ORIGIN AND CHARACTERISTICS OF SALT AFFECTED SOILS IN MAFIGA - CHAMWINO LOWLAND AREA, MOROGORO - TANZANIA

BY

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ABSTRACT

Salt affected soils is a major problem limiting crop growth in majority of the flood plains in Tanzania, the Mafiga-Chamwino lowland in Morogoro district being one of them. A detailed study was conducted to investigate the distribution and characteristics of salt affected soils in the Mafiga-Chamwino lowland in Morogoro district. The objectives were characterisation, classification and mapping the extent of distribution of salts; determination of spatial distribution of salts and corresponding crop performance; and investigation of the sources of salt accumulation.

Distribution of different types of soils was studied by carrying out grid survey at 50 m spacing while the spatial distribution of salts and the corresponding crop performance was done at 10 m spacing. The corresponding maps were drawn at a scale of 1:10 000 and 1:1 000 respectively. Detailed laboratory characterization was done on the salt affected soils, surface and ground waters as well as rocks from the weathering front.

Four types of soils: Gleyic Solonchak, Chromic Luvisols, Gleyic Luvisols and Sodic Solonchak exist in the studied area. These were categorized as saline soil, intergrade between sodic and normal soil, sodic soil and saline-sodic soil respectively. The calcium-magnesium and sodium-calcium types of cation salinization, and sodium carbonate-chloride anion types of salinization dominated in the soils. Large variations of salinity and alkalinity accompanied by corresponding rice crop performance occurred at a short distance in the area studied. Leaching from the weathering of the dominating basic rocks in the vicinity of the study area accounts for the salinization of both surface and ground waters. These waters are the primary source of salts in the soils. Fluctuation of the ground water determines salt distribution in the soil solum.

Each of the four soils requires a different approach in order to control salt problems.

DECLARATION

I, **Elmens Lutaleka Kaboni**, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor concurrently being submitted for a degree in any other University.

Signature.....Kaboni.....

Date..7 November 1996..

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CHAPTER ONE

INTRODUCTION

The global demand for food and fibre are constantly increasing. On the contrary, there already exist a gap between food production and its demand in several developing countries. Of late, decline in food production is becoming a rule rather than exception in the intertropical belt of Africa. For instance, the per capita food production has declined by 11% for the seven year period ending 1997 (Bryceson, 1992). The causes for the lack of sustainable food systems in Tanzania and similar countries include rapid population growth, low agricultural technology and increased land degradation which, together with the ever increasing unreliability of the rainfall, have contributed to the decrease in the acreage of potential agricultural land. In Tanzania, for instance, the per capita arable land is merely 0.4 hectares. One of the solutions which small farmers have adopted to solve the problem of shortage of potential agricultural land is to practice intensive use of the lowlands, particularly depressions and river valleys where water resources are more prevalent to meet the crop requirement. However, these are the very areas where natural and/or man provoked salinization and/or alkalization of the soils is frequently encountered.

Proper knowledge is needed for controlling salt accumulation and reclaiming the already salinized soils in lowlands. This need is prompted by the fact that these soils have the potential for both food production and water storage. They could be considered as one of the dependable water source for human in the future.

A salt affected soil is defined as a soil that has been adversely modified for the growth of most crops by the presence or action of soluble salts (James *et al.*, 1982). This category of soils exists in many countries, particularly in the arid and semi-arid regions of Asia, Africa and South America.

Salt affected soils cause considerable problems regarding the natural environment, the national economy and hinder agricultural production (Szabolcs, 1984). Salinization and alkalization are associated with decline in productivity of the land. The reduction of productivity of salt affected soils is attributed to the imbalance of nutrients, osmotic stress, specific ion effect, ionic antagonisms, toxicities caused by ions released by cation exchange and effects of ionic activities (Allison, 1964; Ponnamperuma and Bandyopadhya, 1980), high pH, high exchangeable sodium percent (ESP) and the resulting poor physical conditions (Gupta *et al.*, 1982). A wide range of crops is adversely affected by salinity and sodicity. This problem is commonly reported both under irrigated agriculture (Arar, 1971; Elgabaly, 1971b; Khatib, 1971; Szabolcs, 1984; FAO, 1985; Rhoades, 1993) and on unirrigated lands

(Reeve and Fireman, 1967; Peck, 1978).

The primary source of salts in soils is the primary minerals in the exposed rocks of the earth's crust (Richards, 1954; Reeve and Fireman 1967; Abrol *et al*., 1988). However, the occurrence of different types of salt affected soils is attributed to a number of other factors such as irrigation practices, depth of the ground water table, soil permeability, evapotranspiration rate and, rainfall amounts and distribution (Rhoades and Corwin, 1984; Rhoades, 1993). Soils which occur in areas affected by salinity and sodicity are bound to experience changes of their properties over time as well as the extent of distribution of salts. Accordingly therefore maps of salt affected areas cannot strictly be considered accurate over long period of time (Rhoades, 1993). Such maps need a regular upgrading.

The occurrence of salinity in the soils of Mafiga lowland was indicated by Mpepo (1986), yet no measures have been taken to date to evaluate its development. Therefore, there is a need to study in details the occurrence of salinity in these soils. Information regarding the type of salinity, its distribution and origin would be vital for the management of these soils.

The main objective of this study was to carry out a detailed characterization and classification of the salt affected soils of Mafiga-Chamwino lowland area with an intention of fulfilling the following specific objectives:

1. To establish the nature and extent of distribution of salts in the studied soils.
2. To determine spatial variation of the major type of salinity on the land and its effect on rice crop performance.
3. To investigate the sources of salt accumulation in the studied area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of salt affected soils

Several attempts have been made to define salt affected soils based on their content of soluble salts in relation to plant growth. James *et al*. (1982) and Arunin (1984), define "a salt affected soil" as a soil that has been adversely modified for the growth of most crops by the presence or action of soluble salts. According to Reeve and Fireman (1967), salt affected soils are defined as soils having excessive concentrations of soluble salts or adsorbed sodium or both. Depending on the content of soluble salts and adsorbed sodium or both, salt affected soils have been categorized into three different types, namely, saline, sodic and saline-sodic soils (Richards, 1954; Allison, 1964; Reeve and Fireman, 1967). Richards (1954) distinguishes clearly the three types of salts. Accordingly, saline soils are soils which have soluble salts in such quantity that they interfere with the growth of most crop plants. Sodic soils are those soils with sufficient exchangeable sodium to interfere with the growth of most crop plants, either with or without appreciable quantities of soluble salts. Saline-sodic soils are soils which have sufficient exchangeable sodium to interfere with the growth of most crop plants and have appreciable quantities of soluble salts. These definitions are considered inadequately accurate since salt injury depends on the plant species and/or variety of crop grown, growth stage and environmental factors (Ponnamperuma and Bandyopadhya, 1980). Saline soils correspond to Hilgard's "white alkaline", while sodic soils correspond to Hilgard's "black alkali" (Allison, 1964; James *et al*., 1982; Tan, 1982). The term "black alkali" corresponds with sodic soils due to the dark colour caused by the dispersion of the organic matter by the exchangeable sodium at a high pH (Soil Survey Staff, 1951). Due to dispersed nature of sodic soils and their occurrence in patchy distribution, such soils have also been termed "slick spots" (McNeal, 1974; Tan 1982). Saline-sodic soils are also referred to as saline-alkali soils (Soil Survey Staff, 1951).

2.2 Characteristics and Classification of salt affected soils

2.2.1 Characteristics of salt affected soils

The most important characteristics of salt affected soils are the physical and chemical characteristics. Each type of salt affected soil has a unique set of characteristics.

2.2.1.1 Physical characteristics

Saline soils are usually friable (Soil Survey Staff, 1951). The high salt concentration keeps the soil in a flocculated condition (Richards, 1954; James *et al*., 1982). The permeability of these soils to water and air and other physical characteristics are generally comparable to those of normal soils (Allison, 1964; Abrol *et al.*, 1988). However, in medium to fine textured subsoils, when the bulk density exceeds 1.7 Mg/m^3, the hydraulic conductivity is reduced, hence causing drainage problems (Richards, 1954). The soils may be recognized by the presence of a white inflorescence or salt crust on the surface or by an oily looking surface devoid of vegetation (Soil Survey Staff, 1951; Allison, 1964).

Sodic soils have a columnar or prismatic structure in the B horizon (Raheja, 1966). The presence of excessive amounts of exchangeable sodium in soils promotes the dispersion and swelling of clay minerals (FAO, 1985). As the proportion of exchangeable sodium increases, the soil tends to become dispersed, less permeable to water and air (FAO, 1985), exhibit poor tilth (Allison, 1964) and the soil structure becomes unstable (Abrol *et al.*, 1988). The infiltration and hydraulic conductivity decrease to the extent that little or no water movement occurs, the soil becomes plastic and sticky when wet, hard when dry and soil crusting develops (Allison, 1964; FAO, 1985). There is a tendency of soil organic matter to disperse under high sodium content and low salt condition (McNeal, 1974). Dispersed organic matter may accumulate at the surface of poorly drained areas and impart a black colour, hence the common name "black alkali" (Bohn *et al.*, 1985). Dispersion reduces or blocks soil porosity, whereas swelling reduces pore sizes (Frenkel *et al.*, 1978).

Hence, alkali soils containing expanding type of clay minerals particularly montmorillonite exhibit unfavourable physical properties at levels of ESP greater than 15 (Gupta and Gupta, 1987).

The morphology, appearance and properties of saline-sodic soils are generally similar to those of saline soils, as long as excess salts are present and clays do not swell or become dispersed (Soil Survey Staff, 1951). Accordingly, decrease in the salt concentration is accompanied with the dispersion of the clays as in alkali soils.

The bulk densities of salt affected soils are generally high (Gupta and Gupta, 1987), reaching as high as 1.8 Mg/m^3. However, low bulk density values have been reported in soils with a high sodium saturation on the exchange complex (Varallayay, 1977; Gupta and Gupta, 1987).

2.2.1.2 Chemical characteristics

Salt affected soils have a wide range of chemical properties. Among the most important ones are the pH of the saturation extract (pHs), the electrical conductivity of the saturation extract (ECe), the exchangeable sodium percentage (ESP) and the sodium adsorption ratio of saturation extract (SAR). These properties are widely accepted criteria for grouping salt affected soils into different categories (Richards, 1954; James *et al.*, 1982; Gupta and Gupta, 1987; Abrol *et al.*, 1988; Rhoades, 1993).

Saline soils consist mainly of neutral salts such as the chlorides and sulphates of sodium, calcium and magnesium (Soil Survey Staff, 1951; Richards, 1954; Allison, 1964). Sodium ion in saline soils seldom comprises more than half of the soluble cations and, therefore it is not adsorbed to any significant extent in the soil exchange complex (Allison, 1964). However, in certain saline soils, sodium may become the most predominant adsorbed cation (Soil Survey Staff, 1951; Allison 1964). The presence of compounds such as gypsum ($CaSO_4.2H_2O$) and lime [$CaCO_3$, $CaMg(CO_3)_2$] in saline soils is common (James *et al.*, 1982). Saline soils have an ECe of greater than 4 dS/m at 25°C and ESP of less than 15 (Richards, 1954; Allison, 1964; James *et al.*, 1982). The pHs is usually less than 8.5 (Reeve and Fireman, 1967). According to Abrol *et al.* (1988), the pHs for saline soils is less than 8.2. However, soils with pHs range of 7.5 to 8.5 have been included in the category of saline soils (Gupta and Gupta, 1987).

In sodic soils the predominant cation is sodium, and the anions present consist mostly of chloride, sulphate and bicarbonate, with small to moderate amounts of carbonate, depending on the pH of soil (Richards, 1954; Allison, 1964). Raheja (1966), reported carbonate and bicarbonate to be the predominant anions in sodic soils. Arshad and Pawluk (1966a) consider both exchangeable sodium and magnesium as being responsible for the typical morphology of Solonetz soils. Other authors (Panov *et al.*, 1989) have reported the presence of hydrophillic silicon compounds in sodic soils. Sodic soils have ESP of greater than 15 (Richards, 1954) and often reaching 50 and sometimes more (Duchaufour, 1982). The SAR of these soils is greater than 13 (James *et al.*, 1982). Bohn *et al.* (1985) proposed to restrict the limit of the SAR of sodic soils to be greater than 15.

Sodic soils have ECe which is less than 4 dS/m at 25°C and the pHs is usually greater than 8.5 (Richards, 1954; Allison, 1964). According to Abrol *et al.*(1980, 1988), the pHs for such soils is more than 8.2. Such pHs increases with increasing amounts of sodium carbonate (Na_2CO_3) and may be as high as 10.0 to 10.5. Increase in pHs is due to the higher solubility of sodium carbonate (Na_2CO_3) and therefore the greater potential for hydrolysis (Abrol *et al.*, 1988). Gupta and Gupta (1987), reported the pH range of sodic soils in saturation extract to be 8.2 to 10.0 while that of soil water suspension (1:2) ranged from 9.0 to 10.8.

However, it has also been shown that a sodic soil does not necessarily have a high pH, but may even show an acidic reaction (van Beek and van Breemen, 1973; Kamphorst and Bolt, 1976). Many sodic soils are neutral in reaction (Kamphorst and Bolt, 1976). Some sodic soils with ESP of more than 15 have pH values of less than 8.5 if the other exchangeable cations are mainly hydrogen (Soil Survey Staff, 1951).

In the saline-sodic soils chloride, sulphate and carbonate predominate while sodium and calcium occur in high and low proportion in that order respectively (Raheja, 1966). In many parts of the world saline-sodic soils have been found to contain large quantities of both soluble sodium carbonate and exchangeable sodium (Abrol and Bhumbla, 1971; Elgabaly, 1971b; Abrol and Dahiya, 1974). Saline-sodic soils have ESP of greater than 15, ECe of greater than 4 dS/m at 25°C and pHs which are usually less than 8.5 (Richards, 1954; Allison, 1964; James *et al*., 1982; Gupta and Gupta, 1987). However, if gypsum is present in appreciable quantities, the pHs of saline-sodic soils may be as low as 8.2 (Allison, 1964). ECe greater than 2 dS/m and SAR greater than 15 were also reported by Bohn *et al*. (1985) in this group of soils. The pHs range of 8.5 to 10.0 and that of soil - water suspension (1:2) of 9.0 to 10.5 were reported by Gupta and Gupta (1987). In the Indo-Gangetic plains of Northern India, some soils with ECe and ESP values characteristic of saline-sodic soils (Richards, 1954) have been termed sodic soils and not saline-sodic soils because of the fact that the chief soluble salt is Na_2CO_3 (Bhargava *et al*., 1976).

2.2.2 Classification of salt affected soils

Of the several systems of soil classification which exist, only the system developed by the United States Department of Agriculture (USDA) and the

FAO-Unesco legend of the Soil Map of the World are known to enjoy wide international recognition (Landon, 1984). As far as the USDA Soil Taxonomy (USDA, 1990) is concerned, the classification of salt affected soils is based on the presence of salts distributed throughout the profile and on the presence of salts in specific horizons termed calcic, petrocalcic, gypsic, petrogypsic, natric and salic horizons. Accordingly, the calcic horizon is a horizon of accumulation of calcium carbonate or of calcium and magnesium carbonate.

The petrocalcic horizon is a continuous, cemented or indurated calcic horizon that is cemented by calcium carbonate or in some places by calcium and some magnesium carbonate. The horizon may also contain accessory silica.

The gypsic horizon is a non cemented or weakly cemented horizon enriched with secondary sulphates. The horizon is 15 cm or more thick, has at least 5% more gypsum than the C horizon or the underlying stratum, and the product of its thickness in centimetres and the percentage of gypsum is 150 or more.

The petrogypsic horizon is a gypsic horizon that is strongly enough cemented with gypsum that dry fragments do not slake in water and that roots cannot enter. The gypsum content commonly is far greater than the minimum requirements for the gypsic horizon and usually exceeds 60%.

The natric horizon is a special kind of argillic horizon. It has, in addition to the properties of the argillic horizon: (i) either, (a) prisms or, more commonly, columns in some part, usually the upper part, that may or may not break to blocks; or (b) rarely, blocky structure and tongues of an eluvial horizon, in which there are uncoated silt or sand grains, extending more than 2.5 cm into the horizon; and (ii) either, (a) the SAR is 13 or more (or 15% or more saturation with exchangeable sodium) in some subhorizon within 40 cm of the upper boundary; or (b) more exchangeable magnesium plus sodium than calcium plus exchangeable acidity (at pH 8.2) in some subhorizons within 40 cm of the upper boundary if the SAR is 13 or more (or ESP is 15 or more) in some horizons within 200 cm of the surface.

A salic horizon is a horizon, 15 cm or more thick that contains a secondary enrichment of salts more soluble in cold water than gypsum. It contains at least 2% salt, and the product of its thickness in centimetres and salt percentage by weight is 60 or more.

According to the FAO (1988), soil classes showing accumulations of salts have been named in accordance to the dominating cation or salt compound. They include: Calcisols, Gypsisols, Solonchak and Solonetz.

Calcisols are soils which have, among other properties, one or more of the following properties: a calcic horizon, a petrocalcic horizon or concentrations of soft powdery lime within 125 cm of the surface while Gypsisols are soils which have a gypsic or a petrogypsic horizon, or both, within 125 cm of the surface.

Solonchaks are soils which do not show fluvic properties, having salic properties and having no diagnostic horizons other than an A horizon, a histic H horizon, a cambic B horizon, a calcic or a gypsic horizon. Salic properties refers to an electrical conductivity of the saturation extract of more than 15 dS/m at 25°C at some time of the year, within 30 cm of the surface or of more than 4 dS/m within 30 cm of the surface if the pH (H_2O) exceeds 8.5.

Solonetz are soils having a natric B horizon. A natric B horizon is characterized, in addition to the properties of the argic B horizon and among other properties, by a columnar or prismatic structure in some part of B horizon and a saturation with exchangeable sodium of more than 15% within the upper 40 cm of the horizon.

2.3 Genesis of salt affected soils

2.3.1 Origin of salts

Rocks contain sodium, potassium, magnesium and calcium in the form of silicates; though chlorides, sulphur, sulphides or sulphates may be rarely encountered (van der Molen, 1984). These salt constituents are gradually released to the surrounding water from the process of chemical weathering of rocks and minerals (Richards, 1954; Allison, 1964; van der Molen, 1984; Abrol *et al.*, 1988). Although several studies had indicated weathering of primary minerals to be the primary source of nearly all soluble salts (Soil Survey Staff, 1951; Richards, 1954; Abrol *et al*., 1988), there are probably a few instances where sufficient salts have accumulated in place from this source alone to form saline and sodic soils. According to Richards (1954), the direct source of salts in the soils is the surface and ground waters, notably when they contain dissolved salts.

2.3.2 Factors influencing the accumulation of salt in soils

The accumulation of salts in soils is influenced by many factors (Chapman, 1966; Szabolcs, 1984). Among these, the most important ones include: nature of parent materials (Dubey *et al*., 1986; Sharma *et al*. 1987), precipitation and temperature (Chapman, 1966; Reeve and Fireman, 1967), topography (Dubey *et al*., 1984; Landon, 1984; Dubey and Sharma, 1987), nature of the characteristics of the soil (Soil Survey Staff, 1951), soil drainage (Arshad and Pawluk, 1966a; Landon, 1984), floods (Arar, 1971), surface water, chemical composition and depth of ground water table, capillary rise of water table (Richards, 1954; Reeve and Fireman, 1967; Yadav and Pathak, 1967; Bhargava *et al*., 1981), irrigation (James *et al*., 1982; Szabolcs, 1984), wind (Soil Survey Staff, 1951; Richards, 1954; Ballantyne, 1978), seepage of salty water (Richards, 1954; Peck, 1978), vegetation (Soil Survey Staff, 1951; Chapman, 1966) and erosion (Ballantyne, 1978).

2.3.2.1 The influence of climate on salt formation

Salts tend to accumulate due to the scarcity of rainfall (Bohn *et al.*, 1985). During low precipitation there is high evaporation of water which causes salts to remain in the soil (Doering *et al.*, 1964; van der Molen, 1984). Saline and sodic soils occur in areas with an annual average precipitation of less than 500 mm (James *et al.*, 1982; Tan, 1982). However, in the state of Haryana in India, sodic soils occur in areas whose mean annual precipitation is as high as 600-900 mm (Bhargava *et al.*, 1980). In certain areas, salts accumulate in soils by the action of blowing wind. The Solonetzic soils of Saskatchewan, Canada are typical examples. The salts in these soils were blown from dry saline lake beds (Ballantyne, 1978).

2.3.2.2 The influence of topography and soil drainage on salt formation

Topography of the land is another factor which influence the formation of salt affected soils (Sharma *et al.*, 1987). The slope of the land surface determines the drainage pattern, hence, the distribution of salts on the land surface (Chapman, 1966). Working in the soils of south-eastern Saskatchewan Canada, Ballantyne (1963) found that there is a definite increase in salt content and, in water soluble sodium and magnesium percentage where the slope changes from 8 to 2%. According to the work of Chapman, (1966) and Abrol *et al.* (1988), soluble salts move from areas of higher to lower elevations where they accumulate. Flat topography is one of the prerequisite for the accumulation of salts in the surface layer (Poonia and Bhumbla, 1973; Sharma *et al.*, 1987).

Restricted drainage is a factor that usually contributes to the salinization of soils and it may involves the presence of a high ground water table or low permeability of soil or both (Richards, 1954; Hesse, 1971). Development of waterlogged soils is mainly associated with low-lying lands of poor soil physical conditions and internal drainage (Khatib, 1971).

2.3.2.3 The influence of nature of the characteristics of the soil on salt formation

The nature of soil influence the formation of salt affected soils (Soil Survey Staff, 1951; Chapman, 1966; Szabolcs, 1984). Unfavourable soil texture or structure or presence of indurated layers could affect soil permeability resulting into poor soil drainage, hence contributing to soil salinization (Richards, 1954).

A soil that initially possesses a high proportion of clay or silt as compared with the sand fraction, will be much more unsatisfactory in the presence of excess sodium and magnesium, and also it will be more difficult to remove the excess alkali from such soils (Chapman, 1966). Slightly difference in texture in the soil may result in unequal movements of salt water and hence cause or result into large differences in salt accumulation (Soil Survey Staff, 1951). Smectites are very important in poorly drained environments and, their expansive nature and negative charge cause them to be extremely reactive in soil environment (Borchardt, 1989). Also smectites accounts for the high CEC in the soil. According to van Hoorn (1971), the higher the cation exchange capacity the greater the risk of salinization and alkalization in the presence of water rich in salts.

2.3.2.4 The influence of water on salt formation

Richards (1954) reported that the direct source of salts in the soils is surface and ground waters. According to Richards (1954), both of them contain dissolved salts, the concentration of which depend upon the salt content of the soil and geologic materials with which the water has been in contact. Surface water add salts to soils under natural conditions by flooding low-lying areas (Richards, 1954; Arar, 1971; Khatib, 1971). Dissolved salts move with the water (Arar, 1971; van der Molen, 1984), and accumulate within the soil or at the surface from where the water evaporates (Soil Survey Staff, 1951).

Salt transport and accumulation is greatly influenced by the phenomena of seepage and capillary rise (Arar, 1971; van der Molen, 1984). The ground water rises sharply soon after each irrigation or rainfall and drops back very slowly, hence, causing soil salinization through capillary action (Arar, 1971).

The nearer is the depth of ground water table to the surface the more will be the soil salinity (Greenlee *et al.*, 1968; Bandyopandya, 1973; Chang *et al.*, 1985). Where water table exists within 1.2 to 1.5 m of the soil surface there is a likehood of development of saline soils because of the upward movement of saline ground water and its subsequent evaporation (Allison, 1964). According to Richards (1954) when the water table rises to within 1.5 to 1.8 m of the soil surface, ground water moves upward into the root zone and to the soil surface hence contributing to salinization.

Quality of surface and ground waters is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area (Arar, 1971; Gupta and Gupta, 1987). The most important characteristics which are commonly used in determining their quality are electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), residual sodium bicarbonate (RSBC), specific ions which may cause toxic effects to plant and total salt content (Richards, 1954; van Hoorn, 1971; Bohn *et al.*, 1985; FAO, 1985; Gupta and Gupta, 1987). Richards (1954), established four classes of salinity hazard based on the electrical conductivity of water (ECw).

Accordingly, water with EC values of 0.1 to 0.25, 0.25 to 0.75, 0.75 to 2.25 and 2.25 to 5 dS/m is regarded as low, medium, high and very high salinity water respectively. However, work by Gupta (1979) led to the establishment of the following water salinity categories: normal (0.2-1.5), low (1.5-3.0), medium (3.0-5.0), high (5.0-10.0) and very high salinity water (> 10.0) dS/m.

Total salt content in water which is commonly expressed in g/l, me/l or ppm is employed to indicate the water's quality with regard to the salinity (van Hoorn, 1971; Raj and Pal, 1986). Several attempts have been made to classify the salinity level in water based on this approach. According to Richards (1954), water with total salt content of less than 0.2, 0.2 to 0.5, 0.5 to 1.5 and 1.5 to 3 g/l is considered as low, medium, high and very high salinity water respectively.

FAO (1985) established the following sodicity hazard categories based on the SAR of the irrigation water: none (< 3), slight to moderate (3 - 9) and severe (> 9). Richards (1954) considered water with SAR values of 0 to 10, 10 to 18, 18 to 26 and 26 to 31 to be low, medium, high and very high sodicity water respectively. Eaton (1950) evaluated the quality of irrigation water based on the RSC content. According to this author, irrigation waters containing RSC below 1.25, 1.25 - 2.5 and above 2.5 m.e/l are considered as satisfactory, marginal and unsatisfactory respectively. FAO (1985) evaluated the quality of irrigation water based on the bicarbonates and chlorides content.

Accordingly, waters having bicarbonates below 1.5, 1.5 to 8.5 and above 8.5 me/l were considered as none, slight to moderate and severe hazard water respectively, while waters having chloride ions below 4, 4 to 10 and above 10 me/l, were regarded as none, slight to moderate and severe water respectively.

2.3.2.5 The influence of man on salt formation

In the past, saline and alkali soils were most often formed as a result of salt accumulation due to natural causes such as floods, impaired drainage and the evaporation of salty ground waters (Reeve and Fireman, 1967). In recent centuries, vast areas of salt affected soils have developed from man made causes such as irrigation (Reeve and Fireman, 1967) and soil management (Massoud, 1984). Among all factors which influence salinization of soils, irrigation alone accounts for the formation of many millions of hectares of saline or alkali soils in different parts of the world (Szabolcs, 1984).

2.3.2.6 The influence of vegetation on salt formation

The influence of vegetation on soil salinity has been well summarized by Chapman (1966). With decrease of vegetation cover, surface evaporation tend to increase. The effect of increase in evaporation and high temperatures, lead to salt concentration on soil surface layers (Soil Survey Staff, 1951;

Chapman, 1966). Some growing shrubs take in large amounts of salts and "pump" them from the deeper horizons to the soil surface (Soil Survey Staff, 1951). Accordingly, the salt content in the soil may vary in accordance to differences in vegetation.

2.4 Variability of salt affected soils

Field soil characteristics vary in terms of biological, chemical and physical properties (Carter and Pearen, 1985). Research interest in soil variability has been oriented towards soil testing for agronomic purposes (Cameron *et al*., 1971), soil mapping units (Topp *et al*., 1980), soil physical properties (Cassel and Bauer, 1975) and soil chemical properties (Ball and Williams, 1968). Soil variability is not the same at all depths, nor does it change with depth in the same way at all seasons for all properties (Beckett and Webster, 1971). However, soil variability has been grouped into two broad categories, namely, systematic and random (Wilding and Drees, 1978, 1983). Systematic variability is a function of landform, geomorphic elements, soil forming factors and interactions of these factors while random variation is caused by differential lithology, intensity of weathering, erosion, biological factors and hydrology (Mokma, 1987).

In salt affected soils variation and heterogeneity seem to be the rule rather than the exception (Elgabaly, 1971a). Salts may be localized in the surface soil or in a lower horizon, or they may be more or less uniformly distributed through the soil profile (Soil Survey Staff, 1951). Within a small area, soils of widely different characteristics may be found, and at any one spot the salt content may fluctuate with the seasons, weather conditions, and irrigation management (Soil Survey Staff, 1951; Rhoades and Corwin, 1984; Rhoades, 1993). Slight differences in soil texture which cause unequal movements of salt water could result into large differences in salt accumulation (Soil Survey Staff, 1951). In the great plains of Canada and USA, generally Solonetzic soils show extreme variability in properties over short distances (Cairns, 1961; Sandoval and Reichman, 1971). This is due in part, to differing ground water and capillary fluctuations or differential leaching of the saline parent materials as expressed by the intimate association of Solonetz of Solod soils (Carter and Pearen, 1985).

In the presence of high spatial variability the results of field sampling may be difficult to interpret (Gallichand *et al.*, 1992). Based on the studies of Rhoades and Corwin (1984), monitoring of soil salinity is complicated due to its spatial variability.

Hooda *et al.* (1986) found, while working in a watershed in the south western part of Haryana state, India, that the ground water salinity bears no spatial variance structure, and therefore is spatially independent, implying that at two sites in the same field, the ground water salinity may be quite different. Gupta (1986) concluded that large variation in EC found in unreclaimed and reclaimed fields in India was probably due to salt movement during many wetting and drying cycles over a period of years.

The analysis of soil variability is a complex procedure (Wright and Wilson, 1979) hence, if the distribution of studied properties is normal, then for comparative purposes, the mean and variance (or standard deviation) are suitable measures of variability. However, the authors consider that if the distribution is not normal the mean, the variance and the skewness of the distribution may be more appropriate for measuring the variability.

CHAPTER THREE

MATERIALS AND METHODS

The aspects covered below include a detailed background of the study area together with the details of the procedures employed to carry the study both in the field and in the laboratory.

3.1 The environment of the studied area

3.1.1 Location

This study was carried on a 250 ha piece of land located at 3 km west of Morogoro Municipality at the border between the Sokoine University of Agriculture (SUA) farm and Chamwino village. This area occurs within the Ngerengere river flood plain, the least elevated portion of the Uluguru Mountain - Ngerengere river landscape. It lies between latitudes 6°49'00" and 6°49'31" S and longitudes 37°37'35" and 37°38'10" E (Fig.1).

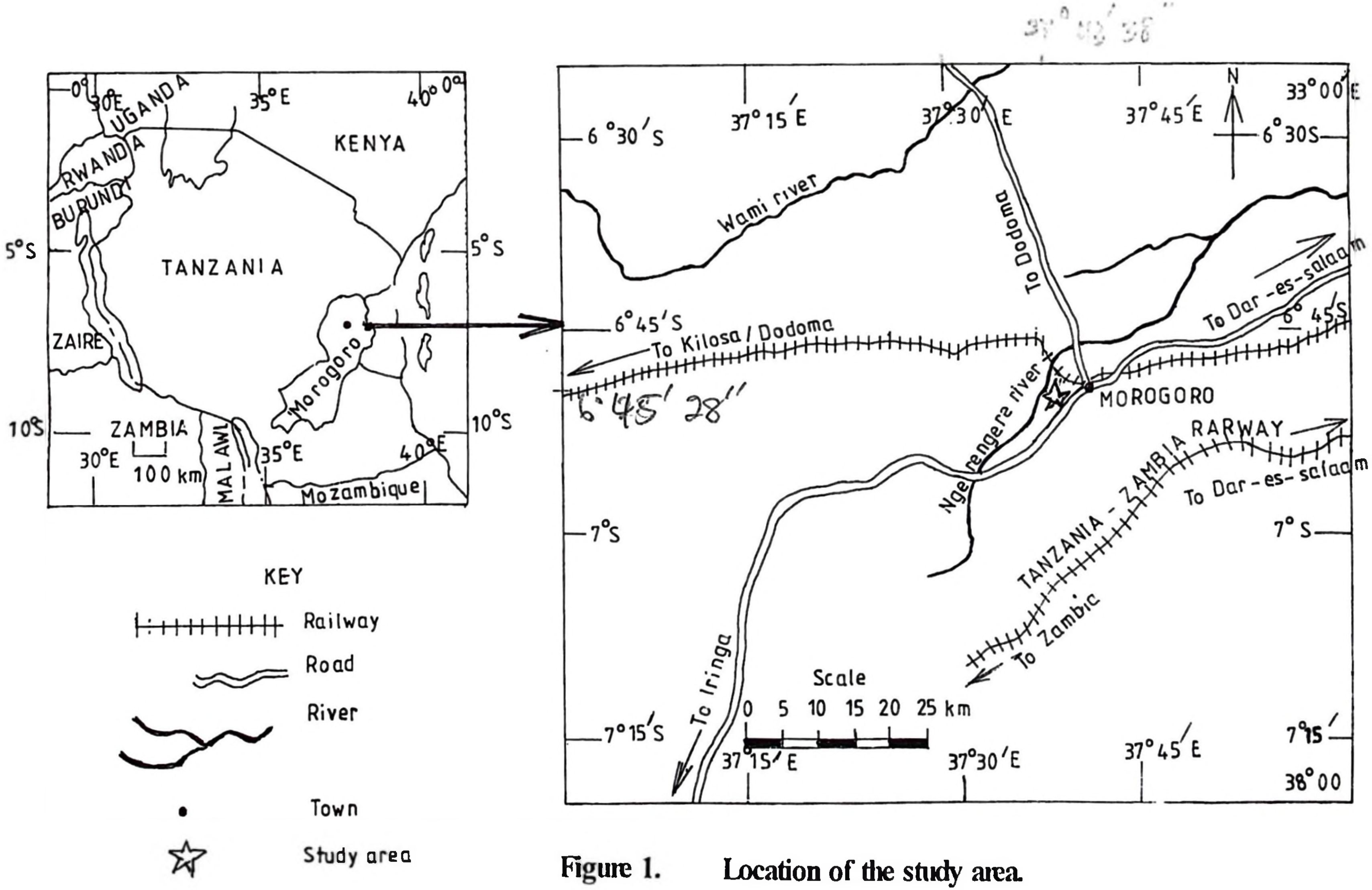

Figure 1. Location of the study area.

3.1.2 Geology

The geology and petrography of the areas surrounding the Morogoro Municipality have been described in detail by Sampson *et al.* (1961). Based on this study, the Uluguru Mountains are composed of basic metasediments in which pyroxene granulates (plagioclase, oligoclase, quartz, diopside, hornblende, garnet and hypersthene) dominate. Such pyroxene granulates are fine textured and rich in plagioclase which is interwoven with biotite sheets. These rocks are low in silica resulting in clayey soil upon weathering.

3.1.3 Geomorphology and drainage pattern

The geomorphological features of the studied area have been described by Msanya (1980), Moberg (1981) and Mpepo (1986). Based on the study of Moberg (1981), the landscape extending from the Uluguru to the Mindu Mountains is made up of the following elements: at one end is the mountainous area of the Uluguru Mountain ranges in the south-east, and at the other end is the Mindu Mountain in the west (Fig.2). Alluvial fans are present both below the Uluguru and Mindu Mountains. A peneplain stretches from the alluvial fans below the Uluguru Mountains almost to the terraces close to the Ngerengere river. Such a feature is absent on the Ngerengere river - Mindu Mountain landscape.

The study area is drained by the Ngerengere river and few seasonal streams. There are a number of seasonal streams which originate from the slopes of the Uluguru and Mindu Mountains, and Lugala Hills which drain into Ngerengere river. The Chamwino stream traverses the studied area. Most of these streams remain dry for some weeks during the dry season.

3.1.4 Climate

The mean annual precipitation is 841 mm which fall into two seasons of unequal length (Table 1). The short season extends from November to January while the long one is experienced between March and May. The period extending from June to September is dry in most years.

The mean monthly air temperature vary from 21.3 to 26.6°C. The soil temperature regime is isohyperthermic (Msanya, 1980).

Table 1. Rainfall, temperature and relative humidity of the studied area.

Month	Mean rainfall (mm) *	Mean temperature (°C) * Maxi.	Mini.	Mean	Mean relative humidity (%) **
January	96.5	31.5	21.2	26.4	66.3
February	80.3	32.0	21.0	26.6	66.0
March	130.4	31.6	20.8	26.2	69.1
April	185.2	29.6	20.4	25.0	79.5
May	90.1	28.5	18.8	23.7	76.7
June	19.9	27.7	15.8	21.8	70.8
July	12.9	27.5	15.1	21.3	67.8
August	7.6	28.0	15.6	21.8	64.1
September	10.6	29.8	16.7	23.3	59.9
October	32.1	31.2	18.1	24.7	58.0
November	68.5	32.1	20.0	26.1	58.5
December	106.7	31.7	21.1	26.4	63.7

maxi. = maximum   mini. = minimum
* = Average values for 20 years (1971 - 1990)
** = Average values for 11 years (1971 - 1981)

Source: SUA Agrometeorological station, Morogoro.

3.1.5 Vegetation and land use

Most of the natural vegetation has been removed long time ago due to cultivation and other human activities. The previous natural vegetation is considered to be "miombo" woodland (Lind and Morrison, 1974). Following the removal of the natural vegetation, the area was put under sisal plantation during the 1930s - 1969 period. From 1970 to date the area has been cultivated with rice, maize, beans, sorghum, sugarcane and coconut. Maize and rice are the major crops grown in this area. During dry season, short season crops such as tomatoes are usually grown along the Ngerengere river flood plain.

3.2. The field work

Prior to the field work, information on the location, geology, geomorphology, drainage, climate, vegetation and land use was collected. The existing geological and topographical maps, and aerial photographs of the area were used to prepare a base map at a scale of 1:5 000.

Three major types of studies were carried out in the field. The first one dealt with detailed characterization and identification of different types of salt affected soils and the associated soils existing in the studied area. The second type of study involved the assessment of the causes of the development of salts in the study area, while the third one was concerned with the determination of the variability of alkalinity, salinity and rice crop performance in a selected portion of the study area.

3.2.1 Soil survey

The characterization work involved systematic augering in which auger observations were made at an interval of 50 m up to a depth of 200 cm unless otherwise obstructed by presence of rocks and heavy clay. At each auger observation point the following parameters were recorded: soil colour using Munsell soil colour chart (Munsell Colour Co., 1975), soil texture by the feel method, pH and electrical conductivity (EC) of soil-water suspension. The latter two were measured using portable pH and EC meter respectively. The presence of carbonates was determined by using 10% HCl acid (FAO, 1977). Based on this information, different mapping units were established. To each mapping unit, a representative soil profile was excavated. These profiles served as source of data for both soil classification and their categorization into different types of salt affected soils. The soil profiles excavated were successively designated as ChP for the one located at Chamwino village, while those situated in the SUA farm, were successively designated as MfP1, MfP2 and MfP3. The corresponding soil profile description was done according to (FAO, 1977, 1990). Both disturbed and undisturbed soil samples were collected from each horizon or layer for laboratory analyses in accordance to the guidelines laid down by FAO (1979). A map was produced at a scale of

1:10 000, each mapping unit being defined in terms of topography, drainage, soil texture and soil depth.

3.2.2 Rock and water sampling

In view of the importance of the mineralogical composition of rocks and the quality of drainage and ground water on salt accumulation in soils, both rock and water samples were collected for salt content determination. The sampling points were as indicated in Fig. 2.

The selection of the sampling points for both stream water and rock specimens was done in order to attempt to take into account the influence of solutions from the weathering zone of the up slope part of the Uluguru Mountains - Ngerengere river drainage system on the salinization process in the lowlands. Fresh rock samples were collected from five different places which were either situated within the vicinity of the studied area or linked to the Ngerengere river drainage system. The samples were obtained following excavation of pits to remove both the soil and the saprolite overlying the fresh rock. The respective rock samples were petrographically identified and the content of bases analyzed in the laboratory as shown on section 3.3.

Waters samples were collected from the Ngerengere river and several streams which form the major part of the drainage network between the foot slopes of the Uluguru Mountains and the Ngerengere river. Sampling was done three times in a year in order to cover the distinctive periods of the year with respect to the water volume in the drainage system. The water samples were collected on the 4 December 1994 (end of the dry season), 30 March 1995 (start of the rain season) and 26 May 1995 (end of the rain season). These dates correspond with low, medium and high volume of water both in the Ngerengere river and the various streams sampled.

The second kind of water sampling was carried out on underground water. Several pits were excavated to the level of the ground water. Collection of the water was done and the corresponding samples were brought to the laboratory for analysis as shown on section 3.3. Sampling of the ground water was done only once during the end of dry season (December 1994). Attempts to carry out sampling during the other seasons was not possible because of the mixing of such water with deposited run off water from rainfall.

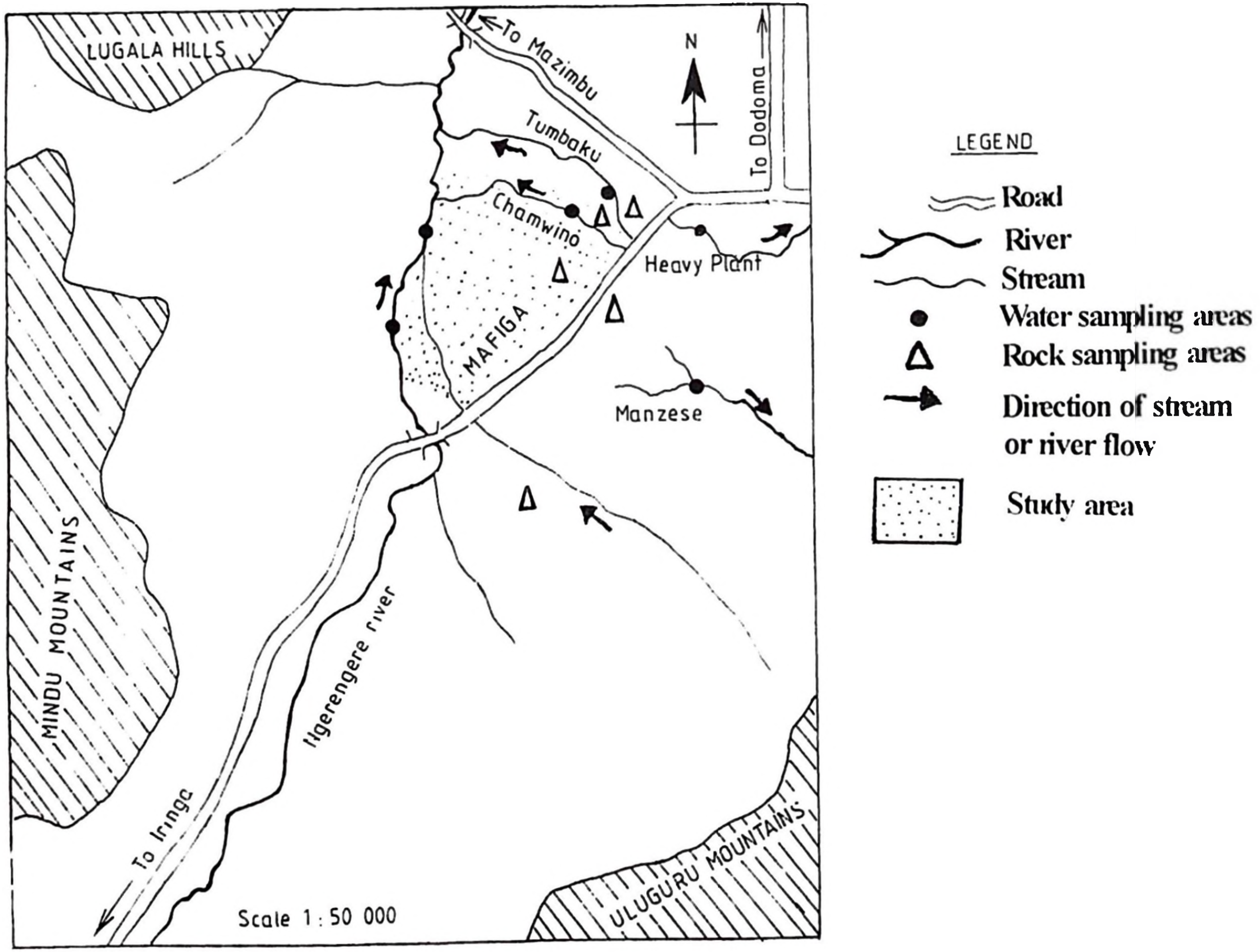

Figure 2. **Surface water and rock sampling areas.**

3.2.3 Investigations of the variability of field measured pH and electrical conductivity

This work was restricted to the saline-sodic soil. The choice of this type of soil was based on the high percentage of land spots with dead crop, and the size and pattern of these spots. These characteristics were less prominent in the other type of soils.

The parameters selected for the study were pH and EC. Their choice corresponds with the fact that these are the only parameters which could be measured in the field more accurately. The study covered a 2 hectares area. The pH and EC measurements were done on samples collected from the 0 - 30 cm depth at a grid spacing of 10 m x 10 m. Due to lack of established categories of field measured pH and EC ranges the data was classified following laboratory based classes of salinity (Abrol *et al.*, 1988) and alkalinity (Euroconsult, 1989). The classes were eventually used to plot a map of salinity and alkalinity of the area. Standard statistics were applied to analyze the grid point data. In this approach, mean, standard deviation (Sd), coefficient of variability (CV), minimum and maximum values of pH and EC measurements were calculated in accordance to Steel and Torrie (1980).

3.3 Laboratory work

Laboratory analyses were done on soil, rock and water samples. The soil samples were analyzed for particle size distribution, bulk density, pH, ECe, soluble and exchangeable bases (Ca, Mg, K, Na), cation exchange capacity (CEC), soluble anions (CO_3, HCO_3, SO_4 and NO_3), and organic carbon. Rock samples were analyzed for the content of bases and mineralogical composition. Both the drainage (river and streams) and ground waters were analyzed for pH, EC, soluble cations and anions according to FAO (1979).

Prior to any analysis, the soil samples were air dried, ground and sieved through a 2 mm sieve (van Reeuwijk, 1987). The laboratory determinations were performed on the fine earth fraction and results were expressed on oven dry basis.

3.3.1 Particle size distribution

Particle size distribution was determined by the hydrometer method after dispersing the soil samples with Sodium hexametaphosphate solution (Gee and Bauder, 1986).

3.3.2 Bulk density

The bulk density was determined by core method, and the values were expressed in Mg/m^3 (Blake and Hartge, 1986).

3.3.3 Clay mineralogy

X-ray diffraction was done on the clay fraction of individual soil samples using a Shimadzu model XD-D1 refractometer. Four soil samples, each collected from a subsurface horizon of the four representative soil profiles were used for this study. Prior to the x-ray diffraction, the soil samples were treated with hydrogen peroxide to remove organic matter and leached to get rid of the soluble salts. This was followed by dispersion of the soil with sodium hydroxide at pH < 8.5 and extraction of the clay separate. The clay samples were both magnesium and potassium saturated and air dried. The air dried magnesium saturated samples were then treated with glycerol (glycerol - solvated samples) and analyzed with x-ray. The analyzed air dried potassium saturated samples were then heated at a temperature of 350°C for one hour and analyzed with x-ray after cooling, and then reheated at a temperature of 550°C for one hour, cooled and again analyzed as above. (Whittig and Allardice, 1986; Dixon and Weed, 1989)

3.3.4 Determination of the content of bases in the rock samples

The rock samples were first ground and passed through a 100 μm sieve. 2g of the rock powder were heated in 4.5 M sulphuric acid for 10 minutes and then 1 ml of 60% perchloric acid was added (Jackson *et al.*, 1986). The acid decomposed rock was neutralized with 1 N ammonium acetate solution. The cations present in the solution were determined by atomic absorption spectrophotometer. The values obtained were expressed in terms of cmol(+)/kg of rock powder. Prior to the determination of the bases, petrographic microscope techniques (Cady *et al.*, 1986) were employed to supplement the routine identification of minerals contained in the studied rock samples.

3.3.5 Organic carbon (O.C)

Organic carbon was determined by the Walkley and Black wet combustion method (Allison, 1965).

3.3.6 Cation exchange capacity

The CEC of soil samples with pH below 7.5 was determined by ammonium acetate saturation method (Hesse, 1971), while that of the samples with pH above 7.5 was determined by sodium acetate saturation method (Chapman, 1965; Hesse, 1971). The values obtained were expressed in terms of cmol(+)/kg soil.

3.3.7 Preparation of the saturated soil paste extract

The saturated soil paste was prepared following the procedure outlined by van Reeuwijk (1987). The saturation extract of each soil sample was obtained by centrifugation of the paste at 12,000 r.p.m for 5 minutes (Chesnin and Johnson, 1950; Bower *et al.*, 1952). The saturated soil paste extract was used for the determination of pH, EC, soluble cations and anions.

3.3.8 pH

The pH measurements were done on water samples, soil-water suspension, and saturated soil paste extract. Measurement of pH on the soil-water suspension was done at a 1:2.5 soil water ratio (Rhoades 1982; van Reeuwijk, 1987).

3.3.9 Electrical conductivity

The electrical conductivity of a saturated soil paste extract (ECe) and that of water samples (ECw) was determined with an electrical conductivity meter at 25°C (van Reeuwijk, 1987). The electrical conductivity values obtained were expressed as dS/m.

3.3.10 Soluble cations

The soluble cations (calcium, magnesium, potassium and sodium) in the saturated soil paste extracts, surface and ground waters were analyzed by atomic absorption spectrophotometer (Rhoades, 1982; Thomas, 1982; van Reeuwijk, 1987). The results were expressed in terms of cmol(+)/kg soil and m.e/l for the soil and water samples respectively.

3.3.11 Exchangeable cations

The soil samples were extracted with an excess of 1.0 N ammonium acetate solution at pH 7.0, following the procedure developed by Richards (1954). The extracted cations were analyzed by atomic absorption spectrophotometer. The content of a particular exchangeable cation was obtained by subtracting the content of the soluble cation in the saturated soil paste extract from the content of the same cation measured in the extract by the excess 1.0 N ammonium acetate solution (Richards, 1954). The results were expressed in terms of cmol(+)/kg soil.

3.3.12 Exchangeable sodium percent (ESP)

The ESP was calculated in accordance to van Reeuwijk, (1987) using the formula:

$$ESP = \frac{\text{Exchangeable Na} \times 100}{\text{CEC}}$$

The values of the CEC and exchangeable sodium (Na) were obtained from the determinations carried out as shown on sections 3.3.6 and 3.3.11.

3.3.13 Sodium adsorption ratio (SAR)

SAR was calculated from the values of soluble sodium (Na), calcium (Ca) and magnesium (Mg) according to van Reeuwijk (1987) using the formula:

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

for water samples in which Ca, Mg and Na were expressed in m.e/l.

$$SAR = \frac{44.7 \times Na}{\sqrt{SP(Ca+Mg)/2}}$$

for saturation extract of the soil where Ca, Mg and Na were expressed in cmol(+)/kg soil and SP is saturation percentage.

3.3.14 Soluble anions

Soluble anions in the saturated soil paste extract and water samples were determined according to the procedures outlined below:

3.3.14.1 Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{2-}) anions

Carbonate anions were determined by titrating a known volume of the extract or water sample with 0.01 N standard sulphuric acid (H_2SO_4) using 1% phenolphthalein as an indicator. Bicarbonate anions were then determined by titrating the same extract or water with the same acid, using 0.05% methyl orange solution as an indicator (Richards, 1954). The results were expressed as cmol(-)/kg soil. Based on the measured values of soluble calcium, magnesium, carbonate and bicarbonate, the corresponding residual sodium carbonate (RSC) was calculated by subtracting the values of (Ca + Mg) from those of (CO_3 + HCO_3) (Richards, 1954; Gupta and Gupta, 1987).

3.3.14.2 Chloride (Cl^-) anions

The chloride anions were determined on the same sample used for the determination of the carbonate and bicarbonate anions by titrating the extract with 0.02 N silver nitrate solution, using potassium chromate solution as an indicator (Bower and Wilcox, 1965; Hesse, 1971). The values obtained were expressed as cmol(-)/kg soil.

3.3.14.3 Sulphate (SO_4^{2-}) anions

Sulphate anions were determined by the gravimetric method (Richards, 1954; Hesse, 1971). The procedure involved the precipitation of sulphate as barium sulphate, using 1 N hydrochloric acid and 1 N barium chloride. Some of steps involved include: evaporation of the extract to about 5 ml in water bath, treatment of the evaporated extract with methyl orange, 1 N hydrochloric acid and 1 N barium chloride, heating the mixture in a water bath, cooling, centrifuging, decanting and draining by inversion, drying over night in an oven at 105°C, cooling in a desiccator and weighing.

3.3.14.4 Nitrate (NO_3^-) anions

Nitrate anions were determined by steam distillation method (Bremner, 1965; Keeney and Nelson, 1982). The procedure consisted of two stages of steam distillation. The first stage involved steam distillation of the extract or water sample with magnesium oxide for the removal of ammonium nitrogen. In the second stage the very extract was treated with Devarda alloy to obtain nitrate nitrogen following destruction of nitrite nitrogen with sulfamic acid. The distillate was then titrated with 0.005 N standard sulphuric acid. The results were expressed as cmol(-)/kg soil.

3.4 Soil classification

The studied soils were classified in accordance to their physical, chemical and morphological characteristics following the principles established by FAO (1988) and USDA (1990). The soils were also categorized in terms of types of salt affected soils following the criteria established by Richards (1954).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characteristics and classification of Mafiga-Chamwino lowland soils.

Based on the slope of the area, drainage classes, texture of top soils and soil depth, four mapping units were identified in the study area, namely, $10C_1$, $22B_1$, $21C_1$ and $11C_1$. The distribution of the mapping units is shown in Figure 3. The details of the characteristics used to define the mapping units are indicated on Table 2. The coding system adopted is similar to the one used by Mpepo (1986).

4.1.1 General characteristics of soil mapping units

The summary of morphological features of soils in each mapping unit are presented in this subsection. The detailed soil morphological and physical properties together with descriptions of representative soil profiles are given in Appendix 1.

(i) Mapping unit $10C_1$

The soils of this mapping unit were represented by profile ChP. The soils were very deep (>150 cm), poorly drained and mottled. The size and abundance of mottles increased with soil depth. Top soils were very dark brown to dark greyish brown with dark greyish brown to brown subsoils. The soils were characterized by the presence of Cambic B horizon (Table 3).

(ii) Mapping unit 22B_1

The soils of this mapping unit were represented by profile MfP1. They were very deep (>150 cm), well to imperfectly drained and they were mottled. The size and abundance of mottles increased with soil depth. They had dark brown to dark reddish brown top soil and red to dark red subsoil. They had an argic B horizon (Table 3).

(iii) Mapping unit 21C_1

The soils of this mapping unit were represented by profile MfP2. The soils were very deep (>150 cm), poorly drained and mottled. The size and abundance of mottles increased in the subsoil. They had nodules which were more abundant in the subsoil. The top soil was dark brown to very dark greyish brown while the subsoil was dark brown to dark yellowish brown. These soils had an argic B horizon (Table 3).

(iv) **Mapping unit 11C_1**

The soils of this mapping unit were represented by profile MfP3. The soils were very deep (>150 cm), poorly drained and mottled. The size and abundance of mottles increased with soil depth. They had nodules which were more abundant in the subsoil. The top soil was dark yellowish brown over reddish brown to yellowish red subsoil. They have Natric B horizon (Table 3).

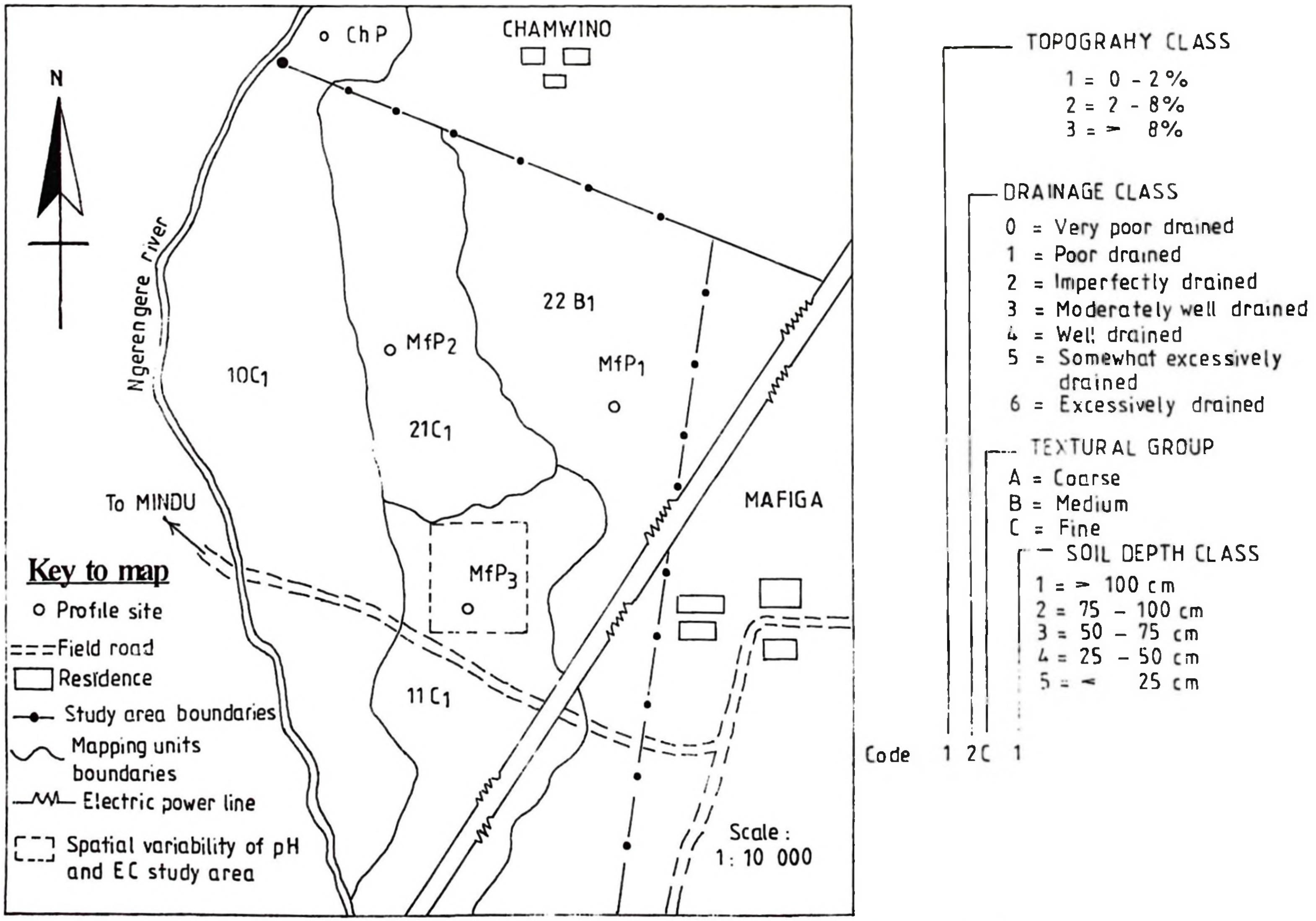

Figure 3. Distribution of mapping units and location of the soil profiles studied.

Table 2. Soil Map Legend.

Mapping unit	Slope (%)	Soil drainage	Top soil texture	Soil depth (cm)
$10C_1$	0 - 2	very poor	clay loam	> 100
$22B_1$	2 - 8	imperfect	sandy clay loam	> 100
$21C_1$	2 - 8	poor	sandy clay	> 100
$11C_1$	0 - 2	poor	sandy clay	> 100

Table 3. Diagnostic features and horizons of the studied soils.

Profile	Diagnostic features	Diagnostic horizon
ChP	Salic properties Calcareous (Aquic soil-moisture regime)*	Cambic B horizon
MfP1	Calcareous (Ustic soil-moisture regime)* Sodic properties	Argic B horizon (Argillic horizon)*
MfP2	Calcareous (Ustic soil-moisture regime)* Gleyic properties Sodic properties	Argic B horizon (Argillic horizon)*
MfP3	Salic properties Calcareous Sodic properties (Ustic soil-moisture regime)*	Natric B horizon (Natric horizon)*

* Terminology based on the USDA (1990) soil classification system

4.1.2 Soil physical characteristics

The data pertaining to laboratory soil physical properties for the profiles studied are indicated on Table 4. All soil profiles were dominated by clay separate. The clay content generally increased with soil depth in all profiles to attain a maximum level either in one of the intermediate or deepest subsurface horizon. The silt separate varied in a non systematic manner with soil depth. In certain profiles such as ChP the silt content was considerably higher in the upper horizons while in others such as MfP1 the opposite trend was observed.

The bulk density ranged from 1.2 - 1.7 Mg/m^3 (Table 4). Differences among profiles were small. Like clay content, the bulk density also increased with soil depth.

Table 4. Selected physical characteristics of the representative soil profiles.

Profile	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	B.d* (Mg/m^3)
ChP	Apz	0-15	38.3	20.1	39.0	1.3
	BA	15-30	36.5	13.3	50.2	1.5
	Bg1	30-64	25.5	7.6	66.9	1.5
	Bg2	64-92	29.6	7.1	63.2	n.d
	Bg3	92-200+	39.6	9.2	51.3	1.6
MfP1	Ap	0-15	55.8	11.1	33.2	1.6
	Bg	15-45	40.7	7.1	52.1	1.6
	Btgn	45-115	34.3	15.4	50.3	1.6
	Btg	115-200+	33.9	23.9	38.9	1.7
MfP2	Apz	0-35	42.6	9.2	42.9	1.2
	Btgn1	35-110	47.2	6.5	46.4	1.6
	Btgn2	110-200+	39.3	7.3	53.4	1.6
MfP3	Apz	0-10	70.5	15.6	13.9	1.5
	Btgn1	10-20	33.9	5.5	60.7	1.5
	Btgn2	20-35	27.5	7.1	65.4	1.6
	Btgn3	35-125	12.9	7.5	79.7	1.6
	Btgn4	125-200+	13.5	16.0	71.4	1.4

* B.d = Bulk density
n.d = not determined

4.1.3 Soil chemical characteristics

Data on soil chemical characteristics are given on Table 5. The organic carbon content ranged from trace to 1.8% with little differences existing among similar horizons of different profiles. Most of the organic carbon was concentrated in the surface and immediately underlying horizons.

The pH of soil-water suspension ranged from 6.9 - 8.8, 7.5 - 9.5, 8.5 - 9.5 and 9.4 - 10.3 in soil profiles ChP, MfP1, MfP2 and MfP3, respectively. The pH increased with soil depth in all soil profiles except in soil profile MfP3 where the opposite trend was noted.

The CEC ranged from 20.0 - 42.8 cmol(+)/kg soil and it tended to increase with soil depth in all profiles. Exchangeable calcium dominated in profiles ChP, MfP1 and MfP2 while exchangeable sodium was the highest in the profile MfP3. Exchangeable potassium was very low, ranging from 0.2 to 1.1 cmol(+)/kg soil. Where exchangeable calcium dominated, the content of exchangeable magnesium was also relatively high. Consequently, the content of exchangeable divalent bases (Ca+Mg) exceeded that of monovalent bases (K+Na) in all horizons of soil profiles ChP, MfP1 and MfP2.

The percent base saturation ranged from 53.7-92.5, 54.5-100, 70.3-100 and 74.7-93.4% in profiles ChP, MfP1, MfP2 and MfP3 respectively. In all profiles the percentage base saturation increased in the deeper horizons.

Table 5. Selected chemical characteristics of the representative profiles of the soils studied.

Profile	Horizon	Depth (cm)	O.C (%)	pH (H_2O) (1:2.5)	Exchangeable bases* Ca	Mg	K	Na	CEC*	CEC **	B.S (%)
ChP	Apz	0-15	1.6	6.9	12.4	2.2	1.0	1.8	26.8	68.7	64.6
	BA	15-30	0.9	7.9	8.6	5.3	0.6	1.5	29.8	59.4	53.7
	Bg1	30-64	1.0	7.6	11.3	6.4	0.6	3.7	38.2	57.2	57.6
	Bg2	64-92	0.7	8.5	10.4	7.7	0.3	6.8	38.5	60.1	65.2
	Bg3	92-200+	0.2	8.8	12.1	6.7	0.3	5.5	26.6	51.8	92.5
MfP1	Ap	0-15	1.2	7.5	6.4	3.1	0.6	0.8	20.0	60.2	54.5
	Bg	15-45	0.8	7.7	6.4	4.8	0.2	3.1	25.0	48.0	58.0
	Btgn	45-115	0.3	9.1	8.4	6.2	1.1	10.3	26.5	52.7	98.0
	Btg	115-200+	trace	9.5	13.9	6.7	0.3	12.7	27.2	51.6	100.0
MfP2	Apz	0-35	1.4	8.5	9.7	7.3	0.6	4.4	31.3	73.0	70.3
	Btgn1	35-110	0.5	9.3	14.3	6.4	0.4	11.0	29.0	62.5	100.0
	Btgn2	110-200+	0.2	9.5	23.5	8.4	0.4	14.3	35.0	65.5	100.0
MfP3	Apz	0-10	0.6	10.3	10.2	1.0	0.6	9.4	26.1	187.7	81.2
	Btgn1	10-20	0.6	10.0	5.2	3.5	0.9	16.2	34.4	56.7	74.7
	Btgn2	20-35	0.5	10.0	6.7	5.4	0.9	9.9	33.1	50.6	66.6
	Btgn3	35-125	0.3	9.9	4.0	5.8	0.9	16.4	37.4	47.2	72.6
	Btgn4	125-200+	0.2	9.4	15.0	5.5	0.6	18.9	42.8	59.9	93.4

* cmol(+)/kg of soil, ** cmol(+)/kg of clay

Table 6. Classification of the studied soils.

Profile No.	Mapping unit	Soil classification FAO (1988)	Soil classification USDA (1990)
ChP	$10C_1$	Gleyic Solonchak, Sodic phase	Vertic Halaquepts
MfP1	$22B_1$	Chromic Luvisols, Sodic phase	Typic Natrustalf
MfP2	$21C_1$	Gleyic Luvisols, Strongly Sodic phase	Typic Natraqualf
MfP3	$11C_1$	Sodic Solonchak	Salorthidic Natrustalfs

The presence of mottles in all soils is an indication of water saturation due to poor internal soil drainage. The variation of mottles with soil depth is of a particular interest since it reflects the zone of movement of the soil solution. The presence of more mottles in the subsoils compared to the upper horizons is an indication of the zone of the ground water table fluctuation. Features associated with mottling could be employed to demonstrate the contribution of the ground water to soil genesis.

The high clay content probably could be linked to the ferromagnesian nature of the parent material of the Uluguru Mountain landscape which is dominated by hornblende, biotite and amphibolite, all of which weather to yield clays (Moberg, 1981). The increased clay content with soil depth in all profiles could partly be explained by clay migration from surface to lower horizons. This is supported by the presence in abundance of typical clay illuvial features such as ferriargillans in the B horizon of profiles MfP1, MfP2 and MfP3. The high clay content especially in the subsoils could considerably account for the poor drainage of these soils.

The increase of bulk density with soil depth in all profiles is related to clay content which vary in that manner. The increase of the bulk density with soil depth could be explained either by the decrease of organic matter content and extent of aggregation in the subsurface horizons, or compaction caused by the weight of the overlying layers (Brady, 1984; Landon, 1984). The relatively high bulk density in the subsoils may be accompanied by a decrease of percolation rate which could consequently be associated with water logging (Hamad, 1992).

In accordance to the criteria employed by ILACO (1981) the organic carbon content in the soils studied ranged from very low to medium; which implies a very low to medium organic matter content. The low organic matter content could be partly accounted for by the poor vegetation cover of the studied area and partly by the rapid decomposition of organic residues under the prevailing hot climatic conditions (Tiwari *et al*., 1983)

The increase of pH with soil depth is an indication of increase in alkalinity in the subsoils. The pH increase is associated with the presence of relatively high proportion of exchangeable bases especially sodium which is known to yield high pH on hydrolysis (Abrol *et al*., 1980, 1988). This variation could be due to the influence of leaching of bases from the upper to the lower horizons, but also the content of salts in the ground water.

If reference is made to the rating of CEC values par Euroconsult (1989) the level of this parameter in the soils of mapping unit $10C_1$, $22B_1$, $21C_1$ and $11C_1$ may be considered, high, medium to high, high and high to very high respectively. The variation of CEC with soil depth could be due to the clay content since both of them varied in a similar manner with soil depth. The low organic carbon content in all profiles eliminates the possibility of associating the high CEC with the organic matter. It is also possible that the clay mineralogy had an influence over this parameter. The presence of 2:1 type of clay minerals (Fig.6) especially smectites could contribute to the high CEC since smectites are responsible for most of the high CEC in soils (Borchardt, 1989).

Of the identified mapping units, profiles ChP, MfP1 and MfP2 are classified as Vertic Halaquepts, Typic Natrustalf and Typic Natraqualf (USDA, 1990). The corresponding names in accordance with the FAO (1988) classification are Gleyic Solonchak with Sodic phase, Chromic Luvisols with Sodic phase and Gleyic Luvisols with strongly Sodic phase respectively (Table 6). The MfP3 profile was classified as Salorthidic Natrustalfs (USDA, 1990) or Sodic Solonchak (FAO, 1988).

Therefore, the area studied is formed of Gleyic Solonchak, Sodic phase; Chromic Luvisols, Sodic phase; Gleyic Luvisols, Strongly Sodic phase and Sodic Solonchak. From the morphological and chemical properties, these soils are hence associated with salinity problems. The aspect of salinity is dealt with in the following section.

4.2 The status of the properties of salt affected soils

The properties which are characteristic of salt affected soils are presented below. They include pH of the saturated soil paste extract (pHs), electrical conductivity of the saturated soil paste extract (ECe), soluble bases, sodium adsorption ratio (SAR), exchangeable sodium percent (ESP), and soluble anions.

4.2.1 pHs, electrical conductivity of the saturated soil paste extract and exchangeable sodium percent

The pHs varied from 6.4 - 8.2, 7.2 - 8.8, 8.1 - 9.2 and 9.1 - 10.0 in Gleyic Solonchak, Chromic Luvisols, Gleyic Luvisols and Sodic Solonchak (Table 7). In all soils except the Sodic Solonchak, the pHs values increased with soil depth.

The Chromic Luvisols and Gleyic Luvisols had relatively low ECe values compared with the rest of the soils studied. The ECe ranged from 0.7 - 2.3 and 1.5 - 1.7 dS/m in these soils respectively. The Gleyic Solonchak and Sodic Solonchak had the highest values of ECe in the surface horizon (74.3 and 40.7 dS/m). There was a sharp decrease in ECe between the upper and the lower horizons in the Gleyic Solonchak and Sodic Solonchak. In these soils, the lower horizons had ECe values comparable to those measured in the Chromic Luvisols and Gleyic Luvisols. The variation of the ECe with soil depth conforms to that of pHs values in all soils.

The levels of ESP varied considerably among the soils studied. The lowest levels were measured in Gleyic Solonchak (4.9 - 20.6) while the highest ones were recorded in the Sodic Solonchak (27.2 - 46.9). ESP values increased with soil depth in the Chromic Luvisols and Gleyic Luvisols. The increase was sharp between the surface and the immediately underlying horizon but remained gradual between the latter and the underlying horizon in the Gleyic Luvisols. In the Chromic Luvisols, ESP increased generally with soil depth but interhorizon changes were irregular.

Table 7. pHs, electrical conductivity of the saturation extract and exchangeable sodium percent.

Soil type	Depth (cm)	pHs	ECe (dS/m at 25°C)	ESP
Gleyic Solonchak	0-15	6.4	74.3	6.8
	15-30	6.6	11.2	4.9
	30-64	7.3	3.7	9.7
	64-92	7.6	2.4	17.5
	92-200+	8.2	1.7	20.6
Chromic Luvisols	0-15	7.2	0.7	3.9
	15-45	7.2	1.2	12.5
	45-115	8.7	2.2	38.7
	115-200+	8.8	2.3	46.8
Gleyic Luvisols	0-35	8.1	1.7	13.9
	35-110	8.8	1.5	37.9
	110-200+	9.2	1.5	40.9
Sodic Solonchak	0-10	10.0	40.7	35.9
	10-20	9.8	19.6	46.9
	20-35	9.9	11.5	27.2
	35-125	9.7	6.5	44.0
	125-200+	9.1	3.8	44.0

4.2.2 Distribution of soluble cations and anions in the soils studied

The content of sodium ranged from 1.71 - 41.70, 0.08 - 1.56, 1.65 - 2.16 and 5.68 - 17.60 cmol (+)/kg soil in Gleyic Solonchak, Chromic Luvisols, Gleyic Luvisols and Sodic Solonchak respectively (Table 8). The content of sodium exceeded that of other cations in all soils irrespective of the horizon in question. The levels of soluble potassium were the least of all bases and ranged from 0.01 to 0.07 cmol/kg in all the soils. The magnitude of the concentration of potassium was comparable to that of calcium and magnesium in all the horizons studied except in the surface horizon of the Gleyic Solonchak where the latter two attained levels of 4.09 and 9.26 cmol/kg soil respectively.

The SAR tended to decrease with soil depth in the Gleyic Solonchak, Gleyic Luvisols and Sodic Solonchak. In the Chromic Luvisols, the SAR followed the opposite trend. The Sodic Solonchak had exceptionally very high values of SAR compared to the rest of the soils. It ranged from 84.6 - 433 with the highest values being measured in the 0 - 20 cm layer. It is important to note that the SAR values were also high in the rest of the soils ranging from 17.1 - 59.9, the only exception being the Ap horizon of the Chromic Luvisols which had a values of 10.

The four soils studied show marked difference in the content of soluble cations which are concentrated near the soil surface or the upper part of the soil solum, within the root zone. For instance the Sodic Solonchak contains 126 times more cations than Chromic Luvisols in the surface horizon. Similarly, the SAR values for the same horizon differ by a factor of 43.

The content of chloride dominated in all soils irrespective of the horizon in question (Table 9). It ranged from 3.1 to 11.5 cmol(-)/kg soil. The distribution of chloride did not show a similar pattern with soil depth. The bicarbonate and carbonate content was relatively high in the Sodic Solonchak compared to the rest of the soils. The corresponding values for the two anions ranged from 0.4 to 3.3 and 1.0 to 2.3 cmol(-)/kg respectively. In the rest of the soils, the levels of carbonates and bicarbonates varied from trace to 0.7 and 0.1 - 1.7 cmol(-)/kg soil respectively. The distribution of carbonates and bicarbonates with soil depth followed a similar pattern as the pHs and soluble sodium nearly in all soils. The sulphates and nitrates were low in all soils, ranging from trace to 2.2 and trace to 0.5 cmol(-)/kg soil respectively.

Table 8. Distribution of soluble cations in the different soils.

Soil type	Depth (cm)	Soluble cations [cmol (+)/Kg]				
		Ca	Mg	K	Na	SAR
Gleyic Solonchak	0-15	4.09	9.26	0.07	41.70	59.9
	15-30	0.25	0.13	0.04	5.37	50.2
	30-64	0.12	0.06	0.01	4.83	41.5
	64-92	0.06	0.03	0.01	2.90	34.3
	92-200+	0.05	0.03	0.01	1.71	23.8
Chromic Luvisols	0-15	0.01	0.01	0.01	0.08	10.0
	15-45	0.01	0.02	0.01	0.67	17.1
	45-115	0.01	0.02	trace	1.56	36.9
	115-200+	0.01	0.01	trace	1.27	51.9
Gleyic Luvisols	0-35	0.07	0.07	0.01	2.05	29.9
	35-110	0.02	0.05	0.02	1.65	25.8
	110-200+	0.02	0.03	0.01	2.16	24.3
Sodic Solonchak	0-8	0.01	0.01	trace	13.88	433.9
	10-20	0.01	0.01	0.01	17.60	346.3
	20-35	0.01	0.02	0.05	17.30	84.6
	35-125	0.02	0.01	0.02	10.23	227.5
	125-200+	0.02	0.02	0.02	5.68	134.7

Table 9. Distribution of soluble anions in the different soils.

Soil type	Depth (cm)	Soluble anions [cmol (-)/kg] CO_3	 HCO_3	 Cl	 SO_4	 NO_3
Gleyic Solonchak	0-15	trace	0.2	4.7 4	0.4	0.5
	15-30	0.1	0.2	3.1	1.4	0.1
	30-64	0.1	0.5	7.5	1.1	0.1
	64-92	0.1	0.5	11.5	0.1	0.1
	92-200 +	0.2	0.7	7.0	0.1	0.1
Chromic Luvisols	0-15	trace	0.1	3.5	0.5	trace
	15-45	0.3	0.3	3.4	2.0	trace
	45-115	0.4	0.8	4.3	trace	trace
	115-200 +	0.4	1.0	3.7	0.1	0.1
Gleyic Luvisols	0-35	0.1	0.5	3.4	trace	trace
	35-110	0.5	1.3	5.3	0.2	0.1
	110-200 +	0.7	1.7	7.7	trace	0.1
Sodic Solonchak	0-10	3.3	2.1	7.5	0.9	0.4 ✓
	10-20	2.4	2.3	6.2 7.4	0.5	0.3
	20-35	1.8	2.3	7.1	trace	0.2
	35-125	1.6	2.0	4.6	2.2	0.1
	125-200 +	0.4	1.0	6.4	0.6	0.2

The fact that the pHs values of the soils studied is above 7 indicates that these soils are alkaline (Richards, 1954). The increase of pHs with soil depth is also a sign of increase in alkalinity in the subsoils. This increase coincides with the presence of relatively high proportion of carbonates and bicarbonates of sodium which are capable of undergoing hydrolysis and hence increase the pHs (Allison, 1964; Abrol *et al*., 1988). Tiwari *et al*. (1983) made similar observations while working with some soils in India. According to Msanya (1980) the manner by which pH of soil vary with soil depth could probably be explained by the leaching of bases in the upper horizons or layers. Hamad (1992) gave similar reasons when explaining the variation of soil pH with soil depth in the soils of some major rice-growing areas in Zanzibar Island. Pathak and Patel (1980) consider increase in pHs with soil depth to indicate alkalization process taking place in the lower layers.

On the basis of the established ranges of pHs for grouping soils with different degrees of salinity and sodicity levels (Richards, 1954; Allison, 1964; Reeve and Fireman, 1967), the Gleyic Luvisols and Sodic Solonchak exhibit sodic or saline-sodic property because they have pHs above 8.5 in the root zone (0-50 cm). The other soils notably the Gleyic Solonchak and the Chromic Luvisols do not have this property.

The low ECe values observed in the Chromic Luvisols and Gleyic Luvisols indicates a low accumulation of soluble salts while the presence of high values of ECe in the Gleyic Solonchak and Sodic Solonchak corresponds to high accumulation of soluble salts. The decrease of ECe values with soil depth observed in the Gleyic Solonchak, Gleyic Luvisols and Sodic Solonchak coincides with the decrease of soluble calcium, magnesium and sodium. Increased ECe in the upper layers of soils is an indication of prevailing favourable conditions for salt accumulation at or near the soil surface, such as evaporation and absence or limited leaching (Mediratta *et al.*, 1985; More *et al.*, 1988). According to Bandyopadhya (1973) such an accumulation could result from rise of solutes due to capillary movement of solution enhanced by evaporation.

The increased ECe with soil depth in the Chromic Luvisols is probably due to the increased magnesium and sodium salts in the lower horizons. Similar observations were made by Msanya (1980) who reported that increase of salt accumulation in the subsoil is due to the leaching of bases from top soil and poor subsoil drainage.

The question which still needs to be answered is why in the former three soils the distribution of salts with depth was different from the one observed in the Chlomic Luvisols.

If one refers to already established categories of salinity based on ECe values (FAO, 1988; Abrol *et al.*, 1988), only the Gleyic Solonchak and Sodic Solonchak are faced with strong salinity while the rest of the soils are non saline. By the fact that ESP values of the Gleyic Solonchak, Chromic Luvisols and Gleyic Luvisols are below the 15 limit within 30 cm of the soil surface these soils do not have sodic property while the opposite is true for the Sodic Solonchak (FAO, 1988). On the basis of the criteria developed by Abrol *et al*., (1988), the Gleyic Solonchak and Chromic Luvisols have none to slightly sodicity hazard while the Gleyic Luvisols and Sodic Solonchak have slight to moderate and moderate to high sodicity hazard respectively. The increased ESP values in all subsoils coincides with increased exchangeable sodium in the corresponding horizons. According to Pathak and Patel (1980), the manner by which ESP vary with soil depth could be explained in relation to previous leaching of saline constituents to lower layers.

When the values of pHs, ECe and ESP of the rooting zone are examined together, the soils studied can be put under three categories as follows: (a) soils low in pHs, ECe and ESP values, (b) soils low in pHs and ESP but with very high ECe and (c) soils with very high pHs, ECe and ESP values. The Chromic Luvisols and Gleyic Luvisols belong to the first category while the Gleyic Solonchak and Sodic Solonchak are typical examples of the second and third groups respectively. Thus, the Gleyic Solonchak, Chromic Luvisols, Gleyic Luvisols and Sodic Solonchak exhibit the properties of saline soils, intergrade between sodic and normal soil, sodic soil and, saline-sodic soils respectively. Accordingly therefore, on the basis of the approach used for the classification of salt affected soils (Soil Survey Staff, 1951; Richards, 1954; Allison, 1964; James *et al*., 1982; Landon, 1984; Abrol *et al*., 1988; Dubey and Sharma, 1990) the Gleyic Solonchak and Chromic Luvisols are categorized as saline and intergrade sodic-normal soils respectively. On the same basis, the Gleyic Luvisols and Sodic Solonchak are classified as sodic and saline-sodic soils respectively.

The high amount of soluble sodium and chloride in all soils studied probably could be explained by assuming that the conditions which favour the increase in concentration of the two ions are optimal in the water catchment influencing these soils. Another reason which could account for the dominance of sodium in the soils studied is solubility product of other compounds such as carbonates of calcium and magnesium. According to Vinayak *et al*. (1981) the waters containing appreciable amounts of carbonates and bicarbonates get precipitated as calcium carbonate ($CaCO_3$). The precipitation of $CaCO_3$ causes an increase in soluble sodium which tends to dominate the exchange complex, saturating or even over saturating it. Also the precipitation of calcium and magnesium into calcrete in the soils (Appendix 1) could limit the availability of the two bases in the soil solution.

The domination of soluble chlorides in all soils could be explained on the basis of its relative adsorption by the soil clays. Basically, sulphate ions are adsorbed more strongly than chloride ions on the exchange sites of clays and oxides in a soil (Agrawal and Ramamoorthy, 1970).

Based on the salinization types established by Euroconsult (1989), the four soils exhibit different types of salinization (Appendix 2). The main types of cation salinization encountered in these soils are calcium-magnesium and sodium-calcium while the main type of anion salinization is sodium-carbonate-chloride. There is a clear difference of distribution of salinization between surface and subsurface horizons among soils. The presence of different types of salinization clearly confirm the salt variation among the four soils and among individual horizons.

The manner by which salts vary in the soil could be explained by unequal movements of salt water, due to differences in soil texture (Zonn, 1986). Regardless how small such textural differences could be they may contribute to large differences in salt accumulation (Soil Survey Staff, 1951; Zonn, 1986).

4.3 Variation of field measured pH and electrical conductivity in the saline-sodic soils

The data pertaining to statistics for the variability of both pH and EC are given on Table 10. The pH varied from 6.0 - 10.1 with mean value of 7.8. The coefficient of variability (CV) was 12%. The EC varied from 0.1 - 42.4 dS/m, with mean of 5.8 and the CV was 143%. The spatial variability of the pH, EC and the corresponding rice crop performance is shown on Figure 4. The field variation of the pH appeared to be related to the rice crop performance. pH tended to be higher in the areas with wilted and dead rice crop. In the areas with healthy rice crop the average pH was 7.1. In the areas with wilted and dead rice crop the average pH was 8.1 and 9.0 respectively (Table 11).

The variation of the EC along a given direction was irregular. In some cases there was a gradual change of EC over a given distance and in some others the changes were abrupt. The sharing of border between the non saline to slightly zone with the moderately saline one (Fig. 4) is typical of the former case while the existence of the strongly to very strongly saline area in contact with the non saline to slightly saline patch is an illustration of the second case. The rice crop performance tended to be related to the EC values. Health rice plants were found in areas with average EC values of 0.5 dS/m while in the zones with wilted and dead rice, the EC averaged 4 and 20.2 dS/m respectively. The performance of rice crop in relation to salinity and alkalinity are summarized on Table 12.

The field measured pH and EC data show some relationship with those of laboratory although the latter are much higher (Table 13a and 13b).

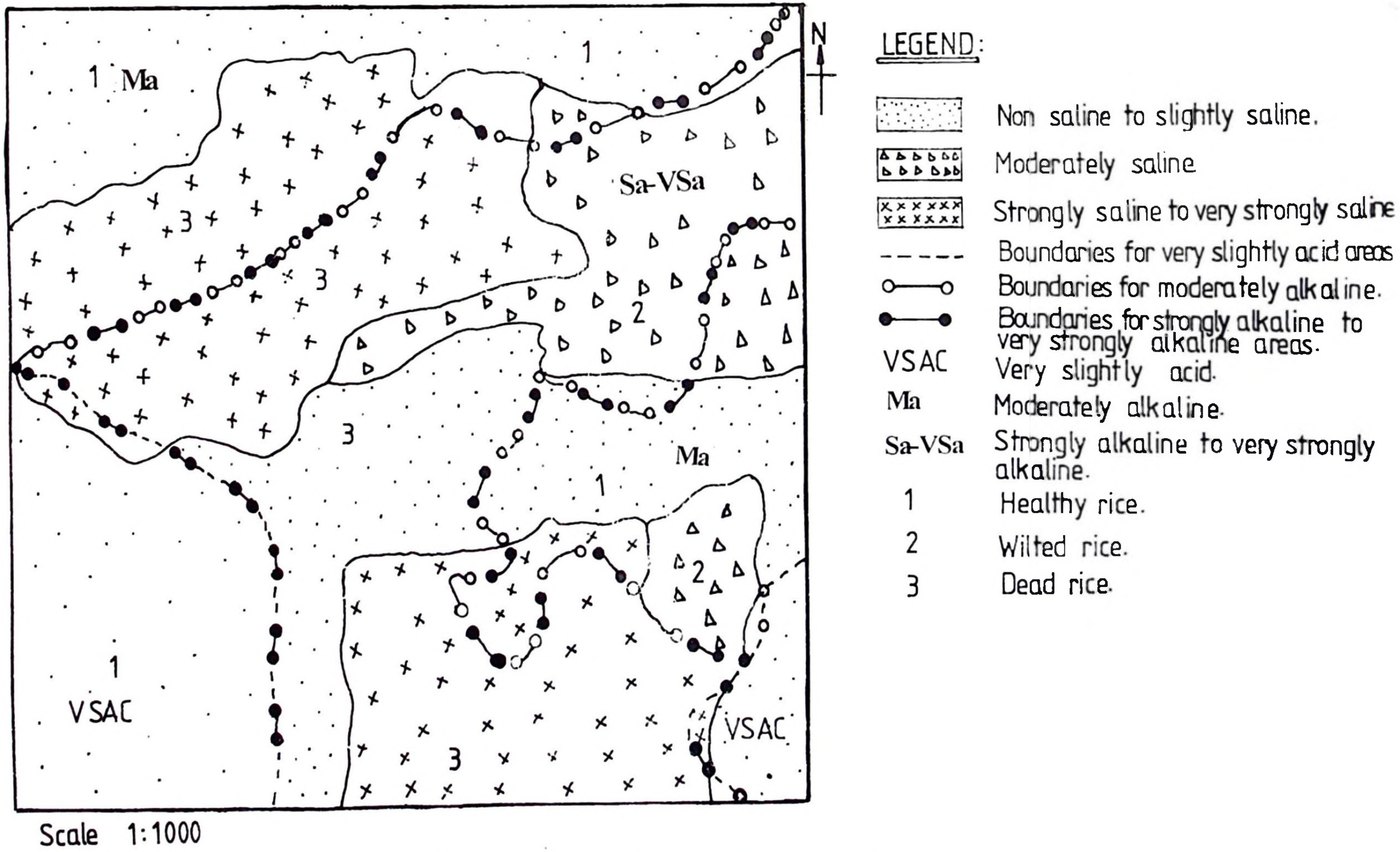

Figure 4. Spatial variability of field measured pH, EC and rice crop performance.

Table 10. Variability of pH and electrical conductivity in the saline-sodic soil.

	Electrical conductivity (dS/m)	pH
Minimum	0.1	6.0
Maximum	42.4	10.1
Mean	5.8	7.8
Median	2.9	7.9
Sd	8.3	1.0
CV (%)	143.0	12.0

Sd = standard deviation

Table 11. Variability of electrical conductivity, pH and rice crop performance in the saline-sodic soil.

	EC (dS/m)			Soil pH		
	Hr	Wr	Dr	Hr	Wr	Dr
Mini.	0.1	1.3	8.3	6.0	6.1	6.9
Maxi.	1.9	8.5	42.4	8.5	9.0	10.1
Mean	0.5	4.0	20.2	7.1	8.1	9.0
Median	0.3	4.1	18.1	7.0	8.2	8.9
Sd	0.5	1.6	10.3	0.7	0.6	0.9
CV (%)	100.0	40.0	51.0	9.9	7.4	10.0

Mini. = minimum value

Maxi. = maximum value

Hr = Health rice

Wr = Wilted rice

Dr = Dead rice

Table 12. Salinity, alkalinity and rice crop performance.

Alkalinity/salinity		Crop performance
(i)	Very slightly acid and non saline to slightly saline	Healthy or good rice crop
(ii)	Moderately alkaline and non saline to slightly saline	Healthy or good rice crop
(iii)	Strongly to very strongly alkaline and moderately saline	Wilted or poor rice crop
(iv)	Moderately alkaline and moderately saline	Wilted or poor rice crop
(v)	Moderately alkaline and strongly saline	Bare
(vi)	Strongly to very strongly alkaline and strongly to very strongly saline	Bare

Table 13 a. **Field and laboratory measured electrical conductivity values of selected soil samples.**

Sample number	Field measured EC (dS/m)	Laboratory measured EC (dS/m)
1	1.7	11.0
2	1.0	9.0
3	0.1	1.0
4	3.4	15.4
5	2.8	9.0
6	2.0	9.2
7	5.9	20.3
8	4.5	10.4
9	4.1	8.6
10	10.5	35.7
11	9.0	30.6
12	8.5	53.6
13	16.5	64.2
14	17.8	63.9
15	20.6	123.8

Table 13 b. **Field and laboratory measured pH values of selected soil samples.**

Sample number	Field pH	pH of the saturation extract
1	7.1	8.3
2	7.2	9.8
3	8.5	9.6
4	7.1	9.7
5	7.5	9.8
6	6.8	9.6
7	8.0	8.2
8	8.1	8.4
8	8.8	9.6
9	8.0	8.8
10	8.6	9.7
11	8.7	9.3
12	9.0	10.0
13	9.4	10.5
14	9.6	11.8

The use of laboratory determined pH and EC to characterize salt affected soils is world wide adopted practice (Richards, 1954; Rhoades, 1993). However the laboratories specialized in this type of analysis are few in number and have a limited capacity. The expenses associated with characterization of salt affected soils and the laborious nature of these determinations are among problems associated with the dependency of laboratory determined data on salt affected soils. In view of these difficulties, there exists a need for developing a rapid and reliable field salinity evaluation procedure. The attempt made in this work to try to relate the crop performance and the EC and pH as measured in the field should be tried more extensively while basing the evaluation on statistical grounds.

The size of individual salinity or alkalinity units are highly variable and the smallest units have length of 40 m and width of about 5 m while the largest units have length of 100 m and width of 85 m. Such variation in size would have an adverse impact on the management. The details found in this study would not be obtained if high intensity soil surveys (at a scale of (1:10 000 to 1:20 000) was carried out. This would be due to the limitations caused by the low intensity of observations associated with the mapping scale. It means that more detailed surveys would be appropriate for this type of problems. However the shift from high intensity soil survey to a very high intensity soil survey (scale larger than 1:10 000) is associated with a sharp increase of survey costs (Beckett, 1971; Bie and Ulph, 1972) which may not be economical when the benefits of the crop to be grown is taken into account. Decision on the level of detail to which similar studies should be carried need to take into account other considerations such as social economic situation of the land owner at that particular time.

The large variation of EC over very short distances has important implications from both soil genesis and land management point of view. The causes for this variation are beyond the scope of this work. In order to properly manage the problem of salinity in this area, it is advised that a keen interest be developed to look into the causes for the heterogenous distribution of salts.

4.4 Causes for the accumulation of salts in the Mafiga-Chamwino lowland area

The accumulation of salts in the studied area is examined in terms of the principle sources of salts and some factors which influence their accumulation and distribution in the studied soils. The sources examined include the weathering rocks, surface and ground water.

The parameters used to characterize the salt in both surface and ground waters were pH, electrical conductivity of water (ECw), total soluble salt concentration (TSSC) and content of cations and anions.

4.4.1 Surface waters

4.4.1.1 pH, electrical conductivity (ECw) and total soluble salt concentration (TSSC) of surface water

The data of the pH, ECw and TSSC of water collected from the Ngerengere river and the various streams are indicated on Table 14. The pH of the water collected from streams and Ngerengere river ranged from 7.3 to 8.4. The Chamwino stream had slightly higher pH values compared to the rest of the water sources.

The ECw was lowest in the Ngerengere river and highest in the Chamwino stream. The TSSC ranged from 0.1 to 0.2 g/l in the Ngerengere river while that of the stream water varied from 0.3 to 1 g/l. Of all stream waters, the Chamwino stream had the highest values of TSSC.

The pH, ECw and TSSC values of waters collected at the end of the rain season were slightly higher than those of the same waters collected during the other periods of the year.

Table 14. pH, electrical conductivity and total soluble salt concentration of the surface waters.

Water source	Sampling season	pH	EC at 25°C (dS/m)	TSSC (g/l)
Ngerengere River	1	7.5	0.3	0.2
	2	7.7	0.2	0.1
	3	8.1	0.2	0.1
Chamwino stream	1	8.0	1.6	1.0
	2	8.2	1.4	0.9
	3	8.4	1.3	0.8
Tumbaku stream	1	7.4	1.0	0.6
	2	7.8	1.0	0.6
	3	8.0	1.2	0.8
Heavy plant stream	1	7.3	1.5	1.0
	2	7.4	0.4	0.3
	3	7.6	0.5	0.3
Manzese stream	1	7.5	0.8	0.5
	2	7.5	0.6	0.4
	3	7.9	1.0	0.6

1 = end of the dry season (4 December, 1994).
2 = start of the rain season (30 March, 1995).
3 = end of the rain season (26 May, 1995).

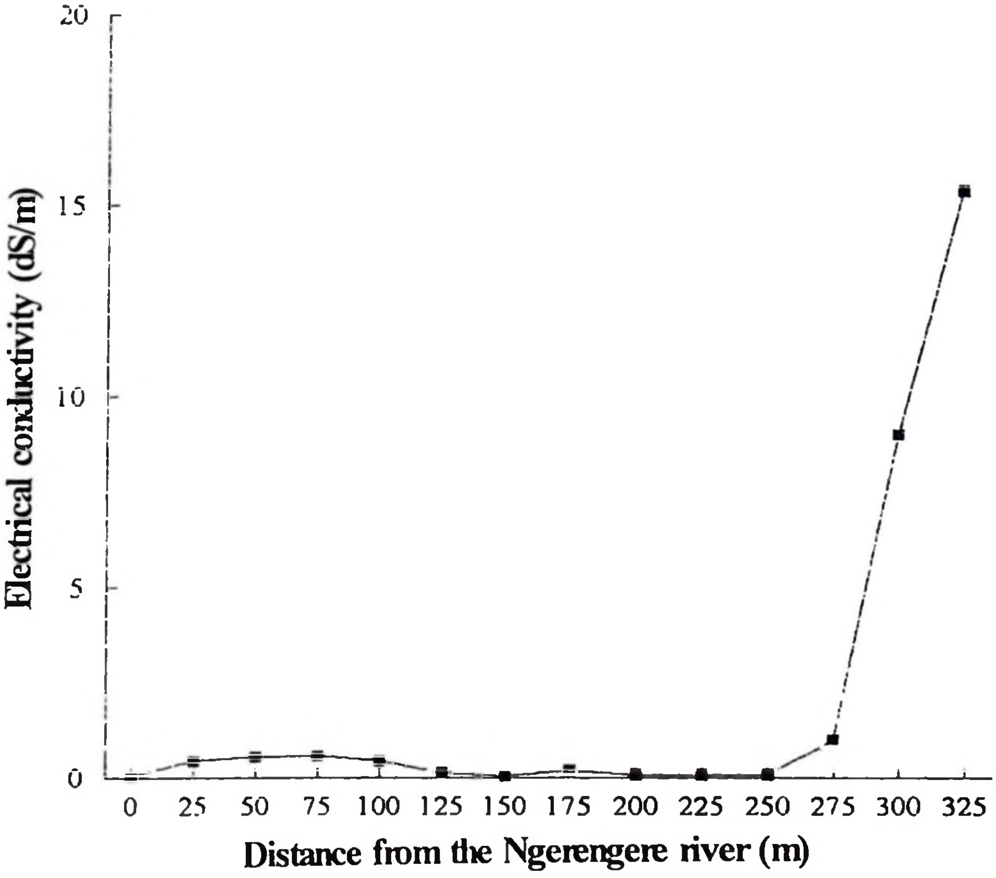

Figure 5. **Variation of salt accumulation from the Ngerengere river to most salt affected soils.**

4.4.1.2 The ionic composition of studied surface waters

The concentration of soluble cations in the Ngerengere river and the various streams studied is shown on Table 15. The content of sodium ranged from 0.3 - 29.5 me/l while that of calcium varied from 0.4 to 2.5 me/l. The concentration of calcium, sodium and magnesium were in general several folds higher than that of potassium. In most cases, the concentration of magnesium was comparable to that of calcium. The content of calcium and magnesium in a given water varied considerably with the sampling period of the year. The content of calcium tended to dominate that of sodium in the samples collected in the end of the dry season while the opposite was true for the sampling done at the end of the rainy season. This phenomenon was clearly demonstrated in the Chamwino and Heavy plant streams. The content of sodium in the Ngerengere river reached a maximum of 29.9 me/l during the end of the dry season. In between the start and end of the rain season the concentration of this element remained almost constant at a narrow range of 0.3 - 0.4 me/l. The concentration of calcium and magnesium almost followed the same trend, the only exception being that the interseasonal differences were very narrow.

The chlorides dominated over the rest of the anions in all water sources studied. It ranged from 8.0 to 40.6 me/l with an average of 31.4 me/l at the end of the dry season. The concentration of this anion at the start and end of the rain season was as follows (average values in brackets): 4.0 - 14.0 (7.6) me/l and 8.8 - 16.0 (11.2) me/l respectively. The concentration of the sulphates varied from 6.1 to 9.8 (7.9) me/l at the end of the dry season. The content of both bicarbonates and carbonates did not vary appreciably from the dry to the rain season. The corresponding average content ranged from 5.1 to 7.3 me/l for the bicarbonates and 1.8 to 2.8 me/l for the carbonates. The nitrate content was very low in all water sources. It ranged from 0.2 to 1.2 me/l. The concentration of the different anions at the end of the dry season followed the order: $Cl^- > SO_4^{2-} > HCO3^- > CO3^{2-} > NO3^-$. Contrary to the rest of the water sources, the Manzese stream had its concentration of chlorides increased from the dry to the rainy season. The content of this anion doubled during the transition from the end of the dry season to the end of the rainy season.

Table 15. Soluble cations and SAR of the surface waters.

Water source	Date	Soluble cations (m.e/l)				
		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	SAR
Ngerengere River	1	1.6	0.5	0.09	29.5	29.9
	2	0.7	0.5	0.04	0.4	0.6
	3	0.4	0.3	0.03	0.3	0.5
Chamwino stream	1	1.8	1.0	0.04	1.1	0.9
	2	0.7	1.0	0.20	4.9	5.5
	3	0.9	2.1	0.05	5.3	4.3
Tumbaku stream	1	1.8	0.9	0.01	0.6	0.5
	2	1.3	1.2	0.12	4.1	3.6
	3	1.6	1.4	0.06	4.4	3.6
Heavy plant stream	1	2.5	0.7	0.02	1.3	1.0
	2	1.8	1.1	0.05	1.0	0.8
	3	1.1	1.0	0.05	4.7	4.6
Manzese stream	1	1.2	1.1	0.13	4.8	4.5
	2	1.6	1.2	0.12	5.3	4.5
	3	1.6	1.1	0.11	4.4	3.8

1 = end of the dry season (4 December, 1994).
2 = start of the rain season (30 March, 1995).
3 = end of the rain season (26 May, 1995).

Table 16. Soluble anions and RSC of the surface waters.

Water source	Sampling period	Soluble anions (me/l)					
		CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	RSC
Ngerengere river	1	5.2	3.7	35.0	6.7	0.4	4.2
	2	tr.	2.1	7.8	n.d	n.d	0.9
	3	tr.	2.5	9.6	n.d	n.d	1.8
Chamwino stream	1	2.0	4.6	38.8	7.3	0.6	3.9
	2	1.6	5.2	6.0	n.d	n.d	5.2
	3	2.8	8.0	9.6	n.d	n.d	7.9
Tumbaku stream	1	tr.	2.8	35.8	6.1	1.2	0.1
	2	2.0	7.0	4.0	n.d	n.d	6.5
	3	2.4	8.6	12.0	n.d	n.d	8.0
Heavy plant stream	1	2.4	3.2	40.6	9.8	0.4	2.4
	2	1.2	6.0	6.0	n.d	n.d	4.3
	3	2.4	8.4	8.8	n.d	n.d	8.7
Manzese stream	1	2.5	11.3	8.0	9.8	0.2	11.5
	2	2.0	10.2	14.0	n.d	n.d	9.5
	3	2.4	9.0	16.0	n.d	n.d	8.7

n.d = not determined

1 = end of the dry season (4 December, 1994).

2 = start of the rain season (30 March, 1995).

3 = end of the rain season (26 May, 1995).

If the EC based criterion for distinguishing different categories of water salinity is followed (Gupta, 1979) the water sources studied can be put into two groups. The first group is that of normal water to which the Ngerengere river, Tumbaku, Heavy plant and Manzese stream waters belong. The second category is that of low salinity water which is characterized by the Chamwino stream water. According to this grouping, the Ngerengere river, Tumbaku, Heavy plant and Manzese stream water would not be associated with any danger of salinisation. However this is not the case in the field particularly with the Tumbaku and Chamwino streams which are surrounded on either side by a tract with typical features of salt affected soils. A number of studies (Richards, 1954; Khatib, 1971; Gupta and Gupta, 1987) have demonstrated development of salinity in river plains in which the EC values were similar to those of the river and streams of the first group provided conducive conditions such as low precipitation, high temperatures and evapotranspiration prevail. These conditions are similar to those found in the area studied. A more refined criterion for distinguishing different types of water with reference to the degree of salinisation was worked out by Richards (1954). If this criterion is employed to categorize the waters studied, three groups are obtained. These are: (i) low to medium salinity water characterized by the Ngerengere river water, (ii) medium to high salinity water to which the Heavy plant and Manzese waters belong and (iii) high salinity water, exemplified by the

Chamwino and Tumbaku waters respectively. The use of this criterion seems to correspond better with the field situation. It is interesting to note that all streams with medium to high salinity water are characterized by salt accumulation along their course and in the immediate piece of land which borders such water way. Complimentary to this observation in the low influence of salinisation by the Ngerengere river water probably due to its dilution effect on the land on which the river has influence (Fig. 5). The low level of SAR values in the stream waters signifies that the latter could be considered as low salinity water (Richards, 1954) though in accordance to FAO (1985) the Manzese stream water could be rated as water with slight to moderate sodicity hazard. The rest of stream waters attain the same status during the rainy season. It is important to note that due to the extraordinarily high levels of SAR in the Ngerengere river at the end of the dry season, this water could be considered as very high sodicity water (Richards, 1954) or water with severe sodicity hazard (FAO, 1985). It is interesting to note that the use of the total soluble salt concentration (TSSC) criterion (Richards, 1954) to categorize the water sources studied gave similar results to those provided by the classification of salinity, based on the electrical conductivity of the waters (ECw). The relative domination of soluble sodium over calcium and magnesium in a good number of the water sources correspond with a relatively high content (>2.5 me/l) of residual sodium carbonate (RSC). According to

Eaton (1950), RSC values greater than 2.5 me/l are associated with precipitation of calcium and magnesium carbonate which favours the domination of sodium hence the risk of development of a high sodicity hazard. Change of volume of water due to low or high rainfall affect salt concentration in both river and stream waters (Khatib, 1971). The occurrence of slightly higher pH, ECw and TSSC values recorded at the end of the rain season compared to those measured during the other periods of the year can not be explained. This is because enough data could not be obtained to run a statistical test. The increased pH is probably due to the hydrolysis of carbonates and bicarbonates of sodium (Abrol *et al.*, 1988). Increase of the content of carbonates in river water with increase of rainfall has been reported by Bharambe *et al.* (1992).

4.4.2 Ground waters

4.4.2.1 pH, electrical conductivity and total soluble salt concentration of ground water

The data of the pH, ECw and TSSC of the different ground waters are presented on Table 17. The pH of the waters ranged from 7.3 to 8.3. The water from the pit corresponding with soil profile MfP4 had a relatively higher pH value than the rest. The ECw values ranged from 5.5 to 26.4 dS/m. The water from the pits corresponding with soil profiles ChP1, ChP2 and MfP6 had considerably lower ECw values compared to those collected from the pits corresponding with soil profiles MfP3, MfP4 and MfP5. The TSSC ranged from 3.5 to 16.9 g/l. The TSSC of the MlP3 and MfP5 ground waters was two to three fold higher than that of the rest of the ground waters.

Table 17. pH, electrical conductivity and total soluble salt concentration of ground water studied.

Pit number	pH	ECw (dS/M at 25°C)	TSSC (g/l)
ChP 1	7.9	6.5	4.2
ChP 2	7.3	5.7	3.7
MfP 3	7.9	10.4	6.7
MfP 4	8.3	22.6	14.5
MfP 5	7.7	26.4	16.9
MfP 6	7.6	5.5	3.5

4.4.2.2 The ionic composition of the studied ground water

The concentration of the cations and the corresponding SAR in the ground water studied is shown on Table 18. Examination of the data shows that in all cases, the concentration of sodium dominated that of the rest of the cations. The concentration of potassium was the lowest in all the waters while that of calcium and magnesium were intermediate. The SAR varied from 7.4 to 214.3. The ChP1 and ChP2 ground waters had relatively low (7.4 - 10.6) SAR values. The water from the other pits had higher (34.1 - 214.3) values.

The ground waters were dominated by chlorides which ranged from 28.4 - 43.0 me/l (Table 19). Carbonates and bicarbonates ranged from 9.2 - 56.8 and 7.0 - 32.6 me/l respectively. The water from the pits corresponding with soil profiles MfP4, MfP5 and MfP6 had relatively higher carbonate and bicarbonate values than the rest of ground waters. The content of nitrates was the least (0.3 - 0.9 me/l) while the concentration of the sulphates never exceeded 2.5 m.e/l in all except for MfP5 and MfP6 ground waters in which it was 13.3 and 11.0 me/l respectively. The RSC ranged from 5.5 to 86.4 m.e/l. The waters from the pits corresponding with profiles MfP4, MfP5 and MfP6 had very high RSC values than the rest of ground waters.

Table 18. Concentration of soluble cations and SAR in the ground waters studied.

Pit number	Soluble cations in m.e/l				
	Ca^{2+}	Mg^{2+}	K^+	Na^+	SAR
ChP 1	1.1	1.1	0.02	7.8	7.4
ChP 2	9.0	5.3	0.02	28.4	10.6
MfP 3	1.4	2.0	0.02	44.6	34.1
MfP 4	0.9	2.1	0.05	262.1	214.3
MfP 5	0.8	4.7	0.04	132.0	79.5
MfP 6	2.2	1.0	0.04	106.1	84.2

Table 19. Concentration of soluble anions and RSC in the ground waters studied.

Pit number	Soluble anions in m.e/litre					
	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	RSC
ChP 1	10.0	9.0	28.4	2.5	0.5	16.8
ChP 2	9.2	10.6	29.2	1.2	0.9	5.5
MfP 3	11.6	7.0	43.0	2.5	0.4	15.2
MfP 4	56.8	32.6	32.4	2.5	0.3	86.4
MfP 5	24.8	16.0	41.2	13.5	0.4	35.3
MfP 6	23.2	15.6	40.9	11.0	0.5	35.6

On the basis of the pH values measured, the ground waters studied are alkaline (Richards, 1954). When the ECw and TSSC of ground water studied are compared with established criteria of water quality (Richards, 1954; Gupta, 1979), the ground water can be ranked between high and very high salinity. This implies that such water could results into salt accumulation once raised near to the soil surface and get evaporated. The ground water occurs at a depth of less than 1.8 m from the ground surface in all the pits studied. Early studies conducted by Teakle and Burvill (1945), and Richards (1954) showed that saline soils occur where the ground water exists within 1.5 to 1.8 m. Provided that other factors which favour salt accumulation are maintained, the nearer is the depth of the ground water table to the surface the more is the soil salinity (Nath and Singh, 1984; Chang *et al.*, 1985). The fact that saline ground waters occur within this range of soil depth tends to suggest that the ground water in the study area is one of the important sources of salts in the soils of the area studied.

The domination of salts in the ground water is in accordance with the geology of the slopes of Uluguru Mountains and the associated piedmont which extends towards the Ngerengere river. The main minerals constituting the parent materials of this area are plagioclase feldspars, oligoclase, diopside, biotite, hornblende, garnet and hypersthene which are basic minerals. Upon weathering of these minerals the bases are released and dissolved in the soil solution which constitute the ground water of the low lying areas.

The differences in pH, ECw and TSSC observed in the ground water studied is of great interest in relation to the spatial distribution of salts over the area studied. This affirms the need for conducting detailed survey when studying salt affected soils.

The ionic composition of ground waters also indicates different concentrations of soluble cations and anions. On the basis of the criterion established by Richards (1954), ChP1 and ChP2 ground waters had low sodicity while the rest of the ground waters had very high sodicity hazard.

4.4.3 Mineralogical and chemical composition of rocks

Three types of rocks existed in the studied area. These include basic gneiss, amphibolite and hornblendite (Table 20). There were two types of basic gneiss rocks. The first one had the following minerals in order of decreasing abundance: plagioclase feldspars > quartz > hornblende > anorthite feldspars and garnet. The second gneiss rocks had the following minerals in order of decreasing abundance: hornblende-amphiboles > plagioclase feldspar > pyroxenes-diopside and augite > garnet > quartz and opaque minerals. The amphibolite had the following mineral in order of decreasing abundance: amphiboles > hornblende > plagioclase feldspars > quartz, while the hornblendite had the following distribution hornblende > pyrosine >

plagioclase feldspar > quartz > garnet.

All rocks studied had considerable amounts of bases. in most of the rock samples, such bases were in the order: Mg > Ca > Na > K (Table 20).

Table 20. Content of bases in the different rocks studied.

Rock type	Ca	Mg	K	Na
	-----------cmol(+)/kg-----------			
Basic gneiss	19.5	16.9	6.0	6.2
Basic gneiss	28.7	66.8	6.0	13.3
Amphibolite	21.3	30.1	6.2	8.5
Hornblendite	31.1	49.3	6.6	10.6

According to Bhargava *et al.* (1981), plagioclase releases large quantities of calcium, magnesium, sodium and potassium carbonate on weathering. These cations (salt constituents) could be gradually released to the drainage upon chemical weathering of rocks and minerals, hence, contributing salt accumulation (van der Molen, 1984; Abrol *et al.*, 1988). The high levels of bases in the rocks studied provide some elements which could assist in advancing the hypothesis of the contribution of solutions from the weathering of the rocks to the salinisation of the soils studied.

4.4.4 The clay mineralogy of the soils

The x-ray diffractograms for studied soils are indicated on Figure 6a and 6b. The x-ray diffraction pattern of the clay minerals did not differ very much from one soil to another. The results indicate that the soils studied exhibit mixed clay minerals. Both 1:1 and 2:1 silicate minerals were present in the studied soils. Magnesium (Mg^{2+}) saturated, air dried samples showed sharp x-ray diffraction peaks at 3.2Å, 3.6Å, 4.2Å, 4.4Å, 4.9Å, 5.0Å, 6.5Å, 7.4Å, 7.5Å, 7.6Å, 10.1Å, 10.2Å, 10.3Å, 15.2Å and 15.8Å. Some of peaks formed at 15.2Å and 15.8Å shifted to 17.7Å and 19.2Å respectively upon glycerol solvation, indicating swelling properties. After potassium (K^+) saturation and heating the 15.2Å and 15.8Å peaks collapsed towards 12Å. This behaviour indicates the presence of smectite minerals (Borchardt, 1989). The predominant characteristic peak at 10.1 Å to 10.3 Å and its second order at 5 Å in all treatments indicate the presence of micaceous clay notably illite. The basal spacing of 7.4Å, 4.4Å, 3.6Å and 3.5Å is an indication of the presence of kaolinite or halloysite (Dixon, 1989). The peak at around 4.2Å basal spacing observed in magnesium saturated, air dried samples indicates the presence of goethite (Dixon and Weed, 1989).

The presence of expanding 2:1 clay minerals, notably smectite could affect soil drainage. Since smectites have ability to shrink and swell. This behaviour is known to account for the poor drainage of swelling-shrinking type of soils. Among the consequences of the blockage of pores due to swelling is the slow removal of the excess salts upon irrigation or when it rains. This creates favourable conditions for salt accumulation. Presence of smectites in the soil is associated with relatively high CEC the extent of which depend on the proportion of the former with respect to other clays (Borchardt, 1989). The majority of the horizons of the soils studied have CEC which range between 47 and 65 cmol(+)/kg clay. According to Van Hoorn (1971) the relative high CEC observed could act as a risk factor for the alkalinization and salinisation of these soils.

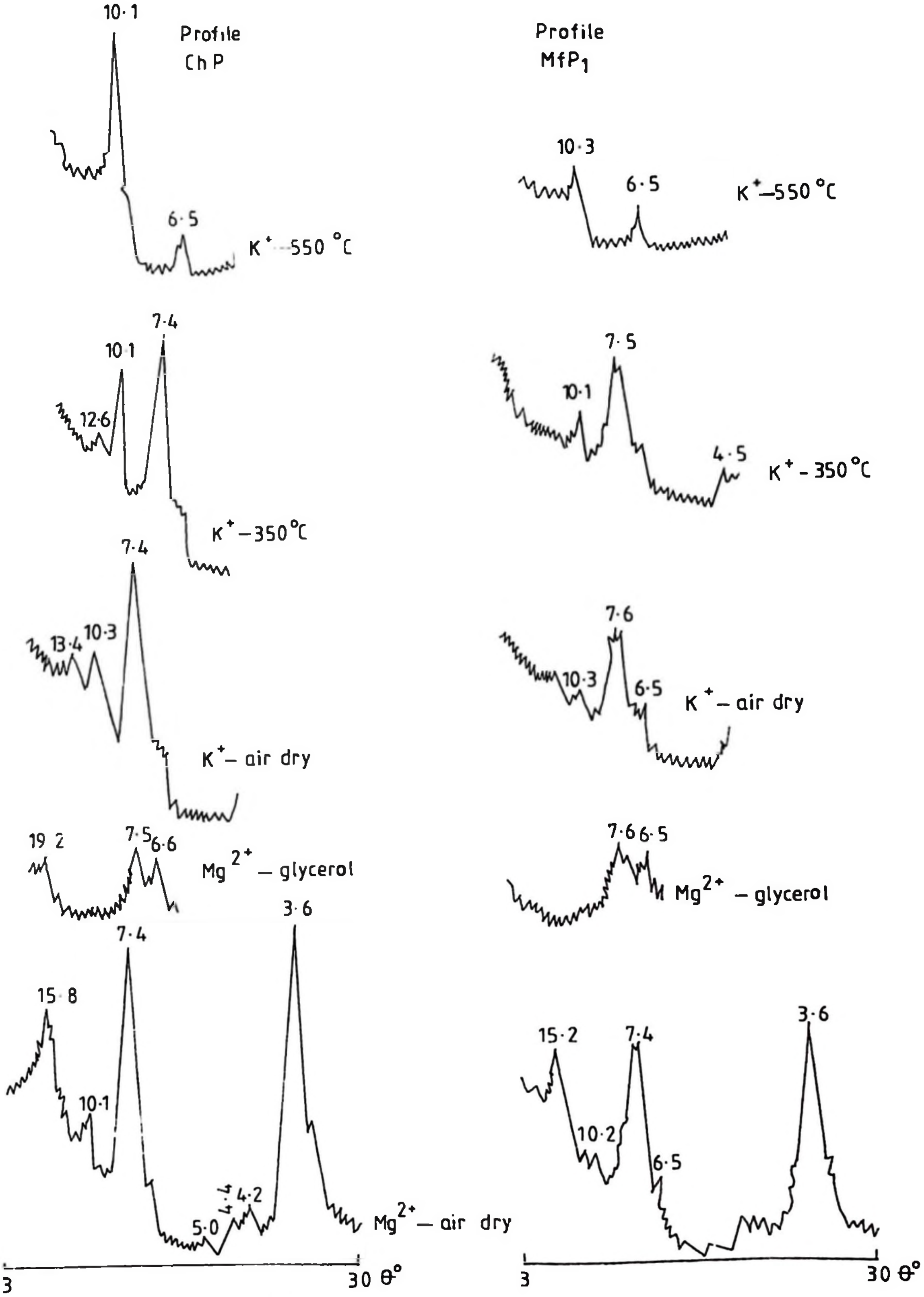

Figure 6a. X-ray diffractograms of clay sample from soil profiles ChP and MfP1 (units in Å).

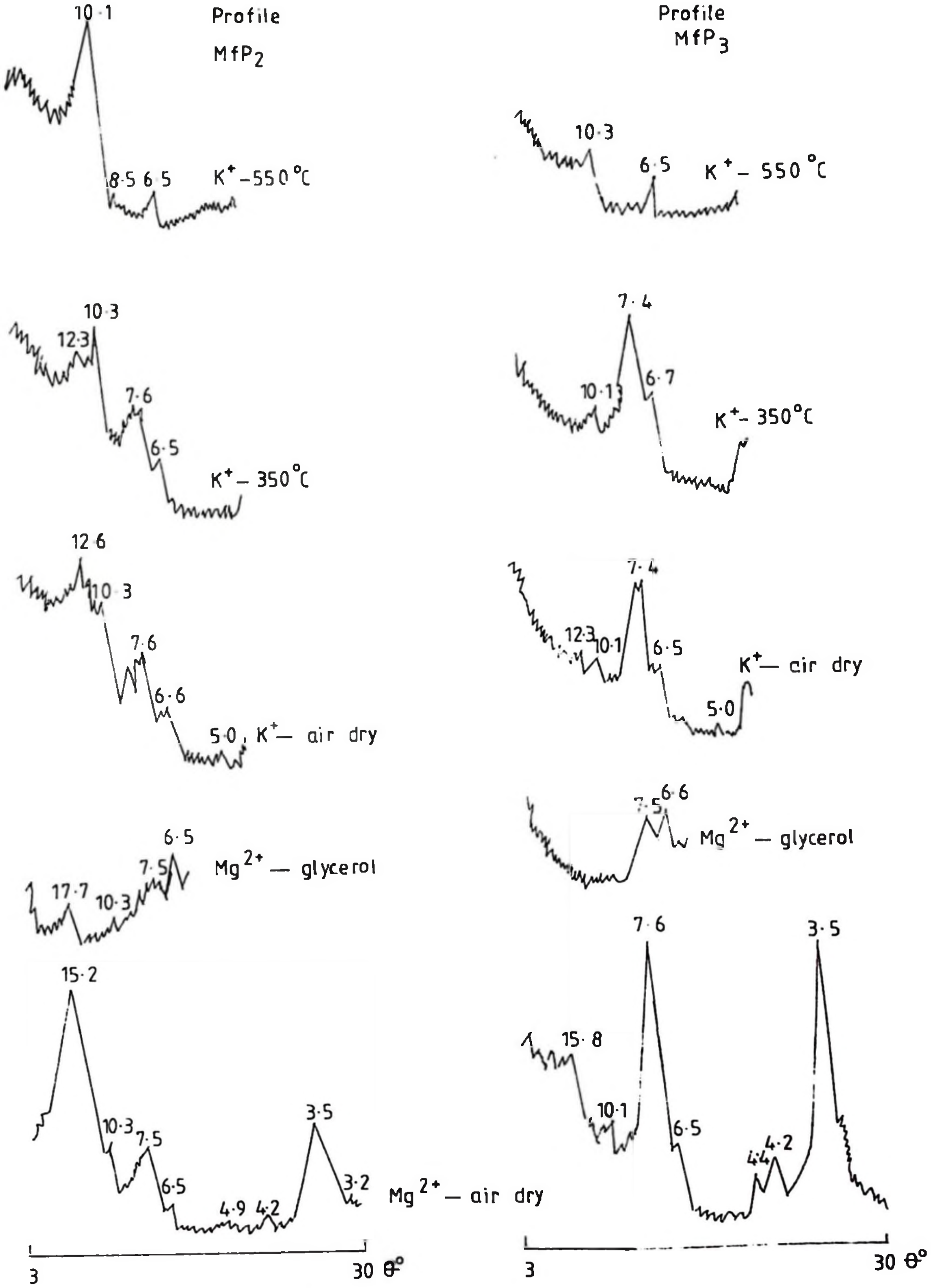

Figure 6b. X-ray diffractograms of clay sample from soil profiles MfP2 and MfP3 (units in Å).

The Ngerengere river water falls under normal to low salinity water with high sodicity hazard (Richards, 1954; Gupta, 1979; FAO, 1985). The Chamwino and Tumbaku water are within high to very high salinity water with slight to moderate sodicity hazard while those from Heavy plant and Manzese streams lie within the medium and high salinity water with slight to moderate sodicity hazard (Richards, 1954; FAO, 1985). All stream and river waters have the potential to cause salinity. Large differences exist among the different waters. This could be reflected on the nature and magnitude of salinity deposited along their course. Changes from dry to wet season or the opposite is associated with large differences in total salt content, pH and the concentration of the individual cations and anions.

The ChP1 and ChP2 ground water could be categorized as very high salinity water with low to medium sodicity hazard, while those from the rest of the soil profiles fall under the very high salinity and sodicity water category (Richards, 1954). Ground water is therefore the major direct source of salinity in the soils studied.

The formation of sodic soils in the study area might have been caused either by the accumulation of sodium, carbonate and bicarbonate under the influence of the ground water (Allison, 1964; Elgabaly, 1971b; Duchaufour, 1982). This may be substantiated by the relatively high content of sodium, bicarbonates and carbonates in nearly all ground waters studied.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This study was carried on a soil affected zone within the Ngerengere river flood plain. Following detailed characterization, the soils occurring in the area were classified as Vertic Halaquepts (Gleyic Solonchak with Sodic phase), Typic Natrustalf (Chromic Luvisols with Sodic phase), Typic Natraqualf (Gleyic Luvisols with Strongly Sodic phase) and Salorthidic Natrustalfs (Sodic Solonchak). These soils are salt affected. The Gleyic Solonchack and the Chromic Luvisols fall under the category of saline and intergrade between sodic and normal soils respectively. The Gleyic Luvisols and Sodic Solonchack correspond with sodic and saline-sodic soils respectively. Large differences exist among them in terms of the type and concentration of individual cations and anions they contain. The vertical distribution of cations and anions in the soil is another important variable in the soils. There is a net domination of chloride and sodium ions in the soils studied, although the content of sulphate, carbonate and bicarbonate may be considerably high in certain areas. The major types of salinity in the root zone (0 - 50 cm) of the soils studied are: calcium-magnesium, sodium-calcium and sodium carbonate chloride.

The distribution of salt affected zones in the field is heterogenous. Patches of salts of different sizes and shapes exist in the study area. These patches differ in the degree of salinization. The latter is related to the rice crop performance. Of all soils studied the largest variations of salt patches exist in the saline-sodic soils.

The area under the study is faced with two main sources of salts, the surface and the ground water. The chemical composition of the surface water varies from one source to another. Three main categories of water appear to influence the zone studied and similar areas within the water catchment of the northern slopes of the Uluguru Mountains. These are: the low salinity, high sodicity hazard water of the Ngerengere river; the medium to high salinity, moderate sodicity water of the Manzese and Heavy plant streams and lastly the high to very high salinity, slight to moderate sodicity hazard of the Chamwino and Tumbaku streams. The soils occurring within or which border these water ways are correspondly affected by the type and extent of salinization. The chemical composition of the water also varies with the season, the most important changes are those associated with the concentration of chloride, sodium and calcium ions. The ground water influenced directly the accumulation of salts in the soils studied. Like the surface water, the ground water was rich in chlorides, carbonates and bicarbonates of sodium. The content of calcium, magnesium and sulphate was much far lower, though the concentration of potassium and nitrate was the lowest. Like with the surface water the chemical composition of the ground water varied considerably. With respect to salinity and/or sodicity categorization, the ground water fell into two main categories: (i) very high salinity, low to medium sodicity hazard and (ii) very high salinity and sodicity hazard waters.

The primary source of salts is the weathering rocks within the drainage system affecting the soils studied. However, comparison between the chemical composition of the weathering rocks and that of ground water show a relative increase of sodium in the ground water and a relative decrease of both calcium and magnesium. The big difference in the composition of bases between the weathering rocks and the ground waters is attributed to the higher affinity of soil clays to bivalent compared to monovalent bases.

The problem of salinity in agricultural lands is an important issue in Tanzania. There is large number of river plains that are put under cultivation particularly for the production of paddy. In these areas problems of salt affected soils exist. Monitoring of salt development is a necessity in these areas. The proposed method of measuring salinity in the field could be a very useful tool for monitoring salt development in these vast lands under production to monitor salt development. It is being advised that more studies be carried along this line in order to develop a field based test procedure which correlates with the standard laboratory method. The advantage of this approach is that there will be less dependence on the high skilled, very expensive very high intensity soil survey which most farmers cannot afford.

From the management point of view, each of the four soils studied require a different approach with respect to control or prevention of the salinization or alkalization process. The saline soils require measures which will leach and drain salts from the root zone and/or below the soil solum. A combination of leaching and drainage construction may suffice to reduce or eliminate the salinity problem. The sodic soils and the intergrade sodic-normal soils need eradication of alkalinity problem which becomes prominent in the lower horizons. Neutralization of the alkalinity by use of gypsum associated with subsurface drainage will ensure removal of the problem. The saline- sodic soils require a combination of measures which will neutralize, leach and drain salts from the root zone. In this case, leaching of salts and neutralization of the alkalinity by use of gypsum associated with subsurface drainage will ensure removal of the problem.

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APPENDICES

Appendix 1: Soil profile descriptions

Appendix 1.1. Soil profile number ChP

General information on the site and soil

Author and date of examination: Kaboni, E.L., 26 December 1994. **Location:** Chamwino village, about 320 m E of Chamwino - Mazimbu electric power line, 406 m E of Ngerengere river, 50 m W of Chamwino village, latitude 6°49'00" S and longitude 37°38'10" E. **Elevation:** 465 m a.m.s.l. **Landform:** river flood plain. **Slope of site:** 0.5 - 1 %. **Vegetation and landuse:** the site is dominated by salt loving shrubs, grasses and very few trees. The land was formally under sisal plantation, currently it is under subsistence agriculture, and crops being grown include: coconuts, bananas, maize and rice. **Season/weather conditions:** two rainy seasons, unreliable, the two are separated by a long dry season. **Parent material:** alluvial/colluvial. **Drainage:** class 1 - poorly drained. **Flooding or ponding:** common during heavy rains. **Moisture conditions in profile or soil:** the soil profile was dry 15 cm from the surface, and moisture increases with depth. **Depth of ground water table**: 200 cm and rises up to 64 cm. **Cracks:** many, 0.5 - 1 cm wide, extending down ward to about 6 cm deep. **Evidence of erosion:** very slight water erosion. **Presence of salt or alkali:** class 3, soils strongly affected by salt or alkali. **Human**

influence: clearing of vegetation for agriculture. **Soils**: very deep, poorly drained, mottled, very dark brown to dark greyish brown top soil with dark greyish brown to brown subsoil, clay, strongly saline with high soluble sodium, slightly calcareous with strongly calcareous deeper subsoil.

Soil classification: Gleyic Solonchak, Sodic phase (FAO, 1988), Vertic Halaquepts (USDA, 1990).

Soil profile description.

Apz 0-15 cm	Dark brown (10YR3/3) moist and dry, few, fine to medium, faint, diffuse, dark yellowish brown mottles; clay loam; strong, fine to very fine coarse granular, angular and subangular blocky structure; sticky, plastic wet, very friable moist, hard dry; many very fine and fine pores and many medium and coarse pores; very few, small, fresh, irregular quartz, feldspars and thin mica; very few, small, hard, spherical and irregular iron - manganese and carbonate nodules; slightly calcareous; few very fine roots; clear, smooth boundary towards BA.
BA 15-30 cm	Very dark brown (10YR2/2) moist and dark greyish brown (10YR4/2) dry, common, fine to medium, faint, diffuse, brown to dark brown mottles; clay; strong, fine to very

coarse angular and subangular blocky structure; sticky, plastic wet, very friable moist, hard dry; many very fine and fine pores and common medium and coarse pores; very few, small, fresh, irregular quartz, feldspars and thin mica; very few, small, hard, angular, black and brown iron - manganese nodules; slightly calcareous; few very fine roots; clear, smooth boundary towards Bg1.

Bg1
30-64 cm
Very dark greyish brown (10YR3/2) moist and dark greyish brown (10YR4/2) dry, common, fine to medium, faint, diffuse, brown to dark brown mottles; heavy clay; strong, fine to very coarse angular and subangular blocky structure; very sticky, very plastic wet, friable moist, very hard dry; common very fine, fine, medium, coarse and very coarse pores; very few, small, fresh, irregular quartz, feldspars and thin mica; very few, small, hard, angular, black and brown iron - manganese nodules; slightly calcareous; few very fine roots; clear, smooth boundary towards Bg2.

Bg2
64-92 cm
Brown to dark brown (10YR4/3) moist and dark yellowish brown (10YR4/4) dry, many, coarse prominent, sharp, dark yellowish brown mottles; heavy clay; moderate, very fine to coarse angular and subangular blocky structure; very

sticky, very plastic wet, friable moist, very hard dry; common very fine, fine and medium pores; very few, small, fresh, irregular quartz and thin mica; very few, small, hard, spherical iron - manganese and irregular, white carbonate nodules; slightly calcareous; few very fine roots; clear, smooth boundary towards Bg3.

Bg3
92-200cm+

Brown to dark brown (7.5YR4/4) moist and strong brown (7.5YR5/6) dry, many, coarse and medium, prominent, sharp, brown to dark brown mottles; clay; moderate, very fine to coarse angular and subangular blocky structure; very sticky, very plastic wet, friable moist, very hard dry; common fine and medium pores; few, medium, fresh, irregular quartz feldspar and mica; few, medium, soft and hard, spherical and irregular, black and brown iron - manganese and whitish carbonate nodules; strongly calcareous; few very fine roots.

Appendix 1.2. Soil profile number MfP1

General information on the site and soil

Author and date of examination: Kaboni, E.L., 29 December 1994. **Location:** Mafiga A, about 150 m E of Ngerengere river 800 m SW of Chamwino village, latitude 6°49' 11" S and longitude 37°38'00" E. **Elevation:** 460 m a.m.s.l. **Landform:** terrace. **Slope of site:** gently sloping (3 %).

Vegetation and landuse: the site is dominated by salt loving shrubs and scattered short grasses. The land was formally under sisal plantation, currently it is not cultivated but the neighbouring areas are cultivated with bananas, maize and rice. The land preparation is usually done by hand hoe or ploughed by a tractor. **Season/weather conditions:** two rainy season, one of them being unreliable, the two are separated by a long dry season. **Parent material:** colluvial. **Drainage:** class 2 - imperfectly drained. **Ponding:** frequent during rainfall. **Moisture conditions in profile or soil:** the soil profile was dry from the surface to 115 cm and moisture increases with depth. **Depth of ground water table**: more than 200 cm and it rises up to 95 cm. **Cracks**: very few. **Evidence of erosion:** very slight water erosion. **Presence of salt or alkali:** class 2, soils moderately affected by salt or alkali. **Human influence:** clearing of vegetation for agriculture.

Soils: very deep, imperfectly drained, mottled, dark brown to dark reddish brown top soil with red to dark red subsoil, sand clay loam to clay, none to slightly saline with relatively high sodium content especially in the subsoil, slightly calcareous.

Soil classification: Chromic Luvisols, Sodic phase (FAO, 1988), Typic Natrustalf (USDA, 1990).

Soil profile description.

Ap 0-15 cm	Dark brown (7.5YR3/4) moist and dry, sand clay loam; moderate, very fine to coarse granular, angular and subangular blocky structure; sticky, plastic wet, very friable moist, hard dry; many very fine and fine pores and common, medium and coarse pores; very few, small, fresh, irregular quartz; many very fine to medium roots; abrupt, smooth boundary towards Bg.
Bg 15-45 cm	Yellowish red (5YR4/6) moist and dark reddish brown (5YR3/4) dry, common, fine, faint, diffuse, dark reddish brown mottles; clay; strong, medium to very coarse angular and subangular blocky structure; very sticky, very plastic wet, extra firm moist, extra hard dry; many micro, very fine and fine pores and few medium and coarse pores; very few, small, fresh, irregular quartz and feldspars; slightly calcareous; many very fine to fine roots; clear, irregular

	boundary towards Btgn.
Btgn 45-115 cm	Dark red (2.5YR3/6) moist and dry, common, fine, distinct, diffuse, dark reddish brown mottles; clay; strong, very fine to medium angular and subangular blocky structure; very sticky, very plastic wet, extremely firm moist, extra hard dry; abundant, moderately thick clay cutans; many micro to fine pores and few medium and coarse pores; very few, small, fresh, irregular quartz and feldspars; slightly calcareous; common very fine roots; gradual, smooth boundary towards Btg.
Btg 115-200 cm +	Red (2.5YR4/6) moist and dry, many, coarse, prominent, sharp, dark reddish brown mottles; clay loam; strong, very fine to medium angular and subangular blocky structure; sticky, plastic wet, friable moist, hard dry; abundant, thick clay cutans; many micro to fine and few medium and coarse pores; few, small, fresh, irregular quartz and thin mica; few, small and medium, hard, spherical and irregular, black, brown iron - manganese and irregular, white carbonate nodules; slightly calcareous; few very fine and very few medium roots.

Appendix 1.3. Soil profile number MfP2

General information on the site and soil

Author and date of examination: Kaboni, E.L., 1 January 1995. **Location:** Mafiga A, about 160 m E of Ngerengere river, 350 m W of Kidatu electric power line, 625 m N of sisal factory, latitude 6°49'19" S and longitude 37°38'02" E. **Elevation:** 450 m a.m.s.l. **Landform:** river flood plain **Macrotopography:** gently undulating. **Slope of site:** gently sloping (2-3%). **Vegetation and landuse:** the site is dominated by scattered short grasses with very few scatter salt loving shrubs. The land was formally under sisal plantation, currently it is under maize cultivation. The land preparation is usually done by hand hoe or by ploughing with a tractor. **Season/weather conditions:** two rainy season, one of them being unreliable, the two are separated by a long dry season. **Parent material:** Alluvial - colluvial. **Drainage:** class 1 - poorly drained. **Flooding or ponding:** very frequent during heavy rains. **Moisture conditions in profile or soil:** the soil profile was dry from the surface to 110 cm and moisture increases with depth. **Depth of ground water table**: beyond 200 cm and it rises up 100cm. **Cracks**: very few. **Evidence of erosion:** very slight water erosion. **Presence of salt or alkali:** class 2, soils moderately affected by salt or alkali. **Human influence:** clearing of vegetation for agriculture.

Soils: very deep, poorly drained, mottled, dark brown to very dark greyish brown top soil over dark brown to dark yellowish brown subsoil, sand clay over clay subsoil, slightly saline with high soluble sodium content, slightly calcareous top soil to strongly calcareous sub soil.

Soil classification: Gleyic Luvisols, Strongly Sodic phase (FAO, 1988), Typic Natraqualf (USDA, 1990).

Soil profile description.

Apz 0-35 cm	Very dark greyish brown (10YR3/2) moist and very dark brown (10YR 2/2) dry, few, fine, faint, diffuse dark yellowish brown mottles; sand clay; strong, fine and coarse granular and subangular blocky structure; very sticky, very plastic wet, firm moist, hard dry; many very fine and few medium and coarse pores; very few, small, fresh, irregular quartz and feldspar; very few, small, hard, spherical and irregular whitish carbonate, brown manganese and iron nodules; slightly calcareous; common very fine roots; clear, smooth boundary towards Btgn1.
Btgn1 35-110 cm	Dark brown (10YR3/3) moist and brown to dark brown (105YR4/3) dry, common, fine and medium, distinct, clear yellowish brown mottles; sand clay; strong, fine to coarse angular and subangular blocky structure; very sticky, very

plastic wet, firm moist, hard dry; many very fine and common fine pores; very few, small, fresh, irregular quartz and feldspars; very frequent, small and medium, hard, round and irregular white carbonate and black manganese nodules; presence of termites burrowing; strongly calcareous; few very fine and fine roots; clear, irregular boundary towards Btgn2.

Btgn2 110-200 cm +	Dark yellowish brown (10YR4/4) moist and dark yellowish brown (10YR4/6) dry, many, coarse, prominent, sharp, dark yellowish brown mottles; clay; strong, fine to coarse angular and subangular blocky structure; very sticky, very plastic wet, firm moist, hard dry; abundant, thick clay cutans; many very fine and few medium and coarse pores; very few, small to medium, fresh, irregular quartz and feldspar , and weathered mica; frequent, small, medium and large, hard, angular and irregular, whitish carbonate, brown and blackish iron and manganese nodules; strongly calcareous; presence of termites burrowing; few very fine and fine roots.

Appendix 1.4. Soil profile number MfP 3

General information on the site and soil

Author and date of examination: Kaboni, E.L., 5 January 1995. **Location:** Mafiga A, 300 m N of sisal factory, 8 m W of Kidatu electric power line, about 250 m E of Ngerengere river, latitude 6°49'31" S and longitude 37°38'02" E. **Elevation:** 460 m a.m.s.l. **Landform:** river flood plain. **Microtopography:** ridges. **Slope of site:** gently sloping (1-2%). **Vegetation and landuse:** the site is dominated by grasses with very few trees and shrubs. The area was formally under sisal estate, currently it under subsistence agriculture and main crops being grown are rice and maize. The land preparation is usually done by hand hoe. **Season/weather conditions:** two rainy seasons, unreliable, the two are separated by a long dry season. **Parent material:** Alluvial/ colluvial. **Drainage:** class 1 -poorly drained. **Flooding or ponding:** very frequent during heavy rains. **Moisture conditions in profile or soil:** the profile was moist throughout and moisture increased with depth. **Depth of ground water table:** 200 cm and it rises up 55 cm. **Cracks:** many, 0.1 - 1.2 cm wide, extending downward to about 15 cm deep. **Evidence of erosion:** slight water erosion. **Presence of salt or alkali:** class 3, soils strongly affected by salt or alkali. **Human influence:** clearing of vegetation for agriculture, ridging and making of bands for rice cultivation.

Soils: very deep, poorly drained, mottled, dark yellowish brown top soil over reddish brown to yellowish red subsoil, sand loam surface soil over heavy clay, with frequent nodules in the deeper subsoil, strongly saline with very high amounts of sodium, strongly calcareous.

Soil classification: Sodic Solonchak (FAO, 1988), Salorthidic Natrustalfs (USDA, 1990).

Soil profile description.

Apz	Dark yellowish brown (10YR4/6) moist, sand loam;
0-10 cm	strong, very fine to coarse granular and subangular blocky structure; non sticky, non plastic wet, very friable moist, soft dry; common micro and very fine pores and few fine and medium pores; strongly calcareous; common very fine and fine, few medium roots; abrupt, smooth boundary towards Btgn1.
Btgn1	Dark brown (10YR3/3) moist and very dark brown
10-20 cm	(10YR2/2) dry, few, medium, distinct, clear, brown to dark brown mottles; clay; strong, fine to coarse angular and subangular blocky structure; very sticky, very plastic wet, firm moist, very hard dry; many micro to fine and common medium pores; very few, small, fresh, irregular quartz; very few, small and medium, hard, round and irregular whitish carbonate, brown and black iron and manganese nodules; strongly calcareous; few

	very fine and fine roots; clear, irregular boundary towards Btgn2.
Btgn2 20-35 cm	Dark reddish brown (10YR3/3) moist and dry, few, medium, distinct, clear, brown to dark brown mottles; heavy clay; strong, fine to coarse angular and subangular blocky structure; very sticky, very plastic wet, firm moist, very hard dry; many micro very fine and fine pores and common medium pores; very few, small, fresh, irregular quartz; few, small and medium, hard, spherical and irregular whitish carbonate, blackish manganese and iron nodules; strongly calcareous; few very fine and fine roots; clear, irregular boundary towards Btgn3.
Btgn3 35-125 cm	Reddish brown (10YR4/4) moist and dry, common, medium and coarse, distinct, sharp, red to reddish brown mottles; heavy clay; strong, fine and coarse angular and subangular blocky structure; very sticky, very plastic wet, firm moist, very hard dry; abundant, moderately thick clay cutans; many micro very fine and fine pores, and few medium pores; very few, small, fresh, irregular quartz; few, small, medium and large, hard, spherical and irregular carbonate, and manganese nodules; strongly calcareous; few very fine roots; gradual, smooth boundary towards Btgn4.
Btgn4	Yellowish red (10YR5/8) moist, many,

125-200 cm +	medium and coarse, prominent, sharp, yellowish red mottles; heavy clay; strong fine medium and coarse angular and subangular blocky structure; very sticky, very plastic wet, friable moist, hard dry; abundant, thick clay cutans; many micro very fine and fine pores, and may medium pores; very few, small, fresh, irregular quartz; frequent, small, medium and large, hard irregular carbonate nodules; strongly calcareous; few very fine and fine roots.

Appendix 2a. Type of salinity based on the ratio of the concentration of selected soluble cations.

Profile	Depth (cm)	Na/Mg	Na/Ca	Mg/Ca	salinity type
ChP	0-15	0.9	0.2	0.2	Ca - Mg
	15-30	0.3	0.2	0.6	"
	30-64	0.6	0.3	0.6	"
	64-92	0.9	0.7	0.7	"
	92-200 +	0.8	0.5	0.6	"
MfP 1	0-15	0.3	0.1	0.5	"
	15-45	0.7	0.5	0.8	"
	45-115	1.7	1.2	0.7	Ca - Na
	115-200 +	1.9	0.9	0.9	Na - Ca
MfP 2	0-35	0.6	0.5	0.8	Ca-Mg,Na-Ca
	35-110	1.7	0.8	0.5	Na - Ca
	110-200 +	1.7	0.6	0.5	"
MfP 3	0 - 8	9.0	0.9	0.1	Na - Ca
	10-20	4.7	3.1	0.7	Ca - Na
	20-35	1.7	1.3	0.8	"
	35-125	2.8	4.1	1.5	Mg - Na
	125-200+	3.4	1.3	0.4	Ca - Na

Appendix 2b. Type of salinity based on the ratio of the concentration of selected soluble anions.

Profile	Depth (cm)	Cl/SO_4	HCO_3/Cl	HCO_3/SO_4	Salinity type
ChP	0-15	11.8	0.1	0.6	Cl
	15-30	2.2	0.1	0.2	SO4-Cl
	30-64	6.7	0.1	0.5	Cl
	64-92	114.8	0.1	5.1	Na_2CO_3-Cl
	92-200 +	76.7	0.1	8.2	Na_2CO_3-Cl
MfP1	0-15	6.7	0.1	0.3	Cl
	15-45	1.7	0.1	0.1	SO_4-Cl
	115-200 +	26.3	0.3	6.9	Na_2CO_3-Cl
MfP2	35-110	35.2	0.2	8.5	Na_2CO_3-Cl
MfP3	0-8	8.6	0.3	2.4	Na_2CO_3-Cl
	10-20	12.7	0.4	4.7	Na_2CO_3-Cl
	35-125	2.1	0.4	0.9	SO_4-Cl
	125-200 +	10.3	0.2	1.6	Na_2CO_3-Cl