

**SOILS OF MTIBWA SUGAR ESTATE: SOME PHYSICAL AND CHEMICAL  
PROPERTIES AND THEIR EFFECT ON CROP PERFORMANCE UNDER  
SPRINKLER IRRIGATION**

**BY**

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**ABSTRACT**

A study was conducted in Mtibwa Sugar Estate, Morogoro, to investigate causes for observed decline in sugarcane production. This involved detailed soil physical characterization of affected areas and that of a bare area. Quality of water for irrigation was also studied.

The results showed that the salt affected blocks have sandy loam topsoil overlying sandy clay subsoil of low permeability (0.5 - 0.9 m/day). The electrical conductivity of saturation extract is low to medium (1.15 - 3.7 dS/m); the level of sodium is very high throughout the profiles of affected blocks (above 2.0 cmol(+)/kg); the calcium content is very low to low (1.10 - 3.39 cmol(+)/kg) while that of magnesium is moderate (1.5 - 2.39 cmol(+)/kg).

It was concluded that the soil of the affected fields is Gleyic Cambisol according to FAO-UNESCO (1989) Classification. It was classified as Typic Tropaquept according to United States Department of Agriculture Soil Classification System (Soil Survey Staff, 1990).

The soil of the non affected field was found to be in the subgroup Typic Ustipsamment (USDA Soil Taxonomy). It was

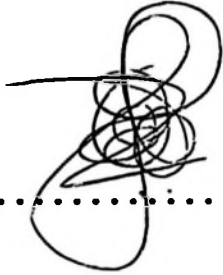
classified as Umbric Regosol (FAO-UNESCO Classification). According to FAO (1976) land suitability classification, the affected fields studied are marginally suitable while the non affected field is moderately suitable.

The electrical conductivity of the irrigation water is low (0.09 dS/m) and that of the groundwater of field 10E is medium (0.55 dS/m). The sodium content in irrigation water is low (0.2 meq/l) but very high (56.35 - 71.04 meq/l) in the groundwater of the affected fields. It was also noted that the chloride content of the groundwater of the affected fields is very high (145.0 - 236.0 meq/l).

It was concluded that salinity, sodium and chloride toxicity are the main problems responsible for the declining sugarcane production at Mtibwa Sugar Estate. The Mtibwa Sugar Company is thus urged to look for means of correcting the observed problems for example by establishing a drainage system for the Estate. The adoption of this suggestion will of course be determined by the economics involved as will be reflected in the drainage plans and designs.

**DECLARATION**

I, John Emanuel Rai Tarimo do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work. I further declare that it has neither been submitted nor being concurrently submitted for a degree in any other institution.



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**DEDICATION**

This work is dedicated to my mother Salama Kisakenyi whose contribution towards my primary and secondary school education was great.

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## 1. INTRODUCTION

An assessment of the properties of soils and their response to management is required in planning for agriculture and other land uses (Msanya, 1980; Moberg *et al.*, 1982 and Kaaya *et al.*, 1994). In formulating (designing) a project there should be a constant effort to minimize costs (but not at the expense of safety), and bring about utilization of the investment in the quickest possible time. The latter will usually necessitate a rapid transformation of the farming practices in the project area. From these considerations, the main themes of an irrigation scheme are as follows: a thorough study of physical resource base, particularly the project area's soils, climate and water supply in order to ensure a sustained crop production and, a thorough study of engineering alternatives for serving and draining the project land in order to ensure that the most appropriate economical but safe solution is achieved (Stavern, 1972).

Irrigation is an old art. Historically, civilization has followed the development of irrigation. Civilization has risen on irrigated land, and has also decayed and disintegrated in irrigation regions. Most ancient cultures depending upon irrigated agriculture declined because of lack of political and community stability. In China where

reclamation was begun more than 4000 years ago, the success of early kings was measured by their wisdom and progress in water control activities (Hansen et al., 1980). Areas requiring irrigation are very extensive and encompass portions of every continent of the world. Irrigation is no longer a regional practice of arid countries, but is becoming a basic part of well developed agriculture throughout the world. The basic principles of irrigation are the same, whether practiced in arid or humid climate (Hansen et al., 1980).

Irrigation in the world today covers approximately 160 million hectares, excluding areas under natural flooding (Nugteren, 1972). About half of this is found in arid and semi-arid subtropical zones. It was particularly in these zones that special drainage measures demanded by irrigation came to be recognized, as over years those areas with insufficient drainage began to show rising of groundwater table, and increasing salinity. In ancient times, as in the days of the various Babylonian kingdoms, salinity and waterlogging gradually reduced the productivity of land (Nugteren, 1972). The problem of salinity in arid and semi-arid regions is due to low rainfall, high evapotranspiration and poor quality irrigation water (Rhoades, 1985). Soils with

low permeability are likely to have waterlogging and salinity problems (Smedema, 1990).

Irrigation is required to replenish soil moisture into the root zone before it reaches a level that restricts evaporation and decrease yields. Daily evaporation plays an important role in determining the time of irrigation. Timing irrigation using evapotranspiration based on meteorological data, has gained considerable attention (FAO, 1977). However none of the existing methods account for the uptake of water from water table. Non saline shallow water tables are potential source of crop sub-irrigation (Tripath, 1992).

Salinisation of soil may be caused in different ways and under different climatological conditions, but the main cause is usually poor drainage. In arid and semi arid regions salinity symptoms may not always be due to present poor drainage but could be the result of poor drainage in geological past (Staveren, 1972).

Irrigated soils receive considerable quantities of dissolved salts, supplied partly by irrigation water itself and partly by inflowing groundwater. Irrigation water even if is of excellent quality, is a major source of soluble salts. An

annual application of 1000 mm water containing only 250 mg/l dissolved salts will add 2500 kg to each hectare each year (Van der Molen, 1972). Capillary rise may cause the groundwater to reach root zone or even the soil surface, where it evaporates leaving salts behind. If the groundwater reservoir is replenished over short periods only, the water table doesn't remain at a high level and the process of salinisation comes to standstill; in such cases the soil salt content is seldom high enough to be harmful to crops. If, however, the groundwater in an area is fed by seepage from else where during the greater part of the year, the process of salinisation continues and severe accumulation of salts will occur (Verhoeven, 1972). A certain amount of leaching is needed to counteract the process of salinisation. An excess of irrigation water is supplied to the soil surface and the salts are washed down and out of the root zone. This water will replenish the groundwater but, if natural drainage is sufficient, it will be discharged without unduly raising the water table.

Natural drainage however is frequently unable to cope with these excessive quantities of water and a drainage system has to be installed to control water balance and salt balance into the root zone (Van der Molen, 1972). Salinity causes

three main problems in agriculture management. These are: osmotic stress, toxicity and deterioration of soil structure. According to James (1988), plant use more energy to extract water from soil solution as the concentration increases. Salinity causes retarded stem growth in crops like sugarcane and poor tillering as well as low sucrose content in the juice (Lakshimikanthan, 1983).

At present Mtibwa Sugar Company has an estate cane area of 4747 ha made up of 1800 ha of sprinkler irrigated land and 2947 ha of rain fed land. The rainfed yield 43 tons/ha while 93 tons/ha is produced on irrigated land (SKIL, 1990). The sugarcane industry in Tanzania consist of four estates which have a total production of 236,000 tons of sugar per annum, and it has been reported that low cane yield is caused by several factors including weeds, pests, diseases and poor soils (SKIL, 1991).

**Table 1.1 Mtibwa Sugar Estates Ltd., harvesting results of fields 7D and 10E (1982-1992)**

FIELD	VARIETY	DATE OF HARVEST	YIELD TONS/HA
7D	NCO 376	SEP 1982	60.0
		JUL 1983	45.0
		JAN 1988	32.0
		NOV 1991	30.3
10E	NCO 376	AUG 1982	103.5
		SEP 1983	119.8
		SEP 1987	96.5
		NOV 1989	62.5
		SEP 1990	47.2
		AUG 1991	53.4
		JUL 1992	61.3

In Tanzania the problems of salinity and sodicity in irrigation schemes are common and wide spread. Among scheme which have such hazards is Kitivo village irrigation scheme (NSS, 1987). According to harvesting reports at Mtibwa Sugar Estates (1982-1992) it is obvious there is decline in cane production (Table 1.1).

The main objectives of the research are to study the physical and chemical properties of the soils under sprinkler irrigation at Mtibwa Sugar Estates and assess how they affect crop yield and to characterize the water used for irrigation

in terms of its quality. The specific objectives are as follows:

1. to characterize fully the soils of the affected and non affected areas including their morphology, physico-chemical properties and classification,
2. to assess the quality of irrigation water and groundwater,
3. to screen out the main problems responsible for decline in sugarcane yields and,
4. to give appropriate recommendations on how to control observed problems and outline future plans.

## 2. LITERATURE REVIEW

### 2.1 Salinity and sodicity

Salinity may be defined as the accumulation of salts into the root zone to the level that it affects crop yield (FAO, 1985). Salinity is the sum of all the ionized dissolved salts in the soil water without specific reference to ions present (James, 1988). Salts occur in the soil in one of the following three forms: salt ions dissolved in the soil water, cations adsorbed on the negatively charged surface of the soil particles and precipitated salts (Smedema and Rycroft, 1983). The main salt ions found in the soil solution of salty soils include the following cations: potassium, sodium, calcium and magnesium. Anions include, chloride, sulphate, carbonate, bicarbonate and nitrate (FAO, 1985). Sodification involves the replacement of other cations on the adsorption complex by sodium. Significant replacement only occurs when sodium becomes a dominant soluble cation in the soil solution. This may occur when the salinising source is sodium rich or when for other reasons the salinisation process favours accumulation of sodium (FAO, 1985).

According to Verhoeven (1972), soil salinity can be categorized into three classes as follows: saline soils, saline sodic soils, and non saline sodic soils.

**Saline soils**

These have electrical conductivity (ECe) higher than 4 decisiemen per meter (dS/m) at 25°C; exchangeable sodium percentage (ESP) lower than 15, and a pH generally below 8.5. Such quantities affect adversely crops. White salt crust may be found on the soil surface, main anions being chloride, sulphate and to lesser extent bicarbonates and nitrates. Insoluble carbonate and sulphate may be present.

**Saline sodic soils**

These have ECe higher than 4 dS/m at 25°C, ESP higher than 15, pH seldom higher than 8.5. Crop growth is seriously impeded. Soil structure is usually fair but may deteriorate on leaching. The soil may then become strongly alkaline. The soil particles will disperse and the permeability diminishes markedly and suitability for tillage is reduced.

**Non saline sodic soils**

These have ECe lower than 4 dS/m at 25°C, ESP higher than 15, pH usually 8.5 to 10 but in lime free soils, pH may be low to 6. In general the important anions are chloride, sulphate and bicarbonate, but carbonate, too, are often present.

## 2.2 Factors affecting salinity and sodicity

### 2.2.1 Direct salinisation by irrigation

Irrigation water from rivers and wells always contain dissolved salts. Thus in irrigation schemes, more salts are added to the land than are taken by plants (FAO, 1979). Most irrigation water originates as rainfall which percolates through the soil towards the groundwater and onwards toward rivers, collecting salts on its way. The use of groundwater for irrigation poses problems of salinity.

This is especially true of arid climates where there is low rainfall and high evaporation, groundwater is not refreshed so frequently as in humid climates and salts tend to become more concentrated. Rivers often have a higher salt content during the low flow season than during flood season while salt conditions may also vary along the river course (Smedema and Rycroft, 1983). The suitability of a water for irrigation is determined not only by the total amount of salts but the kind of salts (FAO, 1985). When the electrical conductivity of irrigation water is above 3 dS/m it must be applied with caution (FAO, 1985). Irrigation water with neutral salts content, the pH of the soil does not normally rise above 8.5, so the problem of alkalinity are typical problems with low concentration of neutral salts. Serious danger of alkalinity

will rise if irrigation water has residual sodium carbonate whose concentration is of 1.25 - 2.5 meq/l (Wild, 1988).

Hanson and Kite (1984) indicated that irrigation schedule under well drained soil involves irrigation when some allowable depletion has occurred. The allowable depletion depends on the soil type, root depth and crop water requirement. In saline soils upward flow may however cause increased soil salinity in the root zone. Frequent irrigation may be necessary to prevent significant yield reduction. The distribution of salts in the soil is highly dynamic due to upward and downward flow of water in the profile. According to FAO (1971), following rain or irrigation, the salt concentration may be found to increase with depth and the reverse situation occur in dry periods.

### **2.2.2 Salinisation from groundwater**

Evaporation of saline groundwater from the soil is a common cause of soil salinisation. The groundwater may evaporate directly from water table when the latter occurs within evaporation zone, or it may be drawn from deeper down as the evaporation create a gradient for upward capillary flow from the water table into the evaporating zone (FAO, 1985). A great deal of irrigated land is underlain at shallow depth by

saline groundwater. Prior to introduction of irrigation, groundwater recharge is usually low, consisting only of deep percolation due to low rainfall in arid regions (Van der Molen, 1972).

Capillary flow upward from a water table can reach to great heights but the rate of flow generally decreases with increasing height above water table. The distance at which the upward capillary flow becomes too small for any significant upward salt movement is called the critical capillary height which depends on soil type and salt concentration of the groundwater (FAO, 1985).

### **2.2.3 Salinisation from poor drainage**

The hydraulic conductivity of the soil profile at and below drain depth is the most important soil physical characteristic when dealing with subsurface drainage. The magnitude of the hydraulic conductivity of a soil depends on pore geometry and the nature of the particle surface. Thus it varies with texture, structure, density of packing of soil grains and grade of cementation.

The effect of the texture, structure, and density are in turn modified by the content of organic matter, the degree of

saturation with calcium, sodium and the type of clay mineral. A clay loam with high ESP and swelling clay mineral may have hydraulic conductivity of 0.01 m/day, while one with good and stable structure may have a hydraulic conductivity of 8 m/day (Staveren, 1972).

Salinisation of soils may be caused in different ways and under different climatological conditions, but the main cause is usually poor drainage. In arid and semi-arid regions salinity symptoms may not always be due to the present poor drainage but could be a result of poor drainage in the geological past (Staveren, 1972).

In arid and semi-arid regions leaching is a prerequisite in agriculture under irrigation. Sometimes rainfall is sufficient to leach salts provided groundwater is low and the soil is permeable. The leaching requirement is the smallest fraction of the applied water that must drain below the root zone to prevent any loss in crop productivity from an excess accumulation of soluble salts (Hoffman, 1985). The amount of leaching necessary to satisfy the crop depends on salinity of the applied water and the crop tolerance (FAO, 1979). According to FAO (1985) crop tolerances have been grouped as shown in Table 2.1.

**Table 2.1 Crop tolerance to salinity (FAO, 1985)**

Relative crop tolerance	Salinity at which yield loss begins (ECe dS/m)
Sensitive	< 1.3
Moderately sensitive	1.3 - 3.0
Moderately tolerant	3.0 - 6.0
Tolerant	6.0 - 10.0
Unsuitable	>10.0

### 2.3 Recognition of salt affected land

Salty soil shows various kinds of salts and high percentage of exchangeable sodium. Heavily salinised soil may even show efflorescence or complete salt crust formed as gypsum, common salt or soda (Verhoeven, 1971). According to Smedema and Rycroft (1983) field appearance may be used to determine saline and sodic soils. Many salty soils have a normal field appearance. The salt content must be quite high before salinity becomes observable in the field.

Soil salinity problems can not therefore be completely assessed in the field but should be measured in the laboratory. Typical symptoms in the soil include the following: efflorescence phenomena; powdery, crystalline deposits on exposed surfaces from which water evaporates, leaving behind the salt especially in high spots, side slopes

of the ditches and the walls of soil pits. Damp oily looking surface is due to hygroscopy of salts especially calcium chloride salts. Mycelia in the soil profile is a result of salt precipitated in fine pores, forming a pattern of the white vein usually carbonates. Crust is formed from concentration of crystalline salts at a certain depth near or on the soil surface or any other evaporating plane in the profile leading to the formation of cemented layer. A dark film on the soil surface may be formed when soil moisture has been evaporated from soil containing organic matter in presence of sodium carbonate.

According to Russell (1973), evaporation of water from saline soil differs from that of non saline soil in that under comparable conditions the soil is likely to loose more water by evaporation during a drought than non saline soil because it maintains moist surface for a longer time. When evaporation rate is too low, poorly developed mulch layers are to be formed and evaporation losses from the soil can continue although at a rather low rate for a long period, drawing water from great depth (Smedema and Rycroft, 1983).

#### **2.4 Effects of salinity and sodicity to crops and soils**

Salinity causes three main problems in agricultural

management. These are: osmotic stress, toxicity and deterioration of soil structure as follows:

#### 2.4.1 Osmotic effects

Salts dissolved in water exerts binding forces on the water equal to osmotic forces. A plant extracting water from the salt solution must overcome these forces in addition to normal moisture retention forces (capillary, gravity and suction) (Smedema and Rycroft, 1983). Plants absorb more water from salt free soil than from salty soil because salts have an affinity for water (Wild, 1988). According to James (1988), plants use more energy to extract water from a soil solution as the concentration increases. Salinity negatively influences crop physiology particularly in cell enlargement, cell division, the production of nucleic acids thus reducing plant mass and yield production. Salinity effects are analogous to those of drought as both results in water stress, reduced growth and necrosis (FAO, 1985). The general effect of a high salt content in the soil is to give a stunted plant, leaves of the crop becomes dull coloured and often bluish green coated with waxy deposits. Many crops grown in saline soils do not display symptoms of wilting very clearly but considerable reduction in yield can occur (Russell, 1973).

#### **2.4.2 Toxicity effects**

Toxicity hazards are caused by relative high concentration of soil solution of some particular cation or anion, or unfavourable salt composition in the soil solution which results in an excess or imbalanced mineral uptake by the plants. The occurrence of toxicity is often linked with a high salt concentration in the soil solution, thus occurring concurrently with osmotic effects (FAO, 1985). Some of the most important toxicity hazards are due to sodium toxicity, chloride toxicity and boron toxicity.

##### **Sodium toxicity**

This occurs when the soil solution contains high concentration of sodium and this reduces the levels of calcium cations in the soil solution. Most crops will tolerate ESP values in excess of 10 to 20 per cent, but will suffer from poor soil structure. Sensitive crops usually show symptoms when the sodium content of the leaf tissue is in excess of 0.25 to 0.50 % (dry weight basis) (Smedema and Rycroft, 1983).

##### **Chloride toxicity**

This problem may be expected when the chloride concentration in the saturation extract exceeds 10 meq/l or when the leaves

of the leaf tissue is in excess of 0.3 and 0.5% (dry weight basis) FAO (1985).

#### **Boron toxicity**

It arises when concentration of boron is above 3 ppm in the soil solution. Boron and molybdenum are not likely to be limiting elements for plant nutrition in sodic soils but may be in toxic levels (FAO, 1988).

#### **2.4.3 High pH problems**

The presence of carbonate and bicarbonate anions in the soil solution is especially important. These anions form salts with calcium cations which are only slightly soluble while the corresponding sodium salts are highly soluble (FAO, 1979). Irrigation water usually contains free bicarbonate ions as well as sodium and if both of these accumulate in the soil, its pH may rise to values as high as 10. The rise in pH can have two undesirable consequences: it will increase the salt concentration to levels that the soil flocculate and it may cause the plant fail to absorb nutrients such as phosphates, zinc, iron and manganese (Russell, 1973). According to FAO (1988), zinc and iron deficiencies have been widely reported for crops grown in sodic soils.

#### 2.4.4 Effects of salinity on soil properties

Lima et al., (1990) observed that high levels of salinity and sodicity change soil physical properties such as infiltration rate, diffusivity and sorptivity but increases water retention characteristics. A high concentration of salts in the soil moisture compresses the layer of soil colloids while the layer expands when salt concentration decreases. Thus soils are more liable to dispersion when the salt concentration of the soil solution is low than when it is high. When the adsorbed cations are mainly divalent especially calcium, the layer is compressed. The layer expands when there is large proportion of monovalent cations especially sodium on the adsorption complex (FAO, 1985). When this salt concentration decreases, due to leaching, dispersion problems arise (Rhoades, 1985). Poor soil properties due to dispersion includes: low hydraulic conductivity due to dispersed colloids, blockade of pores; unfavourable consistency, hard when dry and sticky when moist; formation of surface crusts which inhibits infiltration and become waterlogged as a result of deterioration of drainage characteristics (Smedema and Rycroft, 1983).

#### **2.4.5 Effects of salinity on soil microbes**

Rai (1991) worked on the effect of soil salinity on soil microbes and noted that *Azospirillum spp.* and their associates were adversely affected. Among salts tested, bicarbonates were the most toxic to strains followed by sulphate and chloride. El Sheikh and Wood (1989) indicated that tolerance of *Rhizobia spp.* to salts depends on soil pH and temperature.

#### **2.4.6 Summary**

Soil salinisation generally refers to the development of a non salty soil into salty soil, and especially to the development of a non saline soil into a saline soil. It involves an increase of the soluble salt content of the soil, resulting in an increase of the salt concentration of the soil solution. The ESP, depending on the salt composition, may increase as well and sodic soil may develop. Sodification never occurs in isolation but it is usually triggered off by salinisation. Salinisation is the process underlying the development of almost all salty soils.

### 3. MATERIALS AND METHODS

#### 3.1 Location

Mtibwa Sugar Estates is situated between longitude 37° to 38°E and latitude 6° to 6°10'S near the village of Turiani in Morogoro region Tanzania, (Fig. 3.1). Morogoro which is the nearest largest town lies some 100 km to the South West of the area.

#### 3.2 Topography

The main geomorphological features are presented in Figure 3.1. The altitude of the estate varies from a height of 340 m above sea level in the South to 380 m above sea level to the North. The general slope is towards South and South West. The gradient is however, not much pronounced due to cultivation coupled with land levelling. The Nguru mountains which lie to the West of the area rise to the height of approximately 2135 m above sea level, while Kidudwe hills located to the East have an elevation of about 600 m asl. The Nguru mountains form an escarpment running to the North East and to the South West. Wami river which is the largest river near the area flows along this escarpment. This river together with its tributaries: Diwale, Mjonga and smaller seasonal streams, form the main sediment transporting and depositing agents.

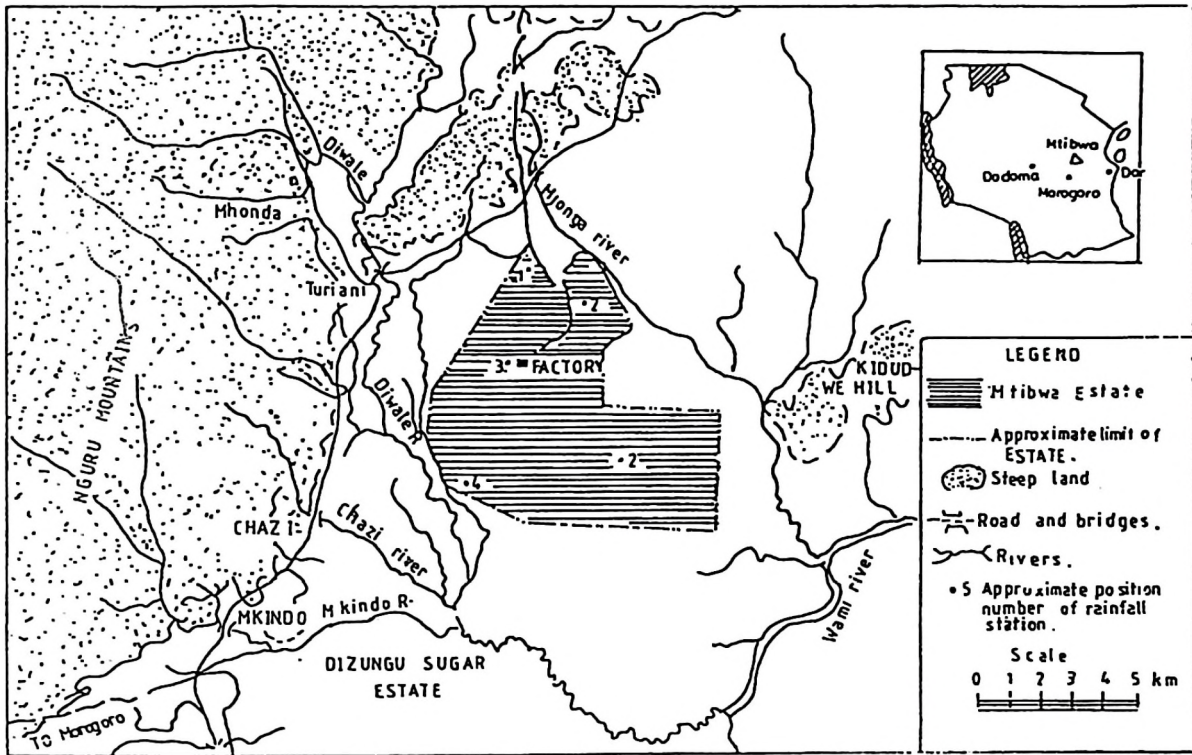


Fig. 3.1 Location of Mtibwa Sugar Estate

### 3.3 Hydrology

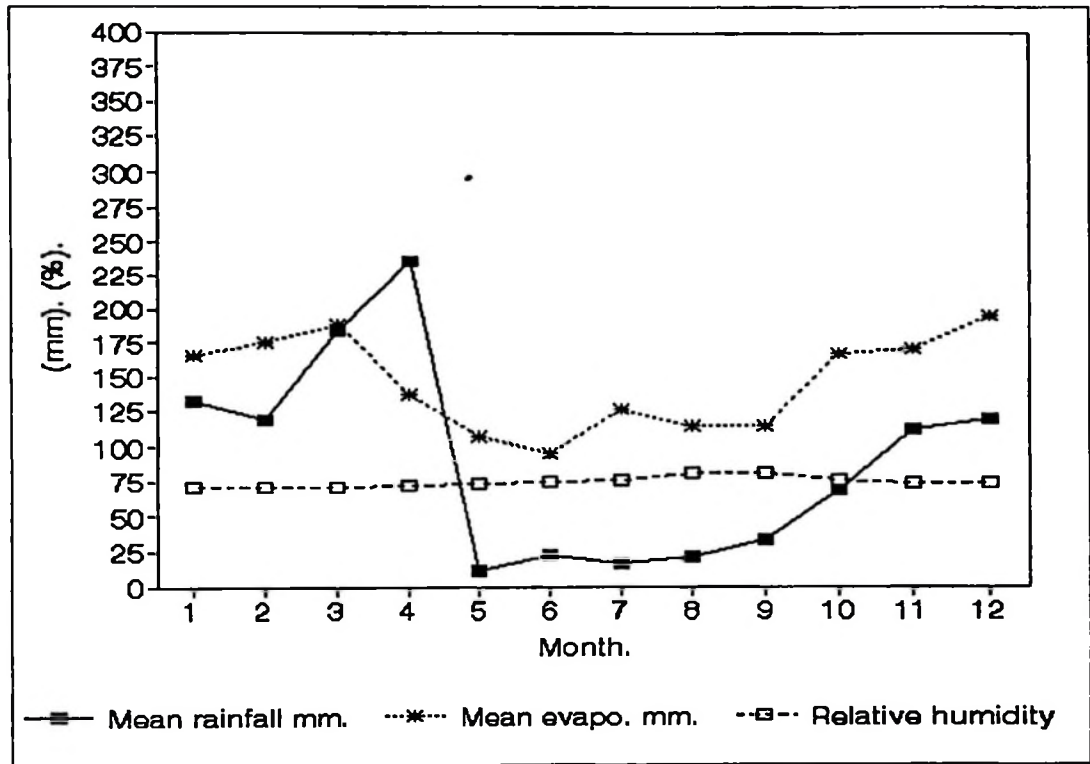
The main drainage of the area is by the Diwale and Mjongga river and other small streams draining into them which finally discharge into the Wami river. Frequent seasonal flooding of the rivers and the small streams has resulted into numerous river course changes, (Fig. 3.1).

### 3.4 Geology

The apparent stratification of the soil in the area, as evidenced by the occurrence of recent deposits overlying relatively older deposits, is a result of the frequent changes of river and/or stream course over the years. Large part of the estate consists mainly of alluvial materials deposited by the Wami river and its tributaries, and colluvial materials deposited by gravity from Nguru mountains and Kidudwe hills.

### 3.5 Natural vegetation and land use

The area constitutes about 3000 hectares, and is currently under sugarcane plantation. Prior to the present sugarcane estate the area was covered by Miombo woodland and savannah grass. Some of the main grass species that are found around the area include *Panicum maximum*, *Pennisetum purpureum* and *Hyperhenia spp.*



**Fig. 3.2 Summary of meteorological data (Mushi, 1983), mean monthly rainfall, evaporation and relative humidity**

### 3.6 Weather

#### 3.6.1 Rainfall

The rainfall pattern is bimodal. Short rains start from November to December and long rains from March to May. The mean annual rainfall around the estate is 1180 mm. Irregularities in the rainfall often causes occasional droughts or floods.

### **3.6.2 Evaporation**

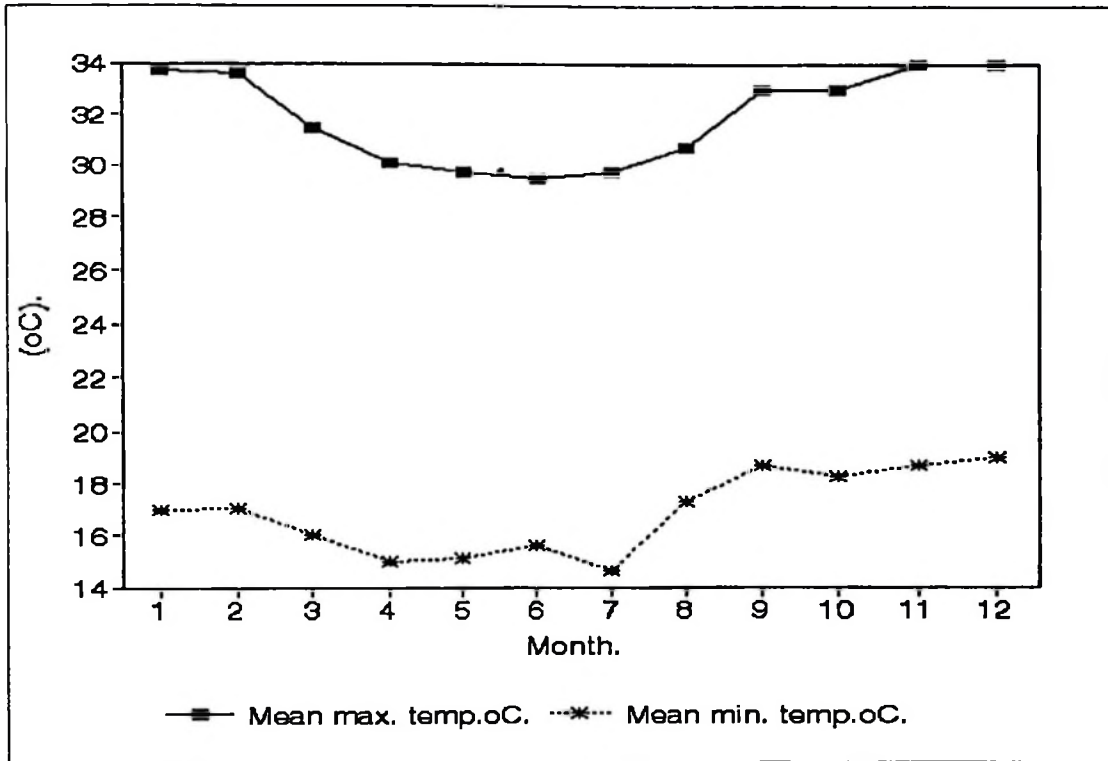
The mean annual evaporation of 1781 mm greatly exceeds the mean annual precipitation of 1180 mm. Peak evaporation of 195 mm/month occurs in the month of December. From the rainfall and evaporation data, there is a clear moisture deficit starting from June to February.

### **3.6.3 Relative humidity**

Relative humidity is high and ranges 75.2% to 80.4% in the rainy season (March to May) and it is moderate (70%) in the dry period (Sept/Nov).

### **3.6.4 Temperature**

Records of temperature show that the maximum air temperature varies from 28°C in the coldest months (June/July), and with an average of 30°C and between 33°C to 36°C in the hottest months (Dec/Jan) with an average of 34°C.



**Fig. 3.3 Mean maximum and minimum monthly temperature  
(after Mushi, 1983)**

### 3.7 Experimental methods

#### 3.7.1 Experimental sites selection

A preliminary soil textural map (scale 1:10000) prepared by Mtibwa Sugar Estate (Mushi and Mbombe, 1980) was used as a base map. Survey of the irrigated fields from line 1 to 11 was done and it was found that the following fields were problematic: 4D, 5D, 5E, 5F, 6E, 6D, 6E, 7C, 7D, 7E, 8D, 8E and 9D (See Fig. 3.4). Experimental fields were selected on the basis of crop performance as follows:

Field 10E with normal cane growth; field 7D with stunted cane and field 5F which was bare.

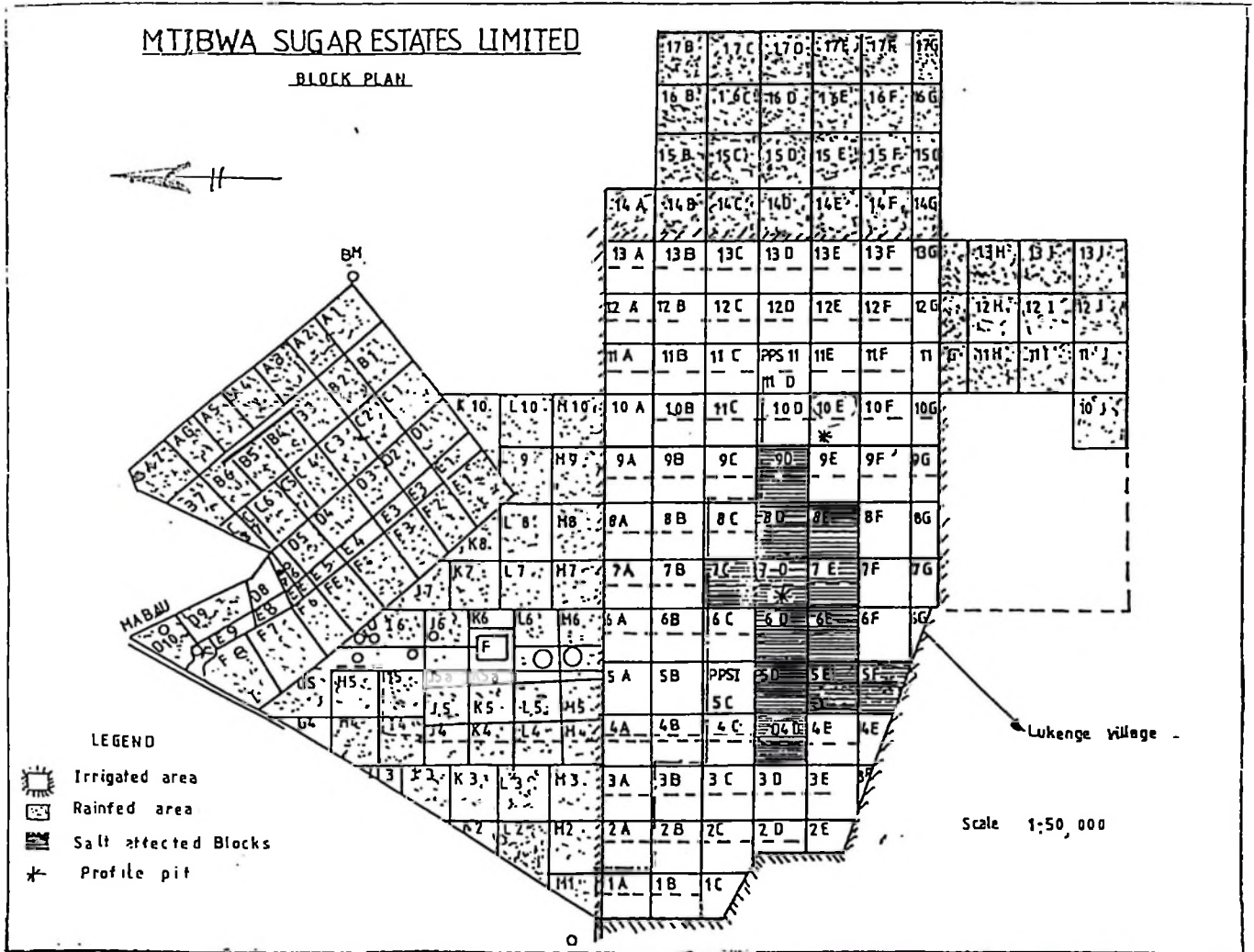


Fig. 3.4 Blockplan Mtibwa Sugar Estate

### **3.7.2 Morphological characteristics**

Representative soil profiles were excavated to a depth of 150 cm in each field. The morphological characteristics of the soil profiles were described in detail according to the FAO guidelines for soil profile description (FAO, 1977). Soil colour was determined using the standard Munsell soil colour charts (Munsell Color Co., 1975). Soil samples were collected from each horizon of the profiles described.

## **3.8 Laboratory methods**

### **3.8.1 Physical characteristics**

#### **3.8.1.1 Particle size distribution**

The particle size analysis involved the separation of the mineral fraction of the soil into various size fractions and then the determination of percentage of each fraction was carried out. Fraction larger than 50 micron were separated by sieving and the fractions smaller than 50 microns were determined using the pipette method (Day, 1965).

#### **3.8.1.2 Bulk density**

Undisturbed soil samples were collected from each horizon following the core method (Black, 1965) for the determination of bulk density. Soil samples were oven dried to constant weight at 105°C and bulk density then

calculated from the ratio of the mass of oven-dry soil to the volume of core. The bulk density was then calculated from the ratio of the mass of oven dry soil to the volume of core.

#### **3.8.1.3 Moisture retention characteristics**

Field capacity was estimated as water retained at 0.3 bar (Sanchez, 1976). This was determined by taking the undisturbed samples, saturating them for two days in the pressure plate extractor and then subjected to pressure of 0.3 bar. Samples were taken for gravimetric moisture content determination. Wilting point was determined as water held at 15 bar pressure. Undisturbed samples were saturated in the pressure membrane extractor overnight, after which they were subjected to 15 bar pressure. Moisture was determined gravimetrically after equilibrium was established (Black, 1965).

#### **3.8.1.4 Hydraulic conductivity**

The drainage characteristics were determined based on the nature of the matrix colour and/or by the presence of hydromorphic mottling features (oxidation-reduction). Saturated hydraulic conductivity was determined by the auger hole method. An auger hole with radius 50 mm was first made to a depth below the water table deep into the layer to be measured. Then water level was allowed to

raise in the hole after it has been removed out until it establishes itself at equilibrium coinciding with the water table. Then a detailed record of the rising water level in the hole was maintained over an appropriate time period. The equations used were based on the assumption that the water table remains constant (Smedema and Rycroft, 1983).

### **3.8.2 Chemical characteristics**

#### **3.8.2.1 Soil pH**

The pH-water of the soil samples were determined potentiometrically as outlined by Hesse (1971).

The pH-KCl of the soil samples were potentiometrically measured in a soil-KCl suspension (ratio 1:2.5) as outlined by Hesse (1971).

#### **3.8.2.2 Salt concentration (ECe)**

The electrical conductivity of soil water suspension (ratio 1:2.5) was determined by electrical conductivity meter as outlined by Hesse (1971).

#### **3.8.2.3 Exchangeable cations and cation exchange capacity**

The soil samples were percolated with an excess of 1M neutral ammonium acetate to saturate the colloidal complex with ammonium. The excess of ammonium acetate was washed

out by ethyl alcohol, and the extracted cations calcium, magnesium, sodium, and potassium were determined from the ammonium acetate leachate by atomic adsorption spectrometry (Hesse, 1971). For the determination of CEC the excess of ammonium was then replaced by percolation with acidified 1M KCl solution. The ammonium in this percolate was distilled and collected in boric acid 2%. The distilled ammonium was titrated with sulphuric acid 0.01M to get the cation exchange capacity (Black, 1965).

#### **3.8.2.4 Organic carbon**

Organic carbon was determined by wet combustion method of Walkey and Black (Allison, 1965). Soil organic matter was oxidised at a temperature of 120°C with a mixture of potassium dichromate, then it was titrated against ammonium ferrous sulphate with diphenylamine as indicator. A weighed sample of fine earth passing through 60 mm sieve was digested with known volume of 1M  $K_2Cr_2O_7$  and concentrated  $H_2SO_4$ . The amount of dichromate utilized in the oxidation was taken as a measure of organic carbon content of the soil. The excess  $K_2Cr_2O_7$  was titrated against a standard 0.5M ferrous ammonium sulphate.

#### **3.8.2.5 Total nitrogen**

Total nitrogen was determined by the macrokjeldhal distillation method (Bremner, 1965).

#### **3.8.2.6 Available phosphorus**

Available phosphorous was determined by Bray and Kurtz method No.1 (Bray and Kurtz, 1945). Phosphorus was extracted with a solution containing 0.03N  $\text{NH}_4\text{F}$  and 0.02N HCl with one minute shaking. Colour was developed using ammonium molybdate and stannous chloride. The molybdenum blue colour intensity was determined calorimetrically at 660 millimicron wavelength and compared with standard curve.

#### **3.8.2.7 Chloride**

The chloride content of the irrigation water and groundwater of field 10E was determined by titration with 0.02M silver nitrate because they have ECe less than 1 dS/m. Chloride in groundwater of field 5F and 7D, 0.10M silver nitrate was used because they had ECe greater than 1 dS/m.

#### **3.8.2.8 Sulphate**

The sulphate content of the irrigation and groundwater samples were determined by the precipitation of the sulphate as barium sulphate in an acid medium (0.05N) with an excess of barium dichromate. The principle is that the dichromate, of which barium is already precipitated as sulphate, is equivalent to the amount of sulphate present in the sample and is hereby transferred into the soluble

chromate. These chromate ions give the solution a yellow colour. The sulphate content is calculated from the spectrophotometrical determination of that yellow colour at 410 nm.

#### **3.8.2.9 Bicarbonate**

Bicarbonate in irrigation water and ground water were determined titrimetrically as outlined in Black (1965). Samples were titrated with hydrochloric acid and sodium hydroxide using methyl orange and phenolphthalein as indicators.

#### **3.8.3 Soil classification**

Using both field and laboratory data the identified soil types were classified up to subgroup level of the USDA Soil Taxonomy (Soil Survey Staff, 1990) and to level -2 of the FAO-Unesco (1989) Soil Classification System.

#### **3.8.4 Land suitability classification**

Using both field and laboratory data the identified soil types were classified up to subclass level of the FAO (1976) Land Suitability Classification System.

#### 4. RESULTS AND DISCUSSION

##### 4.1 Physical properties of the soils

###### 4.1.1 Soil profile morphology

Field 5F and 7D have medium textured soil of sandy loam above a sandy clay loam subsoil, (Table 4.1 and 4.2). The surface layer is thick (greater than 10 cm). The subsoil is grey with prominent mottling. Root distribution is restricted in the top layer and drainage is poor to very poor due to high bulk density of the soil. The details of profiles description are in the Appendix 1.

Field 10E is dominated by coarse textured soil indicating the soil is weakly developed. The surface texture is mainly loamy sand while that of the subsoil is coarse sand and structureless, (Table 4.3). The subsoil consist of abundant mica flakes. The soils are deep and well drained. The details of the morphological properties are in the Appendix 1. The clay content of the top soil is low (10-17%) in profile 5F while it is high (29%) in the subsoil. In profile 7D the clay content is low (16%) in the epipedon and high (22%) in the subsoil, (Table 4.1 and Table 4.2). The silt content is medium (11-24%) in the top soil and relatively low (6-10%) throughout the profile. Textural class of the top soil is sandy loam while that of the subsoil is sandy clay loam.

Table 4.1 Some soil physical properties of profile 5F

Hori-zon	Depth (cm)	Sand %	Silt %	Clay %	Text-ure	B.D g/cc	Water content % 0.3B	15B	AWC %	
Ap	0-17	79	11	10	LS	1.52	15.60	10.35	5.34	5.01
AB	17-43	77	6	17	SL	1.62	18.36	9.08	9.28	
Bwg	43-150	66	5	29	SCL	1.65	24.50	10.30	14.20	

Table 4.2 Some soil physical properties of profile 7D

Hori-zon	Depth (cm)	Sand %	Silt %	Clay %	Text-ure	B.D. g/cc	Water content % 0.3B	15B	AWC %
Ap	0-21	60	24	16	SL	1.50	17.75	9.48	8.27
AB	21-48	75	7	18	SL	1.67	19.28	10.98	8.30
Bwg	48-150	68	10	22	SCL	1.69	29.88	14.28	15.50

Table 4.3 Some soil physical properties of profile 10E

Hori-zon	Depth (cm).	Sand %	Silt %	Clay %	Text-ure	B.D. g/cc	Water content % 0.3B	15B	AWC %
Ap	0-38	77	17	6	LS	1.51	8.35	3.24	6.11
C <sub>1</sub>	38-80	79	6	15	SL	1.67	19.28	6.98	12.30
C <sub>2</sub>	80-150	86	8	6	S	1.80	7.6	3.20	4.40

NB. LS = loamy sand, SL = sandy loam, SCL = sandy clay loam and S = sand

There is a gradual increase of clay with depth in the affected fields. Sugarcane grows well in loam to silt loam top soils above sandy loam to clay loam subsoil; and soil with depth greater than 1.5 m (ILACO, 1985). This indicates that the soil texture and depth of the fields 5F and 7D are marginally suitable for sugarcane production.

The clay content of the soils of field 10E is low (6%) in the top soil, moderate (15%) in the midlayer and it is low

(6%) in the subsoil, (Table 4.3). The silt content is high (17%) in the top soil and low (6-8%) throughout the profile. Textural class of the top soil is loamy sand and that of the subsoil is sand.

#### 4.1.2 Bulk density

The bulk densities of the soils of fields 5F and 7D are medium to high (1.5-1.6 g/cc), (Table 4.1 and Table 4.2). The bulk density increases gradually with soil depth. High bulk densities in these soils is attributed partly to the sand texture and compaction. The tendency of bulk density to increase with depth could either be due to the low organic matter content, less aggregation and root penetration. For adequate sugarcane growth bulk density of less than 1.4 g/cc is recommended (Trowse and Humbert, 1961). High densities have shown to have deleterious effect on sugarcane root growth. The bulk density of the soils of field 10E is medium to high (1.51 - 1.8 g/cc) and increases with soil depth, (Table 4.3). This high density is attributed to the sandy texture. Although the bulk density is high due to the sandy texture, sugarcane growth is normal because the soils are well drained and due to the application of nitrogen fertilizers.

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#### 4.1.3 Hydraulic conductivity and available water capacity

The water table depth below the ground surface at the time of this study was 98 cm in profile 5F and 85 cm in profile 7D. This high groundwater table indicates the possibility of these fields to be waterlogged in rainy season. The saturated hydraulic conductivity is moderately slow 0.5 m/day and 0.9 m/day for profile 5F and 7D respectively. This proves the subsoil of the affected land is relatively impermeable. The available water capacity in the top soil is low (5.01-9.28% in profile 5F; and 8.27-8.30% in profile 7D) as shown in Table 4.1 and Table 4.2. The AWC of the subsoil is relatively high (14.2-15.5%). The high value of AWC of the subsoil is due to the clayey nature of the B horizon.

At the time of the study water table of field 10E was 80cm below the ground surface. The saturated hydraulic conductivity of the soils in field 10E is moderately rapid, 2.9 m/day. This value indicate that the soil is perfectly drained. The available water capacity of the top soil and subsoil is low 6.11% and 4.4% while that of the mid layer is medium (12.30%) (Table 4.3). The high available water capacity of the midlayer is attributed to the clay content.

## 4.2 Chemical properties of the soils

### 4.2.1 pH and ECe

The soil reaction of the affected fields is strong to slightly acid (pH 4.8 - 6.5) in the top layer to neutral (6.4 - 7.0) in the subsoil, as shown in Table 4.4 and Table 4.5. The low pH in the top soil is probably due to the fact that organic matter tend to reduce the reaction by chelating the hydroxylated cation. According to FAO (1985), a pH range of 5.5-7.0 is preferred for most crops. The soil reaction of the soils of field 10E is strongly acidic in the topsoil (pH 5.2), to slightly acid (pH 6.4) (Table 4.6).

The electrical conductivity is moderate (1.2 - 3.7 dS/m) in both fields 5F and 7D (Table 4.4 and Table 4.5). These results indicate concentration of soluble salts is enough to cause poor cane growth in fields 5F and 7D. According to FAO (1985), soil salinity at which yield loss begins for moderately sensitive crops like sugarcane is 1.3-2.0 dS/m. The midlayer probably acts as the transition zone because from the AB layer Ece increases towards the soil surface due to evaporation effect. The Ece value increases towards the groundwater table due to capillary salinisation. The Ece value of the saturation extract of the soils of field 10E is very low (0.05 - 0.15 dS/m) and increases with soil depth, (Table 4.6).

Table 4.4 Some soil chemical properties of profile 5F 1

Horiz- zon	Depth (cm)	pH.H2O 1:2.5	pH.KCl 1:2.5	ECe 1:2.5 dS/m	NH4OAc extract pH 7 cmol(+)/kg				OC%	OM%
					K	Na	Mg	Ca		
Ap	0-17	5.0	4.3	3.7	0.03	4.34	2.07	3.39	0.85	1.47
AB	17-43	4.9	4.1	1.2	0.02	2.41	1.55	2.16	0.50	0.86
Bwg	43-150	6.4	5.6	2.0	0.02	3.96	2.39	2.42	0.32	0.54

Horiz- zon	TEB cmol(+) /kg	CEC cmol(+) /kg	BS%	ESP	SAR	TN%	C/N	Av. P
								(ppm)
Ap	9.83	20.5	48.0	21.2	2.6	0.042	20.3	8.42
AB	6.14	14.4	42.6	16.7	1.8	0.035	14.3	2.10
Bwg	8.79	17.8	49.4	22.2	2.6	0.019	16.6	1.40

Table 4.5 Some soil chemical properties of profile 7D

Horizon	Depth (cm)	pH.H <sub>2</sub> O 1:2.5	pH.KCl 1:2.5	ECe 1:2.5 dS/m	NH <sub>4</sub> OAc extract pH 7 cmol(+)/kg				OC%	OM%
					K	Na	Mg	Ca		
Ap	0-21	4.8	4.0	1.34	0.01	2.72	1.82	2.12	0.58	0.99
AB	21-48	6.5	5.8	1.15	0.01	3.00	1.86	1.10	0.19	0.31
Bwg	48-150	7.0	6.3	1.8	0.01	4.37	2.14	1.82	0.19	0.31

Horizon	TEB cmol(+) /kg	CEC cmol(+) /kg	BS%	ESP	SAR	TN %	C/N	Av. P (ppm)
Ap	6.67	16.2	41.1	16.8	1.9	0.027	21.3	11.2
AB	5.97	15.4	38.8	19.5	2.5	0.010	18.5	5.61
Bwg	8.34	18.8	44.4	23.2	3.1	0.014	13.3	1.40

Table 4.6 Some soil chemical properties of profile 10E

Horizon	Depth (cm)	pH.H <sub>2</sub> O 1:2.5	pH.KCl 1:2.5	ECe 1:2.5 dS/m	NH <sub>4</sub> OAc extract pH 7 cmol(+)/kg				OC%	OM%
					K	Na	Mg	Ca		
Ap	0-38	5.2	4.9	0.05	0.02	1.34	1.37	2.26	1.49	2.55
C <sub>1</sub>	38-80	6.4	5.7	0.12	0.02	0.26	1.16	3.17	0.49	0.83
C <sub>2</sub>	80-150	5.6	4.2	0.15	0.01	0.21	1.17	1.13	0.19	0.31

Horizon	TEB cmol(+) /kg	CEC cmol(+) /kg	BS%	ESP	SAR	TN%	C/N	Av.P (ppm)
Ap	4.99	15.0	33.3	0.09	0.99	0.092	16.1	5.61
C <sub>1</sub>	4.61	11.2	41.2	0.02	0.18	0.026	22.1	2.10
C <sub>2</sub>	2.52	5.5	45.8	0.04	0.02	0.02	9.25	1.40

#### 4.2.2 Extractable bases and CEC

The sodium level of the soils of fields 5F and 7D is very high (above 2.0 cmol(+)/kg) as indicated in Table 4.4 and Table 4.5. Its value increases towards the soil surface and to the groundwater table from midlayer AB. This high concentration of sodium has probably attributed to the poor growth of sugarcane and the poor soil structure. The exchangeable potassium is very low (less than 0.1 cmol(+)/kg) throughout the profile. The calcium content is low (2-5 cmol(+)/kg) and decreases with soil depth (Table 4.4 and Table 4.5). The magnesium content is medium to high (1.82 -3.96 cmol(+)/kg) and increases with soil depth. The content of extractable sodium in the soils of field 10E is relatively high (1.34 cmol(+)/kg) in the topsoil and low (0.21 cmol(+)/kg) in the subsoil, (Table 4.6). This indicates that sodium is leached to deeper layers and to the groundwater. The potassium content is very low (0.02 - 0.01 cmol(+)/kg) throughout the profile. The calcium content is low (2.26-1.13 cmol(+)/kg) while that of magnesium is moderate (1.37-1.17 cmol(+)/kg) throughout the profile and decreases with the soil depth, (Table 4.6). These results indicate calcium and potassium deficiency, therefore supplementation through fertilizer or sugarcane pulp ash is important.

The cation exchange capacity of the soil of fields 5F and 7D is medium (14.4 - 20.5 cmol(+)/kg) and the base saturation is medium (41.1 - 49.4%). The CEC of the soils of field 10E is low to medium (5.5 -15.4 cmol(+)/kg) and base saturation is low to medium (21-60%). Soil vary in the ability to hold cations depending upon the nature and quantity of colloidal particles. In general, soil with high organic matter content have higher CEC than those with low in organic matter content.

#### **4.2.3 Organic matter, total nitrogen and available phosphorus**

The organic matter in the profile is low to very low (1.47 - 0.54%) in field 5F; and (0.99 - 0.31%) in field 7D. Total nitrogen is low (less than 0.095%) throughout the profiles of fields 5F and 7D. The level of available phosphorus is moderate to low (8.42-1.40 ppm in field 5F and 11.2-1.4 ppm in field 7D), (Table 4.4 and Table 4.5). The organic matter content, total nitrogen and available phosphorus of these profiles decreases with soil depth. The high content of organic matter in the upper horizon is due to the incorporation of plant residues. The organic matter content of the non affected field is medium to low (2.55 - 0.83%) in the epipedon, very low (0.31%) in the subsoil and decreasing with soil depth, (Table 4.4 and Table 4.5). The total nitrogen is very low (less than

0.095% N) throughout the profile. The amount of phosphorus is medium to low (11.2 -1.4 ppm) in the affected fields.

#### 4.3 Soil classification

The soils of the affected blocks are moderately developed, very deep, of alluvial parent material. Drainage is moderately slow while the epipedon is thick, dark grey, with loamy sand overlying sandy clay loam subsoil. The soils of the affected blocks are Typic Tropaquept (USDA Soil Taxonomy); Gleyic Cambisol (FAO-Unesco Classification). The soils of the non affected block (10E) are weakly developed, very deep, well drained loamy sand overlying sandy subsoil. It is classified as Typic Ustipsamment (USDA Soil Taxonomy); Umbric Regosol (FAO-Unesco Classification) (Table 4.7 and Table 4.8).

Table 4.7 Summary of salient morphological and diagnostic features of the soils studied

Profile	Diagnostic horizons	Other diagnostic features	Soil depth
5F	Ochric epipedon (* ochric A); Cambic horizon (* Cambic B)	Aquic SMR (* gleyic properties); isohyperthermic STR; * greater than 6% ESP with 100 cm	Very deep
7D	Ochric epipedon (* ochric A); Cambic horizon (cambic B)	Aquic SMR (* gleyic properties); isohyperthermic STR; * greater than 6% ESP within 100 cm	Very deep
10E	Umbric epipedon (* umbric A)	Ustic SMR; isohyperthermic	Very deep

NB. \* terminology used particularly in the FAO-Unesco Classification, those without \* are in USDA system.

Table 4.8 Classification of the studied soils

Profile	USDA Soil Taxonomy				FAO-Unesco Classification	
	Order	Suborder	Greatgroup	Subgroup	Level -1	Level -2
5F		Aquept	Tropaquept	Typic Tropaquept	Cambisol (CH)	Gleyic Cambisol (CHg)
		Inceptisol				
7D	Inceptisol	Aquept	Tropaquept	Typic Tropaquept	Cambisol (CH)	Gleyic Cambisol (CHg)
10E	Entisol	Psamment	Usti- psamment	Typic Usti- psamment	Regosol (RG)	Umbric Regosol (RGu)

Table 4.9 Land suitability classification of the studied soils

Profile	Order	Class	Subclass
5F	Suitable (S)	Marginally suitable (S3)	Drainage limitation; alkalinity limitation (S3w, S3a)
7D	Suitable (S)	Marginally suitable (S3)	Drainage limitation; alkalinity limitation (S3w, S3a)
10E	Suitable (S)	Moderately suitable (S2)	Available moisture limitation; fertility limitation (S2m, S2f)

#### 4.4 Land suitability classification

The fields 5F and 7D according to FAO (1976) are marginally suitable for sugarcane production. Main limitation include poor drainage and alkalinity. Field 10E is moderately suitable but the main limitations include low available water capacity and low fertility, (Table 4.9).

#### 4.5 Irrigation water and groundwater quality

##### 4.5.1 pH, ECe and SAR

The reaction of irrigation water is pH 8.8 and the values for groundwater in field 5F, 7D and 10E are 8.1, 7.8 and 8.4 respectively, (Table 4.10). This high pH may be attributed to the presence of soluble salts. The pH is an indicator of the acidity or basicity, but it is seldom a

problem by itself. The normal pH range for irrigation water is from 6.5 to 8.4. Any change in soil pH caused by water will take place slowly since the soil is strongly buffered and resist changes (FAO, 1985). The high pH value of irrigation water is an indicator of alkalinity problems in the irrigated fields. The ECe of irrigation water is very low (0.09 dS/m) and that of groundwater from field 10E is low (0.55 dS/m), (Table 4.10). Therefore the irrigation water and groundwater from field 10E are of good quality for irrigation as they contain small amount of dissolved salts. The ECe of the groundwater from fields 5F and 7D are very high (21.2 and 15 dS/m). This water is of poor quality for irrigation and in shallow water tables they may cause accumulation of salts into the root zone by capillary.

According to James (1988) SAR is generally a good indicator of the exchangeable sodium status of the soil and it can be determined more readily than ESP. According to USDA (1954), the irrigation water is in the class C1S1, that is of low salinity hazard and low sodicity hazard, and that of groundwater of field 10E is (C2S1), it is of medium salinity hazard and low sodicity hazards. The groundwater from fields 5F and 7D fall in class (C4S4), that it has very high salinity hazards and very high sodicity hazards.

#### 4.5.2 The exchangeable cations

The sodium content in irrigation water is low (0.20 meq/l) and that of groundwater of field 10E is medium (0.7 meq/l). The sodium content in the groundwater of fields 5F and 7D is very high (71.04 and 56.35 meq/l), (Table 4.10). Potassium content in irrigation water and groundwater of field 10E is low (0.06 meq/l). Potassium in groundwater of field 5F is medium (0.39 meq/l) while in groundwater of field 7D is low (0.15 meq/l). Calcium content is low (2 - 5 meq/l) in both the irrigation water and in the groundwater of field 10E as shown in Table 4.10. Magnesium is moderate (2.70 - 2.8 meq/l) in both irrigation water and groundwater of field 10E while it is low (1.4 - 1.7 meq/l) in groundwater of fields 5F and 7D. These results indicate irrigation water and groundwater of field 10E are of good quality for irrigation as recommended by FAO (1985). See Appendix 3.

#### 4.5.3 The exchangeable anions of chloride and bicarbonate

The level of chloride in irrigation water is low (0.3 meq/l) and it is medium (0.96 meq/l) in groundwater of field 10E while it is very high in groundwater of field 5F and 7D (236.0 - 145.0 meq/l), (Table 4.10). This indicates the possibility of chloride toxicity to plants growing in field 5F and 7D. The level of bicarbonate in irrigation water is very low (0.66 meq/l), moderate (3.5

meq/l) in groundwater of field 10E while it is high (7.06 and 8.8 meq/l respectively) in the groundwater from field 5F and 7D, (See Table 4.10). The high concentration of bicarbonate and sodium in soil solution may lead to high pH and make the plant fail to absorb nutrients such as zinc and iron (FAO, 1988).

Table 4.10 Some chemical properties of irrigation water and groundwater of field 5F, 7D and 10E

Source	pH	ECi dS/m	Exchangeable cations (meq/l)				Ex. anions (meq/l)			SAR	Class
			K	Na	Mg	Ca	Cl	SO <sub>4</sub>	HCO <sub>3</sub>		
IRW	8.8	0.09	0.06	0.20	2.70	2.3	0.30	0.38	0.66	0.09	C1-S1
GW 5F	8.1	21.2	0.39	71.04	1.40	1.0	236.0	-	7.06	57.20	C4-S4
GW 7D	7.8	15.0	0.15	56.35	1.30	1.2	145.0	0.09	8.88	50.40	C4-S4
GW 10E	8.4	0.55	0.06	0.71	2.80	1.7	0.96	1.00	3.51	0.47	C2-S1

## 5. CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

Three field units were identified in the surveyed area under sprinkler irrigation based on sugarcane growth performance. Field 5F and 7D were in the affected area while field 10E was in the non affected area. It was identified that in the affected fields the soil is Gleyic Cambisol and the soil of the non affected field is Umbric Regosol (FAO-Unesco, 1989). The affected fields studied are marginally suitable while the non affected field is moderately suitable for sugarcane production.

The affected fields studied have sandy loam topsoil overlying sandy clay loam subsoil. The Ece of the affected field is moderate (1.2 - 3.7 dS/m), this level of salt concentration is enough to cause poor cane growth according to FAO (1985). The sodium content of the affected fields is very high (above 2 cmol(+)/kg). This high concentration of sodium has probably attributed to the poor soil structure and poor cane growth.

The irrigation water has a pH 8.8 and this predict soil alkalinity of the irrigated fields. According to USDA Soil Salinity Classification (1954), the irrigation water is in class (C1S1), that is, it has low salinity hazards and low sodicity hazards. The Ece of the groundwater of fields 5F

and 7D is very high (21.2 - 15 dS/m). This groundwater is of poor quality for irrigation and in shallow water tables they may cause accumulation of salts into the root zone by capillary. The level of chloride in the irrigation water is low (0.3 meq/l) and it is very high (145 - 236 meq/l) in the groundwater of the affected fields. This high values of chloride indicate the possibility of having chloride toxicity in the affected fields. Therefore the affected fields are poorly drained and cane growth is impeded by the salinity, sodicity and chloride toxicity.

## 5.2 Recommendations

1. A subsurface drainage system survey should be carried out for the irrigated fields at Mtibwa Sugar Company. In the preparation of drainage plan the following three groups of variables have to be defined: the physical characteristics of the drainage system; suitable type of drains and structures; determination of alignments, spacings, depths, capacities; the financial implications related to construction of the drainage structures.
2. A ditch drainage system should be constructed in order to lower the water table and thus leach out the excess salts into the root zone in the irrigated fields.

3. Subsoiling should be practiced as a tillage method in order to improve the soil structure and permeability.
4. Application of sugarcane pulp as mulch should be practiced in order to improve the soil structure and fertility.

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## APPENDICES

## Appendix 1. Soil profile descriptions

General information on the site of profile 5F

Survey area: Mtibwa Sugar Estate

Region: Morogoro

District: Morogoro Rural

Location: 100 km from Morogoro town

Elevation: 340 m asl

Parent material: alluvium derived from materials of diverse origin

Land form: nearly flat (0-2%)

Erosion: no evidence of erosion

Vegetation and land use: originally Miombo woodland; previously under sugarcane, recently under fallow

Effective soil depth: very deep

Natural drainage: moderately slow

Soil: loamy sand epipedon overlying sandy clay loam subsoil

Soil moisture regime: aquic SMR

Soil temperature regime: isohyperthermic STR

Described by: J.E.R. Tarimo, E. Magasta and T.O. Mushi

Date: 23-11-1992

Ap 0-17 cm. Very dark grey (2.5 YR 3/0, moist); loamy sand; moderate fine crumbly; non sticky non plastic wet; very friable when moist; many fine pores; many

very fine roots; clear smooth boundary.

AB 17-43 cm. Grey (5 YR 5.5/1, moist); sandy loam; weak fine subangular blocky; slightly sticky slightly plastic wet; friable when moist; few fine pores; many fine roots; clear wavy boundary.

Bwg 43-150 cm. Grey (5 YR 5.5/1, moist); abundant fine and distinct mottles; sandy clay loam; moderate fine sub angular blocky; massive coherent; sticky and plastic when wet; firm when moist; few fine pores; few fine roots.

General information on the site of profile 7D

Survey area: Mtibwa Sugar Estate

Region: Morogoro

District: Morogoro Rural

Location: 100 km from Morogoro town

Elevation: 340 m asl

Parent material: alluvium derived from materials of diverse origin

Land form: nearly flat (0-2%)

Erosion: no evidence of erosion

Vegetation and land use: originally Miombo woodland; currently is under stunted sugarcane in thick weed

Effective soil depth: very deep

Natural drainage: moderately slow

Soil: loamy sand epipedon overlying sandy clay loam subsoil

Soil moisture regime: aquic SMR

Soil temperature regime: isohyperthermic STR

Described by J.E.R. Tarimo, E. Magasta and T.O. Mushi

Date: 23-11-1992

Ap 0-20 cm. Black (5 YR 2.5/1, moist); sandy loam; very weakly developed structure falling down to single grains; non sticky non plastic wet; very friable when moist; few medium pores; abundant medium fine roots; clear smooth boundary.

AB 20-48 cm. Dark grey (7.5 YR 4/0, moist); sandy loam; weak medium semicrumbly; slightly sticky and slightly plastic wet; very friable when moist; many medium pores; many fine roots; gradual wavy boundary.

Bwg 48-150 cm. Grey (5 YR 5/1, moist); abundant fine and distinct mottles; sandy clay loam; moderate fine sub-angular blocky; massive coherent; sticky and plastic wet; firm when moist; few fine pores; frequent small sub angular quartz fragments; few fine and medium roots.

General information on the site of profile 10E

Survey area: Mtibwa Sugar Estate

Region: Morogoro

District: Morogoro Rural

Location: 100 km from Morogoro town

Elevation: 380 m asl

Parent material: alluvium rich in mica

Slope: gentle slope (2-6%)

Vegetation and land use: originally Miombo woodland;  
currently under sugarcane which is growing vigorously

Effective soil depth: very deep

Natural drainage: moderately rapid

Soil: sandy loam top soil over sandy subsoil

Soil moisture regime: ustic SMR

Soil temperature regime: isohyperthermic STR

Described by: J.E.R. Tarimo, E. Magasta and T.O. Mushi

Date: 23-11-1992

Ap 0-38 cm. Dark reddish brown (5 YR 3/3, moist); loamy  
sand moderate fine crumby; non sticky non plastic  
when wet; very friable when moist; many random fine  
pores; few fine to medium roots; clear smooth  
boundary.

- C1 38-80 cm. Reddish brown (5 YR 4/3, moist); sandy loam; weak fine sub-angular blocky; slightly sticky non plastic when wet; very friable when moist; many random fine pores; few common fine to medium roots; few mica flakes; clear smooth boundary.
- C2 80-150 cm. Reddish brown (5 YR 4/4, moist); sand; structureless single grained; non sticky non plastic wet; very friable when moist; many random fine pores; few fine roots.

Appendix 2. Guide to general evaluation of some soil chemical and physical properties

1. Organic matter and total nitrogen

	Very low	Low	Medium	High	Very high
Organic matter %	<1.0	1.0-2.0	2.1-4.2	4.3-6.0	> 6.0
Organic C %	<0.60	0.60-1.25	1.26-2.50	2.51-3.50	> 3.50
Total N %	<0.10	0.10-0.20	0.21-0.50	> 0.50	

C/N ratios give more information about the availability of nitrogen than total N levels only.

C/N ratios indicate the quality of the organic matter:

C/N 8 - 13 : good quality

C/N 14 - 20: moderate quality

C/N > 20 .: poor quality

2. Soil reaction

Soil reaction (pH H<sub>2</sub>O) is classified as follows:

extremely acid	pH below 4.5	neutral	pH 6.6 to 7.3
very strongly acid	pH 4.5 to 5.0	mildly alkaline	pH 7.4 to 7.8
strongly acid	pH 5.1 to 5.5	moderately alkaline	pH 7.9 to 8.4
medium acid	pH 5.6 to 6.0	strongly alkaline	pH 8.5 to 9.0
slightly acid	pH 6.1 to 6.5	very strongly alkaline	pH above 9.0

The neutral class, if necessary, can be subdivided into:

very slightly acid pH 6.6 to 6.9

neutral pH 7.0

very mildly alkaline pH 7.1 to 7.3

3. Available phosphorus

mg/kg	Low	Medium	High
Avail. P (Bray-Kurtz I)	<7	7-20	>20
Avail P. (Olsen)	<5	5-10	>10

Available phosphorus is determined by the Bray-Kurtz I method if the pH H<sub>2</sub>O of the soil is less than 7.0. In soils with a pH H<sub>2</sub>O of more than 7.0 the Olsen method is used.

4. Cation exchange capacity (CEC)

me/100 g	Very low	Low	Medium	High	Very high
CEC	<6.0	6.0-12.0	12.1-25.0	25.0-40.0	>40.0

CEC is determined using 1M ammonium acetate in soils with pH less than 7.5. In soils with pH greater than 7.5 CEC is determined using 1M sodium acetate.

## 5. Exchangeable calcium

me/100 g	Very low	Low	Medium	High	Very high
Ca (clayey soils rich in 2:1 clays)	<2.0	2.0-5.0	5.1-10.0	10.1-20.0	>20.0
Ca (loamy soils)	<0.5	0.5-2.0	2.1-4.0	4.1-6.0	>6.0
Ca (kaolinitic and sandy soils)	<0.2	0.2-0.5	0.6-2.5	2.6-5.0	>5.0

## 6. Exchangeable magnesium

me/100 g	Very low	Low	Medium	High	Very high
Mg (clayey soils)	<0.3	0.3-1.0	1.1-3.0	3.1-6.0	>6.0
Mg (loamy soils)	<0.25	0.25-0.75	0.75-2.0	2.1-4.0	>4.1
Mg (sandy soils)	<0.2	0.2-0.5	0.5-1.0	1.1-2.0	>2.0

The desired saturation level of exchangeable Mg is 10 to 15 percent; for sandy and kaolinitic soils 6 to 8 percent Mg saturation is still sufficient.  
Ca/Mg ratios of 2 to 4 are favourable.

## 7. Exchangeable K

me/100 g	Very low	Low	Medium	High	Very high
K (clayey soils)	<0.20	0.20-0.40	0.41-1.20	1.21-2.00	>2.00
K (loamy soils)	<0.13	0.13-0.25	0.26-0.80	0.81-1.35	>1.35
K (sandy soils)	<0.05	0.05-0.10	0.11-0.40	0.41-0.70	>0.70

The desired saturation level of exchangeable K is 2 to 7 percent.  
Favourable Mg/K ratios for most crops are in the range of 1 to 4.

## 8. Exchangeable sodium

me/100 g	Very low	Low	Medium	High	Very high
Na	<0.10	0.10-0.30	0.31-0.70	0.71-2.00	>2.00

More important than the absolute level of exchangeable Na is the exchangeable sodium percentage (ESP) calculated by dividing exchangeable Na by CEC (x 100). ESP values are a measure of the sodicity of the soil.

## 9. Soil sodicity

	Non-sodic	Slightly sodic	Moderately sodic	Strongly sodic	Very strongly sodic	Extremely sodic
ESP %	<6	6-10	11-15	16-25	26-35	>35
ESP <15%		-up to 50 percent yield reduction of sensitive crops (maize, beans)				
ESP 16-25%		-up to percent yield reduction of semi-tolerant crops (rice, wheat, sorghum, sugarcane)				
ESP 35%		-up to 50 percent yield-reduction of tolerant crops (barley, cotton)				

## 10. Basic infiltration rate (IR)

IR <0.1 cm/h	extremely slow
IR 0.1-0.3 cm/h	very slow
IR 0.3-0.5 cm/h	slow
IR 0.5-2.0 cm/h	moderately slow
IR 2.0-6.5 cm/h	moderate
IR 6.5-12.5 cm/h	moderately rapid
IR 2.5-25.0 cm/h	rapid
IR >25.0 cm/h	very rapid

Basic infiltration rate is the constant rate at which water enters the (pre-wetted) soil and which develops after 3 to 5 hours of infiltration.

## 11. Available water capacity (AWC)

AWC <25 mm/m	extremely low
AWC 25-50 mm/m	very low
AWC 50-100 mm/m	low
AWC 100-150 mm/m	medium
AWC 150-200 mm/m	high
AWC >200 mm/m	very high

Available water capacity is the capacity of the soil to store water that is readily available for uptake by plant roots; usually expressed in millimeters of water per metre depth of soils; technically the difference between the percentage of soil water at field capacity (normally taken as the water content at pF 2.2) and the percentage at wilting point (taken as the water content at pF 4.2).

Appendix 3. GUIDELINES FOR INTERPRETATIONS OF WATER QUALITY FOR IRRIGATION<sup>1</sup>

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
<b>Salinity (affects crop water availability)<sup>2</sup></b>				
EC <sub>w</sub>	dS/m	< 0.7	0.7 - 3.0	> 3.0
(or)				
TDS	mg/l	< 450	450 - 2000	> 2000
<b>Infiltration (affects infiltration rate of water into the soil. Evaluate using EC<sub>w</sub> and SAR together)<sup>3</sup></b>				
SAR - 0 - 3	and EC <sub>w</sub> -	> 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
<b>Specific Ion Toxicity (affects sensitive crops)</b>				
<b>Sodium (Na)<sup>4</sup></b>				
surface irrigation	SAR	< 3	3 - 9	> 9
sprinkler irrigation	me/l	< 3	> 3	
<b>Chloride (Cl)<sup>4</sup></b>				
surface irrigation	me/l	< 4	4 - 10	> 10
sprinkler irrigation	me/l	< 3	> 3	
Boron (B) <sup>5</sup>	mg/l	< 0.7	0.7 - 3.0	> 3.0
Trace Elements (see Table 21)				
<b>Miscellaneous Effects (affects susceptible crops)<sup>1</sup></b>				
Nitrogen (NO <sub>3</sub> - N) <sup>6</sup>	mg/l	< 5	5 - 30	> 30
Bicarbonate (HCO <sub>3</sub> ) (overhead sprinkling only)	me/l	< 1.5	1.5 - 8.5	> 8.5
pH		Normal Range 6.5 - 8.4		

<sup>1</sup> Adapted from University of California Committee of Consultants 1974.

<sup>2</sup> EC<sub>w</sub> means electrical conductivity, a measure of the water salinity, reported in deciSiemens per metre at 25°C (dS/m) or in units millimhos per centimetre (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l).

<sup>3</sup> SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNa. See Figure 1 for the SAR calculation procedure. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by EC<sub>w</sub>. Adapted from Rhoades 1977, and Oster and Schroer 1979.

<sup>4</sup> For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use the salinity tolerance tables (Tables 4 and 5). For chloride tolerance of selected fruit crops, see Table 14. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops. For crop sensitivity to absorption, see Tables 18, 19 and 20.

<sup>5</sup> For boron tolerances, see Tables 16 and 17.

<sup>6</sup> NO<sub>3</sub> - N means nitrate nitrogen reported in terms of elemental nitrogen. (NH<sub>4</sub> - N and Organic-N should be included when wastewater is being tested).