CHEMICAL AND PHYSICAL PROPERTIES OF SOME SALT AFFECTED SOILS FROM MOROGORO AND KILIMANJARO REGIONS, TANZANIA

BY

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ABSTRACT

A study was undertaken to assess the types and quantities of soluble salts in some soils of Morogoro and Moshi districts, Tanzania which have been suspected to contain substantial amounts of soluble salts that have contributed to poor crop performances. The selection of the sampling sites was based on soil information and crop performance gathered from the farmers, research and extension reports and soils and geological maps. In total 22 soil samples to the depth of 30 cm were collected from eight sites and analysed for the various soil properties for soil fertility characterization and properties used for the characterization of salt affected soils using the standard recommended procedures. The soils from the eight sites varied tremendously in terms of soil fertility status and amounts of soluble salts. Based on the pH, ECe, ESP and SAR, the soils of SUA Farm 1 and 3, Mafiga 2, Kahe 1 and 2, Kikafu chini 2 and Soko 3 were categorized as saline-sodic, those of SUA Farm 2 and 4, Kidamke 1, Mafiga 1, Kikafu chini 1, Soko 1, 2a, 2 and 4 as sodic, and those of Kidamke 2, and 3, Dakawa 1, 2, 3 and Cholima as not salt affected. The dominant cations and anions in the soils were sodium, calcium, sulphate, bicarbonates and chloride, respectively. The soluble salts in the saline-sodic and sodic soils were assumed to be mostly Na_2SO_4 and $NaHCO_3$. The possible formation, development and accumulation of the soluble salts in the soils include weathering of rocks and accumulation due to poor drainage. For increased and sustainable crop production for the saline-sodic and sodic soils, the soluble salts and exchangeable Na, respectively, have to be reduced by leaching and neutralization using gypsum to levels suitable for crop production. The growing of salt tolerant crops like rice could be another soil-crop management option for sustainable use of the saline-sodic and sodic soils.

DECLARATION

I, DONALD GERVAS, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and has not been submitted for a higher degree award in any other University.

Signature...

Date......20/03/2003......

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DEDICATION

To my parents Gervas and Sofia who exhausted their meagre resources to lay down a concrete foundation for my education.

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LIST OF ABBREVIATIONS AND SYMBOLS

^0C = degree Celsius

$AgNO_3$ = Silver nitrate

B^- = Boron ion

Ca^{2+} = Calcium ion

$CaCl_2$ = Calcium chloride

$CaSO_4.2H_2O$ = Gypsum

CEC = Cation exchange capacity

Cl^- = Chloride ion

Cmol(+)/kg = centimole per kilogram

CO_2 = Carbondioxide

CO_3^{2-} = Carbonate ion

CsCl = Cesium chloride

Cu = Copper

dS/m = decisiemen per meter

E = East

EB = exchangeable bases

ECe = Electrical conductivity

ESP = Exchangeable sodium percentage

FAO = Food and Agricultural Organization

Fe = Iron

H_2SO_4 = Sulphuric acid

ha = hectare

HCO_3^- = Bicarbonate ion

K^+ = Potassium ion

K_2CrO_4 = Potassium dichromate

Kg = Kilogram

l = litre

La_2O_3 = Lanthanum oxide

m = metre

mg/kg = milligram per kilogram

mg/l = miligram per litre

Mg^{2+} = Magnesium ion

Mn = Manganese

N = Nitrogen

Na^+ = Sodium ion

Na_2CO_3 = Sodium carbonate

Na_2SO_4 = Sodium sulphate

NaCl = Sodium chloride

NH_4^+ = Ammonium ion

nm = nanometer

NO_3^- Nitrate ion

OC = Organic carbon

S = South

SAR = Sodium adsorption ratio

SO_4^{2-} = Sulphate ion

SUA = Sokoine University of Agriculture

TPC = Tanganyika Planting Company

UNESCO = United Nations Educational, Science and Cultural Organization

y = year

Zn = Zinc

> = greater than

< = less than

CHAPTER ONE

1.0 INTRODUCTION

Salt-affected soils are the soils that have excessive concentrations of soluble salts or adsorbed sodium or both in the root zones to levels that affect most crops in terms of nutrients and moisture availability (James *et al.*, 1982). Salt affected soils occur in all continents and under almost all climatic conditions, but their extent and distribution has not been studied in detail. However, their distribution is relatively more extensive in the low-lying areas of arid and semi-arid regions as compared to the humid regions. The arid and semi-arid areas receive limited amounts of rainfall to wash away the salts from the rootzone, and such soils are characterized by poor natural drainage due to high contents of clay.

In Tanzania about 3.6 million hectares of land have salt problems of one kind or another (Massoud, 1977). A report by De Pauw (1984) shows the occurrence of these soils to be extensive in area with arid and semi-arid climates where precipitation is usually insufficient to meet the evapotranspiration (ET) needs. Based on the FAO/UNESCO Soil Map of the World, of the estimated 3.6 million ha of the salt-affected soils in Tanzania (Massoud, 1977), 1.7 million ha are saline soils, 300,000 ha are sodic soils and 1.6 million ha are saline-sodic soils. The problems of salinity and sodicity of varying degrees are common in irrigation schemes such as at the Tanganyika Planting Company (TPC) Kilimanjaro Region as reported by Kiwale, (1999). Furthermore, the salt problems or salt-affected soils are common in lowlands of arid and semi arid areas of some parts of Dodoma, Mwanza, Shinyanga, Kilimanjaro, Singida, Mara, Rukwa, Coast region, Mtwara, Lindi and Morogoro (Hathout; 1977; De Pauw, 1984).

According to De Pauw (1984), the salt affected soils in Tanzania under cultivation are less than 16% of the 3.6 million ha (576 000 ha). This implies that, more than 84% (3 024 000 ha) of the salt affected soils are not under crop production due to high salinity or sodicity problems or both salinity and sodicity. The total salt affected area in Tanzania is expanding substantially due to some irrigation schemes being abandoned. The abandonment is due to the increase in severity of salinity or sodicity problems which have lead to poor crop performance (Kiwale, 1999). However, with proper management of the soils and water for irrigation many arid and semi-arid salt affected soils could be highly productive especially for salt-loving or salt-tolerant crops or when areas with these problematic soils are used for recreational purposes. The soluble salts can be removed from the rootzone by scraping, flushing, and leaching. On the other hand for sodic and saline-sodic soils, the exchangeable sodium can be replaced by calcium through various soil amendments such as the application of gypsum ($CaSO_4.2H_2O$) (Abrol *et al.* 1988). The effectiveness of the above methods of removing salts from the rootzone are dictated by local conditions, available resources and the kind of crops to be grown on the reclaimed soils.

From the management point of view, each type of salt affected soil requires a different approach with respect to the control or prevention of salinization or alkalization process, due to differences in soil physical and chemical properties

(Abrol *et al.*, 1988). Such properties include dispersion resulting in low permeability to water and air, particularly when the soils are heavy clays, and also increase in pH and toxic effect of some constituents (Abrol *et al.*, 1988). The knowledge of the physical and chemical properties of these soils could lead to designing appropriate technologies for the improvement of the production capacities of the salt affected soils in Tanzania.

Use of salt affected soils has proved highly uneconomical and disastrous in most areas in Tanzania, whereby people invest highly but they get very little out of it (Tanzania Soil Fertility Initiative, 2000). Most irrigation projects in Tanzania, such as Kilingali rice seed farm, Dakawa rice farm, Ruvu rice farm and Kahe maize and Lucerne farms have failed to meet their very high initial capital investments. This may be because critical investigations of the chemical and physical properties, behaviour of the soils as well as the quality of irrigation water, and their response to cultivation were not undertaken. Taking into account that the availability of arable land in Tanzania has decreased, the use of marginal lands like salt affected soils for agricultural production is inevitable. There is a need, therefore, to undertake critical investigations on the chemical and physical properties and behaviour of the various categories of salt affected soils. This will enable various parties to develop management packages for each category of salt affected soils, so as to improve and sustain soil productivity.

The general objective of this study was to determine the types and quantities of soluble salts in the Kidamke (Mkata), Dakawa, Cholima, Mafiga, Kahe, Soko, Kikafu Chini and SUA-farm salt affected soils.

The specific objectives were: -

(a) To determine the concentration or quantities of Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-}, B^-, ECe, ESP and SAR of the soils and pH of the saturated paste extracts;

(b) To determine the concentration or quantities of Na^+, K^+, Ca^{2+}, Mg^{2+} in the soils;

(c) Suggest way of reclaiming the salt affected soils for optimum crop production based on the data generated in (a) and (b).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Definitions and properties of salt affected soils

Different people have defined salt affected soils based on their contents of soluble salts in relation to plant growth. Salt affected soils are therefore defined as soils adversely modified for the growth of most crops by the presence or action of soluble salts (James *et al.*, 1982; Arunin, 1984). Other researchers have defined salt affected soils as soils containing salts that have accumulated in the soils' root zones to levels that adversely affect crop yields (FAO, 1985). According to Verhoeven (1972), salt affected soils can be categorized into three classes namely: saline, sodic and saline-sodic soils. The cations and anions of the soluble salts most dominant in salt affected soils include Na^+, Ca^{2+}, Mg^{2+}, and K^+, and Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, and B,$^-$ respectively.

2.1.1. Saline soils

Saline soils are soils that contain sufficient quantities of neutral soluble salts to adversely affect the growth of most crop plants. The soluble salts in saline soils are chiefly sodium chloride ($NaCl$) and sodium sulphates ($NaSO_4$). Saline soils also contain appreciable quantities of chlorides and sulphates of calcium and magnesium. It has been established that saline soils have an exchangeable sodium percentage (ESP) of less than 15, electrical conductivity (ECe) of greater than 4 decisiemen per metre (dS/m) at 25^0C and pH of the saturated pastes less than 8.5 (James *et al.*, 1982; Abrol *et al.*, 1988). In the presence of excess soluble salts the clay fraction is flocculated and the soils have stable structures. Permeability of soils to water and air and other physical characteristics are generally comparable to normal soils (Abrol *et al.*, 1988; Mnkeni, 1996; Rhoades, 1990). The flocculated nature of the clay fractions in saline soils is attributed to the presence of appreciable quantities of calcium and magnesium chlorides and sulphates.

2.1.2 Sodic soils

Sodic soils are salt affected soils that contain sodium salts capable of alkaline hydrolysis, mainly Na_2CO_3. Such soils have an ESP greater than 15, ECe of less than 4 dS/m at 25^0C, and the pH of the saturated pastes range between 8.5 - 10.5 (James *et al.*, 1982; Abrol *et al.*, 1988). Permeability of such soils to air and water is restricted due to excess exchangeable sodium and high pH (Abrol *et al.*, 1988), which disperses the clay fractions of the soils. The soils are hard and cloddy when dry and tend to crust hence restrict root growth and elongation. Thus if the exchange complexes contain appreciable amounts of sodium relative to calcium and magnesium ions, the soils may become dispersed and puddled, thereby causing poor aeration and low water infiltration (Ademba and Mugah, 1989) hence low hydraulic conductivity.

2.1.3 Saline - sodic soils

Saline-sodic soils are salt affected soils, which contain sufficient contents of both high soluble salts and high exchangeable sodium levels. Saline-sodic soils have ECe of greater than 4 dS/m at 25^0C, pH of less than 8.5 and ESP of greater than 15. (James *et al.,* 1982; Abrol *et al.,* 1988; Mnkeni, 1996). In saline-sodic soils, chlorides, sulphates and carbonates predominate while sodium and calcium occur in high and low proportions, respectively. Saline-sodic soils have been reported to contain large quantities of both soluble sodium carbonate and exchangeable sodium (Abrol and Dahiya, 1974). When excess salts are present as well as excessive sodium, the physical condition of the soil and water intake may be satisfactory, but plant growth may be restricted due to the specific ion effect of certain ions and osmotic pressure effect which inhibits water uptake (Hesse, 1971).

2.2 Origin and sources of salt affected soils

2.2.1 Chemistry of salt affected soils

According to Tanji (1990) and Abrol *et al.* (1988) the major cations in salt affected soils are Na^+, Ca^{2+}, Mg^{2+}, and, to a lesser extent, K^+. The major anions are Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-, and, at high pH, CO_3^{2-}. The ions HCO_3^- and CO_3^{2-} constitute what is referred to as carbonate alkalinity. Other ions that are sometimes present under anaerobic conditions, but neglected from a salinity viewpoint include NH_4^+, NO_2^-, and some organic anions. Although weathering of rocks and primary minerals is the chief sources of all salts, salt affected soils are rarely formed through accumulation of salts in situ (Abrol *et al.*, 1988). The major factors responsible for the formation of the three categories of salt affected soils are quite variable for example weathering, atmospheric deposition, and fossil or secondary deposition.

2.2.2 Weathering

Weathering is a spontaneous process that transforms primary minerals to other minerals that are more stable at the earth's surface. The reagents involved in geochemical weathering include atmospheric water, oxygen, and carbondioxide (CO_2). According to Tanji (1990), three types of reactions describe the chemical weathering of rock-forming minerals, hence the release of salts, namely: congruent dissolution, incongruent dissolution, and reduction-oxidation (redox) reactions.

For the congruent dissolution reaction, the solution products exist in the same proportion as they occur in the mineral and examples of congruent weathering processes include the dissolution of calcite ($CaCO_3$) and quartz (SiO_2), according to the reactions:

(i) $CaCO_3$ (calcite) + $H_2O + CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^-$

(ii) SiO_2 (quartz) + $2H_2O \leftrightarrow H_4SiO_4$ (silicic acid)

For the incongruent dissolution reaction, part of the mineral dissolves and leaves behind a secondary solid phase (secondary alumino-silicate clay minerals) that differs in composition from the original mineral. Incongruent weathering processes/ reactions, could be presented by dissolution of albite and orthoclase. (i) $2NaAlSi_3O_8$ (albite) + $3H_2O \leftrightarrow Al_2Si_2O_5(OH)_4$ (kaolinite) + $4SiO_2$ (quartz) + $2Na^+ + OH^-$

(ii) $3KAlSi_3O_8$ (orthoclase) + $CO_2 + 14H_2O \leftrightarrow 2K^+ + 2HCO_3^- + 6H_4SiO_4$ + $KAlSi_3O_{10}(OH)_2$(mica).

Changes in the oxidation states of minerals modify the weathering processes and trends of formation of minerals and rocks. Redox reactions between ions in solution and minerals in contact with the solution often influence the pH of the solution, as exemplified by the oxidation of iron sulphide;

$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \leftrightarrow Fe\ (OH)_3(S) + 4H^+ + 2SO_4^{2-}$

In this reaction, the protons (H^+) produced have a strong local influence on subsequent weathering through dissolution reactions. This provides a favourable environment for further chemical reactions, which can lead to salt accumulation.

2.2.3 Climate and landscape effects

Weathering is a continuous process in minerals, rocks and soils and occurs universally, and the intensity and extent of the weathering reactions strongly reflect the influence of climate. The presence of water is most important to the weathering process. Water serves as a reactant in mineral transformation and is the medium that transports dissolved and suspended matter from the system. The transport of the weathering products depends on sufficient rainfall to move soluble salts through the surface soil into the ground water, eventually into rivers, and ultimately, the oceans. The oceans' chemical composition reflects the constant inflow of salt from the landmasses as modified by chemical interaction and evapotranspiration and augmented by volcanic activity (Tanji, 1990).

Salt affected soils are natural components of the landscapes in areas with low precipitation. The presence of significant quantities of soluble salts in arid landscapes directly correlates with limited rainfall, that is, the evapotranspiration greatly exceeds precipitation throughout most of the year (Abrol *et al.*, 1988; Gupta and Gupta, 1987). Lack of moisture limits the intensity of the chemical weathering of minerals and rocks. It also limits transportation of the products of weathering (salts), and the secondary minerals formed hence are often constrained to a localized area. In sub-humid areas, the properties of the parent rock largely dictate the properties of the soil formed. Most arid zone soils are classified under the order of entisols and aridisols (Tanji, 1990).

Because water serves as the principal vehicle for the transportation of salts, salinity is closely linked to lowlands or depressions where water drains and accumulates. Salinization is enhanced when restricted soil drainage promotes a high water table and the balance of mineralized ground water is regulated by the evaporation of water, transpiration and evapotranspiration, rather than by surface runoff and drainage. Areas of impeded drainage vary in size from a fraction of a hectare to thousands of square kilometers.

2.2.4 Fossil or secondary deposits

Throughout geological time, saline seawaters have inundated large areas of continents. These submerged areas have subsequently been uplifted and the saline waters have receded. The resulting geologic formations provide parent materials for soils and outcrops and underlying saline strata both of which are important zones of contact for salt loading of surface and ground water (Tanji, 1990). The secondary deposits (sedimentary rocks) from the weathering of continental rock during inundation are substantial sources of salinity and sodicity. The term “fossil salt” has been used to describe the salinity of these deposits (Tanji, 1990).

2.2.5 Atmospheric deposition

The atmospheric deposition of salts could be of localized importance. Dry and aerosol fallout contributes up to 100 kg salts/y-ha to 200 kg salts/y-ha along seacoasts and from about 10 kg salts/y-ha to 20 kg salts/y-ha in the interior (Tanji, 1990). The composition of atmospheric salt deposition varies with distance from the source usually decreasing with increasing distance from the salt source. The salt in the atmosphere deposition/air mass is predominately of NaCl type at the coast and becomes dominated by Ca^{2+} and SO_4^{2-} ions as the air mass moves inland due to tidal currents. Atmospheric contribution to the salt load of arid lands ranges from 10% to 25% of the total yearly contribution by weathering (Bresler *et al.*, 1982). In the salinization of soils, the contribution of atmospheric salts is often overlooked, but it is a factor that must be considered, particularly in highly weathered landscapes, which have poor drainage.

2.2.6 Anthropogenic activities

Soils made saline by mankind are of major historical and economic importance. Industrialization has increased the atmospheric pollution with gaseous nitrogen and sulfur components, both of which increase the salt concentration in the atmosphere and result in acid fallout, which intensifies the soil mineral weathering rate. Energy related mining activities have brought to the surface saline and sodic materials that, if left in the ground, would have had little effect on the environment (Tanji, 1990).

Irrigation has a dramatic effect on the introduction of salts to the terrestrial system. All irrigation waters contain salts in varying amounts and of different types. During evapotranspiration, the plant uses essentially pure water and the salts left behind are added to those already present in the soil. For example, for every 100-mg/l salt in the water, one megagram of salt is added per ha-m of applied water (Tanji, 1990). If one ha-m of water with a salt concentration of 850 mg/l is applied to a crop during the growing season, then 8.5 megagrams of salts are added (Tanji, 1990). Without salinity management, salts will eventually accumulate in the rhizosphere. Application of irrigation water also greatly increases the rate of mineral weathering. The control of salinity or sodicity in the rhizosphere and in surface or ground waters is, therefore, closely associated with soil and water management practices.

2.3 Sources of salt affected soils

2.3.1 Saline soils

The main process and sources of saline soils is the natural weathering of rocks and minerals. Saline soils may also develop due to the use of saline ground water for irrigation, which leads to a build up of salts in the rootzone especially when the internal drainage of the soils is restricted by raised water table. Salinity in soil can also be aggravated by presence at some soil depth of a clay barrier, hard pan, bedrock or even a subsoil textural change and when leaching is inadequate (Szabolcs, 1984;

Abrol *et al.*, 1988). Other sources include saline seeps as a result of excessive leaching that results from reduced evapotranspiration, usually after changes in land use for example from a natural forest vegetation to a cereal grain crop (Mnkeni, 1996). On the other hand ingress of seawater through tidal waves can contribute to salinization. This normally results in salinity if the rainfall of the affected area is approximately equal to or less than the evapotranspiration. Also salinity can occur through wind transport of salt spray (Abrol *et al.*, 1988). These sprays can be deposited in an area from the atmosphere. These salts enter the atmosphere from oceans, and ultimately reach the soil as "dry fall-out" between storms or as "wash-out/rain-out" during storms (Mnkeni, 1996). Bressler *et al.* (1982) estimated the salt spray contribution to the salt load of arid lands at 10-25% of the total yearly contribution due to weathering. Other sources of salts in saline soils are disturbance of water balance between the rainfall and stream flow, ground water table level and evapotranspiration. This balance is disturbed when large additional quantities of water are artificially spread or applied on the land for agriculture, which may lead to the formation of perched water table (Abrol *et al.*, 1988). This in turn can contribute significantly to evaporation from the soil surface and therefore to the rootzone salinization especially if the salinity of the ground water is high and the water table is within 1 to 2 m from the soil surface. Localized redistribution of salts also contributes to formation of saline soils (Mnkeni, 1996; Abrol *et al.*, 1988). Salts in saline soils may also accumulate in areas with restricted natural drainage caused by development activities such as road constructions and other human-induced processes (Oldeman *et al.*, 1991). On the other hand evaporation of stagnant waters in low-lying areas may leave considerable amounts of salts on the soil surface (Bohn *et al.*, 1985). However, in semi-arid and arid areas, the main source of saline soils is weathering of basic rocks and minerals. Due to inadequate precipitation, the salts accumulate in due course.

2.2.2 Sodic soils

Ground water containing carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) is one of the chief contributing factors in the formation of sodic soils (Abrol *et al.*, 1988). Elgabaly (1971) observed that sodic soils could also be formed by desalinization in the absence of enough divalent cations by high carbonate and bicarbonate water and by denitrification and sulphate reduction under anaerobic conditions (Abrol *et al.*, 1988). According to Bhargava *et al.* (1981), the alternate wet and dry seasons and the topographic (drainage) conditions could be some of the contributing factors to the formation of vast areas of sodic soils. Studies by van Beek and van Breemen (1973) pointed out that highly sodic soils could be developed in a closed basin with an excess of evaporation over precipitation if the inflowing water has a positive residual sodicity. Similarly, ground water containing residual sodicity could result in the formation of sodic soils when the ground water table is near the surface and contributes substantially to evaporation (Abrol *et al.*, 1988; Mnkeni, 1996).

2.2.3 Saline - sodic soils

Saline-sodic soils are soils, which form as a result of the combined processes of salinization that is the accumulation of soluble salts in soils and alkalization that is the hydrolysis of Na^+ ions or Na_2CO_3 compounds in sodic soils resulting in a strong alkaline reaction of pH of up to 10 (Mnkeni, 1996). Ground water containing carbonate and bicarbonate is one of the chief contributing factors in the formation of the saline-sodic soils (Elgabaly, 1971). Reductions of sulphate ions under anaerobic conditions and in the presence of organic matter result in the formation of sodium carbonate, which contributes to saline-sodic soil formation. Other saline-sodic forming factors that contribute to the formation of saline-sodic soils are alternate wet and dry seasons and the topographic (drainage) conditions especially if water-containing products of alumino-silicate weathering accumulate in low lying areas. On the other hand, use of saline ground water for irrigation, saline seeps and ingress of seawater through tidal waves can contribute to formation of saline-sodic soils (Abrol *et al.*, 1988). Localized redistribution of salts can also contribute to the formation of saline-sodic soils.

2.3 Occurrence and distribution of salt affected soils in Tanzania

In Tanzania about 3.6 million hectares of land have salt problems of one kind or another (Massoud, 1977). A report by De Pauw (1984) shows the occurrence of these soils to be extensive in area with arid and semi-arid climates where precipitation is usually insufficient to meet evapotranspiration (ET) needs of plants and in areas with impeded drainage. Since ET greatly exceeds precipitation in semi-arid and arid areas over most of the year, essentially no water percolates through the soil under natural conditions. As a result, salts that have accumulated in the soils through various processes and reactions are not leached from the soil, instead they accumulate in amounts and types detrimental to plant growth. The resulting soils could either be saline, sodic or saline-sodic.

Problems of salinity and sodicity of varying degrees are common in irrigation schemes such as Tanganyika Planting Company (TPC), (Kiwale, 1999), Dakawa rice farm, Kilingali rice seed farm; Ruvu rice farm and Kahe maize and lucerne farm just to mention a few. Also these problems are common in lowlands, arid and semi arid areas of some parts of Dodoma, Mwanza, Shinyanga, Kilimanjaro, Singida, Mara, Rukwa, Coast region, Mtwara, Lindi and Morogoro (Hathout; 1977; De Pauw, 1984). Dakawa and Mkata Ranch are also reported to have the same problem as they have limited rainfall and the rainfall distribution is erratic. According to Magoggo (1983), the climate of these areas is characterized by a monomodal rainfall pattern consisting of warm rainy season from December to May, the rest of the year receiving very little rainfall to wash salts out of the rootzone.

2.4 Limitations of salt affected soils with respect to plant growth

2.4.1 Saline soils

Excess soluble salts cause poor and spotty stands of crops and alter plants/vegetation, uneven, stunted growth and poor yields (Abrol *et al.*, 1988). Salinity causes osmotic pressure of the soil solution to increase, and thus renders less water available to plants. Osmotic effect has the net effect of reducing the availability and uptake of water by plants. For example, plants growing on saline soils often appear to be suffering from drought due to inhibition of water uptake by increased osmotic pressure of the soil solution caused by excessive salts in the soil solution. The plant functions that are negatively affected by excessive amounts of salts in the soil solution, hence high osmotic potential of the soil solution include photosynthesis, hormone production, stomata opening and respiration (Gale, 1975). Apart from the osmotic effect, excessive concentration and absorption of individual ions like Na^+ and Cl^- may prove toxic to the plants and may retard the absorption of other essential plant nutrients due to antagonistic ion effects and ionic imbalances (James *et al.*, 1982; Abrol *et al.*, 1988; Mnkeni, 1996). High salinity may interfere with the growth and activity of soil microbial populations (Senkondo, 2001) and thus indirectly affect the transformation and availability of some essential plant nutrients. Nitrogen transformation reactions are most affected in this regard. Both nitrification and symbiotic nitrogen fixation are reduced in saline soils due to toxic effects of salts on the bacteria, which bring about these reactions (Gupta and Gupta, 1987). Rai and Prasad (1991) investigated the effect of soil salinity on soil microbes and noted that *Azospirillum* species and their associates were adversely affected physiologically and in terms of their populations. Among the salts tested, bicarbonates were the most toxic strains followed by sulphate and chloride. From studies conducted by Shlomo *et al.* (1992), it was observed that the presence of salts in soils reduced carbon mineralization by 74% as compared to the mineralization rate in normal soils due to impairment in metabolic activities of the microorganisms involved in organic matter transformations. In the same study, Shlomo *et al.* (1992) reported that nitrogen mineralization was reduced by 50% due to disturbance of metabolic activities by presence of salts in soils where the microorganisms are found. Band *et al.* (1992)

reported that in saline environments, polysaccharides were converted to soluble molecules that were used for osmoregulation rather than being used for the normal physiological processes. However, plants differ widely in their ability to tolerate salts in the soil (Maas and Hoffman, 1977).

With respect to micronutrients, there has been only limited number of studies on the effect of salinity on the nutrition of crops (Mnkeni, 1996). However, based on the high pH of the saline soils, the availability of most of the essential plant micronutrients namely Zn, Cu, Fe, Mn would be highly limited. For example, the solubility in soils and availability to plants of Fe, Mn, and Zn tend to be reduced at high soil pH. Also solubility of calcium and magnesium in the soil solution is reduced as the pH increases due to formation of insoluble calcium and magnesium carbonates (Mnkeni, 1996; Abrol *et al.*, 1988). The above-mentioned effects due to salinity are manifested through reduced plant growth and productivity.

2.4.2 Sodic soils

In sodic soils, plant growth is adversely affected through the dispersive effect of excess exchangeable sodium resulting in poor soil physical properties. The physico-chemical reactions in sodic soils cause the slaking of aggregates and the swelling and dispersion of clay minerals, leading to reduced permeability and poor tilth (Tanji, 1990; Mnkeni, 1996). Other adverse effects of sodicity soil on plants are through the effect of high pH on nutritional imbalances including deficiency of $Ca^{2+}$when there is an excess Na^{+} content. As the salt concentration increases, the uptake of sodium and chloride ions increases sharply to compensate for the increased external osmotic pressure. The excessive uptake of sodium and chloride ions, in turn, results in reduced uptake of some of the essential plant nutrients causing nutrient imbalances and deficiencies. Thus, although the available status of a nutrient in soil might not be in the deficiency range per se, its application might compensate for the decreased uptake by plants resulting from the antagonistic effects of excess uptake of some ions. The high pH of sodic soils lowers availability of calcium and magnesium due to reduced solubility of these elements caused by formation of insoluble calcium and magnesium carbonates. Also solubility of phosphorus, iron, manganese and zinc is reduced by high pH. Another effect is through toxicity of specific ions such as Na^+, and CO_3^{2-} (Gupta and Gupta, 1987).

2.4.3 Saline-sodic soils

In saline-sodic soils, excessive salts are present as well as excessive exchangeable sodium. However, the physical condition of the soil and water intake may be satisfactory, but plant growth may be restricted (Abrol *et al.*, 1988). The restriction in plant growth is .due to the high osmotic potential of the soil solution and hence the soil water potential, thereby reducing water availability to plants. Also due to increase in the concentration of certain ions in the soil solution that have characteristic toxic effects on plant physiological processes beyond the osmotic effect, can cause toxic effects. For example, accumulation of Na^+ to toxic levels in avocado, citrus and stone-fruit causes leaf burn. On the other hand excess exchangeable sodium can lead to soil swelling and root penetration problems (Abrol *et al.*, 1988; Mnkeni, 1996). Further, excess exchangeable sodium can cause ion imbalances which can lead to reduced uptake of the other essential nutrient elements such as potassium or calcium hence the manifestation of K^+ and Ca^{2+} deficiencies symptoms by the plants (Tanji, 1990). This occurs due to excessive adsorption of Na^+, and hence reduced adsorption and uptake of the other essential plant nutrients.

2.5 Reclamation and management of salt affected soils

2.5.1 Saline soils

Since the excess and harmful salts in saline soils are soluble in water, reclamation of such soils for crop production can be accomplished through water management. The most common methods of salt removal from saline soils include the physical removal of salts, flushing, and leaching (Gupta and Gupta, 1987).

(i) *Physical removal of the salts*

The physical removal of salts from saline soils involves the removal of the top layers of the soil. After the removal of the top/surface layers where the soluble salts are concentrated, the lower salt-free layers of the soil can be utilized for crop cultivation. This method is based on the idea that the lower layers of the saline soil profile have lesser accumulation of salts than the surface layers. There are several disadvantages to this method, which provides only a temporary, short-term solution. Over time, this method intensifies the problem. By lowering the ground level in relation to the water table, salts accumulate. There is also a high cost associated with disposing of large quantities of highly saline surface soil. Another problem with this method is that it leads to loss of plant nutrients by their removal with the topsoil.

(ii) *Flushing*

Another method of desalinization is to flush the soil with water. This method is appropriate for soils with very high permeability and for soils that have a high salinity in their surface layer. After washing the surface of the soil with water, the salts are carried down slope by excess irrigation water and rainwater. A sufficient downward gradient is required to carry the water away, therefore, this method is not practical in landlocked fields. Flushing is most effective initially; however, as salt concentrations diminish, the efficiency decreases due to dispersion of the clay fraction of the soils (Gupta and Gupta, 1987). While the surface soil is being somewhat remedied that is free from soluble salts the rest of the soil profile would remain salt affected.

(iii) *Leaching*

Leaching is the process of applying excessive amounts of water onto the soil surface in order to wash salts down through the soil profile along with water. There are two methods of leaching namely continuous ponding and intermittent ponding. The continuous ponding method consists of ponding water at the soil surface, while the intermittent ponding consists of several small applications of water at intervals (Gupta and Gupta, 1987; Mnkeni, 1996).

Continuous ponding is the preferred method when time is a limiting factor. This method can pass the same amount of water through the soil profile much quicker. As a general rule, this type of leaching requires one centimetre of water for each centimetre unit of the soil profile to be reclaimed. However, the amount of water needed for leaching will vary, depending on the texture of the soil, the concentration of salts in the soil and in the leaching water (Gupta and Gupta, 1987). The amount of leaching water required can be more accurately estimated using the equation proposed by Hoffman (1980) $C/Co = k/(Diw/Ds)$, where C= average salt concentration after leaching (or required salinity); Co= initial salt concentration in the soil; Diw= depth of leaching water applied; Ds= depth of soil to be leached; k= an empirical coefficient that ranges from 0.1 (for sandy loam) to 0.3 (for clay, silt clay loam, silt clay, and clay loam). This constant is 0.1 irrespective of soil type, under intermittent ponding with 5 cm to 15 cm per application. Oster *et al.* (1972) found that splinkler irrigation of silty clay soils produced a similar coefficient. The above equation applies after the actual drainage has begun or in the range of $Diw/Ds > k$. The Hoffman equation can be used to calculate the amount of water needed to leach salts from a desired depth of soil for a specified initial and desired salinity. The salt transport efficiency decreases sharply when Diw to Ds ratios exceed 0.5 for sandy loam and 0.75 for clay loam to clay.

When water is the limiting factor, the intermittent ponding should be used. This is the best of the two leaching methods for extremely arid regions because it is most water efficient. The amount of water needed is 30-35% lower than the amount needed for continuous ponding. One disadvantage to intermittent ponding is that it is much slower than the continuous ponding method (Gupta and Gupta, 1987).

Whichever method is used, it is important to have a reliable estimate of the quantity of water required to accomplish salt leaching. The initial salt content of the soil, desired level of soil salinity after leaching, depth to which reclamation is desired and soil characteristics are major factors that determine the amount of water needed for reclamation (Abrol, *et al.*, 1988). The amount of leaching water required could be more accurately estimated using the equation proposed by Hoffman (1980).

In order to have a successful leaching program it is necessary to first level the land. But it is important to plough first to increase infiltration rate. Another important aspect of a leaching program is the timing of the leaching. It is important to wait until just before the rainy season starts. The water table will be lowest at this time of the year, so there will be less upward movement of the salts into the root zone (Gupta and Gupta, 1987). In addition, the oncoming rainy season will further leach the salts from the soil.

Reclamation of saline soils essentially requires removal of soluble salts from the root zone through leaching and drainage (Abrol *et al.*, 1988). In order to permanently improve saline soil, it is necessary to not only leach the soil, but also to have adequate drainage. The drainage system must provide an outlet for the removal of the leached water as well as keep the water table deep enough to prevent salt-laden groundwater from moving up to the root zone. This is particularly a problem for soils with a shallow, saline water table (Schilfgaarde, 1974). For saline soils, provision of drainage is an essential prerequisite of the reclamation. Before reclamation, there are several possible drainage methods to control salinization. The drainage methods include the lining of canals, the drainage of borrow pits, and the management of on-site water (Gupta and Gupta, 1987). Application of enough water through soil profiles to remove salts from the root zone is an important step in the reclamation of these soils (Oldeman *et al.*, 1991; Mnkeni, 1996). Management practices to control or minimize the effects of salinity include use of salt tolerant crops such as rice, vegetables and peanut. Agronomic management such as the use of high seed rates, transplanting older seedlings at the age of 35-40 days; and systematic rotation to avoid long fallow, may be helpful (Abrol *et al.*, 1988; Mnkeni, 1996).

2.5.2 Sodic soils

Reclamation of sodic soils essentially requires the replacement of Na^+ (on the soil exchange complex by Ca^{2+} through the use of soil amendments. One way to accomplish this is by applying soil amendment such as gypsum ($CaSO_4.2H_2O$) to the sodic soil according to the reaction;

$$\text{Soil-colloid]-Na} + CaSO_4.2H_2O \leftrightarrow \text{soil-colloid]-Ca} + Na_2SO_4 + H_2O$$

The calcium in the gypsum replaces the sodium on the soil exchange complex forming sodium sulphate, which can be leached from the rooting zone. The amendments include gypsum, calcium chloride, or irrigation water with Ca^{2+} ions.

This is followed by leaching and drainage of salts resulting from reactions of amendments with exchangeable Na^+ (Abrol *et al.*, 1988). The replaced Na^+ must be removed either to lower levels or out of the profile by leaching water. Thus reclamation requires a certain flow of water through the profile and, to be effective, an appropriate profile hydraulic conductivity must be achieved (Abrol *et al.*, 1988; Mnkeni, 1996). This is achieved by providing a sufficiently high electrolyte concentration in the soil solution to counter the influence of exchangeable Na^+. Generally, the higher the electrolyte concentration the higher the ESP at which a "stable permeability" can be maintained (Gupta and Gupta, 1987; Mnkeni, 1996). This relationship is, however, strongly influenced by the soil's clay mineralogy. Soils dominated by kaolinite and sesquioxides tend to be insensitive to variations in soil solution composition in contrast to those dominated by 2:1 clay minerals (Abrol *et al.*, 1988; Mnkeni, 1996).

However, there are two key questions ought to be addressed before embarking on a reclamation exercise that is (1) to what level must ESP be reduced? and (2) over what depth of the soil is the ESP reduction required? For instance, Bernstein (1974) suggested an ESP value of 10 for fine textured and 20 for coarse textured soils. Later, McIntyre (1979), using water with an electrolyte level of 0.7 me/l, reported that there is a continuous and initially very rapid decline in hydraulic conductivity as the ESP increases above zero. Therefore, there appears to be no specific level of ESP, which can be regarded, as critical. Thus in reclamation, the aim should be to reduce the ESP to as low level as possible (Mnkeni, 1996). Shainberg and Oster (1978) suggested

ESP's of 5 and 15 at depths of 0.2 and 1.0 m, respectively, as being adequate for most purposes.

A study by Cairns (1970; 1972) and Rasmussen *et al.* (1972) showed that profile disturbance through deep ploughing is a successful way of reclaiming sodic soils. Management practices to control effects of sodicity and soil salts in general, include selection of salt tolerant crops, reforestation of cleared land to reduce ground water table level, split fertilizer application which will produce healthier plants and also a greater salt tolerance. Use of high seed rates to compensate for reduced germination, use of older seedlings which are more salt tolerant and have a better chance of surviving to maturity, are also helpful. Others include use of mulch to prevent salt accumulation on the surface during dry season and to enable salt to be leached out in wet season (Arunin, 1984).

2.5.3 Saline - sodic soils

If leaching is conducted on a saline- sodic soil, the soil would become sodic and could present more problems than it would have originally (Brady and Weil, 1996). Therefore, care should be taken when leaching these soils. Saline-sodic soils require the leaching to be accompanied by application of amendments (Rowell, 1994).

Reclamation of saline-sodic soils requires that the amount of exchangeable sodium is reduced and excess salts are removed before satisfactory crop growth is realized (Tisdale *et al.,* 1993; Brady and Weil, 1996). Supplying soluble salts can reclaim such soils (Brady and Weil, 1996). If soils contain gypsum within the root zone, additional gypsum may not be needed. Native soil gypsum may supply all or part of the required soluble calcium (Abrol *et al.*, 1988). Irrigation water containing soluble calcium may furnish part of calcium requirement. Also soil amendments with gypsum or calcium chloride or any other amendment such as pyrite or sulphuric acid may be needed. Leaching with water to bring about reaction of the amendment and to flush out the sodium replaced by calcium beyond the rootzone or soil solum is recommended in order to reduce salts.

2.6 Crop performance on salt affected soils.

Crop salt tolerance is defined as the ability of plants to survive and produce economic yields under adverse conditions caused by soil salinity (Maas and Hoffman, 1977). The adverse effects include, increased osmotic pressure, ion imbalance, ion toxicity and swelling and/or dispersion which can cause water infiltration, aeration, and root penetration problems (Abrol *et al.*, 1988; Gupta and Gupta, 1987). For agricultural crops, salt tolerance is expressed in terms of the yield losses associated with increase in soil salinity or as relative crop yield on saline or sodic versus non-saline or non-sodic soils (Maas and Hoffman, 1977). Relative yield (Y) (percent) at any given soil salinity can be calculated by the equation:

$Y = 100(ECo - ECe) / (ECo - EC100)$, where: - EC100 is the salinity threshold value (ECe where $Y = 100$) and ECo the salinity at zero yield (ECe where $Y = 0$).

For ornamental plants, salt tolerance, is better expressed on the basis of survival and appearance of shoots and leaves, because yield is not generally important for such species. Crops vary considerably in their ability to survive and produce economic yields under adverse conditions caused by salinity, sodicity or both. Some crops, which are sensitive to salinity in the root zone, with their salinity threshold in brackets (in dSm^{-1}) (Maas and Hoffman, 1977), include apple (ECe 1.0), avocado (ECe 1.0), bean (ECe 1.0), carrot (ECe 1.0), lemon (ECe 1.0), onion (ECe 1.2), orange (ECe 1.7), and pear (ECe 1.0). The moderately sensitive crops include alfalfa (ECe 2.0), cauliflower (ECe 2.5), cabbage (ECe 1.8), corn (*Zea Mays* L) (ECe 1.8), cowpea (ECe 1.3), cucumber (ECe 2.5), potato (ECe 1.7), rice (ECe 3.0), sugarcane (ECe 1.7), sweet potato (ECe 1.5) and tomato (ECe 2.5). The moderately tolerant crops include barley, forage (ECe 6.0), sorghum (ECe 4.8), safflower (ECe 6.5), wheat (ECe 6.0), and soybean (ECe 5.0). The tolerant crops include barley-grain (ECe 8.0), cotton (ECe 7.7), date (ECe 4.0), and sugarbeet (ECe 7.0) (Mnkeni, 1996). On the other hand tolerance of various crops to exchangeable-sodium percentage (ESP) under non-saline conditions, was summarized by Pearson (1960) as cited by Mnkeni, (1996). The extreme sensitive (ESP=2-10) include deciduous fruits, nuts, citrus and avocado. Sensitive (ESP=10-20) crop include bean and moderately tolerant (ESP= 20-40) crops include clover, oats and rice. The tolerant (ESP=40-60) include crop such as wheat, cotton, alfalfa, barley, tomatoes and beets. The most tolerant ones include tall wheatgrass and rhodes grasses.

2.7 Extent of agricultural use of the saline, sodic and saline-sodic soils in Tanzania

According to De Pauw (1984), salt-affected soils cover an extensive area of Tanzania (Approximately 3.6 million ha). Out of that area only less than 16% (576 000 ha) is used for irrigation. This implies that, more than 84% (3 024 000 ha) of the area is not under irrigation hence crop production, due to either high salinity or sodicity or both. The salt-affected area is expanding due to the abandonment of some irrigation schemes, which have in the due course developed severe salinity or sodicity problems (Kiwale, 1999) due to poor management. Factors contributing to the limited use of salt-affected soils in Tanzania among other things include lack of adequate research on physical and chemical properties of these soils, and lack of proper characterization of crops according to salt tolerance and inadequate water for irrigation.

2.8 Future prospects for the utilization of saline, sodic and saline-sodic soils in Tanzania for crop production

Saline, sodic and saline-sodic soils are common in arid and semi-arid areas of Tanzania, which comprise an important country resource because of their wide extent, high natural fertility and potential for multiple cropping (De Pauw, 1984). With proper management and availability of water for irrigation many arid and semi-arid soils can be highly productive. Irrigation holds the key to stabilizing agricultural production in Tanzania to improve food security, increase farmers' productivity and incomes and also to produce higher valued crops such as vegetables and flowers (FAO, 1993; 1997). On irrigated lands, however, salinization is the major cause of land being lost from production and is one of the most prolific adverse environmental impacts associated with irrigation (Tanji, 1990). Saline conditions severely limit the choice of crop, adversely affecting seed germination and yields, and can make soils difficult to work with. Careful management can reduce the rate of salinity build-up and minimize the effects on crops. Management strategies include: leaching which involves applying large volumes of water to the soil to transport soluble salts out of the rooting zone, and drainage to remove excess water. Other techniques include adjusting crop patterns; and incorporating soil amendments such as gypsum, calcium chloride, sulphuric acid, sulphur and pyrite. All such management practices, which may be very costly, would require careful study to determine their local suitability. Therefore, comprehensive soil studies are essential to the successful management of irrigated areas.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Some information of the study areas

3.1.1 Location

Kahe, Kikafu and Soko areas are located in Moshi district, Kilimanjaro region. The study area lies between latitude 6^0 32' S and longitude 37^0 20' E. The altitude is around 700m above sea level. The whole of the area declines gently at a gradient of 1% towards the south. Mkata Ranch in Morogoro is located approximately between 37^0 20' E and 37^0 33' E, and 6^0 43' S and 6^0 54' S.

The SUA-farm is located near the town of Morogoro, Tanzania. The farm is approximately at 37^0 39' E and 6^0 51' S. It is bordered by Morogoro town to the east, Uluguru Mountains to the Southeast, Mindu Mountains to the West and Lugala hills to the northwest. Dakawa and Cholima are located approximately between 37^0 30' E and 37^0 40' E, and between 6^0 20' S and 6^0 30' S. The altitude of this area is around 400m above sea level. Kidamke (Mkata) is located within latitudes 37^0 15' E and 37^0 42' E and longitudes 6^0 45' S and 7^0 00' S. The altitude of this area is around 500m above sea level.

3.1.2 Geology

The soils of Moshi district are mixtures of fluvial, lacustrine and eolic (ash) sedimentation (Sloot, 1987). The origin is volcanic, from the Kilimanjaro Mountain in the north. The eroded materials have been deposited relatively recently. The East

African soil map indicates the materials as being of the quaternary sediments. The volcanic material was brought down from the slopes of the Kilimanjaro by air and water. It is assumed that the alluvium filled up an old lake or swamp, which existed in between the Lelatema Mountains in the west and Pare Mountains in the east. The differences in soil type are mainly due to variations in parent material and the different ways of transport and deposition.

Geological survey of Morogoro area by Sampson *et al.* (1961) indicated that the Kidamke (Mkata) and Dakawa areas consist of Neogen system comprising superficial deposit of mbuga and alluvial soils. The alluvium is of diverse origin transported by water from nearby hills and mountains, which are predominantly underlain by gneisses and granulites of the Uluguru block. The SUA-farm is at the footslope of Uluguru Mountains. The mountains belong to the metasediments of the Usagaran system of the Mozambiquan belt (Saggerson, 1962). In this area pyroxene granulates are dominant. Such pyroxene granulites 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 Drainage pattern

The drainage pattern in Kahe, Kikafu and Soko is sub-parallel. Most rivers flow in a north-south direction with the exception of the spring fed Kikuletwa which flows eastwards to join the Weruweru. The Weruweru, Rau and Pangani have dissected the plain by rather deep canyons, which become less pronounced towards the south. The whole area in between the mountains of Kilimanjaro, Pare and Lelatema drains to the Pangani River. There are signs of underground water flows in the areas, that is seepage from the mountain slopes, resulting in the natural springs of Miwaleni and Kikuletwa. With the prevailing climatic condition of the study area, seepage can easily be associated with dangers of salinization.

Two seasonal streams namely Mgambazi and Magadu from the Uluguru Mountains drain the SUA-farm area. These streams remain dry for most of the time in a year except during the heavy rains period, which is March to May/June.

3.1.4 Climate

The areas of Kahe, Kikafu and Soko experience low rainfall, which is unevenly distributed and cannot suffice the high water demand of maize crop. Therefore irrigation becomes imperative. The mean annual precipitation averages about 540 mm (Kiwale, 1999). There are two rainy seasons, the long season, which extends between March and May while the short rains extend between November and December. The period extending from June to October is dry in most years. However, it is important to note that considerable differences occur within the area of study. Northern areas are usually wetter and may receive rainfall as high as 700 mm/year, whereas areas in the far southeast may get hardly 350 mm/year.

The climate at SUA-farm is of a sub-humid tropical type (Sharma, 1987). The area experiences bimodal rainfall characterized by two rainfall peaks in a year. The shorter and lighter rains last from November to January with their peak in December. These rains are followed by a short dry period in mid January or February. The long and heavier rains last from March to May with their peak in April. The distribution pattern of these long rains is also irregular and unreliable. The SUA-farm is on the leeward side of the Uluguru Mountains and this is likely to be responsible for the low rains received at the farm. The annual rainfall at SUA-farm is 861.4 mm. The mean annual air temperature is 24.4 ^{0}C, the average soil temperature is 25.4 ^{0}C, hence isohyperthermic temperature regime.

3.1.5 Vegetation

The natural vegetation of Kahe, Kikafu and Soko areas is an open woodland savannah with some areas covered with shrubs. Towards the south the vegetation changes from savannah bush into a typical salt-bush. The dominant species are *Acacia zanthropica, Eleusina indica and Setaria verticillata.*

The natural vegetation of SUA-farm area has been interfered by man through cultivation. The local vegetation is mainly grassland dominated by *Andropogons spp., Hyperrhenia spp , and Themeda spp.* The vegetation of Mkata Ranch is mainly Acacia wooded savanna, *Acacia nigrescens* being dominant tree species. Other tree species include *Dalbergia melanoxylon*, *Harrisonia abyssinica* and *Cussonia arborea*. *Hyperrhenia rufa* dominates the herbaceous species.

3.2 Soil sampling and preparation

Soil samples for the study were taken from SUA-farm, Kidamke (Mkata), Dakawa Cholima and Mafiga in Morogoro and from Kahe, Kikafu and Soko in Kilimanjaro regions. These locations are known to contain salt-affected soils. Based on the detailed information gathered from previous studies (Kaboni, 1996, Kaaya, 1998, Kiwale, 1999, Baitilwake, 1999), people living in the area and from soil and topographic maps, representative composite soil samples were sampled from the six study areas. At least three soil samples were collected from each study area. The sampling depth was 0-30 cm and 2 kg soil was collected from each sampling site/location. Prior to any analysis, the soil samples were air dried, ground and sieved through a 2 mm sieve (Van Reeuwijk, 1987). Each sieved soil sample was again thoroughly mixed in an effort to homogenize it. Laboratory determinations were performed on the fine earth fraction and results were expressed on oven-dry weight basis. The sieved soil samples were used for laboratory analysis.

3.3 Laboratory soil analyses

Laboratory analyses were done on soil samples in the Department of Soil Science laboratory, SUA, Morogoro. These samples were analyzed for particle size distribution, pH, ECe, water soluble and exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), cation exchange capacity (CEC), soluble anions (CO_3^{2-}, HCO_3^{-}, B^{-}, Cl^{-} and SO_4^{2-},), and organic carbon, total nitrogen and plant available phosphorus.

3.3.1 Routine analyses for soil characterization

3.3.1.1 Particle size distribution, soil pH, Olsen P, OC, total N, and ECe

Particle size analysis was determined by the Bouyoucos hydrometer method (National Soil Service, 1987). Soil pH was determined in 1:2.5 soil: water suspensions by the potentiometric method (McLean, 1982). The electrical conductivities of soil suspensions of the 1:2 soil:water suspensions were determined according to the procedure by van Reeuwijk (1987). Plant available phosphorus was determined by Olsen method as described by Watanabe and Olsen (1965). Soil organic carbon was determined by the wet digestion method of Walkley and Black as described by Nelson and Sommers (1982). Total nitrogen was determined by the digestion-distillation method as described by Bremner and Mulvaney (1982).

3.3.1.2 Cation exchange capacity (CEC) and exchangeable bases (EB)

The cation exchange capacity and exchangeable bases were determined by the unbuffered salt extraction method (Sumner and Miller, 1996) after leaching of the soluble salts (Rhoades, 1982). Ten-gram soil sample portions of the soils were weighed into centrifuge tubes and 20 ml of distilled water added, then shaken for one hour on a shaker. The suspensions were centrifuged at 5 000 revolution per minute (rpm) for 30 minutes. The clear solution was decanted and then discarded. Another 20 ml of water, were added into the soils in the centrifuge tubes, thoroughly stirred, shaken for one hour, and again centrifuged at 5 000 rpm for 30 minutes. The solution was decanted and then discarded. The exchangeable bases, namely Ca^{2+}, Mg^{2+}, K^+ and Na^+ and CEC of the supposedly soluble salts free soils in the centrifuge tubes were determined by the unbuffered salt extraction method, using 0.2 M NH_4Cl and 0.2 M KNO_3-solutions, respectively (Sumner and Miller, 1996). The amount of the exchangeable K^+ and Na^+ in the decanted supernatant solutions were determined following the procedure by Helmke and Sparks (1996), exchangeable Ca^{2+} and Mg^{2+} following the method by Suarez (1996), and CEC using the procedure by Mulvaney (1996).

3.3.2. Analyses for soluble salts

3.3.2.1 Water soluble cations and anions

Water soluble cations and anions were determined from a suspension of soil: water at a ratio of 1: 2. as described by Rhoades (1982), National Soil Service (1987) and Moberg (2000). One hundred gram of soil sample portions were mixed with 200ml of water to make 1:2 soil:water suspensions. The suspensions were shaken for one hour in a shaker. Thereafter the suspensions were centrifuged at 5 000 rpm for 30 minutes. The clear solutions were decanted into 100 ml plastic containers ready for cations and anions determinations.

3.3.2.2 Calcium and magnesium

By means of a pipette 4 ml of each of the extracts were transferred to small, dry plastic containers, and 4 ml 1% La_2O_3 solution were added to each container. After mixing, the Ca^{2+} and Mg^{2+} contents, in the solutions were determined by atomic absorption spectrophotometer at 422.7 nm and 285.2 nm, respectively. Then the concentrations of the cations were calculated and expressed in cmol (+)/kg.

3.3.2.3 Potassium and sodium

Four milliliters of each of the extracts were transferred to small, dry plastic containers, and 4 ml 0.1 % CsCl solution were added to each container. After mixing, the absorbences of K and Na were determined by flame emission spectrophotometer at 766.5 nm and 589.0 nm, respectively. Then the concentrations of the cations were calculated and expressed in cmol (+)/kg.

3.3.3 Water soluble anions

3.3.3.1 Carbonate and hydrogen carbonate

Carbonate and bicarbonate were determined by titrimetric method (Bower and Wilcox, 1965). By means of a pipette 10 ml of each of the extracts was transferred to conical flasks, three drops of phenolphthalein indicator solution were added to each flask and mixed. The mixtures were then titrated by drop-wise addition of 0.01 M H_2SO_4 standard solution until the light reddish colour disappears. Where no colour appeared with the addition of the phenolphthalein indicator solution, then it was assumed that no carbonates were present in the extracts. Then the concentrations of CO_3^{2-} were calculated from the volumes of H_2SO_4 used and expressed in cmol(-)/kg soil.

After reading the amount of 0.01 M H_2SO_4 on the burette used for titration of the carbonate, one drop of methyl orange indicator solution was added and titrated with 0.01 M H_2SO_4 until colour changed from orange-yellow to red. Then the concentrations of HCO3- were calculated from the volume of H_2SO_4 used in titration, and expressed in cmol(-)/kg soil.

3.3.3.2 Sulphate

Sulphate contents in the extracts were determined photometrically according to Dewis and Freitas (1970; and National Soil Service (1987). Ten milliliters of each of the same extracts were pipetted into 50 ml plastic bottles, 10 ml acid seed solution and 5 ml of turbidimetric reagent were added, and swirled frequently for 20 minutes. Thereafter the absorbences were read by spectrophotometer at 535 nm, and concentrations were expressed in cmo(-)/kg soil after calculation.

3.3.3.3 Chloride

Water-soluble chloride was determined titrimetrically (by Mohr's titration method) according to Bower and Wilcox. (1965) and National Soil Service (1987). Twenty-five milliliters of each of the soil filtrate were pipetted into 150-ml plastic containers, 4 drops of 10 % K_2CrO_4 indicator were added and mixed together. Samples with ECe greater than 1.0 dS/m were titrated with 0.1 M solution of silver nitrate ($AgNO_3$), and those with ECe less than 0.1 dS/m were titrated with 0.02 M $AgNO_3$ until the colour changed from white yellow into reddish brown. The calculations of chloride contents were calculated using the volumes of $AgNO_3$ used in the titrations. The chloride values were expressed in terms of cmol(-)/kg soil.

3.3.3.4 Boron

Water-soluble boron was determined by spectrophotometric method (the Azomethine-h procedure) as described by Rhoades (1982) and Moberg (2000). Fifteen-gram of each soil were mixed with 30 ml 0.01 M $CaCl_2$ into dry digestion tubes. The mixtures were boiled at 110^0 C for 5 minutes, and the tubes were immersed in cold water and allowed to cool for 15 minutes. Thereafter, the suspensions were filtered into dry plastic bottles using dry filters (Whatman no 42). Two milliliters of each of the soil extracts were pipetted and mixed with 4 ml of buffer solution into 50-ml plastic containers. Then 4 ml of Azomethine-h reagent were added, shaken for 10 minutes, and allowed to stand at room temperature for 30 minutes. Absorbence was determined by a colour spectrophotometer at 420 nm. The concentrations of boron in samples were obtained by calculation using the absorbence values. The B concentration values were expressed in terms of cmol(-)/kg soil.

3.3.3.5 Exchangeable sodium percentage

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

ESP = (Exchangeable Na / CEC) X 100

Where: ESP = Exchangeable sodium percentage

CEC = Cation exchange capacity

The values of the CEC and exchangeable sodium (Na^+) were obtained from the determinations carried out as shown above in routine analyses.

3.3.3.6 Sodium adsorption ratio (SAR)

SAR was calculated from the values of exchangeable sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) according to van Reeuwijk (1987) using the formula:

$$SAR = (\text{Exchangeable } Na^+) / \{(Ca^{2+} + Mg^{2+})/2\}^{1/2}$$

Where Ca^{2+}, Mg^{2+} and Na^+ were expressed in cmol (+)/kg soil.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Some physico-chemical properties of the soils

The physico-chemical properties of the soils were as presented in Table 1. The textural classes of the SUA-farm, Kidamke, Dakawa, Cholima, and Mafiga, varied from sandy clay to clay, sandy clay to clay, sandy clay loam to clay, sandy clay loam, and sandy clay loam, respectively. For the Kahe, Kikafu, and Soko soils, the textural classes varied from, sandy clay loam to loam, sandy clay to clay loam; and clay, loams, and silt loam to clay loam, respectively. The high contents of sand and clay in most of the studied soils could be attributed to the nature of the parent materials from which the soils were formed and the extent of weathering and soil development. The soils occur in semi-arid areas, hence not extensively weathered and leached. The clay fraction mineralogy of the soils could possibly be mostly mixtures of the 2:1 and 1:1 clay minerals and amorphous oxides of Al and Fe. The soils consist of erosion depositional materials.

The pH of the SUA-farm, Kidamke, Dakawa, and Mafiga soils ranged from 7.78 to 8.37, 7.76 to 9.03, 7.21 to 7.87, 8.14, and 8.16 to 8.28 with mean values of 8.01, 8.45, 7.59, 8.14, and 8.22, respectively. The pH of the Kahe, Kikafu and Soko soils ranged from 7.92 to 9.58, 9.35 to 10.92, and 8.00 to 10.58 with mean values of 8.75, 10.14, and 9.49, respectively. The high pHs of these soils are probably associated with the presence of high proportions of exchangeable bases and the soils developed from basic parent materials. The high pH could also be due to impeded leaching and hence the possibility of accumulation of soluble salts. Since all the soils have pH above 7, it indicates that these soils are alkaline and consequently either sodic, saline, or saline-sodic. The pHs are not suitable for optimum production for many crops, as they can indirectly lower the availability of some of the essential plant nutrients such as P, Fe, Cu, and Zn. High pH can also reduce the solubility of calcium and magnesium in the soil solution due to the formation of insoluble Ca and Mg carbonates (Mnkeni, 1996; Abrol *et al.*, 1988). Microbial population and activities can also be affected by high pH, thus indirectly affecting the transformation and availability of some essential plant nutrients (Senkondo, 2001; Gupta and Gupta, 1987; Rai and Prasad, 1991).

The pH values obtained from the Kahe, Kikafu and Soko soils are almost similar to those obtained by other workers for soils from TPC (Kiwale, 1999; Baitilwake, 1999). The pH obtained from SUA-farm, Kidamke, and Mafiga soils were almost similar to those obtained by other workers in Chamwino-Mafiga, SUA-farm, Mkata Ranch and Dakawa soils (Kaboni, 1996; Kaaya, 1989; Kaaya, 1998). They observed that the high soil pH coincided with the presence of relatively high proportion of carbonates and bicarbonates, which are capable of undergoing hydrolysis and hence increase the soil pH. The current use of the soils is paddy production, under irrigation because of limited and unreliable precipitation.

Table 1. Some of the physical and chemical properties of the soils

Sample name	Particle size distribution			Textural class	pH water 1:2.5	OC %	Total N %	Olsen P mg/kg	CEC cmol(+)/kg
	% sand	% silt	% clay						
SF1	45.3	4.8	49.9	SC	7.88	0.93	0.05	0.14	23.66
SF2	46.64	5.36	48.0	SC	8.37	1.05	0.07	0.10	38.28
SF3	49.18	2.82	48.0	SC	7.78	0.62	0.04	0.31	44.89
SF4	41.92	2.88	55.2	C	8.05	0.79	0.04	0.30	22.27
KDK1	42.4	4.8	52.8	C	9.03	0.67	0.05	0.17	14.62
KDK2	66.4	4.8	28.8	SCL	8.55	0.51	0.05	0.65	8.35
KDK3	64.0	4.8	31.2	SCL	7.76	0.64	0.07	1.57	11.83
DKW1	61.28	7.52	31.2	SCL	7.21	0.68	0.04	1.18	26.80
DKW2	70.96	0.24	28.8	SCL	7.70	1.00	0.05	2.27	46.28
DKW3	39.5	10.1	50.4	C	7.87	0.78	0.07	1.28	24.36
CHOL	70.96	2.64	26.4	SCL	8.14	0.78	0.06	1.73	31.67
MAF1	68.8	4.8	26.4	SCL	8.28	1.04	0.08	0.69	9.40
MAF2	64.0	4.8	31.2	SCL	8.16	1.86	0.14	3.90	15.66
KAH1	48.96	29.44	21.6	L	7.92	1.04	0.24	1.61	22.97
KAH2	53.6	15.2	31.2	SCL	9.58	0.97	0.15	2.30	17.4
KIK1	48.96	15.04	36.0	SC	9.35	1.50	0.14	4.97	35.84
KIK2	32.24	38.96	28.8	CL	10.92	0.89	0.04	9.42	45.24
SOK1	46.18	34.62	19.2	L	10.37	0.38	0.05	2.73	33.76
SOK2a	39.68	26.72	33.6	CL	8.01	1.30	0.07	0.98	28.54
SOK2	23.44	69.36	7.2	SiL	8.00	1.25	0.03	1.41	17.75
SOK3	44.32	12.48	43.2	C	10.58	1.17	0.07	8.65	45.94
SOK4	28.08	31.12	40.8	C	10.47	1.11	0.11	7.79	49.07

KEY:

SF = SUA-farm MAF = Mafiga KDK = Kidamke KAH = Kahe

DKW = Dakawa KIK = Kikafu CHOL =Cholima SOK = Soko

The organic carbon of SUA farm, Kidamke, Dakawa, and Mafiga soils ranged from 0.62 to 1.05, 0.51 to 0.67, 0.68 to 1.00, 1.04 to 1.86 % with mean values of 0.85, 0.59, 0.82, and 1.45 %, respectively. The organic carbon of the Cholima soil was found to be 0.78, while that of the Kahe, Kikafu and Soko soils ranged from 0.97 to 1.04, 0.89 to 1.50, 0.38 to 1.30 % with mean values of 1.01, 1.19, and 1.04 %, respectively. Landon (1991) and EUROCONSULT (1989) categorized organic carbon values as follows; very high (>3.5%), high (2.51-3.50%), medium (1.26-2.50%), low (0.60-1.25%) and very low (<0.6%). According to the categorization by Landon (1991) and EUROCONSULT (1989) the percent organic carbon contents of these soils generally ranged from very low to low in almost all soils, except for the Mafiga and Kikafu soils which ranged from low to medium. These low to medium values of organic carbon imply very low to medium organic matter contents. The low organic matter contents could be partly accounted for by poor vegetation cover of the areas, and partly by the rapid decomposition of the small amounts of organic residues under the prevailing conditions of hot climate (Tiwari *et al.*, 1983). The poor vegetation is due to inadequate moisture, high pH and excess soluble salts which lead to salinity or alkalinity or both. Burning could also contribute to low organic carbon contents due to tendencies of some farmers to burn their crop residues after harvesting the crops.

Total nitrogen of SUA-farm, Kidamke, Dakawa and Mafiga soils ranged from 0.04 to 0.07, 0.05 to 0.07, 0.04 to 0.07, 0.08 to 0.14 % with mean values of 0.05, 0.056, 0.05, and 0.11%, respectively. Total nitrogen for the Cholima soil was 0.06, while that of the Kahe, Kikafu, and Soko soils ranged from 0.15 to 0.24, 0.04 to 0.14, 0.03 to 0.11% with mean values of 0.19, 0.09, and 0.07%, respectively. EUROCONSULT (1989) and Landon (1991) categorized soil total nitrogen as follows; high (> 0.5%), medium (0.21-0.50%), low (0.10-0.20%) and very low (<0.10%). Based on this categorisation, the total nitrogen of the SUA-farm, Kidamke, Dakawa, Mafiga, Kikafu and Soko ranged from very low to low, while that of Kahe ranged from low to medium. Other workers have reported almost similar results of total nitrogen (Kiwale, 1999; Baitilwake, 1999; Kaboni, 1996; Kaaya, 1998). They concluded that total nitrogen was generally low in TPC, Chamwino-mafiga, and Lubungo-Mkata areas respectively. The percent total nitrogen in the soils to a large extent conforms to the percent organic matter contents in the soils. The low percent total nitrogen contents in the soils could be due to the low organic matter contents and minimal or non-use of inorganic N-fertilizers and manure.

The Olsen extractable P of SUA-farm, Kidamke, Dakawa, and Mafiga ranged from 0.1 to 0.31, 0.17 to 1.57, 1.18 to 2.27, and 0.69 to 3.90 mg P/kg with mean values of 0.21, 0.79, 1.58, and 2.29 mg P/kg, respectively. The Olsen extractable P for the Cholima soil was found to be 1.73 mg P/kg. The Olsen extractable P of Kahe, Kikafu, Soko soils ranged from 1.61 to 2.30, 4.97 to 9.42, 0.98 to 8.65 mg P/kg with mean values of 1.95, 7.19, and 4.312 mg P/kg, respectively. Landon (1991) and EUROCONSULT (1989) categorized Olsen available phosphorus as follows; high (>10 mg P/kg), medium (5-10 mg P/kg) and low (< 5 mg P/kg). Based on this categorization, the Olsen P of SUA-farm, Kidamke, Dakawa, Cholima and Mafiga soils can be rated as low, while those of Kahe, Kikafu and Soko soils can be rated as low to medium. The low P content in soils of SUA-farm, Kidamke, Dakawa, Cholima and Mafiga could be due to low P contents in parent material, or P occurring in forms not extractable by the Olsen-P- reagents. The medium P content in the Kahe, Kikafu and Soko soils could be due to use of P-fertilizers in these areas for rice production, and substantial amounts of native P in parent materials of the soils.

The CEC of the SUA-farm, Kidamke, Dakawa and Mafiga soils ranged from 22.27 to 44.89, 8.35 to 14.62, 24.36 to 46.28, 9.40 to 15.66 cmol(+)/kg with mean values of 32.28, 11.6, 32.48, 12.53 cmol(+)/kg, respectively. The CEC of the Cholima soil was found to be 31.67 cmol(+)/kg while those of Kahe, Kikafu and Soko soils ranged from 17.4 to 22.97, 35.84 to 45.24, 17.75 to 49.07 cmol(+)/kg with mean values of 20.19, 40.54, and 35.01 cmol(+)/kg, respectively. Landon (1991) and EUROCONSULT (1989) categorized cation exchange capacity of soils as follows; very high (>40), high (25.0-40.0), medium (12.1-25.0), low (6.0-12.0) and very low (<6.0). Based on this categorization, the CEC of the studied soils range between medium to high. The medium to high CEC values observed in these soils is probably due to the influence of soil texture, predominance of 2:1 clays and amorphous materials. According to Rhoades (1982), clayey soils have higher CEC than sandy soils due to presence of high exchange sites on the clays. This property can cause a greater risk of soluble salts, sodium accumulation in the presence of water rich in salts and nutrient imbalances (van Hoorn, 1971). Furthermore, soils of high CEC have high exchangeable bases, which lead to high pH values. Therefore the high pH values tend to reduce the solubility and hence availability of elements such as Fe, Cu and Zn (Tisdale, 1993; Brady and Weil, 1996) as a result of the formation of insoluble compounds through precipitation.

4.2 Exchangeable cations

Results for exchangeable cations for the soils were as presented in Table 2. Calcium values for SUA-farm, Kidamke, Dakawa and Mafiga soils ranged from 6.97 to 16.12, 3.97 to 6.06, 11.91 to 22.47, 1.93 to 2.34 cmol Ca(+)/kg with mean values of 11.88, 5.05, 15.92, and 2.14 cmol Ca(+)/kg, respectively, while that of Cholima soil was 15.56 cmol Ca(+)/kg. Calcium values for Kahe, Kikafu, and Soko soils ranged from 3.08 to 9.19, 0.75 to 10.77, 2.06 to 7.38 cmol Ca(+)/kg with mean values of 6.14, 5.76, and 5.70 cmol Ca(+)/kg, respectively. Landon (1991) categorized exchangeable calcium as follows, very high (>20.0), high (10.1-20.0), medium (5.1-10.0), low (2.0-5.0) and very low (<2.0). Based on this categorization the calcium content of the soils varied from medium to high, except for Kikafu soils which ranged from very low to high. The high levels of calcium content in these soils could probably be due to basic parent material, minimum leaching and weathering. The high calcium content could reduce availability of other ions such as Zn in the soil solution due to the formation of $CaCO_3$, which adsorbs Zn on its surface (Tisdale *et al.*, 1993). Therefore due to high content of Ca^{2+}, crop response to addition of Ca^{2+} containing fertilizers is unlikely, and the high content could lead to nutrient imbalances. Based on the pH of these soils and the exchangeable calcium, the possibility of the presence of soluble and insoluble calcium salts in the soils is highly likely.

Table 2. The quantities of exchangeable bases for the soils used in the study

	Exchangeable bases (cmol(+)/kg soil)			
Sample name	Ca^{2+}	Mg^{2+}	K^+	Na^+
SF1	8.49	5.63	2.87	6.67
SF2	16.12	11.73	4.39	6.04
SF3	15.95	10.45	5.51	12.98
SF4	6.97	8.53	0.21	6.57
KDK1	6.06	4.59	1.48	2.49
KDK2	3.97	1.65	2.32	0.41
KDK3	5.13	2.81	2.32	1.57
DKW1	13.39	5.86	7.53	0.03
DKW2	22.47	10.73	11.74	1.33
DKW3	11.91	5.20	6.70	0.55
CHOL	15.56	3.19	12.37	0.55
MAF1	1.93	1.19	0.74	5.54
MAF2	2.34	1.95	0.39	10.99
KAH1	9.19	1.74	7.44	4.60
KAH2	3.08	0.35	2.74	11.23
KIK1	10.77	6.19	4.59	14.29
KIK2	0.75	0.15	0.59	43.75
SOK1	6.29	0.89	5.39	21.18
SOK2a	7.07	2.28	4.79	14.39
SOK2	2.06	0.61	1.45	13.63
SOK3	5.72	1.423	4.29	34.51
SOK4	7.38	1.34	6.05	34.31

Exchangeable magnesium values for SUA-farm, Kidamke, Dakawa and Mafiga ranged from 5.63 to 11.73, 1.65 to 4.59, 5.20 to 10.73, 1.19 to 1.95 cmol Mg(+)/kg with mean values of 9.09, 3.02, 7.26, and 1.57 cmol Mg(+)/kg, respectively. Magnesium value for Cholima soils was 3.19 cmol Mg(+)/kg while that for the Kahe, Kikafu, and Soko soils ranged from 0.35 to 1.74, 0.15 to 6.19, 0.61 to 2.28 cmol Mg(+)/kg with mean values of 1.05, 3.17, and 1.31 cmol Mg(+)/kg, respectively. Landon (1991) and EUROCONSULT (1989) categorized exchangeable magnesium as follows; very high (>6.0), high (3.1-6.0), medium (1.1-3.0), low (0.3-1.0) and very low (<0.3). Based on this categorization, almost all soils have exchangeable magnesium ranging from medium to very high, except for Kahe and Kikafu soils which had relatively low values. Based on this categorization, generally these soils have high content of exchangeable Mg^{2+}, and hence crop response to addition of Mg^{2+} containing fertilizers is unlikely. The high content of magnesium could be due to basic parent material, which might contain substantial amounts of magnesium, minimum leaching and weathering leading to accumulation of magnesium salts.

Exchangeable sodium values for the SUA-farm, Kidamke, Dakawa and Mafiga ranged from 6.04 to 12.98, 0.41 to 2.49, 0.03 to 1.33, 5.54 to 10.99 cmol Na(+)/kg with mean values of 8.07, 1.49, 0.64.and 8.27 cmol Na(+)/kg, respectively. Sodium values for Cholima soils were found to be 0.55 cmol Na(+)/kg. Sodium values for the Kahe, Kikafu, Soko soils ranged from 4.60 to 11.23, 14.29 to 43.75, 13.63 to 34.51 cmol Na(+)/kg with mean values of 6.50, 29.02, and 23.6 cmol Na(+)/kg, respectively. Landon (1991) categorized exchangeable sodium as follows; very high

(>2.0), high (0.71-2.00), medium (0.31-0.70), low (0.10-0.30) and very low (<0.10). Based on this categorization, almost all soils have high to very high exchangeable sodium except Dakawa and Cholima soils, which recorded low to medium values. Therefore due high concentration of exchangeable sodium in these soils, some soil physical properties could be impaired leading to poor root penetration, water infiltration problems and likelihood of sodium toxicity. The high values of sodium in these soils could be due to basic parent material, which might contain substantial amounts of sodium, minimum leaching and weathering leading to accumulation of sodium salts.

Exchangeable potassium values for the SUA-farm Kidamke, Dakawa of Mafiga ranged from 0.21 to 5.51, 1.48 to 2.32, 6.70 to 11.74, and 0.39 to 0.74 cmol K(+)/kg with mean values of 3.25, 2.04, 8.66, and 0.57 cmol K(+)/kg, respectively. Exchangeable potassium value for Cholima soil was 12.37 cmol K(+)/kg, while that of Kahe, Kikafu, and Soko soils ranged from 2.74 to 7.44, 0.59 to 4.59, 1.45 to 6.05 cmol K(+)/kg with mean values of 5.09, 2.59, and 4.39 cmol K(+)/kg, respectively. Landon (1991) categorized the exchangeable potassium in soils as follows; very high (>2.0), high (1.21-2.00), medium (0.41-1.20), low (0.20-0.40) and very low (< 0.20). Based on this categorization, the exchangeable potassium was generally high in almost all soils studied. Therefore, crop response to potassium fertilization is unlikely since the exchangeable potassium in these soils is above the critical level of 0.2 to 0.8 (Yates, 1977; Landon, 1991). The high values of potassium could be due to basic parent material, which might contain substantial amount of potassium, minimum leaching and weathering leading to accumulation of potassium salts.

4.3 Water soluble cations and anions

Results for water-soluble cations and anions were as presented in Table 3. The content of sodium for SUA-farm, Kidamke, Dakawa and Mafiga soils ranged from 5.77 to 12.92, 2.09 to 9.08, 4.52 to 6.96, 6.46 to 19.43 cmol Na(+)/kg with mean values of 9.13, 4.89, 5.77, and 12.95 cmol Na(+)/kg, respectively. The content of sodium in the Cholima soil was 11.27, while that of Kahe, Kikafu, and Soko soils ranged from 14.29 to 30.33, 8.7 to 54.75, 9.64 to 36.97 cmol Na(+)/kg with a mean of 22.31, 31.73, and 25.36 cmol Na(+)/kg, respectively. The high sodium contents imply low leaching process due to impeded drainage, upward movement of salts or due to the use of salt water for irrigation, which can lead to nutrient imbalance, hence poor crop performance.

Soluble calcium levels for the SUA-farm, Kidamke, Dakawa and Mafiga soils ranged from 1.51 to 7.66, 1.61 to 5.02, 1.75 to 7.75, 3.25 to 3.44 cmol Ca(+)/kg with mean values of 4.21, 3.86, 5.48, and 3.35 cmol Ca(+)/kg, respectively. The soluble calcium in Cholima soils was 1.16, while that of the Kahe, Kikafu, and Soko soils ranged from 13.23 to 18.17, 5.15 to 5.36, 6.59 to 33.15 cmol Ca(+)/kg with mean values of 15.7, 5.26, and 17.0 cmol Ca(+)/kg, respectively. Although there is no categorization for soil soluble salts with respect to Ca^{2+}, these values seem to be high, hence could lead to soil salinity.

Table 1. Quantities of water soluble cations and anions in the soils used for the study

Name	Ca	Mg	K	Na	CO_3	HCO_3	SO_4	Cl^-	B	Sum-cations	Sum-Anion
	cmol(+)/kg					cmol(-)/kg				cmol(+)/kg	cmol(-)/kg
SF1	5.66	7.58	5.22	8.55	0.00	7.92	9.00	9.72	0.00	27.01	26.64
SF2	7.66	2.02	3.71	5.77	0.00	1.88	16.30	0.86	0.00	19.16	19.04
SF3	1.51	7.02	5.53	12.92	0.00	6.95	13.62	6.39	0.00	26.98	26.96
SF4	1.99	0.38	10.27	9.26	0.00	9.91	7.43	4.54	0.00	21.90	21.88
KDK1	1.61	1.95	2.41	2.09	0.04	0.26	7.50	0.05	0.00	8.06	7.80
KDK2	5.02	7.51	1.33	9.08	0.00	0.95	21.44	0.42	0.01	22.94	22.82
KDK3	4.94	7.23	3.16	3.50	1.39	1.72	15.18	0.41	0.04	18.83	18.74
DKW1	6.94	1.32	4.57	4.52	0.00	1.22	15.21	0.81	0.00	17.35	17.24
DKW2	7.75	4.32	4.64	6.96	0.37	4.63	17.12	1.32	0.18	23.67	23.62
DKW3	1.75	5.39	2.17	5.84	0.00	3.80	8.60	2.70	0.00	15.15	15.10
CHOL	1.66	11.42	9.46	11.27	0.00	9.25	21.73	2.22	0.40	33.81	33.60
MAF1	3.44	4.19	2.59	6.46	1.86	10.23	2.32	2.02	0.15	16.68	16.58
MAF2	3.25	3.58	4.04	19.43	0.48	5.00	21.25	3.47	0.08	30.30	30.28
KAH1	13.23	16.75	4.87	14.29	0.00	2.14	46.7	0.13	0.13	49.14	49.10
KAH2	18.17	20.64	1.69	30.33	1.43	6.29	58.00	4.43	0.21	70.83	70.63
KIK1	5.15	9.61	5.22	8.70	0.84	1.54	24.46	1.65	0.14	28.68	28.63
KIK2	5.36	0.99	0.93	54.75	22.87	16.24	22.43	0.45	0.00	62.03	61.99
SOK1	10.61	15.50	3.48	11.65	8.17	7.10	25.55	0.10	0.25	41.24	41.18
SOK2a	33.15	28.41	3.54	36.97	0.00	7.25	91.56	2.40	0.80	102.07	102.01
SOK2	27.29	16.23	4.16	9.64	0.00	5.78	40.46	10.54	0.30	57.32	57.28
SOK3	7.36	9.30	1.90	36.57	17.96	29.15	6.99	0.91	0.00	55.13	55.10
SOK4	6.59	11.14	3.93	31.97	17.06	22.41	13.52	0.58	0.00	53.63	53.57

Magnesium values for the SUA-farm, Kidamke, Dakawa and Mafiga ranged from 0.38 to 7.58, 1.95 to 7.51, 1.32 to 5.39, 3.58 to 4.19 cmol Mg(+)/kg with mean values of 4.25, 5.56, 3.68, and 3.89 cmol Mg(+)/kg, respectively. Magnesium value for Cholima was found to be 11.42 cmol Mg(+)/kg, while that of the Kahe, Kikafu, and Soko soils ranged from 16.75 to 20.64, 0.99 to 9.61, 9.3 to 28.41 cmol Mg(+)/kg with mean values of 18.69, 5.3, and 16.12 cmol Mg(+)/kg, respectively. These high values imply that there is limited leaching of the magnesium salts due to low precipitation and the parent material could be having high content of magnesium. Although there is no categorization for soil soluble salts with respect to Mg^{2+}, these values seem to be high, hence could lead to soil salinity.

Potassium levels for the SUA-farm, Kidamke, Dakawa and Mafiga ranged from 3.71 to 10.27, 1.33 to 3.16, 2.17 to 4.64, 2.59 to 4.04 cmol K(+)/kg and had mean values of 6.18, 2.3, 3.79, and 3.32 cmol K(+)/kg, respectively, while potassium level for Cholima was 9.46 cmol K(+)/kg. Potassium levels for the Kahe, Kikafu, and Soko ranged from 1.69 to 4.87, 0.93 to 5.22, 1.9 to 3.54 cmol K(+)/kg and had mean values of 3.28, 3.08, and 3.40 cmol K(+)/kg, respectively. The high contents of soluble potassium could be due to low leaching process due to impeded drainage, or upward movement of salts. Although there is no categorization for soil soluble salts with respect to K^{+}, these values seem to be high, hence could lead to soil salinity.

Sulphate contents in the SUA-farm, Kidamke, Dakawa, and Mafiga ranged from 7.43 to 16.3, 7.5 to 21.44, 8.6 to 17.12, 2.32 to 21.25 cmol(-)SO_4^{2-}/kg with mean values of

11.58, 14.71, 13.64 ,and 11.79 cmol(-)SO_4^{2-}/kg, respectively. Sulphate content for Cholima soil was 21.73 cmol(-)SO_4^{2-}/kg, while that of Kahe, Kikafu, and Soko soils ranged from 46.7 to 58.0, 22.43 to 24.46, 6.99 to 91.56 cmol(-)SO_4^{2-}/kg with mean values of 52.35, 23.45, and 35.02 cmol(-)SO_4^{2-}/kg, respectively. The high values of sulphates could be due to limited leaching because of low precipitation, leading to accumulation of sulphates. Although there is no categorization for soil soluble salts with respect to SO_4^{2-}, these values seem to be high, hence could lead to soil salinity.

Bicarbonates recorded high values in SUA-farm, Kidamke, Dakawa, and Mafiga which ranged from 1.88 to 9.91, 0.26 to 1.72, 1.22 to 4.63, 5.0 to 10.23 cmol(-)HCO_3^-/kg with mean values of 6.66, 0.97, 3.22, and 7.62 cmol(-) HCO_3^-/kg, respectively. Bicarbonates for Cholima soil recorded high value, which was 9.25 cmol(-)HCO_3^-/kg. In Kahe, Kikafu, and Soko soils, bicarbonates ranged from 2.14 to 6.29, 1.54 to 16.24, 5.78 to 29.15 cmol(-)HCO_3^-/kg with mean values of 4.21, 8.89, and 14.34 cmol(-)HCO_3^-/kg, respectively. These high values imply that there is limited leaching of the bicarbonates due to low precipitation and the parent material could be having high content of carbonates. Although there is no categorization for soil soluble salts with respect to HCO_3^-, these values seem to be high, hence could lead to soil salinity.

Soluble carbonates were found in trace amounts in all SUA-farm and Cholima soils, while in Kidamke, Dakawa, and Mafiga, ranged from trace to 0.04, trace to 0.37, 0.48 to 1.86 cmol(-) CO_3^{2-}/kg with mean values of 0.47, 0.12, and 1.78 cmol(-)CO_3^{2-}

/kg, respectively. Carbonates in Kahe, Kikafu, and Soko ranged from trace to 1.43, 0.84 to 22.87, trace to 17.96 cmol(-)CO_3^{2-}/kg with mean values of 0.72, 11.85, and 8.64 cmol(-)CO_3^{2-}/kg, respectively. These values indicate that there is accumulation of soluble salts, probably due to limited weathering of the parent material. Although there is no categorization for soil soluble salts with respect to CO_3^{2-}, these values seem to be high, hence could lead to soil salinity.

The chloride contents in the SUA-farm, Kidamke, Dakawa and Mafiga soils ranged from 0.86 to 9.72, 0.05 to 0.42, 0.81 to 2.7, 2.02 to 3.47 cmol(-)Cl^-/kg with mean values of 5.37, 0.29, 1.61, and 2.75 cmol(-) Cl^- /kg, respectively. Cholima soils recorded a value of 2.22 cmol(-)Cl^-/kg, while that in the Kahe, Kikafu, and Soko soils ranged from 0.13 to 4.43, 0.45 to 1.65, 0.1 to 10.54 cmol(-)Cl^-/kg with mean values of 2.28, 1.05, and 2.91 cmol(-)Cl^-/kg, respectively. Although there is no categorization for soil soluble salts with respect to Cl^-, these values seem to be high, hence could lead to soil salinity.

Boron contents in SUA-farm soils were very low (traces), while that of Kidamke, Dakawa, and Mafiga soils ranged from trace to 0.04, trace to 0.18, 0.08 to 0.15 cmol(-)B^-/kg with mean values of 0.02, 0.06, and 0.12 cmol(-)B^- /kg, respectively. Boron content in Cholima was found to be 0.4 cmo(-) B^-/kg, while in Kahe, Kikafu, and Soko soils ranged from 0.13 to 0.21, trace to 0.14, and trace to 0.8 cmol(-)B^- /kg with mean values of 0.17, 0.07, and 0.27 cmol(-)B^- /kg, respectively. Although there is no categorization for soil soluble salts with respect to B^-, these values seem to be high, hence could lead to soil salinity.

The high amount of sodium, sulphate, bicarbonate and chlorides in the studied soils could be explained by assuming that the conditions, which favour the increase in concentration of these ions, are optimal in the water catchment influencing the soils. The solubility product of other compounds such as carbonates of calcium and magnesium could be another reason, which accounts for the dominance of sodium in most of the soils studied. Appreciable amounts of carbonates and bicarbonates contained in water get precipitated as calcium carbonates (Vinayak *et al.*, 1981). The precipitation of calcium carbonates causes an increase in soluble sodium, which tends to dominate the exchange complex.

4.5 Electrical conductivity, exchangeable sodium percentage, pH, and SAR

The results for, ESP, ECe pH and SAR were as presented in Table 4. Properties which are characteristic of salt-affected soils include pH of the soil extract, electric conductivity of the soil extract (ECe), exchangeable sodium percentage (ESP)(see appendix 1), and water soluble cations and anions (see Appendix 1). The ESP values for SUA-farm, Kidamke, Dakawa, and Mafiga soils ranged from 15.78 to 29.49, 4.86 to 17.05, 0.11 to 2.88, and 58.89 to 70.15 % with mean values of 25.59, 11.73, 1.75, and 64.52 %, respectively. The ESP value of Cholima soils was found to be 1.73 %, while that of the Kahe, Kikafu and Soko soils ranged from 20.03 to 64.56, 39.88 to 96.70, 50.43 to 76.79 % with mean values of 42.29, 68.29 and 66.99 %, respectively.

Landon (1991) categorized ESP values as follows; extremely sodic (>35), very strongly sodic (26-35), moderately sodic (11-25), slightly sodic (6-10) and non-sodic (<6). Based on this categorization, the ESP of Dakawa and Cholima soils is low implying that these soils are non-sodic, while the other soils recorded high values hence ranging from slightly sodic to extremely sodic. Generally soils of Mafiga, Kahe, Kikafu and Soko recorded high values of ESP. The high ESP implies that the soils are sodic or saline-sodic because their values are above the 15 % within the 30 cm of the soil surface (FAO, 1988; Abrol *et al.*, 1988). All soils in these areas have higher proportion of sodium, which can cause permeability problems. The rate of water infiltration into and through the soil would be reduced to such an extent that the crop can not adequately be supplied with water and yield could be reduced (Gupta and Gupta, 1987). This could be attributed by poor drainage conditions accompanied by excessive evaporation over precipitation if the inflowing water has a positive residual sodicity. Leaching can reclaim the saline-sodic after they have been amended with gypsum. This is recommended if there is available good quality water to leach the soils without detrimental effects. Alternatively, these soils together with sodic soils can be used to grow salt tolerant crops such as rice (which can tolerate ESP of up to 40) (Maas and Hoffman, 1977). This is because sodic soils are the most difficult to reclaim and the least likely to be worth the cost in time, money, and effort (Troeh and Thompson, 1993).

Table 4. ECe, pH, SAR and ESP of the soils used in the study

Sample name	**ECe**	**pH water 1:2.5**	**SAR**	**ESP**
SF1	4.90	7.88	2.51	28.18
SF2	2.41	8.37	1.62	15.78
SF3	4.26	7.78	2.53	28.92
SF4	2.22	8.05	2.36	29.49
KDK1	0.26	9.03	1.08	17.05
KDK2	0.53	8.55	0.25	4.86
KDK3	0.34	7.76	0.79	13.29
DKW1	0.24	7.21	0.01	0.11
DKW2	0.11	7.70	0.33	2.88
DKW3	0.22	7.87	0.19	2.26
CHOL	0.25	8.14	0.18	1.73
MAF1	2.72	8.28	4.44	58.89
MAF2	7.28	8.16	7.5	70.15
KAH1	5.04	7.92	1.97	20.03
KAH2	18.78	9.58	8.58	64.56
KIK1	0.88	9.35	4.91	39.88
KIK2	6.64	10.92	65.29	96.70
SOK1	2.77	10.37	11.18	62.73
SOK2a	1.00	8.01	6.66	50.43
SOK2	1.00	8.00	11.80	76.79
SOK3	5.83	10.58	18.27	75.11
SOK4	3.58	10.47	16.43	69.92

The ECe values for SUA-farm, Kidamke, Dakawa, and Mafiga ranged from 2.22 to 4.90, 0.26 to 0.53, 0.11 to 0.24, 2.72 to 7.28 dS/m at 25 ^{0}C with mean values of 3.45, 0.38, 0.19, and 5.0 dS/m at 25 ^{0}C, respectively. The ECe value of the Cholima soils was found to be 0.25 dS/m at 25 ^{0}C. The ECe values for Kahe, Kikafu, and Soko soils ranged from 5.04 to 18.78, 0.88 to 6.64, 1.0 to 5.83 dS/m at 25 ^{0}C with mean values of 11.91, 3.76, and 2.84 dS/m at 25 ^{0}C, respectively. Landon (1991) categorized ECe of soils as follows; strongly saline (>15), moderately saline (9-15), slightly saline (5-8) and non-saline (0-4). Based on this categorization, generally soils of SUA-farm, Dakawa and Cholima, MAF1, KIK1, SOK1, SOK2a, SOK2 and SOK4 are in the non-saline range. On the other hand soil of MAF2, KIK2 and SOK3 are in the slight saline range, while that of KAH2 was on the strongly saline range. The high values of ECe in these soils are probably due to the fact that these areas have been fallowed for a long time. Therefore, there is no irrigation going on at least to leach some salts.

Landon categorized salt affected soils as follows; saline (ECe > 4; ESP < 15; pH usually <8.5), saline-sodic (ECe > 4, ESP > 15, pH usually < 8.5) and sodic (ECe < 4, ESP > 15, pH usually > 8.5). Based on Landon and Appendix 1) categorization soils of SF1, SF3, MAF2, KAH1, KAH2, KIK2 and SOK3 are saline-sodic soils, while SF2, SF4, KDK1, MAF1, KIK1, SOK1, SOK2a, SOK2 and SOK4 are sodic soils, respectively. On the other hand soils of KDK2, KDK3, DKW1, DKW2, DKW3 and CHOL are normal soils. According to Landon (1991) categorization, no saline soils were observed among the soils studied.

SAR for SUA-farm, Kidamke, Dakawa ranged from 1.62 to 2.51, 0.25 to 1.08 and 0.01 to 0.33, with mean values of 2.26, 0.706 and 0.177, respectively. SAR for Cholima was 0.18, while that of Mafiga, Kahe, Kikafu and Soko ranged from 4.44 to 7.5, 1.97 to 8.58, 4.91 to 65.29, and 6.66 to 18.27, with mean values of 5.97, 5.28, 35.1 and 12.868 respectively. The SAR values showed positive relationship with ESP, which is where SAR values were high, ESP values was high and vice versa. The high values of SAR could lead to dispersion of the soil, hence the growth of plants is affected due to poor soil structure and soil permeability.

4.6 Management of the soils for crop production

Currently the soils in the study area are used for salt-tolerant crop (rice and pasture) production because of their salinity and sodicity limitations. In order for these soils to be able to support a variety of crops, proper management packages such as use of amendments, leaching, addition of inorganic fertilizers and manure should be adopted

For better management of the salt affected soils, the first step is to know the quality of the irrigation water and the status of the soil drainage. After the assurance of good quality water and adequate drainage status of the soils, the removal of excess salts can be conducted. The removal of excess salts from saline soils requires access to ample low-salt irrigation water and effective internal soil drainage system that will quickly remove the salt-laden water once it leaches or flushes down through the soil.

If natural soil drainage is inadequate to accommodate the leaching water an artificial drainage network must be installed.

For saline-sodic and sodic soils, attention must first be given to reducing the level of exchangeable Na^+ and then to the problem of excess soluble salts. This can be achieved by addition of amendments such as gypsum. Removing sodium ions from the exchange complex is most effectively accomplished by replacing them with either the Ca^{2+} or the H^+ ion. Several tons of gypsum would be required per hectare for this exercise. The soils must be kept moist to hasten the reaction, and gypsum should be thoroughly mixed and incorporated into the surface soils by cultivation not simply plowed under. The treatment must be supplemented later by a thorough leaching of the soil with irrigation water to leach out most of the sodium sulphate. Once the salt affected soils have been reclaimed, prudent management steps must be taken to be certain that the soils remain productive. For example, surveillance of the ECe and SAR and other pertinent chemical characteristics of the irrigation water are essential. Management adjustments would be needed to accommodate any change in water quality that could affect the soils. Steps should also be taken to monitor appropriate chemical characteristics of the soil such as pH, ECe, and SAR, as well as specific levels of elements such as boron and selenium that could lead to chemical toxicity. These measurements will help determine the need for subsequent remedial practices and/or chemicals. Crop and soil fertility management strategies such as addition of organic matter to maintain satisfactory yield levels is essential to maintain the overall quality of salt-affected soils. The crop residues (roots and above ground stalks) will help maintain organic matter levels and good physical condition of the soil. To maintain high yields, micronutrient and phosphorus deficiency characteristics of other high pH soils will need to be overcomed by appropriate organic and inorganic sources.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

The study was carried on some salt affected soils from part of SUA-farm, Mkata Ranch (Kidamke), Dakawa rice farm, Cholima research station and Mafiga in Morogoro. Others were soils from Kahe, kikafu chini and Soko in Moshi district, Kilimanjaro. Based on categorization by Abrol *et al.*(1988) and Landon (1991), the soils occurring in the study areas were categorized as; sodic, saline-sodic, and normal. Large differences exist among them in terms of the type and concentration of individual cations and anions they contain. There is a domination of sodium and sulphate ions in the soils studied, although the content of calcium carbonates and chloride may be considerably high in certain areas. The primary source of salts in the study areas is probably the weathering of rocks within the drainage system affecting the studied soils.

From the management point of view, each type of the salt affected soils studied requires a different approach with respect to reclamation. The sodic soils need eradication of alkalinity problem, which becomes prominent in some areas. 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 rootzone. 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. Alternative measure is to grow salt-loving or salt-tolerant crops in sodic and/or saline soils, such as rice, which can tolerate high values of ECe and ESP, especially where good quality water for irrigation is a problem. Furthermore, for optimum crop production in these soils, special fertilizer management practices, different from those usually recommended for soluble salt-free soils should be applied. Thus fertilization programs should aim at, supplementing nutrients that are present in insufficient, and/or supplementing nutrients that although present in sufficient amounts, are not taken up in adequate amounts due to antagonistic effect. However, a thorough study on fertilizer recommendation rates in these soils is recommended.

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7.0 APPENDICES

Appendix 1: Traditional and proposed classifications of Salt-Affected Soils

	Normal soils	**Saline soils**	**Sodic soils**	**Saline-sodic soils**
Traditional classification	ECe < 4 dSm-1 ESP < 15% SAR < 15	ECe > 4 dSm-1 ESP < 15% SAR < 15 pH < 8.5	ECe < 4 dSm-1 ESP > 15% SAR > 15 pH 8.5 – 10.5	ECe > 4 dSm-1 ESP > 15% SAR < 15 PH < 8.5
Proposed classification	ECe < 2 dSm-1 SAR < 15	ECe > 2 dSm-1	SAR > 15	ECe > 2 dSm-1 SAR > 15

Source: Modified from Bohn *et al.*, 1985; James *et al*, 1982; Abrol *et al.*, and Tanji 1990