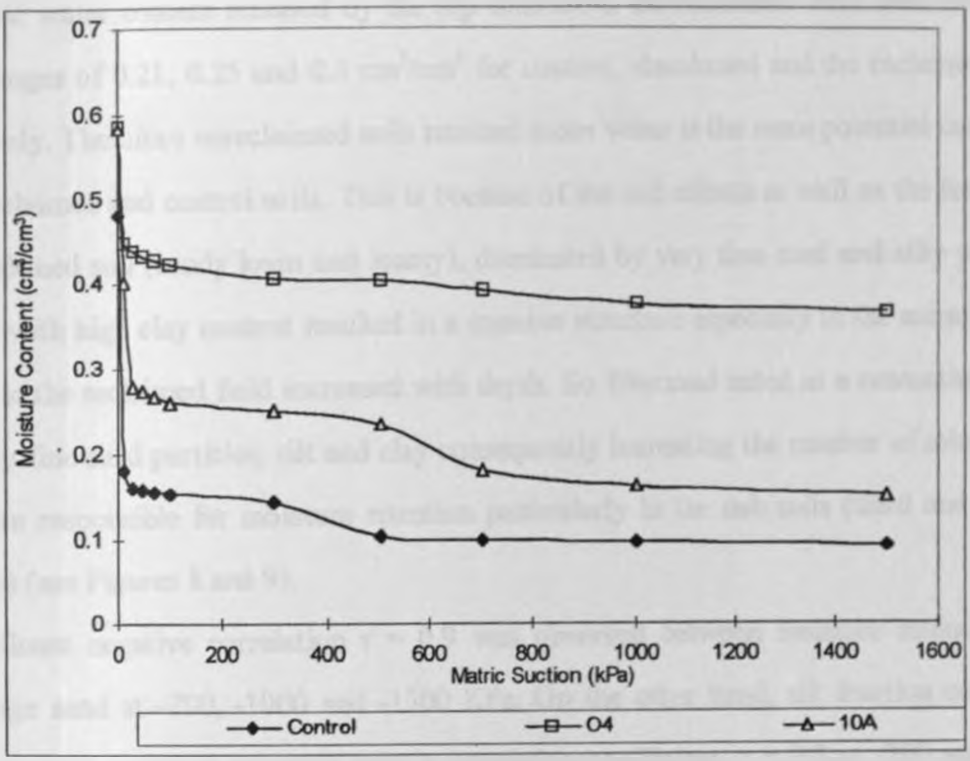

Figure 8: Soil water retention for third horizon for the control, reclaimed and abandoned fields at (68 –100; 45-100 & 78 –100) cm depths respectively

The moisture retention pattern for the reclaimed field (Figure 7) shows that, the top layer retained the highest volumetric water content than the subsoil, which is due to the texture as well as the effect of filtermud. The effects of texture and filtermud counteract the effect of salt in structural damage by providing a good granulated soil responsible for high moisture release and retention.

Volumetric moisture content retained in the fields at each pressure potential was significantly different from each other. Soils from the abandoned field retained more moisture than the soils from the reclaimed field because of the salinity effect and hence water is less available to sugarcane plants, consequently reduced sugarcane yield (Table 12). The volumetric water content retained by the soils from the control field was significantly lower than the volumetric water content retained by the top soils from the reclaimed field with the mean values ranges of 0.21, 0.25 and 0.3 cm^3/cm^3 for control, abandoned and the reclaimed soils respectively. Therefore unreclaimed soils retained more water at the same potential compared to the reclaimed and control soils. This is because of the salt effects as well as the texture of the abandoned soil (sandy loam and loamy), dominated by very fine sand and silty particles together with high clay content resulted in a massive structure especially in the subsoil. Clay content in the reclaimed field increased with depth. So filtermud acted as a cementing agent with very fine sand particles, silt and clay consequently increasing the number of micropores which are responsible for moisture retention particularly in the sub soils (third and second horizons) (see Figures 8 and 9).

A significant negative correlation r = 0.9 was observed between moisture retention and percentage sand at -700, -1000 and -1500 KPa. On the other hand, silt fraction correlated positively with moisture retention with a correlation coefficient, r = 0.8 at -700 and -1000 KPa.

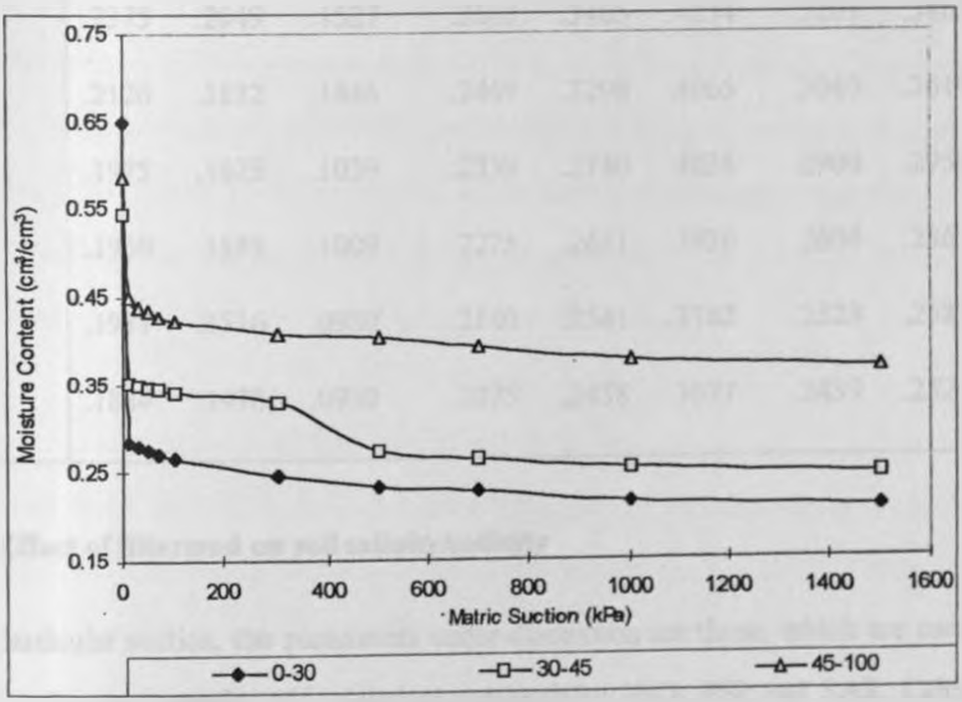

Figure 9: Soil water retention in filtermud reclaimed field.

Table 10: Average Moisture Retention Results at Different Suction Pressures (cm^3/cm^3)

Treatment	Control field			Reclaimed field			Abandoned field		
Depth (cm) / Pressure KPa	0-30	30-68	68-100	0-30	30-45	45-100	0-35	35-78	78-100
0	.6015	.5370	.4820	.6490	.5450	.5865	.6082	.5726	.5831.
10	.3622	.3107	.1824	.2848	.3507	.4499	.3599	.4396	.4034
30	.2899	.2311	.1614	.2800	.3493	.4386	.3377	.4033	.2783
50	.2717	.2240	.1584	.2755	.3470	.4337	.3328	.3978	.2738
70	.2505	.2119	.1558	.2717	.3449	.4284	.3270	.3917	.2676
100	.2375	.2049	.1527	.2663	.3405	.4234	.3201	.3862	.2605
300	.2126	.1832	.1446	.2469	.3296	.4065	.3049	.3619	.2502
500	.1975	.1675	.1039	.2339	.2740	.4038	.2900	.2959	.2340
700	.1950	.1585	.1009	.2275	.2651	.3926	.2604	.2867	.1812
1000	.1917	.1516	.0980	.2140	.2541	.3762	.2529	.2587	.1617
1500	.1884	.1478	.0930	.2075	.2458	.3677	.2439	.2526	.1515

4.1.2 Effect of filtermud on soil salinity/sodicity

In this particular section, the parameters under discussion are those, which are used in soil salinity evaluation, namely: pH, electrical conductivity (EC), ESP and SAR. Calcium and sodium concentration will be discussed, also it was assumed that filtermud used as a source of calcium could displace sodium ion in the soil exchange complex because it has high calcium in concentration as indicated in Table 11.

4.1.2.1 Effect of filtermud on pH

Table 11 gives a comparison of means of changes in pH of the saturated soil extract (1:2.5 soil: water ratio and 0.01M $CaCl_2$). The results indicate that average pH values from the control field were 7.5, 8.0 and 8.5 when measured in water and 7.3, 7.7 and 8.4 when measured in 0.01M $CaCl_2$ for first, second and third horizons respectively. From salinity point of view (Appendix 4a), soils from the control field are moderately alkaline particularly in first and second horizons while the third horizon is strongly alkaline. Therefore alkalinity increased with soil depth. This is probably due to leaching process of the soluble salts deep to subsoil.

A similar trend was observed in the reclaimed field where the soil pH increased with profile depth. The average pH value ranged from 8.0, 7.9 and 8.0 when measured in water and 7.7, 7.7 and .7.8 when measured in 0.01M $CaCl_2$ solutions for first, second and third horizon respectively. As shown in Appendix 4a, these soils are moderately alkaline. But when compared with the control field, the soils are more alkaline than from the reclaimed field. Therefore application of filtermud had lowered the pH values.

Soils from the abandoned field had average pH values ranging from 8.9, 8.6 and 8.3 when measured in water and 8.6, 8.3 and 7.9 when measured in 0.01M $CaCl_2$ solutions for first, second and third horizons respectively. The pH values decreased with profile depth and the soils were moderately to strongly alkaline. When compared with the control and reclaimed fields, the soils from abandoned fields were more alkaline although the difference was not significant (Appendix 2f). Similar findings reported by Weber and Van Rooyen (1971). Normally soils with pH values above 8.0 have a high percentage of Na^+ ions in their exchange sites (Brady, 1984).

4.1.2.2 Effect of filtermud on Electrical Conductivity (EC)

Table 11 shows that mean EC values were 0.6, 0.4 and 0.6 dsm^{-1} for first, second and third horizons for the soils from the control field respectively. This meant that the soils were non-saline as classified in Appendix 4a. Soils from the reclaimed field had EC values ranging from 0.8, 0.6 and 0.6 dsm^{-1} for the first, second and third horizons respectively. And hence were non-saline. Soils from the abandoned field had the EC values ranging from 3.7, 3.1 and 2.7 dsm^{-1} for first, second and third horizons respectively were moderately saline (Appendix 4a). Therefore filtermud significantly lowered the EC values of soils from the reclaimed field when compared to the EC values from abandoned and control fields (Appendix 2g). However, the EC values of the topsoils of the reclaimed field were high compared to the soils from the control field, though the difference was not significant. This is probably due to the effect of irrigation water in the reclaimed field. The EC values in the abandoned field decreased with depth and a similar trend observed for pH values. This means that the higher the pH value, the higher the EC value and vice versa.

4.1.2.3 Effect of filtermud on ESP and SAR

Table 11 shows that, the exchangeable sodium percentage (ESP) values were 4.1, 7.6 and 109.8 for the first, second and third horizons of the control field respectively. The values increased with depth while the topsoil (first and second horizon) were non sodic according to Table 1. The soil from the third horizon was sodic having ESP values greater than 15. A similar trend was observed for sodium adsorption ratio (SAR) values. The SAR values increased with depth and the subsoils were sodic having a SAR value greater than 13. Their SAR values were 1.0, 1.4 and 18.5 for first, second and third horizons respectively. Soils from the reclaimed field had ESP values of 12.8, 25 and 43.3 for first, second and third horizons respectively while the SAR values were 3.8, 5.9 and 10.3 respectively. According to the ESP values the topsoils are non sodic while the subsoils (first and second horizons) are sodic since their ESP values are greater than 15.

Soils from the abandoned field have ESP values of 40.0, 31.3 and 20.1 for first, second and third horizons respectively. Meaning that the soils are sodic and the sodicity decreased with depth. The SAR values were 10.5, 8.0 and 6.9 for first, second and third horizons respectively, the SAR values also indicated that the soils from abandoned field are sodic. However, Appendix 7.2j and 7.2k show that there was no significant change that took place in ESP and SAR values. This is probably because of the high calcium and magnesium content of the soils hence displacing sodium ion in the soil exchange complex in all the fields.

4.1.2.4 Effect of filtermud on Calcium Content

Filtermud significantly increased calcium content of the reclaimed soils. Calcium values of soils from the reclaimed field were 216.7, 239.0 and 238.0 me/l for first, second and third horizons respectively. Calcium values for the control fields were 197.7, 133.8 and 91.7 me/l for first, second and third horizons respectively and values for abandoned field were 210.0, 210.0 and 146.7 me/l for first, second and third horizons respectively. Therefore filtermud significantly increased calcium level in the soil (Appendix 2h).

4.1.2.5 Effect of filtermud on Sodium

Table 11 shows that the sodium levels were high in all the three fields. The average values from the control field were 11.7,12.5 and 155 me/l for first, second and third horizons respectively. From the abandoned field, the values were 128.3, 101.7 and 73.3 me/l for first, second and third horizons respectively, that no significant change took place in response to filtermud applied because of the high concentration of sodium almost in all the three fields throughout the profiles (Appendix 2j). This indicates that the soil by itself has high concentration of sodium as shown by the high value of percentage base saturation (BSP)

100% in all the fields, (Table 11). Also more sodium was being added to the irrigation water because the soils from the reclaimed field had also high sodium levels. Therefore moderately saline sodic soils from the abandoned field affected sugarcane growth, which consequently caused a decline in sugarcane yield as indicated in Table 12.

Table 11: Mean Values of Some Soil Chemical Properties and the related Salinity indices

Site	Soil depth (cm)	pH		$EC_{25°C}$ dSm^{-1}	CEC me/100g	Organic matter %	Exchangeable cations and soluble anions (me/l)						Salinity indices		Base saturation %
		H_20 1:1.25	$CaCl_2$ 0.01M				Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^-	CO_3^-	ESP	SAR	
Control field	0-30	7.5	7.3	0.6	28.7	9.2	197.7	69.9	11.7	58.3	4.11	TR	4.1	1.0	100+
	30-68	8.0	7.7	0.4	19.9	2.7	133.8	17.3	12.5	50.8	5.5	0.1	7.6	1.4	100+
	68-100	8.5	8.4	0.6	14.6	3.2	91.7	48.0	155.0	55.0	2.1	0.2	109.8	18.5	100+
field O4	0-30	8.0	7.7	0.8	30.6	2.7	216.7	86.8	39.2	52.5	2.5	0.7	12.8	3.8	100+
	30-45	7.9	7.7	0.6	30.7	0.8	239.0	103.7	76.7	80.0	3.4	0.4	25.0	5.9	100+
	45-100	8.0	7.8	0.6	31.9	0.9	238.3	113.0	136.3	85.0	2.8	TR	43.3	10.3	100+
field 10A	0-35	8.9	8.6	3.7	32.0	2.0	210.0	96.5	128.3	140.0	6.0	1.3	40.0	10.5	100+
	35-78	8.6	8.3	3.1	32.7	0.8	210.0	113.0	101.7	133.3	4.1	1.3	31.3	8.0	100+
	78-100	8.2	7.9	2.7	25.2	0.4	146.7	82.5	73.3	116.7	2.0	0.3	20.1	6.9	100+

Results are means of three profiles

TR = Trace

O4 = Filtermud reclaimed field (50 ton/ha of FM applied)

10A = Abandoned field (unreclaimed salt affected field)

From Table 12 it is seen that sugarcane yield improved after the application of 50 tons/ha of filtermud in the reclaimed field. The yield increased from 72.3 tons/ha to 123 tons/ha after the application of filtermud.

Table 12: Yield Pattern of Fields O4 and 10A in different years (Tons/ha)

Field\Year	89/90	90/91	91/92	92/93	93/94	94/95	95/96
O4	-	-	-	123.5	86.3	30.3	54.1
10A	46.7	82.8	34.7	-	-	32.8	13.0

Source: TPC Ltd. (1996)

4.2 Water Analysis

Samples of irrigation waters from the three rivers Weruweru, Kikuletwa and Ruvu (Kikuletwa mix 1 km below), the field canals, stagnant water and the boreholes (pumps) were taken for re determination of their suitability for irrigation. The results for Ca^{2+}; Mg^{2+}; K^{+}; Na^{+}; $HCO^{-2}{}_{3}$; $CO^{-2}{}_{3}$; $SO_4{}^{-2}$; Cl^{-}; pH, SAR, SAR_{adj} and electrical conductivity are given in Table 13.

4.2.1 Salinity

It was observed that electrical conductivity (EC) of the irrigation water from the rivers was 0.2, 0.4 and 1:1 dsm^{-1} for Weruweru, Ruvu and Kikuletwa rivers respectively. Water from Weruweru and Ruvu rivers are not saline and can be used safely for irrigation without posing any salinity problem (Ayers and Westcot, 1985). However, water from Kikuletwa river was slightly moderately saline and its use may cause an increasing problem of salinity to the soil. Water from Kikuletwa river when joined with the non-saline water from Weruweru river resulted to a non- saline water from Ruvu river. Therefore water from Weruweru and Ruvu rivers are of excellent quality and pose no danger to salinity build up. However, water from Kikuletwa river (slight to moderate saline, can be used only on soils with adequate drainage and for crops with moderate salt tolerance for example sugarcane, provided management practices for salinity control are applied (FAO, 1976).

Water from pumps BO and Q had EC values of 0.6 and 0.8 dsm^{-1} respectively. Ayers & Westcot (1985), suggest that such water has no restriction on use for irrigation purposes because its quality is good (non-saline).

Tap water, canal water, drainage water and hydrant water from east area fields had the EC values of 0.8, 0.8, 0.8 and 0.9 dsm^{-1} respectively. Therefore all these water samples were slight to moderate saline and their use for irrigation is restricted to where special management practices for salinity control are applied for crop production (Ayers & Westcot, 1985).

Water samples from field R8, (canal water after diversion), and canal at the beginning and stagnant water had the EC values of 0.6, 0.7 and 4.9 dsm^{-1} respectively. Canal water in field R8 was non-saline so both canal waters can be used for irrigation in almost all types of soils with adequate leaching without developing any problem of salinity. Sugarcane can be grown, using such water for irrigation, provided management practices for salinity control are applied. The stagnant water from field R8 was highly saline and its use may pose a severe problem of soil salinity as far as irrigation is concerned. From irrigation point of view, such water is of poor quality and unsatisfactory for irrigation purpose. However, such water can be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate with considerable leaching provided that salt tolerant crops are grown for example forage crops like tall wheat grass (Ayers and Westcot, 1985; FAO, 1976; Malcom, 1993). The chloride ion concentrations observed in all water samples were within the acceptable range. See Table 13 (Ayers and Westcot, 1985).

Table 13: Some chemical characteristics of irrigation water

Sample Description	p^H	$EC_{25^\circ C}$ dSm^{-1}	Exchangeable cations and Soluble anions me/L								Salinity Indices		
			Ca	Mg	Na	K	CO	HCO	SO_4	Cl^-	SAR	SARadj	RSC
Kikuletwa river 7/5/97	8.1	1.1	0.2	2.3	6.1	3.3	2.8	6.2	1.6	0.7	5.5	12.2	6.6
Weruweru river 7/5/97	7.0	0.2	0.1	0.1	0.5	0.6	Trace	0.2	0.3	0.2	0.9	0.5	0.1
Kikuletwa mix 1 Km below 7/5/97	7.8	0.4	0.1	0.7	2.4	1.5	0.7	3.7	0.5	0.3	3.9	5.4	3.6
BO pump 6/5/97	8.4	0.6	0.1	1.7	2.7	3.0	1.6	3.4	0.9	0.6	2.9	5.5	3.2
Q-pump 6/5/97	8.2	0.8	0.1	0.8	5.6	2.2	2.6	3.6	1.0	0.3	8.1	13.7	5.2
Tap water 8/5/97	7.1	0.8	0.1	0.9	4.4	2.1	2.1	4.5	0.6	1.5	6.1	10.4	5.6
Hydrant water from East area fields 7/5/97	7.3	0.9	2.8	7.5	6.1	4.4	3.2	0.1	0.6	0.5	2.7	6.2	7.1
Canal water 6/5/97	7.5	0.8	0.1	0.7	6.1	3.9	2.6	6.4	0.5	0.8	9.7	16.4	8.2

Drainage Water 6/5/97	7.7	0.8	0.3	1.8	5.2
R_8 Stagnant water 6/5/97	9.1	4.9	0.1	0.1	47.0
R_8 field canal at the beginning 6/5/97	8.3	0.7	0.1	0.9	4.4
R_8 field canal after diversion	8.0	0.6	0.1	0.8	3.5

6.2	1.2	4.1	0.7	1.0	5.3	10.1	3.3
11.8	28.0	22	1.1	2.0	209.8	272.8	50.0
2.3	1.9	4.3	0.8	0.2	6.4	10.9	5.2
2.3	2.9	3.1	0.9	0.1	5.1	8.7	5.1

4.2.2 Sodicity

The pH values observed for Weruweru, Ruvu and Kikuletwa water samples were 7.0, 7.8 and 8.4 respectively, which are within the normal range. Water from two pumps BO and Q had pH values of 8.4 and 8.2 respectively, both values are within the normal range too. pH values for water samples from east area fields were 7.1, 7.3, 7.5 and 7.7 for tap, hydrant, canal and drainage water respectively and were within the normal range of 6.5-8.4 (Ayers and Westcot, 1985).

Water samples from field R8 had pH of 8.0, 8.3 and 9.1 for canal water after diversion, canal water at the beginning and stagnant water respectively. Both canal water will have little danger of developing harmful level of sodium in the soil when used for irrigation, since their pH values are within the acceptable range (Ayers and Westcot, 1985). However, the stagnant water from field R8 had a pH of 9.1, which reflects strongly alkaline to extremely alkaline water (Landon, 1991).

4.2.3 Specific Ion Toxicity

The calculated sodium adsorption ratio (SAR) values were 0.9, 3.9 and 5.5 for Weruweru, Pangani and Kikuletwa water samples respectively. According to Table 7, water from Weruweru river has no problem as far as sodium ion concentration is concerned, because its water is suitable for surface irrigation with little danger of developing harmful levels of exchangeable sodium in soils. Both Kikuletwa and Pangani river water are slightly to moderately sodic. Their use for surface irrigation may develop an appreciable sodium hazard specifically in fine textured soils having high cation exchange capacity, especially under low leaching conditions unless gypsum is present in the soil (FAO, 1976). Such water may be used for irrigation on coarse textured or organic soils with good permeability (FAO, 1976).

The SAR value for water sample from Ruvu river which was high despite the low sodium ion concentration (2.4 me/L), the high SAR value was probably due to high concentration of bicarbonate ion (3.7 me/L) which may precipitate calcium and magnesium in soil solution hence increase alkalinity level especially under surface irrigation (Eaton, 1950; Landon, 1991).

The adjusted sodium adsorption ratio (SAR_{adj}) values were 12.2, 0.5 and 5.4 for Kikuletwa, Weruweru and Ruvu waters respectively, following similar trend in SAR values. Kikuletwa water had sodium ion concentration of 6.1 me/l, greater than 3 me/l, thus sodium level for Kikuletwa water was slight to moderate as far as sodium ion concentration is concerned under sprinkler irrigation. Such kind of water when used for irrigation may develop harmful level of exchangeable sodium in soils especially when no precautions for sodicity control are taken. The sodium ion concentration for Ruvu and Weruweru water was 2.4 and 0.5 me/l respectively, thus sodium is less than 3 me/l therefore their waters are suitable for irrigation under sprinkler irrigation (Ayers & Westcot, 1985).

Regarding residual sodium carbonate (RSC) as a criterion for alkalinity, Kikuletwa, Weruweru and Ruvu rivers had the RSC values of 6.6, 0.1 and 3.6 respectively. According to Eaton (1950, Landon (1991) water sample from Kikuletwa and Ruvu rivers are unsuitable for irrigation since their RSC values were greater than 2.5. However, water sample from Weruweru river was safe for irrigation.

The adjusted sodium adsorption ratio (SAR_{adj}) was 5.5 and 13.7 for BO and Q pumps water samples respectively. Such waters are unsuitable for surface irrigation because both are sodic, slightly to moderately sodic and highly sodic for BO and Q pumps respectively (Ayers and Westcot, 1985). When such waters are used for surface irrigation this can cause some problem as far as sodium hazard is concerned. The high values of SAR_{adj} were due to low concentration of calcium and magnesium ions with high concentration of carbonate and bicarbonate ions present in the water samples. The residual sodium carbonate (RSC) values for BO and Q pumps were 3.2 and 5.2 respectively, so their waters are unsuitable for irrigation (Eaton, 1950; Landon, 1991).

Sodium adsorption ratio (SAR) values for tap water, hydrant water, canal water and drainage water from east area fields were 6.1, 2.7, 9.7, and 5.3 respectively. Thus only the hydrant water was suitable for surface irrigation as far as sodium hazard is concerned, because the water was non-sodic despite the presence of high sodium content. This was due to high level of calcium and magnesium observed in that particular water sample. The SAR values for tap and drainage waters were both greater than 3, hence both are slightly to moderately sodic and can cause problem of surface irrigation as far as sodium toxicity is concerned (Ayers & Westcot, 1985).

Water samples from BO and Q pumps had SAR values of 2.9 and 8.1 respectively, so water from BO pump is non sodic hence safe and good for surface irrigation in almost all soils with little danger of developing harmful levels of exchangeable sodium. However, sodium sensitive crops such as avocados can be affected. Contrary to water sample from Q pump, which was slightly to moderately sodic and hence of poor quality for surface irrigation as far as sodium hazard is concerned (Ayers and Westcot, 1985). Such water when used for irrigation may present appreciable sodium hazard under low leaching conditions like TPC Ltd unless gypsum is present in the soils. However, such water may be used for irrigation on coarse-textured or organic soils with good permeability (FAO, 1976).

Therefore using such waters for surface irrigation may cause permeability problem to soils unless the use of soil amendments is adopted (FAO, 1976). Water sampled from east area field canal was highly sodic, because its SAR value was high. Therefore such water when used for surface irrigation may produce an appreciable sodium hazard in fine textured soils having high cation exchange capacity, especially under low leaching conditions like TPC unless gypsum is present in the soil (FAO, 1976). The SAR_{adj} values for water samples from the tap, hydrant, canal and drainage were 10.4, 6.2, 16.4 and 10.1 respectively. From irrigation point of view, (Table 7) such waters may develop harmful levels of sodium in soils, otherwise good management practices for controlling sodium hazard are needed. The calculated residual sodium carbonate values for these water samples were 5.6, 7.1, 8.2 and 3.3 for tap, hydrant, canal and drainage water respectively. So their qualities are unsuitable for irrigation (Eaton, 1950; Landon, 1991).

Water sampled from field R8 had the SAR values of 209.8, 6.4 and 5.1 for stagnant water, field canal water at the beginning and field canal water after diversion respectively. So all the three water sampled from field R8 had sodic level ranging from slight to moderate for both canal waters and very high for the surface waters (Ayers & Westcot, 1985). Thus under surface irrigation both canal waters may be used for irrigation provided that good management practices for sodicity control are applied for example the use of soil amendments with provision of adequate drainage (FAO, 1976).

However, the stagnant water from field R8 was of poor quality and unsatisfactory for irrigation because the water was very sodic. Severe permeability problem will be expected under surface irrigation if such kind of water will be used. Such water can be used occasionally under very special circumstances, the soil must be permeable, drainage must be adequate with considerable leaching and very high sodium tolerant crops should be grown (FAO, 1976). The SAR_{adj} values were 272.8, 10.9 and 8.7 for stagnant water, canal water at the beginning and after diversion respectively. However, their values were higher than the later because of high concentration of carbonate and bicarbonate observed in the samples. The calculated RSC values were 50.0, 5.2 and 5.1 for stagnant water, canal water at the beginning and after diversion respectively which indicated that water sampled from field R8 was unsuitable for irrigation because of high sodium carbonate and bicarbonate contents with low calcium and magnesium contents (Eaton, 1950; Landon, 1991)

The sodium ion content was higher than 3 me/l in all water samples except for water sampled from Weruweru, Ruvu rivers and BO pump. Stagnant water from field R8 had the highest sodium content while the other samples had slightly to moderately sodium content (Table 7). Therefore, such waters when used for irrigation under sprinkler method may pose a danger of sodium toxicity to crops concerned (Ayers and Westcot, 1985; FAO, 1976).

All water samples except Weruweru water and hydrant water have bicarbonate content greater than 1.5 me/l which caused the SAR_{adj} values to be higher than SAR value despite low sodium content observed in the samples. So under overhead sprinkler irrigation, such waters are of poor quality as far as bicarbonate toxicity is concerned. All the samples were slightly to moderately toxic while stagnant water from field R8 was severely toxic in terms of bicarbonate content (Ayers & Westcot, 1985).

All the water sampled for quality test was collected soon after the rain season, so it is expected that during the dry season the salinity levels observed might be higher than the levels observed because of the extreme drought condition favouring high evaporation rate. So concentration of salts on water bodies will be inevitable (Rowel, 1994). It has been observed that the problem of TPC irrigation water is more of specific ion toxicity than the salt content. This is due to sodium and bicarbonate ions concentrations being high while calcium and magnesium contents are low, consequently increased level of sodicity. This observation was also reflected in the past reports of water quality analysis, (Appendix 5), where it can be seen that water from Pangani river had high sodium, carbonate and bicarbonate ions concentration with low calcium and magnesium content which was reflected by high SAR values.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results presented it can be concluded that:

1. Water from Weruweru and Pangani rivers and BO pump are non-saline, while water from Kikuletwa river and Q pump are saline. Water from east area fields (tap, canal drainage and hydrant) is slightly to moderately saline. Only water from Weruweru river, BO pump and east area hydrant water is free from sodium, the other sources including Kikuletwa river, Pangani river, Q pump east area drainage and canal water are slightly to moderately sodic. Therefore only water from Weruweru and BO pump are of excellent quality hence suitable for irrigation. However, the irrigation water from other available sources seem to have high concentration of sodium, carbonates and bicarbonates which is reflected by high values of SAR, SAR_{adj} and residual sodium carbonate (RSC).

2. Stagnant and drainage water from field R8 is highly saline and sodic, so it is of poor quality and unsuitable for irrigation.

3. At the moment, many fields lack surface and subsurface drainage, which is extremely important in irrigated agriculture under semi arid condition in order to control salinity.

4. The nature of soil itself is slightly saline with high concentration of sodium, which makes it moderately saline and sodic. However, the soils from the area investigated were found to be sodic with salt content increasing with depth in all fields, which means leaching has taken place during the rain season and salts deposited in the subsoil.

5. Soil sodicity have increased due to the additional sodium from irrigation water particularly water from Kikuletwa, Pangani, Q pump, field channels, with combining

effect of insufficient natural drainage, absence of adequate (artificial) drainage, hence the soils undergo sodification process.

6. Filtermud showed a rapid decline of its effecf on saline sodic soils, because it induced a highly favourable physical and chemical state in the soil on a short term as reflected in the high yield of sugarcane (123 tons/ha in 92/93 season). After that particular season, the yield started to decline again. Therefore, it is a fast working amendment as can be seen from the quantitative observations of the cane yield obtained in 1993 after its application.

7. Regarding the improvement of saturated hydraulic conductivity, moisture release and retention, and mean infiltration rate, it can therefore be concluded that filtermud can be used to improve the physical properties of the salt affected soils, thereby increasing exchangeable calcium and magnesium contents of the soil which counteract the adverse effects of saline sodic soils within a measurable short time.

8. Therefore the main beneficial effects of this ameliorant (filtermud) would be to increase the degree of aggregation of the surface soil thereby increasing the saturated hydraulic conductivity, and mean infiltration rate. Also the increased exchangeable calcium and magnesium in the reclaimed soil is useful in order to counteract the adverse effect of sodium in saline sodic soils.

5.2 Recommendations

1. In general, the cheaper amendments (organic amendments for example filtermud) are slower to react, consequently if immediate replacement of exchangeable sodium is desired, therefore, the company should go for one of the quicker acting but more expensive amendments for example gypsum. However, filtermud like other organic amendment it should be applied regularly in order to get effective changes in soil

properties.

2. Sufficient drainage (surface and subsurface) should be provided in all fields in order to reduce the ground water level to below rooting zone. Excessive application of water should be avoided as this raises the water table and leads to increased salt accumulation on the soil surface by capillary movement.

3. In the light of the evidence provided here, it seems justified to emphasize the need of further attention to be given to this problem of salinity at TPC Ltd. Future research in this field must be intensified in comparing different levels of filtermud application with other amendments, and also trying to use agroforestry as a management tool in reclaiming the salt affected soils.

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APPENDICES

Appendix.1 (a): Profile description No. Crtl PR1

General Site Information

Survey area/district:	Moshi rural/TANZANIA
Observation No./date:	9/5/97/WET
Soil classification:	Cambic Usticsol, Sodic phase
Ecological formation:	Basement System Rocks
Parent material:	Volcanic rich in quartz and mica
Physiography:	Lowland/plain
Relief Macro:	Flat
Relief Micro:	NIL
Slope:	1 - 2%
Vegetation/landuse:	Bushland with a big tree/grazing
General groundwater:	Deep (not observed)
Drainage class:	Somewhat excessively drained

Profile description

0-30cm	Black (10YR 2/1 moist; 10 YR 3/1 dry); loamy sand, disturbed single grain structure, friable when dry, loose when moist, non sticky when wet, many coarse roots, clear and smooth transition to:
30-68cm	Black (2.5Y 2/1 moist; 2.5Y 3/2 dry); sandy loam, predominantly coarse sand with small stones, loose when dry, non sticky and non plastic when wet, few coarse fine roots, many coarse pores, abrupt and wavy transition to:
68-100cm	Brownish black (10YR 2/3 moist; 10YR 6/2 dry); sandy loam, disturbed structure less (single grain), many small stones and gravel, loose when dry, non sticky and non plastic when wet, many coarse pores, abrupt and wavy transition to parent material

Appendix.1 (b): Profile description No. Crtl PR2

General Site Information

Survey area/district:	Moshi rural/TANZANIA
Observation No./date:	9/5/97/WET SEASON
Soil classification:	Cambic Usticsol, Sodic phase
Ecological formation:	Basement System Rocks
Parent material:	Volcanic rich in quartz and mica
Physiography:	Lowland/plain
Relief Macro:	Flat
Relief Micro:	NIL
Slope:	1 - 2%
Vegetation/landuse:	Bushland with a big tree/grazing
General groundwater:	Deep (not observed)
Drainage class:	Somewhat excessively drained

Profile description

0-30cm	Black (10YR 2/1 moist; 10 YR 3/1 dry); loam sandy, medium subangular blocky, friable when dry, non sticky and plastic when wet, many coarse roots, medium pores, clear and smooth transition to:

30-68cm Black (10YR 2/1 moist; 10YR 2/3 dry); sandy loam, moderately weak loose when dry, non sticky and not plastic when wet, many coarse pores with whitish and greyish mottles, few fine roots present, abrupt and wavy transition to:

68-100cm Brownish black (10YR 2/3 moist; 10YR 6/2 dry); sandy loam, disturbed structure (single grain), loose when dry, non-sticky and non-plastic when wet, many coarse pores, abrupt and wavy transition to parent material:

Appendix.1(c): Profile description No. Crtl PR3

General Site Information

Survey area/district: Moshi rural/TANZANIA
Observation No./date: 9/5/97/WET SEASON
Soil classification: Cambic Usticsol, Sodic phase
Ecological formation: Basement System Rocks
Parent material: Volcanic rich in quartz and mica
Physiography: Lowland/plain
Relief Macro: Flat
Relief Micro: NIL
Slope: 1 - 2%
Vegetation/landuse: Bushland with a big tree/grazing
General groundwater: Deep (not observed)
Drainage class: Somewhat excessively drained

Profile description

0-30cm Black (10YR 1.7/1 moist; 10 YR 2/2 dry); loam sandy, medium sub angular blocky, friable when dry, non sticky and non plastic when wet, many coarse roots, medium pores, clear and smooth transition to:

30-58cm Brownish black (10YR 2/3 moist; 10YR 5/2 dry); sandy loam, very loose when dry, singe grain structure, non sticky and non plastic when wet, few fine roots with many pores, greyish mottles found, abrupt and wavy transition to:

58-100cm Brownish black (10YR 2/3 moist; 10YR 6/2 dry); sandy loam, disturbed single grain structure with coarse sand particles and gravel, very loose when dry, non sticky and non plastic when wet, many coarse pores, with whitish mottles, abrupt and wavy transition to parent material

Remarks: The soils were very porous from second horizon onwards downward the profile 100 cm + quartz gravel with stones.

Appendix 1(d): Profile description No. O4PR1

General Site Information

Survey area/district: Moshi rural/TANZANIA
Observation No./date: 7/5/97/WET SEASON
Soil classification: Haplic Usticsol, sodic phase
Ecological formation: Basement System Rocks
Parent material: Volcanic rich in mica
Physiography: Lowland
Relief Macro: Depression
Relief Micro: NIL
Slope: 2 - 4%

Vegetation/landuse: Shamba/cultivation (Zea may)
General groundwater: Deep (not observed)
Drainage class: Moderately well drained

Profile description

0-30cm Brownish black (10YR 2/2 moist; 10 YR 4/1 dry); loam sandy, moderately medium subangular blocky, friable when dry, non sticky and non plastic when wet, fine and very fine few roots, clear and smooth transition to:

30-45cm Brownish black (10YR 2/3 moist; 10YR 5/2 dry); sandy loam, medium subangular blocky, slighty hard when dry, friable when moist, non sticky and non plastic when wet, many medium pores, clear and wavy transition to:

45-100cm Dark brown (10YR 3/4 moist; 10YR 5/3 dry); loam, coarse subangular blocky, hard when dry, slightly sticky when wet and slightly plastic when wet, abrupt and wavy transition to parent material:

Appendix 1(e): Profile description No. O4PR2

General Site Information
Survey area/district: Moshi rural/TANZANIA
Observation No./date: 7/5/97/WET SEASON
Soil classification: Haplic Usticso,l Sodic phase
Ecological formation: Basement System Rocks
Parent material: Volcanic rich in quartz and mica
Physiography: Lowland
Relief Macro: Depression
Relief Micro: NIL
Slope: 2 - 4%
Vegetation/landuse: Shamba/cultivation (Zea may)
General groundwater: Deep (not observed)
Drainage class: Moderately well drained

Profile description

0-30cm Brownish black (10YR 2/2 moist; 10 YR 4/1 dry); sandy loam. medium subangular blocky, friable when dry, non sticky and non plastic when wet, fine and very fine few roots, coarse pores, clear and smooth transition to:

30-45cm Brownish black (10YR 2/3 moist; 10YR 5/3 dry); sandy loam, medium subangular blocky, slighty hard when dry, friable when moist, non sticky and non plastic when wet, many medium pores, clear and wavy transition to:

45-100cm Brown (10YR 4/4 moist; 10YR 5/3 dry); loam, coarse subangular blocky, hard when dry (massive), slightly sticky and slightly plastic when wet, abrupt and wavy transition to parent material

Appendix.1 (f): Profile description No. O4PR3

General Site Information
Survey area/district: Moshi rural/TANZANIA
Observation No./date: 7/5/97/WET SEASON

Vegetation/landuse: Shamba/cultivation (Zea may)
General groundwater: Deep (not observed)
Drainage class: Moderately well drained

Profile description

0-30cm Brownish black (10YR 2/2 moist; 10 YR 4/1 dry); loam sandy, moderately medium subangular blocky, friable when dry, non sticky and non plastic when wet, fine and very fine few roots, clear and smooth transition to:

30-45cm Brownish black (10YR 2/3 moist; 10YR 5/2 dry); sandy loam, medium subangular blocky, slighty hard when dry, friable when moist, non sticky and non plastic when wet, many medium pores, clear and wavy transition to:

45-100cm Dark brown (10YR 3/4 moist; 10YR 5/3 dry); loam, coarse subangular blocky, hard when dry, slightly sticky when wet and slightly plastic when wet, abrupt and wavy transition to parent material:

Appendix 1(e): Profile description No. O4PR2

General Site Information

Survey area/district: Moshi rural/TANZANIA
Observation No./date: 7/5/97/WET SEASON
Soil classification: Haplic Usticso,l Sodic phase
Ecological formation: Basement System Rocks
Parent material: Volcanic rich in quartz and mica
Physiography: Lowland
Relief Macro: Depression
Relief Micro: NIL
Slope: 2 - 4%
Vegetation/landuse: Shamba/cultivation (Zea may)
General groundwater: Deep (not observed)
Drainage class: Moderately well drained

Profile description

0-30cm Brownish black (10YR 2/2 moist; 10 YR 4/1 dry); sandy loam, medium subangular blocky, friable when dry, non sticky and non plastic when wet, fine and very fine few roots, coarse pores, clear and smooth transition to:

30-45cm Brownish black (10YR 2/3 moist; 10YR 5/3 dry); sandy loam, medium subangular blocky, slighty hard when dry, friable when moist, non sticky and non plastic when wet, many medium pores, clear and wavy transition to:

45-100cm Brown (10YR 4/4 moist; 10YR 5/3 dry); loam, coarse subangular blocky, hard when dry (massive), slightly sticky and slightly plastic when wet, abrupt and wavy transition to parent material

Appendix.1 (f): Profile description No. O4PR3

General Site Information

Survey area/district: Moshi rural/TANZANIA
Observation No./date: 7/5/97/WET SEASON

Soil classification: Haplic Usticsol, Sodic phase
Ecological formation: Basement System Rocks
Parent material: Volcanic rich in quartz and mica
Physiography: Lowland
Relief Macro: Depression
Relief Micro: NIL
Slope: 2 - 4%
Vegetation/landuse: Shamba/cultivation (Zea may)
General groundwater: Deep (not observed)
Drainage class: Moderately well drained

Profile description

0-30cm: Brownish black (10YR 2/2 moist; 10 YR 4/1 dry); sandy loam, medium subangular blocky, friable when dry, non sticky and non plastic when wet, many fine roots, coarse pores, clear and smooth transition to:

30-45cm: Brownish black (10YR 2/2 moist; 10YR 4/1 dry); sandy loam, subangular blocky, slighty hard when dry, friable when moist, slightly sticky when wet, few very fine pores, clear and wavy transition to:

45-100cm: Dark brown (7.5YR 3/4 moist; 7.5YR 6/3 dry); loam, coarse subangular blocky, hard when dry, slightly sticky and slightly plastic when wet, abrupt and wavy transition to parent material

Remarks: Observation in a maize field. Pockets of blackish bareland surrounded by stunted yellowish maize plants observed.

Appendix 1(g): Profile description No. 10A PR1

General Site Information

Survey area/district: Moshi rural/TANZANIA
Observation No./date: 8/5/97/WET SEASON
Soil classification: Haplic Usticsol, sodic phase
Ecological formation: Basement System Rocks
Parent material: Volcanic rich in quartz
Physiography: Volcanic plain/ gently undulating
Relief Macro: ridged furrows/ old irrigation furrows
Relief Micro: NIL
Slope: 2 - 5%
Vegetation/landuse: Stunted sugarcane plants with few grasses and weeds (formerly cultivated and now abandoned)
General groundwater: Deep (not observed)
Drainage class: Imperfectly drained

Profile description

0-35cm: Greyish brown (7.5YR 4/2 moist; 7.5 YR 4/1 dry); sandy loam, moderately medium subangular blocky, friable and soft when dry, sticky and slightly plastic when wet, common few fine roots, clear and smooth transition to:

35-78cm: Greyish brown (7.5YR 4/2 moist; 7.5YR 6/2 dry); sandy loam, hard when dry, non sticky when wet, few very fine common

	roots, medium pores, clear and wavy transition to:
78-100cm	Brownish (10YR 2/3 moist; 10YR 5/4 dry); sandy loam, medium subangular, friable when dry, non sticky when wet, few medium pores, clear and smooth transition to parent material

Appendix 1(h): Profile description No. 10A PR2

General Site Information

Survey area/district:	Moshi rural/TANZANIA
Observation No./date:	8/5/97/WET SEASON
Soil classification:	Haplic Usticsols, sodic phase
Ecological formation:	Basement System Rocks
Parent material:	Volcanic rich in quartz
Physiography:	Volcanic plain/ gently undulating
Relief Macro:	ridged furrows/ old irrigation furrows
Relief Micro:	NIL
Slope:	2 - 5%
Vegetation/land use:	Stunted sugarcane plants with few grasses and weeds (formerly cultivated and now abandoned)
General groundwater:	Deep (not observed)
Drainage class:	Imperfectly drained

Profile description

0-35cm	Olive black (5Y 3/4 moist; 5 Y 6/2 dry); sandy loam, medium subangular blocky, hard when dry, friable when moist, slightly sticky when wet, many fine common roots, clear and smooth transition to:
35-78cm	Brownish black (2.5Y 3/2 moist; 2.5Y 5/2 dry); sandy loam, friable when dry, non sticky when wet, few very fine and fine common roots, medium pores, clear and wavy transition to:
78-100cm	Yellowish brown (2.5Y 5/2 moist; 2.5Y 6/2 dry); sandy loam, friable when dry, non sticky when wet, few medium pores, clear and smooth transition to parent material

Appendix.1 (i): Profile description No. 10A PR3

General Site Information

Survey area/district:	Moshi rural/TANZANIA
Observation No./date:	8/5/97/WET SEASON
Soil classification:	Haplic Usticsols, sodic phase
Ecological formation:	Basement System Rocks
Parent material:	Volcanic rich in quartz
Physiography:	gently undulating
Relief Macro:	ridged furrows
Relief Micro:	NIL
Slope:	2 - 5%
Vegetation/landuse:	Stunted sugarcane plants with few grasses and weeds (formerly cultivated and now abandoned)
General groundwater:	Deep (not observed)
Drainage class:	Imperfectly drained

Profile description

0-35cm	Brownish black (10YR 2/2 moist; 10 YR 5/2 dry); sandy loam, moderately medium subangular blocky, soft when dry, slightly sticky and slightly plastic when wet, common fine roots, clear and smooth transition to:
35-60cm	Dark brown (10YR 3/3 moist; 10YR 5/2 dry); sandy loam, hard when dry, slightly sticky and gritty when wet, abrupt and wavy transition to:
60-100cm	Greyish yellow (10YR 4/2 moist; 10YR 6/2 dry); sandy loam, medium subangular, friable when dry, non sticky and gritty when wet, clear and smooth transition to parent material

Appendix.2 (a): Analysis of variance for bulk density (Pb) gm/cm^3

By depth plot

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	0.056	4	0.014	1.784	0.294
Depth	0.55	2	0.27	3.480	0.133
Field	0.001	2	0.001	0.089	0.917
Main effects	0.056	4	0.014	1.784	0.294
Residual	0.032	4	0.08		
Total	0.088	8	0.011		

9 cases were processed

One-way Pb by depth (1, 3)/ranges lsd (0.05)/stat all.

Bulk density by variable depth

Source	Df	Sum of squares	Mean squares	F ratio	F prob.
Between fields	2	0.0549	0.0274	4.998	0.0528
Within fields	6	0.0329	0.0055		
Total	8	0.0878			

One way analysis

Field	Count	Mean	Standard deviation	Standard error	95% confidence interval for mean
Control	3	0.09	0.0854	0.0493	0.8778 to 1.3022

O4	3	1.2467	0.0231	0.0133	1.1893 to 1.304
10A	3	1.2633	0.0929	0.0536	1.0325 to 1.4942
Total	9	1.2000	0.1048	0.0349	1.1195 to 1.2805
Fixed effects model			0.0741	0.0247	1.1396 to 1.2604
Random effects model				0.0552	0.9624 to 1.4376
Random effects model - Estimate of between component variance					0.0073

Group	Minimum	Maximum
Control	1.00	1.17
O4	1.22	1.26
10A	1.20	1.37

Multiple range test - LSD procedure

Mean	Group	1	2	3
1.0900	Grp 1			
1.2467	Grp 2	*		
1.2633	Grp 3	*		

(*) Denotes pairs of groups significantly different at the 0.05 level

Appendix .2(b): Analysis of variance for saturated hydraulic conductivity (K_{sat})

By variable field, depth

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	1724.67	4	435.669	45.586	0.111
Depth	6.151	2	3.076	0.322	0.742
Field	1736.53	2	868.263	90.850	0.000
Explained	1742.67	4	435.669	45.586	0.001
Residual	38.228	4	9.557		
Total	1780.91	8	222.613		

9 cases were processed

One-way K_{sat} by field (1, 3)/ranges lsd (0.05)/stat all.

K_{sat} by variable field

Source	Df	Sum of squares	Mean squares	F ratio	F prob.
Between fields	2	1736.5256	868.2628	117.3835	0.0000
Within fields	6	44.3793	7.3966		
Total	8	1780.9050			

One-way analysis

Field	Count	Mean	Standard deviation	Standard error	95% confidence interval for mean
Control	3	30.9333	4.0501	2.3383	20.8722 to 40.9945
O4	3	1.7733	2.2171	1.2801	-3.7344 to 7.2810
10A	3	1.1700	0.9331	0.5387	-1.1480 to 3.4880
Total	9	11.2922	14.9202	4.9734	-1175 to 22.7609
Fixed effects model			2.7197	0.9066	9.0740 to 13.5105
Random effects model				9.8221	-30.9693 to 53.5538
Random effects model - Estimate of between component variance					286.955

Field	Minimum	Maximum
Control	27.3000	35.3000
O4	0.3800 4.3300	
10A	0.1600 2.0000	

K_{sat} by variable field

Multiple range test - LSD procedure

Mean	Field	3	2	1
1.1700	10A			
1.7733	O4			
30.9333	Control	* *		

(*) Denotes pairs of groups significantly different at the 0.05 level

Appendix 7.2(c): Analysis of variance for moisture retention

By variable field, depth
Pressure

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	1.212	14	0.087	109.506	0.000
Depth	0.006	2	0.003	4.026	0.026
Pressure	0.911	10	0.09	115.219	0.000
Field	0.295	2	0.147	186.426	0.000
2-way interactions	0.256	44	0.006	7.366	0.000
Depth x pressure	0.016	20	0.001	1.002	0.481
Depth x plot	0.216	4	0.054	68.422	0.000
Pressure x plot	0.024	20	0.001	1.518	0.128
Explained	1.469	58	0.025	32.020	0.000
Residual	0.032	40	0.001		
Total	0.500	98	0.015		

99 cases were processed

By variable field

Source	Df	Sum of squares	Mean squares	F ratio	F prob.
Between fields	2	0.2949	0.1474	11.7408	0.0000
Within fields	96	1.2055	0.0126		
Total	98	1.5003			

One-way analysis

Field	Count	Mean	Standard deviation	Standard error	95% confidence interval for mean
Control	33	02230	0.1192	0.0207	0.1808 to 0.2653
O4	33	0.3488	0.1072	0.0187	0.3108 to 0.3868
10A	33	0.3251	0.1094	0.0190	0.2863 to 0.3639
Total	99	0.2990	0.1237	0.0124	0.2743 to 0.3237
Fixed effects model			0.1121	0.0113	0.2766 to 0.3213
Random effects model				0.0386	0.1329 to 0.4650
Random effects model - Estimate of between component variance					0.0041

Multiple range test

Mean	Field
0.2230	Control
0.3251	10A*
0.3488	O4*

Appendix.2 (d): Mean Infiltration rate By variables, time (1, 2, 60, 120 and 180 minutes) Field

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	35148.4	6	5858.1	16.6	0.000
Time	26155.7	4	6538.9	18.5	0.000
Field	8992.7	2	4496.3	12.8	0.003
Explained	35148.4	6	5858.1	16.6	0.000
Residual	2821.1	8	352.6		
Total	37969.5	14	2712.1		

By variable field

Source	Df	Sum of squares	Mean squares	F ratio	F prob.
Between fields	2	8992.7	4496.3	1.8620	0.1976
Within fields	12	28976.9	2414.7		
Total	14	37969.5			

Field	Minimum	Maximum
O4	8.7	120.0
10A	5.2	60.0
Control	36.1	180.0

Appendix.2 (e): Correlations between some soil parameters

Correlations	Sand	Silt	Clay	Base saturation %
K_{sat} cm/hr	0.9329**	-0.8421*	-0.6307	
Moisture retention at 700 KPa	-0.8970*	0.8045*		
1000 KPa	-0.8830*	0.7986*		
1500 KPa	-0.8724*			
Exchangeable sodium				0.8249*

** = Significant at 0.001 level
* = Significant at 0.01 level

Appendix.2 (f): pH in water

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	0.6980	4	0.174	0.946	0.521
Depth	0.016	2	0.008	0.042	0.959
Field	0.682	2	0.341	1.849	0.270
Explained	0.698	4	0.174	0.946	0.521
Residual	0.738	4	0.184		
Total	1.436	8	0.179		

pH in 001M $CaCl_2$

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	0.553	4	0.138	0.669	0.647
Depth	0.047	2	0.023	0.113	0.896
Field	0.507	2	0.253	1.226	0.384
Explained	0.553	4	0.138	0.669	0.647
Residual	0.827	4	0.207		
Total	1.380	8	0.173		

Appendix.2 (g): $EC_{25□C}$ of soil extracts

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	13.478	4	3.369	47.383	0.001
Depth	0.276	2	0.138	1.938	0.258
Field	13.202	2	6.601	92.828	0.000
Explained	13.478	4	3.369	47.383	0.001
Residual	0.284	4	0.071		
Total	13.762	8	1.720		

$EC_{25°C}$ by variable field

Source	Df	Sum of squares	Mean squares	F ratio	F prob.
Between fields	2	13.2022	6.6011	70.7262	0.0001
Within fields	6	0.5600	0.0933		
Total	8	13.7622			

Field	Count	Mean	Standard deviation	Standard error	95% confidence interval for mean
Control	3	0.5333	0.1155	0.667	0.24665 to 0.8202
O4	3	0.6667	0.1155	0.0667	0.3798 to 0.9535
10A	3	3.1667	0.5033	0.2906	1.9163 to 4.4170
Total	9	1.4556	1.3116	0.4372	0.4474 to 2.4637
Fixed effects model			0.3055	0.1018	1.2064 to 1.7047
Random effects model				0.8564	-2.2294 to 5.1405
Random effects model - Estimate of between component variance					2.1693

Field	Minimum	Maximum
Control	0.4000	0.6000
O4	0.6000	0.8000
10A	2.7000	3.7000

Multiple range test

Mean	Field
0.5333	Control
0.6667	O4
3.1667	10A**

Appendix.2 (h): Exchangeable sodium

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	9780.307	4	2445.077	0.768	0.598
Depth	7186.860	2	3593.430	1.129	0.409
Field	2593.447	2	1296.723	0.407	0.690
Explained	9780.307	4	2445.077	0.768	0.598
Residual	12735.713	4	3183.928		
Total	22516.020	8	2814.503		

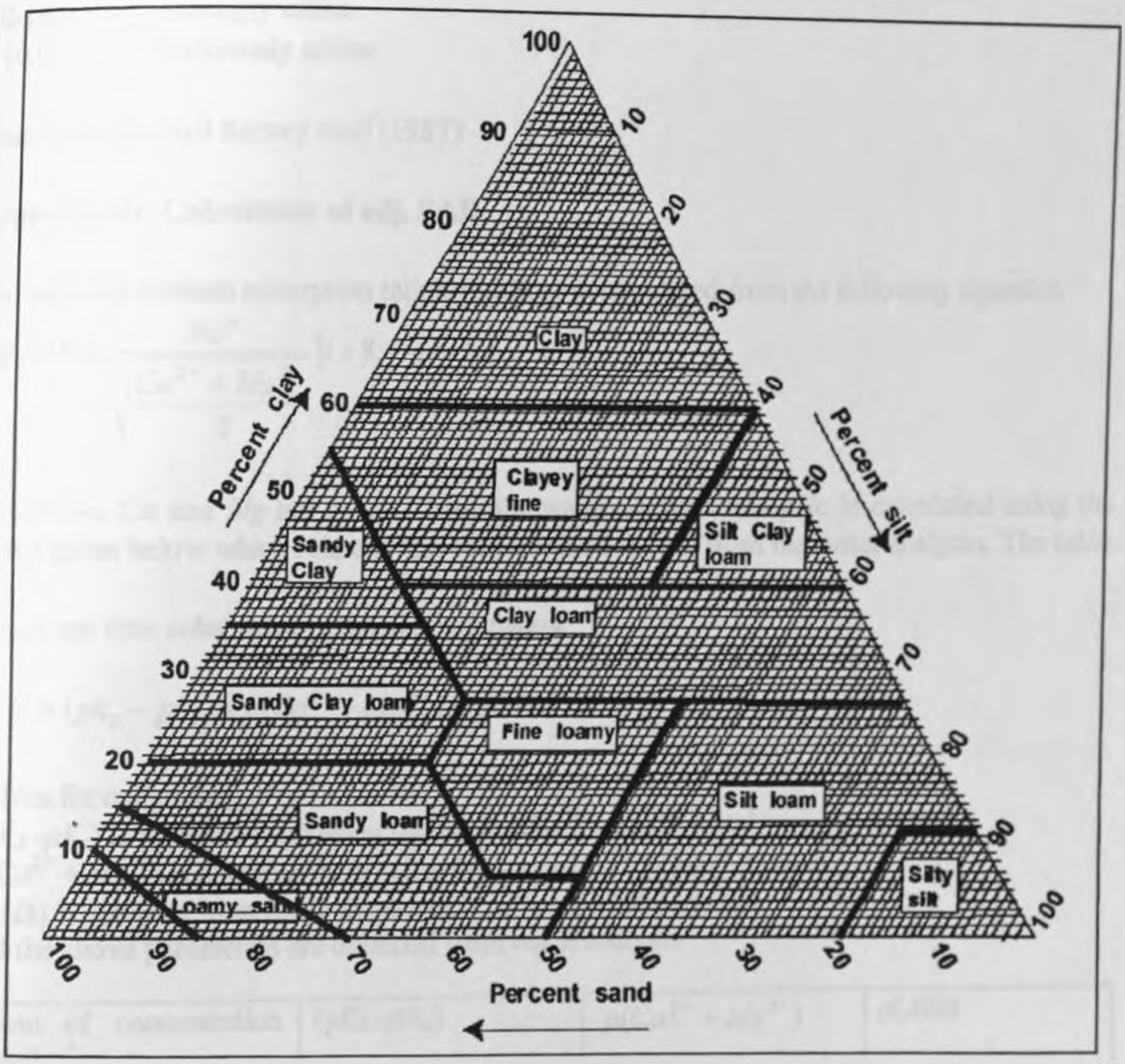
Appendix.2 (i): ESP

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	3631.271	4	907.818	0.829	0.570
Depth	3359.242	2	1679.621	1.534	0.320
Field	272.029	2	136.014	0.124	0.886
Explained	3631.271	4	907.818	0.829	0.570
Residual	4380.324	4	1095.081		
Total	8011.596	8	1001.449		

Appendix 2(j): SAR

Source of variation	Sum of squares	Df	Mean square	F	Significance of F
Main effects	97.875	4	24.469	0.717	0.622
Depth	92.118	2	46.059	1.350	0.356
Field	5.757	2	2.879	0.084	0.921
Explained	97.875	4	24.469	0.717	0.622
Residual	136.429	4	34.107		
Total	234.304	8	29.288		

Appendix.3: USDA Triangle used to determine the soil textural classes



Source: Kenya soil Survey staff (1987)

Appendix.4a: Soil pH and EC values

pH Levels:

< 5.5 strongly acid
5.6-6.6 moderately acid
6.7-7.3 Neutral
7.4-8.3 moderately alkaline
8.3-9.0 strongly alkaline
> 9.0 Extremely alkaline

EC Levels: dsm^{-1}

0-1.2 Non saline
1.2-2.5 Slightly saline

2.5-5.0	Moderately saline
5.0-10.0	Strongly saline
> 10.0	Extremely saline

Source: Kenya soil Survey staff (1987)

Appendix.4b: Calculation of adj. SAR

The adjusted sodium adsorption ration (SAR_{adj}) is calculated from the following equation

$$adj.SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}[1 + 8.4 - pHc]$$

Where *Na*, *Ca* and *Mg* are in me/l from the water analysis and *pHc* is calculated using the tables given below which relate to the concentration values from the water analysis. The table values are then substituted in the *pHc*'s equation

$$pHc = (pk_2 - pk_c) + p(Ca^{2+} + Mg^{2+}) + p(Alk)$$

Tables for calculating *pHc*
$(pK_2 - pK_c)$ is obtained from using the sum of $Ca^{2+} + Mg^{2+} + Na^+$ in me/l
$p(Ca^{2+} + Mg^{2+})$ is obtained from using the sum of $Ca^{2+} + Mg^{2+}$ in me/l
$p(Alk)$ is obtained from using the sum of $CO^{-2}_3 + HCO^{-2}_3$ in me/l
All the above parameters are obtained from water analysis

Sum of concentration me/l	$(pK_2 - pK_c)$	$p(Ca^{2+} + Mg^{2+})$	$p(Alk)$
.05	2	4.6	4.3
.10	2	4.3	4
.15	2	4.1	3.8
.20	2	4	3.7
.25	2	3.9	3.6
.30	2	3.8	3.5
.40	2	3.7	3.4
.50	2.1	3.6	3.3
.75	2.1	3.4	3.1
1.00	2.1	3.3	3
1.25	2.1	3.2	2.9
1.5	2.1	3.1	2.8

2.0	2.2	3.0	2.7
2.5	2.2	2.9	2.6
3.0	2.2	2.8	2.5
4.0	2.2	2.7	2.4
5.0	2.2	2.6	2.3
6.0	2.2	2.5	2.2
8.0	2.3	2.4	2.1
10.0	2.3	2.3	2.0
12.5	2.3	2.2	1.9
15.0	2.3	2.1	1.8
20.0	2.4	2.0	1.7
30.0	2.4	1.8	1.5
50.0	2.5	1.6	1.3
80.0	2.5	1.4	1.1

Source: Ayers and Westcot (1985)

Example pHc calculation

Given: Ca = 2.32 me/l
Mg = 1.44 me/l
Na = 7.73 me/l
Sum = 11.49 me/l

CO_3 = 0.42 me/l
HCO_3 = 3.66 me/l
Sum = 4.08 me/l

From Tables and using the equation for pHc

$pK_2 - pK_c = 2.3$

p(Ca + Mg) = 2.7
p(ALK) = 2.4
pHc = 7.4

substituting

$$adj.SAR = \frac{7.73}{\sqrt{\frac{3.76}{2}}}\left[1 + 8.4 - 7.4\right]$$

$$adj.SAR = 5.64(2.0) = 11.3$$

NOTE:

Values of pHc above 8.4 indicate the tendency to dissolve lime from the soil through which the water moves; values below 8.4 indicate a tendency to precipitate lime from water used for irrigation.

Appendix.5: Summary of irrigation water quality of TPC Ltd

Date sampled	Location	pH	EC_{25}°c dsm^{-1}	milliequivalent/litre								
				Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-2}	Cl^{-1}	SO_4^{-2}	SAR
26/5/71	Pangani river		0.8	1.1	1.3	5						4.6
26/5/71	Pangani river		0.8	0.9	1.2	5.3						5.2
24/9/71	Pangani river		0.7	0.7	1.7	35.0	0.3			0.7	NIL	3.5
24/9/71	Nyumba ya Mungu		0.7	0.6	2.1	3.0	0.3			0.7		2.9
24/9/71	Nyumba ya Mungu		0.5	0.6	2.0	3.7						3.2
30/12/71	Pangani river		0.8	0.6	1.4	4.7	0.3			1.0		5.1
20/1/72	Nyumba ya Mungu		0.7	0.6	1.4	4.5						3.9
20/1/72	Nyumba ya Mungu		0.7	0.5	1.7	4.0						3.8
27/10/2	Handeni	8.3	0.9	0.6	0.3	12.6		3.6		0.9	0.3	11.3
12/12/72	Korogwe	8.1	0.8	0.6	0.3	9.5		3.5		1.0	0.3	9.1
30/12/72	Pangani		0.7	0.5	1.7	4.0	0.4			0.9	TV	4.1
19/1/72	Pangani river		0.2	1.7	0.3	0.3						
29/3/73	Pangani river		0.9	1	1.8	6.5						5.5
6/7/73	Pangani river	-	0.7	4.3	0.3	0.5						1.5
7/8/73	Korogwe	7.7	0.6	0.5	1.2	3.5		2.9		0.8	0.3	3.8
3/11/73	Korogwe	7.7	0.8	0.7	1.6	4.3		3.7		1.0	0.4	3.9
29/11/73	Mswaha	7.6	0.9	0.5	1.7	3.5		3.6		1.0	0.3	3.2
29/11/73	Mswaha intake after	8.5	0.8	0.5	1.6	3.8		3.5		1.0	0.3	11

29/11/73	Mandera	8.6	0.8	0.5	1.5	4.0				0.9	0.4	3.9
21/3/74	Pangani	8.8	1.0	0.4	1.5	5.3		1.0	7.7	0.2		5.6
17/4/74	Handeni	7.9	0.8	0.4	1.7	6.0		3.4		1.2	0.5	5,6
17/4/74	Mswaha	8.2	1.0	0.4	1.8	5.9				1.2	0.6	5.5
17/4/74	Korogwe	8.0	0.8	0.4	1.7	5.8		3.6		1.2	0.6	5.6
15/6/74	Nyumba ya Mungu	8.5	0.7	0.3		6.1	0.8				TV	
15/6/74	Kiriya	8.8	0.7	0.3		6.4	0.8				TV	
10/5/74	Pangani	8.5	0.8	0.1		7.8	0.8				TV	
15/5/74	Pangani	8.3	0.8	0.1		4.2	0.8					11.0
28/6/74	Pangani	9.0	0.7	0.4		3.8	0.7				TV	
28/7/74	Pangani	8.9	0.7	0.4		3.7	0.7				TV	
16/10/74	O fields borehole	7.3	0.6	7.0		20.0	16.0	NIL			TV	
16/10/74	Karanga borehole	8.3	0.7	3.0		14.0	14.0	3.0	195.2	23		
16/10/74	Kikayu river before joining Weruweru river	7.5	0.5			TV			128.1	18		
8/1/75	O fields borehole	8.7	0.7	10.0		59.0	29.0		360.0	40	TV	
12/4/75	O fields borehole	6.9	0.4	4.0		54.0	32.0	TV	226.0	50	TV	

TV = Trace value

Source: TPC Ltd.