EFFECTS OF SOME AMENDMENTS ON SOIL PROPERTIES AND MAIZE YIELD GROWN IN SODIC SOIL: A CASE STUDY OF MTO WA MBU, ARUSHA, TANZANIA

BY

NESTORY CHARLES WARIOBA GWASSO

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ABSTRACT

A study was conducted at Mto wa Mbu, Arusha, Tanzania to evaluate the effects of some amendments on soil properties and yield of maize grown in sodic soils. The soil of Mto wa Mbu was classified as sodic with a clay loam texture. The soil was characterized in this study for its physical and chemical properties prior to planting maize as a test crop. The soil laboratory analytical data showed that the soil was alkaline, clay loam textured and compact (bulk density ranging from 1.39 to 1.45 gcm^{-3}). The soil pH ranged from 9.80 to 10.45, ECe from 1.6 to 3.57 dSm^{-1} and ESP ranged from 92 to 99%. Total N, available P, % OC, exchangeable Ca, Mg, CEC, and DTPA extractable Cu, Zn, Fe and Mn were in the low range while exchangeable K and Na were high. In the field a randomized complete block design was used to evaluate the effects of the amendments using maize as a test crop. Gypsum was applied at 0, 7.5, 15, 22.5 and 30 tha^{-1} and sulphur at 0, 1.4, 2.9, 4.3 and 5.7 tha^{-1}, corresponding to 0, 25, 50, 75, and 100% of laboratory gypsum requirement. The amendments were surface mixed at 0-15 cm depth. The rates of farmyard manure were 0 and 20 tha^{-1}. Prior to soil incorporation, the amendments (FYM and gypsum) were analyzed for their chemical properties. In gypsum treated plots maize grain yields ranged from 0 (control) to 1.32 tha^{-1}. The maize grain yields in sulphur amended plots ranged from 0 to 0.32 tha^{-1} and that of FYM treated plots ranged from 0 to 0.35 tha^{-1}. When gypsum and sulphur were combined with FYM the maize grain yields ranged from 0 to 1.42 and 0 to 0.53 tha^{-1} respectively. Therefore, maize grain yield was significantly higher in gypsum and FYM when applied alone than in sulphur amended plots. But it was much higher when gypsum and sulphur were mixed with FYM. Application of sulphur caused only slight yield increases, but was more effective when combined with FYM. The economic analysis showed that the application of amendments was uneconomical due to low maize grain yield. At the end of growing season the soil was analyzed to evaluate the residual effect of the amendments on soil properties. Available P, ECe, % OC, total N, exchangeable bases, CEC in the plots amended with gypsum, sulphur and FYM increased in the top 15 cm of soil relative to the control. Soil pH and ESP in all treated plots was significantly reduced except in S_{25} and S_{50} treatments. Bulk density in all amended plots was not significantly different to the control. DTPA extractable Zn, Fe, Cu and Mn increased slightly following the application of amendments. Regression analysis between soil variables and maize grain yield showed that soil pH and Ca were significantly affected the yield ($P<0.05$). ECe was slightly correlated with the yield. The rest of the variables (P, %OC, Total N, excahngeable bases and DTPA extractable Zn, Fe, Cu, Mn) were not linearly correlated with the yield. Though maize grain yields from the treated plots were low compared to that of normal soils which range from 1.2 to 2.4 tha^{-1}, the results from the field suggested that, the amendments especially G_{100} + FYM can ameliorate sodicity and produce satisfactory plant growth and yields.

DECLARATION

I, NESTORY CHARLES WARIOBA GWASSO, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has not been submitted for award of a degree in any other university.

Signature:...................................

Date:..........14/11/2003...........

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DEDICATION

This work is dedicated to my parents. My farther Samwel Mugagya Murundi and my mother Sophia Nyangi Ndimira for their role as parents. I also wish to dedicate this work to my late grand mother Minza Nyamhinga (may her soul rest in peace).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

CEC	Cation exchange capacity
CRBD	Complete randomized block design
DMRT	Duncan's Multiple Range Test
DSS	Department of Soil Science
DTPA	Diethylenetriaminepentacetic acid
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization
ILO	International Labour Organization
ILRI	International Livestock Research Institute
NSS	National Soil Service
SAR	Sodium adsorption ratio
SARI	Selian Agricultural Research Institute
SPWP	Special Public Works Program
SUA	Sokoine University of Agriculture
TARO	Tanzania Agricultural Research Organization
TPC	Tanganyika Planting Company
TPRI	Tropical Pesticides Research Institute
TRA	Tanzania Revenue Authority
UFI	Universal Farm Implements

CHAPTER ONE

1.0 INTRODUCTION

Tanzania's economy depends to a large extent on agriculture with approximately 94% of the population engaged in agriculture (Ngana, 1993). Rain fed agriculture has been a major traditional way of farming and the production is often coupled with irregular fluctuation of yields caused by unreliable rainfall. It has been estimated that only 30 to 40% of the country receives sufficient rainfall for agricultural production. At the same time, the more favoured and productive areas of the country are beginning to succumb to the pressure of overpopulation (Arens, 1979).

Based on the fact that agriculture constitutes about 70% of the total exports of the nation (TRA, 1999), and 94% part of the population is engaged in agriculture, it has been realised that irrigation farming must be an important input in increasing crop production on a sustainable basis for areas which have ample water for irrigation. Irrigation will reduce the effects of erratic rains and drought and can potentially double the harvest. However, poorly designed and/or managed irrigation is a major cause of salinisation and alkalisation in the country (Barrow, 1992).

In Tanzania, about 3.6 million ha of land have salt problem of one type or another (Massoud, 1977). According to De Pauw (1984) these soils occur extensively in areas within arid and semi-arid zones characterised by high evapotranspiration combined with low and erratic rainfall to meet plant need. Since evapotranspiration greatly exceeds precipitation for most of the year, no water percolates through the soil under natural conditions. As a result, salts are not leached from the soil; instead they accumulate in the profile in amounts and/or types detrimental to plants.

On irrigated lands, salinisation leads not only to an adverse effect on crop production but also has major effect on land degradation and is one of the major factors with adverse environmental impacts (Dougherty and Hall, 1995). For instance, problems of salinity and sodicity of varying degrees are common in rice irrigation schemes at Lower Moshi, Ndungu, Ruvu, Mbarali, Kapunga, Dakawa and Mto wa Mbu. Others include sugarcane estates such as TPC, Mtibwa and Kilombelo (Mnkeni, 1996; Kunda, 1996; Baitilwake, 1999; Kiwale, 1999). Some of these schemes, including Mto wa Mbu (Yanda, 1989), have either been abandoned because of the hostile conditions on the crops or they are producing at a minimal level.

Mto wa Mbu irrigation project was among the potential areas for agriculture in the country, producing maize, paddy, bananas, millet, beans and vegetables under irrigation (Martens *et al.*, 1987; Yanda, 1989; Blackwell *at al.*, 1992). It was upgraded by International Labour Organisation (ILO) financial and technical assistance under Special Public Works Program (SPWP) in order to control flood and to improve existed traditional smallholder infrastructures. However, the project did not consider the farmers' participation in the decision-making especially on the issue of day-to-day maintenance of the irrigation canals. Consequently, the canals collapsed (Yanda, 1989; Blackwell *et al.*, 1992; Kihupi and Dihenga, 1995). According to the authors, the collapse of the canals led to waterlogging due to raised water table. Consequently, the raised water table resulted in accumulation of salts in the area. According to Yanda (1989) soil salinity has become the greatest factor contributing to the failure of the project such that crop production has been reduced drastically.

Most of the proposed management systems for salt-affected soils like micro irrigation and subsurface drainage are so expensive and laborious that smallholder farmers cannot afford them (Tanji 1990). However, some studies conducted by Dargan *et al.* (1976); Chand *et al.* (1977); Prasad and Verma (1987); Sekhon and Bajwa (1993) and Pandiyarajan and Kannaiyan (1996) have shown that the use of gypsum, sulphur and farmyard manure has a substantial effect on improving the productivity of salt-affected soils. In turn this may lead to sustainable crop production. The general objective of this study therefore, was to evaluate the effect of some amendments on soil properties and maize yield grown in sodic soil at Mto wa Mbu. The specific objectives were:

i. To determine the optimum rate of gypsum, sulphur and farmyard manure and their effects on maize yield.

ii. To evaluate the effects of gypsum, sulphur and farmyard manure amendments and their combinations in ameliorating sodicity.

CHAPTER TWO

2.0 LITERATURE REVIEW.

2.1 Occurrence of salt affected soils in Tanzania

Salt affected soils are widely spread in Tanzania. The soils are found in the areas that experience unreliable rainfall under rainfed agriculture. According to Abrol *et al.*, (1988), Tanzania has a total salt affected land of about 3,573,000 ha of which about 2,954,000 ha are saline and 583,000 ha are sodic. Most of these areas are utilized for either fullscale or traditional smallscale irrigation schemes. They include Mto wa Mbu in Arusha region; Lower Moshi, Ndungu, Kahe, Hedaru and TPC in Kilimanjaro region; Usangu plains in Mbeya region; Ruvu plains in Coastal region; and Dakawa and Kilombero in Morogoro region (Mnkeni, 1996).

2.2 Sodic soils

Sodic soils are those which have an exchangeable sodium percentage (ESP) of more 15. They have columnar or prismatic structure in the B horizon (Van Alphen, 1975). The studies conducted by Abrol *et al.* (1988) revealed that sodic soils have high pH and high amounts of exchangeable sodium, resulting in the dispersion of clay, and unstable soil structure. As the proportion of exchangeable sodium increases, the soils tend to become dispersed, less permeable to water and air. The infiltration and hydraulic conductivity decrease to the extent that little or no water movement occurs. Moreover, Acharya and Abrol (1978) noted that the soils become plastic and sticky when wet, hard when dry and soil crusting develops. Dispersed organic matter may accumulate on the surface of poorly drained areas and impart a black colour hence the common name "black alkali" (Bohn *et al.* 1985, Cardon and Mortvedt, 2001). In sodic soils, sodium is the dominant cation while the anions present consist mostly chlorides, sulphates, and bicarbonates with small to moderate amounts of carbonates depending on the pH of the soil (Rhoades, 1976). Sodic soils have ECe generally less than 4 dSm^{-1} and ESP greater than 15 at 25°C and the pH is more than 8.2. According to Beek *et al.*, (1973) the pH increases with increasing amounts of sodium carbonate ($NaCO_3$) and may be as high as 10 to 10.5. Increase in pH is due to the high solubility of sodium carbonate and therefore the greater potential for hydrolysis (Abrol *et al.*, 1988), as presented by the following equation:

$$Na_2CO_3 + 2H_2O \quad 2Na^+ + 2OH^- + H_2CO_3$$

Gupta and Gupta (1987) reported that the pH range of sodic soils in saturated extract to be 8.2 to 10.0 while that of soil water suspension (1:2) ranged from 9.0 to 10.8.

2.3 Reclamation of sodic soils

The term reclamation of salt-affected soils refers to the methods used to remove salts from the root zone (El-Gabaly, 1971). Emerson and Chi (1977), Khosla *et al*, (1979) and Cardon and Mortvedt (2001) reported that reclamation or improvement of sodic soils requires the removal of part of the exchangeable sodium and its replacement with more favourable calcium ions in the root zone. Furthermore, the authors noted that this can be accomplished in many ways; the best is dictated by soil characteristics, available resources, economic considerations and the kind of crop to be grown on the reclaimed soil. Before actual reclamation which involves the application of soil amendments and leaching, two steps must be observed namely, establishment of adequate drainage in the area so as to lower the water table and levelling of the soil to be covered uniformly.

2.3.1. Drainage

In order to permanently improve salt affected soils, it is necessary to have adequate drainage (You and Wang, 1983). Narayana *et al.*, (1977) noted that 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 salt affected soils, provision of drainage is an essential prerequisite of the reclamation. Before reclamation occurs, there are several possible drainage methods to control salinisation. These include surface and subsurface drainage. Surface drains are open channels, which collect water as it runs off or into irrigated fields. These drains convey water to a stream or channel where it can be carried out safely (ILRI, 1972). The main requirement is that they should be able to convey the maximum expected flow rate without erosion. According to Narayana (1980) these drains are to be broad and shallow at the tail end of irrigated fields to allow easy accessibility of farm machinery. Yanda, (1989); Blackwell *et al.*, (1992); Kihupi and Dihenga, (1995) and Maro, (1996) reported that in Tanzania and particularly Mto wa Mbu area surface drainage is the more common method used for irrigation. This is because surface drains are less expensive in construction and easier to maintain than subsurface drains.

2.3.2 Amendments

Soil amendments are materials, such as gypsum or calcium chloride that directly supply soluble calcium for replacement of exchangeable sodium (Prather *et al.*, 1978 ;Chauhan, 1995). Others include substances such as sulphuric acid and sulphur, that indirectly through chemical or biochemical action, make the relatively insoluble calcium carbonate commonly found in the sodic soils, available for replacement of sodium (Miyamoto *et al.*, 1975;Overstreet *et al.*, 1980).

2.3.2.1 Kind of amendment

According to Cardon and Mortvedt (2001), the purpose of any amendment like gypsum, calcium chloride, sulphur, sulphuric acid, pyrite, iron sulphate or aluminium sulphate is to provide soluble calcium to replace exchangeable sodium ions adsorbed on the clay surface. Chand, *et al.* (1977) broadly grouped the chemical amendments for sodic soil reclamation into two categories namely; soluble calcium salts (gypsum, calcium chloride) and acid or acid forming substances (sulphur, sulphuric acid, pyrite, iron sulphate, and aluminium sulphate).

Gypsum: Chemically, it is $CaSO_4$. $2H_2O$ and is a white mineral that occurs extensively in natural deposits. In Tanzania, it occurs naturally as deposits at Makanya in Same district and near Nyumba ya Mungu dam in Mwanga district, Kilimanjaro region. Chawla and Abrol (1982) observed that it must be ground before it is applied to the soil. According to Aylmore *et al.*, (1971) and Abrol *et al.*, (1979) gypsum is soluble in water to the extent of about one fourth of one percent by weight is a direct source of calcium. Gypsum reacts with both the $NaCO_3$ and the adsorbed sodium as follows:

$$NaCO_3 + CaSO_4 \quad CaCO_3 + NaSO_4 \text{ (leachable)}$$

$$2\text{Na-clay micelle} +.\ CaSO4 \quad \text{Ca-clay micelle} + Na_2SO_4 \text{ (leachable)}$$

Calcium chloride: Calcium chloride is chemically $CaCl_2$. It is a highly soluble salt that supplies calcium directly (Tanji, 1990). Its reactions to sodic soils are similar to those of gypsum. However, calcium chloride is more expensive than gypsum and therefore it is not preferred for sodic soils reclamation by smallholder farmers. Furthermore, it is not locally available as a natural deposit in Tanzania.

$Na_2CO_3 + CaCl_2 \quad CaCO_3 + 2NaCl$ (leachable)

$2Na$-clay micelle $+ CaCl_2$ $\quad$ Ca-clay micelle $\quad$ $2NaCl$ (leachable)

Sulphuric acid: Sulphuric acid is chemically H_2SO_4. It is a corrosive liquid and is usually about 95 percent pure. Miyamoto *et al.*, (1975 and Qadir *et al.*, (1998) observed that upon application to the soil containing calcium carbonate it immediately reacts to form calcium sulphate and provides soluble calcium indirectly). Sulphuric acid is not locally available. It is not preferred to gypsum due to its high cost, slow reacting and corrosive nature.

Chemical reactions involved are:

$Na_2CO_3 + H_2SO_4 \quad CO_2 + H_2O + Na_2SO_4$ (leachable)

$CaCO_3 + H_2SO_4 \quad CaSO_4 + H_2O + CO_2\uparrow$

$2Na$-clay micelle $+ CaSO_4$ $\quad$ Ca-clay micelle $+ Na_2SO_4$ (leachable)

Iron sulphate and Aluminium sulphate (Alum)

Chemically these compounds are $FeSO_4.\ 7H_2O$ and $Al_2(SO_4)_3.\ 18H_2O$ respectively. Both are solid granular materials usually have a high degree of purity and are soluble in water. When applied to soils, they dissolve in soil water and hydrolyse to form sulphuric acid that in turn supplies soluble calcium through its reaction with lime present in sodic soils (Chand *et al.*, 1977). Chemical reactions involved are:

$FeSO_4 + 2H_2O \quad H_2SO_4 + Fe(OH)_2$

$H_2SO_4 + CaCO_3 \quad CaSO_4 + H_2O + CO_2\uparrow$

$2Na$-clay micelle $+ CaSO_4$ $\quad$ Ca-clay micelle $+ Na_2SO_4$ (leachable)

Similar reactions are responsible for improvement of sodic soil when aluminium sulphate is used as amendment. Both amendments are not locally available and therefore are not widely used in sodic soils reclamation.

Sulphur (S): Sulphur is a yellow powder with the highest equivalent S concentration. It is relatively pure consisting of more than 50% purity (Strochlein and Pennington 1986; Abrol *et al.*, 1988; Tandon, 1991). It is not soluble in water and does not supply calcium directly for replacement of adsorbed sodium. Overstreet, *et al.*, (1980) noted that when applied for sodic reclamation, sulphur has to undergo microbiological oxidation to form sulphuric acid that in turn reacts with lime present in the soils to form soluble calcium in the form of calcium sulphate. However, sulphur is expensive, slow reacting and locally unavailable. Hence, it is not preferred to gypsum for sodic soils reclamation.

$2S + 3O_2 \xrightarrow{\textit{Thiobacillus spp}} 2SO_3$

$SO_3 + H_2O \quad H_2SO_4$

$H_2SO_4 + CaCO_3 \quad CaSO_4 + H_2O + CO_2\uparrow$

2Na-clay micelle $+ CaSO_4$ Ca-clay micelle $+ Na_2SO_4$

Pyrite: Pyrite (FeS) is another material that has been suggested as a possible amendment for sodic reclamation. Pyrites deposits are locally found in Geita, Mwanza. Reactions leading to oxidation of pyrite are complex and appear to consist of chemical as well as biological processes (Verma and Abrol, 1980; Chauhan, 1995).

$2FeS + 2H_2O + 7O_2 \quad FeSO_4 + 2H_2SO4$ (non-biological oxidation)

$4FeSO_4 + O_2 + 2H_2SO_4 \quad 2Fe_2(SO_4)_3 + 2H_2O$ (bacterial oxidation-

Thiobacillus ferrooxidans)

$Fe_2(SO4)_3 + FeS_2 \quad 3FeSO_4 + 2S$

Elemental sulphur so produced may be oxidised by *Thiobacillus thiooxidans* and the acidity produced favours the continuation of the process.

$4FeS_2 + 2H_2O + 15O_2 \quad 2Fe_2(SO4)_3 + 2H_2SO_4$

2.3.2.2 Choice of amendments

The studies conducted by Chand *et al.*, (1977) and Prather *et al.*, (1978) show that the choice of amendment at any place will depend on its relative effectiveness as judged from improvement of soil properties and crop growth and the relative costs involved. Furthermore the authors observed that the time required for an amendment to react in the soil and effectively replace adsorbed sodium is also a consideration in the choice of an amendment. Because of its high solubility in water, calcium chloride is the most readily available source of soluble calcium but it has rarely been used for reclamation on an extensive scale due to its high cost. (Abrol *et al.*, 1988) observed the same trend to iron and aluminium sulphate. Since amendments like sulphur and pyrite must first be oxidised to sulphuric acid by soil microorganism before they are available for reaction, the amendments are slow reacting (Cardon and Mortvedt, 2001). Being cheapest and most abundantly available, gypsum is the most widely used amendment (Oster and Frenkel, 1980).

2.3.2.3 Leaching

After the application of soil amendments in order to lower the exchangeable sodium in the soil and to improve the physical properties of the soil, leaching is necessary to remove the leachable salts (Chauhan 1995). According to Bernstein and Francois (1973), leaching is defined as the process of applying an excessive amount of water onto the soil surface in order to push the salts down through the soil profile along with the 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 method consists of several small applications of water at intervals (Hira *et al.*, 1980a). 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 will require one centimetre of water for each centimetre unit of the soil profile to be reclaimed. However, Gupta and Gupta (1987) noted that the amount of water needed for leaching will vary, depending on the texture of the soil. When water is the limiting factor, the intermittent ponding method should be used. This is the better 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 (Hira and Singh 1980b). Since water is not a limiting factor in Mto wa Mbu, continuous ponding is a common method used for irrigation.

2.4 Management and agronomic practices

The studies conducted by Henry *et al*, (1992) show that often, it is too expensive and sometimes impractical to reclaim saline or sodic soils, or even to maintain them at low salinity levels. Also, it may be impossible to adequately drain an area. Amendments may not be available or too expensive, or the water used for irrigation may be of poor quality. In these situations, there are various management practices that will aid in controlling or reducing the impacts of salts or sodium.

2.4.1 Application of manures and other mulches

Organic manures have long been known to facilitate the reclamation of sodic soils (Ponnamperuma 1972; Ugolini and Sletten 1991; Sekhon and Bajwa, 1993). They attribute the beneficial effect of organic matter incorporated into sodic soils to the evolution of carbon dioxide and certain organic acids; lowering of pH and the release of cations by solubilisation of $CaCO_3$ and other soil minerals and the replacement of exchangeable sodium and magnesium which lowers the ESP. According to Massoud (1977) and Henry *et al.* (1992), manuring, besides lowering the pH increases the organic matter content and water holding capacity of the soil. In this way more water is available to the plants even though salts are present (Boyle *et al.*, 1989). Manure also supplies nutrients to plants after undergoing decomposition and mineralization and improves structure and tilth (Tisdale *et al.*, 1993). Through decomposition, mineralization and synthesis of organic matter, some of the products are converted to humus which in turn increases CEC of the soil and influences the types and numbers of both macro and micro organisms in the soil (Edwards and Bohlen, 1996; Dorudoluwa *et al.*, 1999).

Another way of managing sodic soils is the application mulches. Mulch is any material used at the surface of a soil primarily to prevent loss of water by evaporation, to keep down weeds, to reduce temperature fluctuations or to promote soil productivity. The material includes manure, straw, leaves, peat or any other litter that may be spread over the soil surface. The benefits of mulching are suppression of weed growth, conservation of moisture by reducing evaporation and runoff, protection of the soil from erosion, increasing infiltration of water, maintaining soil-temperature fluctuations, enhancing micro and macro organisms growth and addition of organic matter and nutrients derived from a decomposing mulch hence preservation and improvement of soil structure.

As far as salt affected soils are concerned application of mulch should aim at reducing water losses by evaporation through movement of salts. Therefore, disruption of capillary continuity hinders upward movement of water to the soil surface and its loss as water vapour, and consequently reduces salinity built up at the surface. Lal (1976) observed that adequate coverage of mulch on the soil surface, maintained higher levels of soil organic matter, total nitrogen and exchangeable bases than uncovered plots. The mulched plots also showed more favourable soil moisture and temperature regimes. The higher infiltration rate of the soil in the mulched plots also kept the runoff and soil losses to a minimum. During periods of drought stress, maize grown in mulched plots gave higher yields than that grown in bare plots. But, during rainy periods the yields were at par. Therefore, the effectiveness of mulching depends on type of mulch, climatic conditions and soil surface coverage.

2.4. 2 Appropriate and judicial fertilizer management

Sodic soils pose several problems such as high pH, exchangeable Na, poor physical conditions and dominance of salts of carbonates and bicarbonates of sodium. As these soils are generally deficient in the availability of many plant nutrients, more remarkably N, Ca and micronutrients as compared to normal soils (Yadav, 1981), the proper use of fertilizers for enhancing the reclaiming effect of amendments and for increasing crop production is of vital significance. Furthermore, Yadav (1981) observed that, the use of fertilizers is of special significance as they, besides providing the plant nutrients needed to the soil, also help in soil improvement. Nitrogenous fertilizers like ammonium sulphate reduce the pH of the sodic soils and assist in mobilizing soil phosphorous. Studies reported by Abrol *et al.*, (1988) show that crops grown in sodic soils generally respond to higher levels of N application compared to crops grown in non-sodic soils at similar soil and climatic conditions. Therefore, it is generally recommended that crops grown in sodic soils should be fertilized at 25% excess over the rates recommended for normal soils. According to Chhabra and Abrol (1981) and Olson and Sander (1988) as pH exceeds 7.0 with soil saturation of Ca ions the activity of HPO_4^{2-} and ultimately PO_4^{2-} is lowered predominately. Thus, in sodic soils fertilizer P management needs to be directed toward preservation or enhancement of applied fertilizer P solubility.

2.5 Maize yield in Tanzania

Maize is the most important food crop grown and consumed in Tanzania. Most of it is produced on small-scale farms in terms of area cropped and production levels. In Tanzania it has been observed that the yield of maize is low compared to that in other parts of the world where the crop is grown (FAO, 2000). According to TARO, (1987) and FAO, (2000) the maize yields in the country ranged from 1.2 to 2.4 tha^{-1}. However, in some parts of the world where improved maize varieties are grown with good crop husbandry practices coupled with appropriate diseases and pests control measures, yields between 8 and 13.9 tha^{-1} have been recorded (FAO, 2000). The low maize yields in Tanzania could be attributed to salinity problem, inadequate soil moisture, drought, pest and disease infections, genetic variability, poor soil management as well as poor crop management. Higher maize yields could, therefore, be realized in Tanzania and Mto wa Mbu in particular if the above constraints are given due consideration (Yanda, 1989; Blackwell *et al.*, 1992; Kihupi and Dihenga, 1995).

The northern zone of Tanzania (which includes Arusha, Kilimanjaro and Tanga regions) is one of the major producers of maize. According to the National Planning Commission and Arusha Regional Commissioners Office (2000), Arusha region reached the highest maize production in the decade of 389 704 t in the year 1995/96. The highest average maize yield recorded was 2.2 tha^{-1}. Maize is one of the salinity sensitive crops (Henry *et al*, 1992). In Mto wa Mbu maize is grown under irrigation during the dry season in which the effect of salinity is prominent (Yanda, 1989 and Blackwell *et al.*, 1992). The authors observed that the average yields of maize for years 1980, 1985 and 1990 in Mto wa Mbu area was 1800 $kgha^{-1}$, but at present it has dropped to an average 1500 $kgha^{-1}$ (Mayagira, G. personal communication, 2002). This was attributed to salinity increase, insufficient water for irrigation and inadequate rainfall. Therefore, soil amendments can be used to improve the Mto wa Mbu soils, and consequently increase in crop production.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 The study area

Mto wa Mbu Irrigation Scheme is situated in the flood plain of the eastern arm of the Great Rift Valley, at the northern tip of brackish Lake Manyara (920m asl) in Arusha, North Eastern Tanzania (Figure 1). The valley lies approximately between latitude 3°22′ South of Equator and longitude 3°55′ East of Greenwich and it is found at an altitude of about 975 m asl. The Mto wa Mbu settlement is bound by Manyara National Park to the south and the Rift Valley escarpment to the west and it lies along Arusha-Musoma Road about 119 km west of Arusha.

3.1.2 Climate

Mto wa Mbu lies within a semi-arid zone characterized by high evapotranspiration rate combined with low and erratic rainfall (Yanda, 1989). The rainfall pattern in the area is bi-modal with most of the rain falling between March and April. The short rains commence in early November and last until early January while the long rains start in late February to May (Appendix 1). The total rainfall ranges between 280 and 1280 mm with a mean value of 642 mm. The mean monthly maximum temperature is almost uniform throughout the year, ranging from 22^0C to 25^0C.

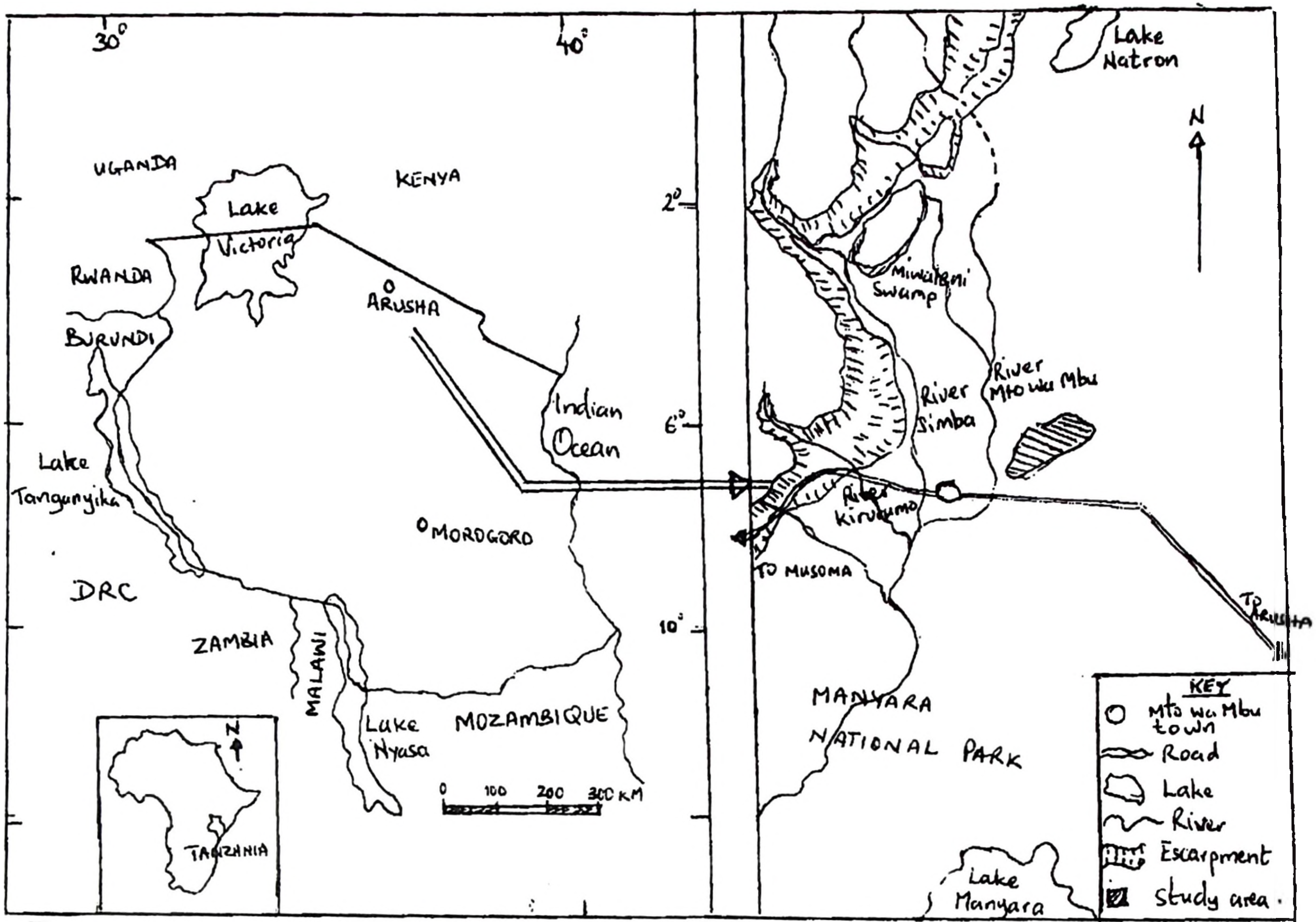

Figure 1: Map of the Study Area
Scource: Mto wa Mbu Irrigation Project

3.1.3 Geology and soils

According to Mwalosi (1989) the area is characterised by volcanic and block-faulting features formed during the plio-pleistocene age. Yanda (1989) characterised the soils of Mto wa Mbu as clay-loamy and sodic with an average dry bulk density of 1.4 gcm^{-3}. Other soils found in the area are loams, clays and to a lesser extent sandy-loams and sandy clay loams. The soils of the area are further classified into two groups, namely soils with an alkaline reaction and non alkaline reaction. The quality of the soil in terms of salinity and alkalinity decreases eastward, towards the maasai steppe, and southward towards Lake Manyara.

3.2 Methodology

3.2.1 Site selection and characterization

A site heavily affected with salts was selected for the field experiment. Signs for excess salinity/sodicity such as stunted and/or spotty growth of plants; white crust or white salt crystal accumulation on the soil surface, poor soil structure and blackish colour on the soil surface due to dispersion of organic matter was observed. The experimental site was randomly selected and set in one of the areas that were abandoned due to salt accumulation.

Composite surface soil samples were randomly sampled. Three soil composite samples were taken using an auger at 0-15, 15-30, and 30-45 cm depths before starting the field experiment. All soil samples were air dried, ground and sieved to pass through a 2 mm screen. Materials larger than 2 mm were discarded. The soil samples were then used for physical and chemical analysis in the soil chemistry laboratory of the Selian Agricultural Research Institute.

Samples for bulk density determination were randomly taken from undisturbed soil samples using core cylinder of known volume. Three samples were taken from three soil depths at 0-15, 15-30, and 30-45 cm.

3.2.1.1 Physical analysis

Particle size was determined by the pipette method, using a constant temperature water bath and pre-treatment of the soil sample with hydrochloric acid and hydrogen peroxide (McKeague, 1978; Gee and Baunder, 1986).

Bulky density of the soil was determined from the core samples. The samples were dried in an oven at 105 °C for 24 hours to determine a dry weight fraction. The dry weight of the soil was divided by known sample volume to determine the bulk density as described by Hillel (1982) and Blake and Hartge (1986).

3.2.1.2 Chemical analysis

Soil pH was determined in water at a ratio of 1:2.5 soil:water on a Beckman Expandomatic SS-2 pH meter with a combination electrode as explained by McLean (1982). Electrical conductivity was measured by means of YSI model conductance meter using 1:2.5 soil:water extract in 1% $(NaPO_3)_6$ as described by Rhoades (1996). Organic carbon was determined by modified Walkey-Black wet oxidation method (Nelson and Sommers, 1982). Total nitrogen was determined by semi-micro kjeldahl method (Bremner and Mulvaney, 1982).

Cation exchange capacity was determined by sodium acetate method at pH 8.2 (National Soil Service (NSS), 1991). Exchangeable cations were determined by the neutral ammonium acetate extraction technique as described by Thomas (1982).

Available P in the soil was determined following the Olsen procedure (Watanabe and Olsen, 1965) and P in the extract was determined spectrophometrically (NSS,1991).

Cu, Zn, Fe, and Mn were extracted using the DTPA method (Lindsay and Norvell, 1978) and then determined by atomic absorption spectrophotometer.

3.2.3 Water sampling and analysis

Water was sampled randomly from river Mto wa Mbu using drinking water bottle of half a litre as described by Yadav and Khera (1993) and Tan (1995). The river was the source of irrigation water in the studied area. Two samples were collected in a day, in the morning (8.30 am) and in the evening (6.30 pm) in four separate days to determine the quality of irrigation water. The pH and ECe of that water was measured using the procedure of Mclean (1982) and Rhoades (1996) respectively. Na and Ca in water were determined by flamephotometer while Mg determination was determined using atomic absorption spectrophotometer technique as described by NSS (1991).

3.2.4 Determination of the gypsum and sulphur requirement

Determination of gypsum requirement was done by leaching the soil sample from 0-15 cm soil depth with 20 ml of 60% ethanol, then shaking it with 100 ml of saturated gypsum solution and determining the decrease in calcium content of gypsum solution as described by Schoonover (1952) and Abrol *et al.*, (1972). The leaching test was performed on soil columns 8 cm long and having a cross-sectional area of 40 cm^2. Soil was uniformly parked according to its bulk density (1.4 gcm^{-3}) in brass cores having a removable perforated base. Gypsum was thoroughly mixed with the soil prior to parking. Soil cores were leached with distilled water maintaining a constant water level 1.5 cm above the soil surface. The leachate was collected in 15 mls aliquots and analyzed for Ca content following the usual analytical procedure. Leaching was continued till the soil attained a nearly constant hydraulic conductivity.

Sulphur requirement was determined quantitatively using equivalent quantities of gypsum requirement whereby 1.00 relative quantity of 100% pure gypsum was taken as equivalent to 0.19 quantity of pure sulphur (Abrol *et al.*, 1988). Gypsum and pure sulphur (agricultural grade, 85% and 100% purity, particle size<2mm) were bought from KIBO GYPSUM COMPANY of Moshi and UFI Ltd (Dar es Salaam) stores respectively.

3.2.5 FYM sampling and analysis

FYM used at the site was randomly sampled from a kraal. Four samples were taken.
Analysis of the farmyard manure for determination of pH, organic carbon, total N, P, Ca, Na, Mg, Cu, Zn, Fe, and Mn was accomplished using wet/acid digestion method described by Okalebo *et al.*, (1993). Total nitrogen in the acid digest was determined through distillation and titration whereby total phosphorous in the acid digest was determined colorimetrically through ascorbic acid procedure without pH adjustment as described by Okalebo *et al.*, (1993). Potassium, calcium, magnesium sodium and the micronutrients in the acid digest were determined by atomic absorption spectrophotometer and flamephotometer technique. This made it possible to quantify nutrients added to soil through application of the farmyard manure.

3.2.6 Field experiment

A field experiment was conducted during 2001/2002 cropping season. There were 5 levels of gypsum (0, 7.5, 15.0, 22.5 and 30.0 tonnesha^{-1} coded as G_0, G_{25}, G_{50}, G_{75}, and G_{100}); and 5 levels of sulphur (0, 1.43, 2.85, 4.28, and 5.7 tonnesha^{-1}, S_0, S_{25}, S_{50}, S_{75} and S_{100} respectively that were applied alone. These levels are represented by 25, 50, 75, 100% of the laboratory estimated gypsum requirements of the surface 15 cm soil. Then, the same treatments of gypsum and sulphur were combined with 2 levels of FYM each at 0 and 20 tonnes FYMha^{-1} as shown in (Table 2). 20 tonnes FYMha^{-1} was twice as much as the rate advised by Mowo *et al.*, (1993) for normal soils due to the poor physical properties and low fertility of sodic soils (Abrol *et al.*, 1988). All treatments were replicated 3 times giving a total of 54 plots. The field experiment was a completely randomized block design (CRBD). The size of the treatment plots was 4 m x 4 m. The different rates of gypsum, sulphur and FYM were uniformly broadcasted onto the treatment plots accordingly and then thoroughly incorporated into the surface soil (0-15 cm) with the help of hand hoes three weeks before the planting of the maize seeds.

3.2.7 Establishment of proper drainage

The plots were laid in between inlet and outlet open ditches. The latter were 30 cm deeper than the former to remove the leached water as well as to keep the water table below the root zone of maize.

3.2.8 Leaching

Adequate amount of water was ponded to facilitate leaching, chemical reaction, and drainage. The water was ponded for two hours in a day after every three days.

3.2.9 Land preparation, planting, thinning and weeding

Land preparation was done in February 2002. It involved ploughing and harrowing ½ an acre of the selected site. After three weeks of contact between the soil and the gypsum, sulphur and FYM, maize seeds of variety H 513 were sown as a test crop. Four maize seeds were sown per hill at a spacing of 75 cm x 25 cm, and two weeks after emergence was thinned to one to give a plant population of 53 333 plants ha^{-1}. Fertilisers Tripple superphosphate (TSP) and Urea at the rate of 30 kg P ha^{1} and 140 kg N ha^{1}, 25% more than the rate recommended by Mowo *et al.*, (1993) were applied because studies reported by Abrol *et al.*, (1988) show that crops grown in sodic soils generally respond to higher levels of N and P application compared to crops grown in non-sodic soils at similar soil and climatic conditions. TSP was applied during seeding while Urea was applied in a split application i.e. two weeks after germination, at knee-height and immediately before flowering. Weeding was done three weeks after germination and immediately before flowering (two months after germination).

3.2.10 Insect-pest and diseases control

With the exception of maize stock borers which were controlled by using Endosulfan dust 4% at the rate of 5.5 kg Endosulfan ha^{-1}, there were no cases of maize diseases at the site.

3.2.11 Crop development assessment

3.2.11.1 Seedling emergence and determination

Seed emergence was determined by counting the total number of hills with emerged seedlings 10 days after seedlings had emerged. The hills, which had no emerged seedlings, were gap filled immediately.

3.2.11.2 Harvesting

After reaching maturity, from each treatment, the crop was harvested and means for respective variables such as the number of cobs per plant and number of seeds per cob were computed. The cobs were hulled and the seeds were dried to attain constant moisture content of 13%. The moisture content was measured by using Computer Controlled Moisture Meter. Immediately after drying and winnowing one hundred maize seed weight and yield from each plot were determined and yields were recorded accordingly. The grain yields were expressed in tha^{-1}.

3.2.12 Statistical Analysis

Analysis of variance as described by Snedecor and Cochran (1980) was performed for maize yield, number of cobs per unit area, plants per unit area, soil physical and chemical properties to determine the treatment effect of these variables. Statistical model was as described by Gomes and Gomez (1984) and is shown below:

$Yij = \mu + \tau i + \beta j + \varepsilon ij$ For i= 1, 2...b; j = 1, 2...t

Where: Yij = Response

μ = General mean common to all observations

τi = Block effect

βj = Treatment effect

εij = Random error

The obtained data were analysed statistically using MSTATC computer statistical package (Lund, 1991). Means were separated using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$ to compare treatment effects on maize yield, seed emergence, number of cobs per plant, number of seeds per cob, and 100 seed weight and chemical properties. Simple correlation was done on some yield variables to determine their relationship with treatment effects.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physico-chemical properties of the soils

4.1.1 Soil physical properties

4.1.1.1 Soil texture

Soil data for selected physical properties of the soil are presented in (Table 1). The results indicate that the soils are of a texture varying from clay loam to clay. The sand content decreased significantly with depth while the opposite was the case for the clay content. The silt content decreased slightly from topsoil to subsoil (from 37 to 26%). The texture of subsurface horizons was clay. This was probably caused by the dispersed clays which moved into subsoil with infiltrating water thereby clogging the pores immediately beneath the surface. Consequently, the surface horizon had a course texture, but below where the clay accumulated, the soil developed a dense layer with low water permeability.

4.1.1.2 Bulk density

The bulk density values of the studied site ranged from 1.39 to 1.45 gcm^{-3} (Table 1). There was a systematic increase in bulk density with soil depth. According to Landon (1991), soils with such bulk density are termed as compact probably because of accumulation of clay in the subsurface horizons with low organic matter content. When the soils were observed physically they consisted of clay pans in the subsoil. The results show that the soil was compact. The compactness of the soil may probably cause mechanical resistance to root penetration that reduces the plant ability to exploit its environment. Also permeability decreases, thus making field crops including maize (which grow well at bulk density between 0.9 to 1.23 gcm^{-3}) more susceptible to adverse effects of waterlogging.

However, Taylor *et al.*, (1966) and Ndaki (2001) observed that such kind of soil can contain sufficient air-filled porosity (Assuming a specific gravity of 2.65gm^{-3}).

4.1.2 Chemical properties

4.1.2.1 Soil pH

The chemical properties of the soil studied are presented in Table 1. The results show that soil pH ranged from 9.8 to 10.5 and decreased with depth. Such results suggest that the soil pH is high. The high pH is probably due to hydrolysis of Na^+ whereby the resulting OH- ions become responsible for high pH. Soils of pH above 8.5 and ESP greater than 15 are characterized as sodic soils. The results are in agreement with those observed by Yanda (1989) who worked with Mto wa Mbu soils. The author found that most soils have high pH and are sodic in nature.

Table 1: Some physico-chemical properties of the site before the experiment started

Parameter	Unit		Soil depth; SD	
Depth	cm	0-15	15-30	30-45
Clay	%	38.10 ± 0.153	58.10 ± 0.11	63.87 ± 0.25
Silt	%	37.15 ± 0.18	29.74 ± 0.25	26. 00 ± 0.3
Sand	%	24.75 ± 0.225	12.16 ± 0.16	10.13 ± 0.306
Bulky density	gcm^{-3}	1.39 ± 0.1	1.40 ± 0.01	1.45 ± 0.02
Textural class		Clay loam	Clay	Clay
pH (1:2 soil-water suspension)		10.45 ± 0.01	10.00 ± 0.03	9.80 ± 0.005
ECe	dSm^{-1}	3.57 ± 0.01	2.03 ± 0.06	1.60 ± 0.015
ESP	%	98.83± 0.10	92.34 ± 0.12	98.33 ± 0.02
Organic C	%	0.11 ± 0.27	0.51 ± 0.01	0.35 ± 0.01
Total N	%	0.1 ± 0.28	0.12 ± 0.01	0.03 ± 0.012
Olsen's Extractable. P	mgkg^{-1}	0.8 ± 0.1	0.20 ± 0.02	0.4 ± 0.1
Exchangeable Ca	Cmol(+)kg^{-1}	1.28 ± 0.012	1.46 ± 0.004	1.96 ± 0.026
Exchangeable Mg	Cmol(+)kg^{-1}	0.56 ± 0.005	1.16 ± 0.008	1.26 ± 0.009
Exchangeable K	Cmol(+)kg^{-1}	2.08 ± 0.009	1.98 ± 0.008	1.74 ± 0.005
Exchangeable Na	Cmo(+)kg^{-1}	11.92 ± 0.012	11.64 ± 0.008	11.17 ± 0.012
CEC (NaAc)	Cmol(+)kg^{-1}	12.12 ± 0.02	12.93 ± 0.005	11.36 ± 0.06
DTPA extractable micronutircnts				
Cu	mgkg^{-1}	0.1 ± 0.012	0.3 ± 0.01	0.96 ± 0.01
Zn	mgkg^{-1}	0.21 ± 0.02	0.26 ± 0.0.02	0.93 ± 0.1
Fe	mgkg^{-1}	0.96 ± 0.12	1.98. ± 0.11	2.49 ± 0.11
Mn	mgkg^{-1}	0.48 ± 0.0	0.48 ± 0.0	0.48 ± 0.0

SD= Standard Deviation

4.1.2.2 Soil electrical conductivity

The data of the composite samples from the experimental site revealed that the value of electrical conductivity decreased with depth (Table 1). Since the soil electrical conductivity is a reflection of neutral soluble salts, the results suggest that neutral soluble salts also decreased with increase in soil depth. The same trend was also observed by Baitilwake (1999). The author found that the ECe that increased towards soil surface may be due to the capillarity effect. Yields of most crops including maize cannot be restricted at that ECe level (1.6-3.6 dSm^{-1}) because optimum soil electrical conductivity for crop production is 1 to 4 dSm^{-1} (Hassan *et al.*, 1970), as cited by Oslon and Sander (1988). However, the yields of most crops in Mto wa Mbu are low. This could be associated with many factors amongst which can be high pH and Na^+.

4.1.2.3 Total nitrogen

Total nitrogen value in 0-15cm depth was 0.1%. The 15-30cm registered nitrogen value of 0.12%, while nitrogen value of 0.03% was observed in 30-45 cm soil depth. According to Landon (1991) system of classification, the N content in the studied soils was categorized as very low. This can be attributed to very low organic matter content. Abrol *et al.*, (1988) observed that N can also be lost under alternate aerobic and anaerobic conditions a situation found within sodic soils.

4.1.2.4 Organic carbon

Table 1 shows that there was a general decrease in organic carbon content with soil depth in the study area. The results reveal that the organic carbon content is low. According to Tisdale *et al.*, (1993) low organic carbon content is a reflection of low organic matter content. Therefore, the results suggest a low organic matter content in the soil as well as low fertility status in Mto wa Mbu soil.

4.1.2.5 Available Phosphorous

The Olsen's extractable phosphorous of the study area ranged from 0.2 to 0.8 $mgPkg^{-1}$ (Table 1). The mean value in the topsoil (0-15 cm depth) was the lowest. There was a systematic increase in the phosphorous content with depth that corresponds with a decrease in pH level. According to EUROCONSULT (1989) and Landon (1991), Olsen's extractable phosphorous content in this soil is very low. Abrol *et al.*, (1988) observed that at high pH level phosphorous is likely to be converted to less soluble Ca-phosphates by native Ca in soils.

4.1.2.6 CEC and exchangeable cations

The CEC values of the studied soils ranged between 11.36 to 12.93 $Cmol(+)kg^{-1}$. There was no systematic trend in CEC levels with soil depths. According to Landon (1991) CEC values of Mto wa Mbu soils are in low range. The low CEC of that soils may be due to very low organic matter content. Consequently, the soils will have very low ability to supply the necessary plant nutrients.

Potassium contents ranged from 1.74 to 2.1 $Cmol(+)kg^{-1}$ (Table 1). The K contents decreased systematically with soil depths. According to Landon (1991) rating system this soil had very high contents of K. The results are in agreement with those reported by Abrol *et al.*, (1988) and EUROCONSULT (1989) that K levels increase with increasing pH. Since the exchangeable K in these soils is above the optimal range of 0.2 to 0.6 $Cmol(+)kg^{-}$

[1] (Sanchez, 1976), cited by Baitilwake (1999) and Kiwale (1999), maize response to K fertilization is unlikely.

Table 1 shows that levels of exchangeable calcium in the soil studied ranged from 1.28 to 1.96 Cmol(+)kg^{-1}. There was a general increase in exchangeable Ca with depth, the highest concentrations of exchangeable Ca occurring in the subsoil. According to EUROCONSULT (1989) Ca content less than 4 Cmol(+)kg^{-1} is considered as low. Abrol *et al.*, (1988) reported that Ca ions can hydrolyse more slowly than those of Na in the soils with higher pH and significant amount of Na^{+}.

The values of exchangeable Mg are shown in Table 1. Exchangeable Mg content in the soils was generally low (EUROCONSULT, 1989). There was a systematic increase in Mg content with soil depth. This is probably associated with decrease in pH with soil depth. The results are in agreement with those reported by Abrol *et al.*, (1988) and EUROCONSULT (1989) that Mg levels decrease with increasing pH.

The Na content values ranged from 11.92 to 11.17 Cmol(+)kg^{-1}(Table 1). The exchangeable Na of the study area was very high according to Baize (1993) classification system. Soils with exchangeable Na greater than 1 Cmol(+)kg^{-1} soil are regarded as potentially sodic. The values decrease with depth and Na content in the topsoil was the highest probably because of capillarity effect and high evaporation rate at the soil surface. The results fall within the range observed by Yanda (1989) who observed that most of the Mto wa Mbu soils had exchangeable Na ranging from 0 to 20 Cmol(+)kg^{-1}. The exchangeable sodium percentage (ESP) was very high ranging from 90 to 98%. Normal soils normally have ESP values of <15% (Tanji, 1990). Therefore, levels of Na and ESP measured here indicate that the studied soil was sodic and unfavourable for most field crops including maize.

4.1.2.7 Micronutrients

DTPA extractable micronutrient levels are indicated in Table 1. Cu content ranged from 0.1 to 0.96 $mgkg^{-1}$, that of Zn ranged from 0.21 to 0.93 $mgkg^{-1}$. Fe registered a range of 0.96 to 2.4 $mgkg^{-1}$, while Mn levels were 0.48 $mgkg^{-1}$ for all soil depths. Cu, Zn and Fe contents increased with depth, the increase that corresponds with the decrease in soil pH. According to Lindsay and Norvell (1978) the critical levels of Cu, Zn, Fe and Mn are 0.2, 0.5-1.0, 1.0 and 4.5-60 $mgkg^{-1}$ respectively. In general, micronutrients levels in the studied soil were low probably because of high pH resulting in precipitation of the micronutrients, low organic matter content and presence of calcium carbonte.

4.2 Gypsum and sulphur requirements

Gypsum and sulphur requirement was carried out in order to determine the amount of gypsum and sulphur needed to reclaim the studied soil. The results in Table 2 show that the gypsum and sulphur requirements were 30 and 5.7 $tonnesha^{-1}$ respectively. Gypsum requirement was high probably because of high exchangeable sodium.

Table 2: Gypsum, sulphur and FYM rates applied to the studied soil

	Treatments	Gypsum and sulphur requirements (tonnes/ha)
T1	Control	0.00
T2	G_{25}	7.50
T3	G_{50}	15.00
T4	G_{75}	22.50
T5	G_{100}	30.00
T6	S_{25}	1.40
T7	S50	2.90
T8	S_{75}	4.30
T9	S_{100}	5.70
T10	20 tonnes FYM/ha	0.00
T11	G_{25} + 20 tonnes FYM/ha	7.50
T12	G_{50} + 20 tonnes FYM/ha	15.00
T13	G_{75} + 20 tonnes FYM/ha	22.50
T14	G_{100} + 20 tonnes FYM/ha	30.00
T15	S_{25} + 20 tonnes FYM/ha	1.40
T16	S_{50} + 20 tonnes FYM/ha	2.90
T17	S_{75} + 20 tonnes FYM/ha	4.30
T18	S_{100} + 20 tonnes FYM/ha	5.70

Footnote: G= gypsum S= sulphur
G_{25} = 25% gypsum requirement G_{50} = 50% gypsum requirement
G_{75} =75% gypsum requirement G_{100} =100% gypsum requirement
S_{25} = 25% sulphur requirement S_{50} = 50% sulphur requirement
S_{75} = 75% sulphur requirement S_{100} = 100% sulphur requirement

4.3 Some of the chemical composition of the amendments used in the study

Some of the chemical properties of farmyard manure used in the study are shown in Table 3. The farmyard manure had an almost neutral pH (7.3). It contained 8.7, 0.24, 11.60, 8.30, 4.93, and 0.47% of OC, total N, total P, total Ca, total Mg, total K, and total Na respectively. According to EUROCONSULT (1989), Landon (1991), Tate (1992) and Tisdale *et al.*, (1993) FYM contained low amounts of total N, and P with wide C/N ratio. The amounts of total Ca, Mg and K were medium. Na and organic carbon were high. The results further indicate that FYM contained high amounts of DTPA extractable Cu (154.2 $mgkg^{-1}$). DTPA extractable Zn (40.2 $mgkg^{-1}$) was considered as medium. The level of DTPA extractable Fe (96.5 $mgkg^{-1}$) was slightly low. The DTPA extractable Mn (196.8 $mgkg^{-1}$) content in the FYM was medium. In general the quality of FYM was poor. The poor quality could be attributed to the different ways of farmyard manure handling and storage. This is due to the fact that the manure was collected from an open kraal; hence some of the nutrients might have been leached out, and/or lost through water runoff. Also, since the animals are fed in an open range system, the type of feeds and grass/pastures consumed by the animals probably contributed to the chemical composition of the manure.

Table 3: Some chemical properties of FYM used in the study

Parameter	Value
pH (H_2O)	7.3
Organic C (%)	8.7
Total N (%)	0.26
C/N ratio	34:1
Total P (%)	0.24
Total Ca (%)	11.6
Total Mg (%)	8.3
Total K (%)	4.93
Total Na (%)	0.47
DTPA extractable Cu ($mgkg^{-1}$)	154.2
DTPA extractable Zn ($mgkg^{-1}$)	40.2
DTPA extractable Fe ($mgkg^{-1}$)	96.5
DTPA extractable Mn ($mgkg^{-1}$)	196.8

The chemical analysis of gypsum is shown in Appendix 2. The results show that gypsum had a pH of 8 and ECe of 2.2 dSm^{-1}. The pH was high, probably due to high content of Ca and the presence of HCO^{-3}. It had K, Ca, Na, and Mg, contents of 16, 710, 4.6, and 4.6 Cmol(+)kg $^{-1}$ respectively as well as Fe, Mn, Zn, and Cu of 5.6, 5.5, 6.5 and 13 ppb respectively. According to Landon (1991) calcium content greater than 28% in gypsum is considered as high. Abrol *et al.*, (1988) ranked sulphur with purity greater than 50% as high. Thus, both gypsum and sulphur that were used in the reclamation of the studied soil had high Ca (85%) and S (100%) contents respectively to carter for the reclamation process.

Generally, the analytical results show that gypsum, sulphur and FYM treatments can contribute appreciable amounts of N, P, K, Ca, Mg, S, Fe, Mn, Zn, and Cu to the soil nutrient pool. However, the availability of nutrient elements in sulphur and FYM treated plots depends on their biological decomposition behaviour in the soil and subsequent soil chemical reactions.

4.4 Quality of irrigation water

The suitability of irrigation water was studied with the aim of assessing whether it had an effect on soil sodicity. The results in Table 4 show that the irrigation water had mean pH of 7.4, an electrical conductivity value (ECw) of 0.66 dSm^{-1} and sodium adsorption ratio (SAR) of 2.25. According to Abrol *et al.*, (1988) and Landon (1991), the data showed that the irrigation waters fall under low sodium water class. Therefore, its contribution to sodicity was very minimal. Yanda (1989) observed that the sodicity in Mto wa Mbu soils was not caused by irrigation waters but rather it was caused by fossil salts, high water table and groundwater salinity.

Table 4: Some chemical properties of irrigation water

Water source (River)	No. of sampling points	Mean					SAR $Na/\sqrt{(Ca+Mg)^{++}/2}$
		pH	Ca^{++}	Mg^{++} (mgl^{-1})	Na^{+}	ECe (dSm^{-1})	
Mto wa Mbu	4	7.4	14.1	21.3	4.2	0.66	2.25

4.5 Effects of soil treatments on some soil physical and chemical properties

4.5.1 Bulk density

The results of the effect of soil treatments on the bulk density for 0-15 cm soil depth are shown in Table 5. The bulk density for gypsum treated plots decreased by 8% from the control to the highest rate. The bulk density from the control plot (1.39 gcm^{-3}) was higher than the values of the same in remaining gypsum; sulphur and FYM amended plots. The bulk density of sulphur treated plots was non significantly reduced by 2%. A combination of gypsum and FYM reduced the same parameter by 82% while that of sulphur and FYM non-significantly reduced the bulk density by 80%. The results further indicated that the bulk density was slightly reduced by G_{75} + FYM and G_{100} + FYM treatments. Gypsum was better in reducing the soil bulk density than sulphur. Overstreet *et al.*, (1980) reported that unlike gypsum, sulphur is less effective because it is not soluble in water and does not supply calcium directly for replacement of adsorbed sodium. Rather, it has to undergo microbial oxidation to form sulphuric acid which reacts with soil lime to form calcium sulphate. Gypsum and sulphur became more effective in reducing the bulky density of the studied soil when combined with FYM in such a way that the lowest bulk density was 1.25 gcm^{-3}. Though all amended plots were not significantly different from the control at ($P<0.05$) there was a slight decrease of bulk density with the application of amendments. The amendments increased the bulk density of the soil by removing part of exchangeable sodium and replaced favourable calcium ions, a condition that made the soil porous. Therefore, the results revealed that the application of amendments can solve the problem of compaction in sodic soils.

4.5.2 Soil pH and ECe

Effect of soil amendments on surface (0-15 cm) pH and ECe of the study area is summarized in Table 5. The levels of pH were reduced by 21% for the gypsum treated plots. The pH significantly ($P<0.05$) declined with the increase in gypsum treatments compared to pH in the control. This may be attributed to the replacement of Na^{+} by Ca in the exchange sites of clay complex through addition of gypsum that supplied soluble calcium directly to the soil (Verma and Abrol, 1980). After sulphur treatments were applied, the levels of pH in the soil were reduced by 19%. The pH decreased significantly ($P<0.05$) with the increase in sulphur treatments probably due to the production of sulphuric acid through microbial oxidation of sulphur. FYM reduced the pH by 11% compared to the control. The same observations were noted by Dargan *et al.*, (1976) that FYM probably increases solubility of native $CaCO_3$ as a result of CO_2 evolution during microbial decomposition. When gypsum, sulphur and FYM treated plots are compared, gypsum was ranked superior to sulphur and FYM when applied alone. Similar results were also reported by Chand *et al.*, (1977), Prasad and Verma (1987), Chauhan (1995) that contrary to gypsum which solubilizes easily in the soil to release enough Ca^{+2} to replace Na^{+}, sulphur and FYM had to undergo microbial oxidation to acids and carbon dioxide respectively, which in turn react with soil lime to form soluble calcium

The combination of gypsum and sulphur with FYM, resulted into pH levels that decreased by 22% and 20% respectively. The effect of levels of different amendments on changes in pH (Table 5) of surface soil showed that at low levels, S_{25} and S_{50} were not significantly different to the control ($P<0.05$). However, when they were combined with FYM the pH decreased significantly ($P<0.05$). This is probably because organic matter increases bacterial populations in the soils which in turn accomplish sulphur oxidation (Strochlein and Pennington, 1986; Tandon *et al.*, 1991 and Tate, 1992). However, the pH levels were not in favour of satisfactory maize production because it grows well within a pH range 6.0-7.0 (Pulseglove, 1988). Olson and Sander (1988) reported that maize could also be grown satisfactorily in soils with pH>8 provided that the deficiencies of micronutrient elements are controlled. Generally, the application of gypsum, sulphur and FYM treatments had a significant effect on soil pH ($P<0.05$) compared to the control.

The gypsum amended soils increased ECe by 69%. Contrary, the sulphur amended soils decreased ECe by 16.5%. The ECe level for FYM treatments increased by 30%. The same trend was observed when gypsum and sulphur were combined with FYM. Gypsum and FYM increased the ECe levels by 89% while sulphur and FYM, though increased the ECe by 68%. The results revealed that lower doses of gypsum showed better effect in reducing the ECe values than the higher levels. The results are in agreement with those by Singh *et al.*, (1980) that the typical behavior of higher doses of gypsum to increase ECe might be due to the increased solubility of gypsum. This was contrary to sulphur whereby ECe values decreased with increased doses of sulphur.

According to Hassan *et al.*, (1970), cited by Olson and Sander (1988), the results are in usual range for field crops growth (including maize) because conductivity in the range of 1 to 4 dSm^{-1} usually cause little or no damage. The crop growth becomes progressively severe between an ECe of 4 to 8 dSm^{-1}. Generally, ECe was not significantly ($P<0.05$) increased with the application of treatments compared to control.

4.5.3 Total nitrogen, organic carbon and available phosphorous

Effect of amendments on surface total nitrogen and available phosphorous in the study area is presented in Table 5.

4.5.3.1 Nitrogen

The results showed that the application of gypsum at the highest rate increased levels of total N by 27%. The total N levels of sulphur treated plots increased by 20%. The total N content for FYM treatment was increased by 13% from the control. When gypsum and sulphur were combined with FYM, the total N levels were increased by 127%. A combination of sulphur and FYM increased N contents by 27%. There was a slight increase in total nitrogen content compared to that values obtained prior to the application of soil amendments.

Total N levels in G_{75} + FYM and G_{100} + FYM were significantly ($P<0.05$) higher than other treatments. The total nitrogen level was generally low for crop production even after the soils have been amended (Table 5). With the exception of G_{75} + FYM and G_{100} + FYM that showed medium level of total N, other treatments showed non significant differences with the control at ($P<0.05$). Therefore, in order to attain an appreciable level of total N additional quantities of organic manure and possibly inorganic N fertilizers are required.

4.5.3.2 Organic carbon

The organic carbon levels of gypsum treated plots increased by 51% and that of sulphur amended plots increased by 32%. The organic carbon level for FYM treatment increased 69%. When gypsum and sulphur were combined with FYM, the contents of organic carbon increased by 174 and 70% respectively. Comparatively, there were no significant differences at ($P<0.05$) in organic carbon content in all treatments other than G_{100} + FYM. The treatments that were combined with FYM increased organic carbon content compared to control whereby G_{100} + FYM treatment ranked superior. Generally, the organic carbon contents were low even after the amendments had been applied.

Table 5: Effect of treatments on bulky density, pH, ECe, %N, OC, and available Phosphorous

Treatment	Bulky density (gcm^{-3})	pH (H_2O)	ECe (dSm^{-1})	Total Nitrogen (%)	Organic Carbon (%)	Available P ($Mgkg^{-1}$)
Control	1.39^{a}	10.30^{a}	2.60^{cd}	0.15^{b}	0.84^{e}	1.1^{d}
G_{25}	1.36^{a}	9.30^{c}	1.10^{e}	0.17^{b}	1.04^{de}	2.3^{c}
G_{50}	1.32^{a}	8.30^{gh}	2.84^{cd}	0.17^{b}	1.05^{de}	3.1^{b}
G_{75}	1.29^{a}	8.23^{h}	3.47^{bcd}	0.18^{b}	1.24^{bcde}	3.5^{ab}
G_{100}	1.28^{a}	8.10^{hi}	4.47^{ab}	0.19^{b}	1.27^{bcde}	3.9^{a}
S_{25}	1.37^{a}	10.03^{ab}	2.24^{d}	0.15^{b}	0.96^{de}	1.2^{d}
S_{50}	1.37^{a}	10.00^{ab}	2.73^{cd}	0.15^{b}	1.04^{de}	1.2^{d}
S_{75}	1.36^{a}	8.93^{de}	2.84^{cd}	0.18^{b}	0.99^{de}	2.0^{c}
S_{100}	1.36^{a}	8.37^{fgh}	2.17^{cd}	0.18^{b}	1.11^{cde}	3.1^{b}
FYM	1.29^{a}	9.17^{d}	3.30^{cd}	0.17^{b}	1.42^{bcd}	2.4^{c}
G_{25}+FYM	1.32^{a}	9.10^{de}	1.18^{e}	0.19^{b}	1.22^{bcde}	2.0^{c}
G_{50}+FYM	1.29^{a}	8.40^{fgh}	3.03^{cd}	0.18^{b}	1.56^{bc}	3.1^{b}
G_{75}+FYM	1.25^{ab}	8.17^{h}	3.47^{bcd}	0.31^{a}	1.67^{b}	3.9^{a}
G_{100}+FYM	1.25^{ab}	8.01^{hi}	4.91^{a}	0.34^{a}	2.30^{a}	4.1^{a}
S_{25}+FYM	1.33^{a}	9.30^{c}	4.36^{abcd}	0.17^{b}	1.11^{cde}	2.0^{c}
S_{50}+FYM	1.30^{a}	9.17^{d}	4.24^{abcd}	0.17^{b}	1.30^{bcde}	2.3^{c}
S_{75}+FYM	1.29^{a}	8.60^{efg}	3.99^{abcd}	0.18^{b}	1.35^{bcd}	2.1^{c}
S_{100}+FYM	1.27^{a}	8.23^{h}	2.53^{cd}	0.19^{b}	1.43^{bcd}	3.5^{ab}
LSD ($P<0.05$)	0.0821	0.3192	1.815	0.0909	0.4098	0.082
CV (%)	14.53	2.11	30.27	27.74	19.42	10.62

Means within the column followed by the same letter are not significantly different at ($P<0.05$)

*Mean of three blocks, n=54

4.5.3.3 Extractable phosphorous

The levels of extractable P increased by 253% for gypsum treated plots. The plots that were treated with sulphur increased extractable P levels by 182%. The extractable P content for FYM treatment increased by 118%. G_{25}, G_{50} and G_{100} were significantly different at $P<0.05$. The results further indicate that the combination of gypsum and FYM increased the extractable P levels by 273% whereas, sulphur and FYM combination increased extractable P by 224%. The increases were significant at $P<0.05$ in G_{25} + FYM and G_{50} + FYM treatments. But, G_{75} + FYM and G_{100} + FYM were not significantly different.

S_{25} and S_{50} treatments had the lowest values of extractable phosphorous that were not significantly different ($P<0.05$) to the control plots. Treatments, which were combined with FYM, performed better, G_{100} + FYM being the most superior. Sekhon and Bajwa (1993) found similar results after applying gypsum and FYM to sodic soils. They reported that it was probably due the fact that organic matter reduces the effect of gypsum to fix phosphorous into complex compounds other than when it was applied alone. At the same time organic matter being a good nutrient réservoir, might have contributed some quantities of available phosphorous in the treated plots. According to EUROCONSULT (1989) and Landon (1991), the level of extractable P was low for proper growth of most field crops including maize. Hence, FYM should be applied regularly to the soils. Generally, there were significant differences ($P<0.05$) in Olsen's extractable phosphorous in all treatments.

4.5.3.4 CEC and exchangeable bases

Results on the effects of amendments on CEC and exchangeable bases are given in Table 6. The levels of CEC increased by 42% for gypsum treated plots. The CEC of sulphur treated plots increased by 44%, whereas the CEC for FYM treatment increased by 11%. When gypsum was combined with FYM, the CEC levels increased by 82%. The combination of sulphur and FYM increased the CEC by 44%. These CEC values were significantly higher ($P<0.05$) than the control plots. According to EUROCONSULT (1989) and Landon (1991) the CEC was still low (Table 5). Therefore, the soil had low ability to supply appreciable amount of nutrients for satisfactory plant growth and production.

The levels of exchangeable K increased by 36% for gypsum treated plots. The exchangeable K for sulphur treated plots increased by 52%. The exchangeable K content for FYM treatment increased by 13%. When gypsum and sulphur were combined with FYM, the exchangeable K levels increased by 62 and 46% respectively. In general the results show that there were no significant differences in all amended plots at ($P<0.05$). But, the values of K were higher than in the control plot. Thus, the observed exchangeable k levels were sufficient for maize crop production (EUROCONSULT, 1989 and Baze, 1991).

In the gypsum treated plots levels of exchangeable Ca increased by 147% compared to exchangeable Ca in the control. The exchangeable Ca in sulphur treated plots increased by 28% while that of FYM treated plots increased by 20%. The combination of gypsum and FYM increased the exchangeable Ca levels by 200% and that of sulphur and FYM increased exchangeable Ca levels by 37%. The results revealed that there was an increase in exchangeable Ca with an increase in the treatment application, the trend that was also observed by Verma and Abrol (1980). The exchangeable Ca content increased compared to that before the application of the treatments. When gypsum treatments are compared to that of sulphur, the latter performed better in increasing Ca content in the soil, whereby G_{100} and G_{100} + FYM were the most superior. Generally, with the exception of G_{75}, G_{100}, G_{75} + FYM and G_{100} + FYM there was no significant difference at ($P<0.05$) between the other treatments and control. According to EUROCOSÜLT (1989) and Landon (1991) therefore, control showed low Ca contents, G_{100} and G_{100} + FYM had high Ca content, while the rest of the treatment plots had medium Ca contents.

The levels of exchangeable Mg increased by 123% for gypsum treated plots. The exchangeable Mg of sulphur treated plots increased by 130%. The exchangeable Mg content for FYM treatment increased by 73%. When gypsum and sulphur were combined with FYM, the exchangeable Mg levels increased 140 and 135% respectively. The results show that there was no systematic trend in increase in exchangeable Mg content with increase in amendments especially where gypsum was applied alone as well as when sulphur was combined with FYM. Although there was no significant difference ($P<0.05$) within the treated plots other than S_{25} and S_{50}, exchangeable Mg increased slightly compared to the control. This is probably because there was a slight decrease in pH with treatments application (Table 5). Generally, Mg contents after application of treatments was observed to be sufficient for maize production (EUROCONSULT, 1989 and Landon, 1991).

In the gypsum treated plots the level of exchangeable Na was reduced by 49% as compared to the control plots. The exchangeable Na in sulphur treated plots was reduced by 54% the same in FYM treated plots was reduced by 16%. The combination of gypsum and FYM reduced exchangeable Na levels by 57% and that of sulphur and FYM reduced the same by 46%.

There was an appreciable decrease in Na concentration compared to values obtained before the application of soil amendments. G_{100} + FYM treatment was the most superior treatment in reducing Na concentration in the studied soils. The results are in agreement with those observed by Abrol and Bhumbla (1979), Verma and Abrol (1980) and Chauhan (1995), that exchangeable Na decreased when gypsum was applied to sodic soils in an increased manner. The authors further observed that gypsum become more efficient in reducing Na concentrations in the soil when combined with organic manure than when applied alone. Possibly this may be associated with a more efficient leaching process when FYM is incorporated into the soil.

The ESP values for the corresponding levels of exchangeable Na decreased from the control by 64% for gypsum treated plots. The ESP for sulphur treated plots decreased by 62%. The ESP value for FYM treatment decreased by 24% from the control.

Table 6: Effect of treatments on K, Ca, Mg, Na, CEC and ESP

Treatment	K	Ca	Mg	Na	CEC	ESP
			Cmol(+)kg^{-1}			%
Control	1.47^{c}	4.94^{f}	2.26^{d}	11.88^{a}	12.10^{e}	98.02^{a}
G_{25}	1.81^{abc}	6.87^{cdef}	4.47^{ab}	10.27^{bc}	13.27^{cde}	77.39^{bc}
G_{50}	1.98^{abc}	6.95^{cdef}	5.43^{a}	9.24^{bc}	13.34^{cd}	69.26^{bcd}
G_{75}	1.93^{abc}	8.92^{cd}	4.86^{ab}	6.42^{cd}	15.14^{bcd}	42.4^{d}
G_{100}	2.0^{abc}	12.21^{ab}	5.05^{ab}	6.11^{cd}	17.20^{bc}	35.52^{d}
S_{25}	1.71^{bc}	5.19^{f}	2.45^{cd}	10.94^{ab}	13.42^{cd}	81.52^{ab}
S_{50}	1.90^{abc}	5.59^{def}	3.35^{bcd}	10.73^{ab}	13.48^{cd}	79.82^{ab}
S_{75}	1.87^{abc}	5.92^{def}	4.61^{ab}	9.62^{bc}	17.47^{bc}	55.0^{c}
S_{100}	2.23^{ab}	6.31^{cdef}	5.19^{a}	6.52^{cd}	17.49^{bc}	37.28^{d}
FYM	1.66^{bc}	5.82^{def}	3.99^{abc}	10.02^{bc}	13.42^{cd}	74.66^{bc}
G_{25}+FYM	2.07^{abc}	6.06^{def}	4.74^{ab}	9.83^{bc}	13.18^{cde}	74.58^{bc}
G_{50}+FYM	2.05^{abc}	8.79^{cde}	4.91^{ab}	9.71^{bc}	13.09^{cde}	74.18^{bc}
G_{75}+FYM	2.10^{abc}	9.72^{bc}	5.01^{ab}	7.67^{bcd}	17.26^{bc}	44.4^{d}
G_{100}+FYM	2.38^{a}	14.86^{a}	5.43^{a}	5.16^{d}	22.0^{a}	23.45^{e}
S_{25}+FYM	1.64^{bc}	5.37^{ef}	3.65^{abcd}	10.18^{bc}	13.22^{cd}	70.0^{bc}
S_{50}+FYM	1.79^{abc}	6.39^{cdef}	4.85^{ab}	10.19^{bc}	13.54^{cd}	76.9^{bc}
S_{75}+FYM	2.12^{abc}	6.42^{cdef}	4.70^{ab}	7.76^{bcd}	16.41^{bcd}	47.64^{cd}
S_{100}+FYM	2.15^{ab}	6.78^{cdef}	5.30^{a}	6.37^{cd}	17.39^{bc}	36.63^{d}
LSD($P<0.05$)	5.512	2.984	1.519	0.4098	51.72	0.51
CV (%)	17.16	24.32	20.53	19.42	25.43	10.23

Means within the column followed by the same letter are not significantly different at ($P<0.05$

*Mean of three blocks, n=54

When gypsum and sulphur were combined with FYM, the ESP values decreased by 76 and 63% respectively. G_{100} + FYM was the best amendment in reducing ESP. ESP decreased with an increase in gypsum and sulphur application. When the effect of different levels of gypsum and sulphur was considered, the gypsum application levels resulted in greater ESP decrease compared with the levels of sulphur application, the results, which were also observed by Verma and Abrol (1980). ESP decreased in gypsum applications through direct supply of soluble calcium. ESP decrease in sulphur applications was expected to result from its reaction with calcium carbonate present in the soil upon oxidation to sulphuric acid. Since the soil pH was high (Table 5), it appeared to be the main limiting factor for the oxidation of sulphur because the activity of sulphur-oxidizing bacteria are maximum in acidic (~4.0) pH range (Bloomfield, 1972), as cited by Verma and Abrol (1980). The ESP was still high because normal soils should have ESP<15% (Abrol *et al.*, 1988, Tanji, 1990 and Tisdale *et al.*, 1993), and it was not reduced to satisfactory levels for maize production. Therefore, regular application of FYM and the amendments is required.

4.5.3.5 DTPA extractable micronutrients

Results of DTPA extractable Cu, Zn, Fe and Mn are presented in Table 7. Values for DTPA extractable Cu were comparatively the same and no significant differences (P<0.05) were observed among the treatments. The values for all treatments ranged from 0.12 to 0.15 $mgkg^{-1}$ and were inadequate according to Lindsay and Norvell (1978). The authors suggested 0.2 $mgkg^{-1}$ of DTPA extractable Cu in soil to be adequate for plant growth.

DTPA extractable Zn of G_{100} + FYM treated plots was significantly (P<0.05) higher than the rest of the treated plots. The values of all treatments ranged from 0.23 to 0.35 $mgkg^{-1}$. Critical value for DTPA extractable Zn was suggested by Lindsay and Norvell (1978) to be 0.5 to 1.0 $mgkg^{-1}$. According to these authors, the amended soils were found to be deficient in zinc. Thus, supplement of zinc from inorganic source will restore soil zinc to acceptable levels.

The levels of DTPA extractable Fe increased four times for gypsum treated plots relative to control. The DTPA extractable Fe for sulphur treated plots and that for FYM treated plots increased three times. The combination of gypsum and sulphur with FYM, increased the DTPA extractable Fe levels seven times as well as five times respectively. Fe value for G_{100} + FYM was significantly the highest compared to all other treatments (P<0.05).

DTPA extractable Fe levels for the G_{100}, G_{50} + FYM, G_{75} + FYM, S_{75} + FYM and S_{100} + FYM were not significantly different (P<0.05). When gypsum and sulphur treated plots are compared, gypsum was superior to sulphur in increasing the amount of Fe in the soil. However, there was an increase in DTPA extractable Fe in all treatments compared to the control. The levels of Fe (Table 7) are considered as inadequate for maize growth. Lindsay and Norvell (1978) reported 4.5-6.0 $mgkg^{-1}$ DTPA extractable Fe in the soil to be sufficient for plant growth. The intervention through the use of amendments did not improve the DTPA extractable Fe to adequate levels for maize growth. Thus, Fe has to be supplemented from inorganic fertilizers.

Table 7: Effect of treatments on DTPA extractable Cu, Zn, Fe and Mn

Treatment	Cu	Zn ($mgkg^{-1}$)	Fe	Mn
Control	0.12^{a}	0.23^{b}	0.5^{d}	0.49^{b}
G_{25}	0.13^{a}	0.24^{b}	1.2^{c}	0.51^{b}
G_{50}	0.13^{a}	0.24^{b}	1.4^{c}	0.53^{b}
G_{75}	0.13^{a}	0.26^{b}	1.4^{c}	0.53^{b}
G_{100}	0.14^{a}	0.27^{b}	2.0^{b}	0.55^{b}
S_{25}	0.12^{a}	0.23^{b}	1.2^{c}	0.5^{b}
S_{50}	0.12^{a}	0.24^{b}	1.24^{c}	0.51^{b}
S_{75}	0.12^{a}	0.25^{b}	1.5^{c}	0.51^{b}
S_{100}	0.13^{a}	0.25^{b}	1.5^{c}	0.52^{b}
FYM	0.14^{a}	0.25^{b}	1.6^{c}	0.5^{b}
G_{25}+FYM	0.14^{a}	0.25^{b}	1.8^{cb}	0.56^{b}
G_{50}+FYM	0.14^{a}	0.27^{b}	2.1^{b}	0.58^{ab}
G_{75}+FYM	0.14^{a}	0.27^{b}	2.2^{b}	0.6^{ab}
G_{100}+FYM	0.15^{a}	0.35^{ab}	3.6^{a}	0.62^{ab}
S_{25}+FYM	0.14^{a}	0.24^{b}	1.5^{c}	0.53^{b}
S_{50}+FYM	0.14^{a}	0.24^{b}	1.7^{cb}	0.53^{b}
S_{75}+FYM	0.14^{a}	0.26^{b}	2.2^{b}	0.53^{b}
S_{100}+FYM	0.14^{a}	0.26^{b}	2.4^{b}	0.54^{b}
LSD (P<0.05)	0.0471	0.094	0.121	0.032
CV (%)	15.12	9.74	14.33	17.91

Means within the column followed by the same letter are not significantly different at (P<0.05)

*Mean of three blocks, n=54

DTPA extractable Mn ranged from 0.49 to 0.62 $mgkg^{-1}$. The results show that except for G_{50-100} levels in combination with FYM there were no significant differences (P<0.05) within the treatments. According to Lindsay and Norvell (1978), 1.0 $mgkg^{-1}$ of DTPA extractable Mn is adequate for plants. In view of these authors, DTPA extractable Mn in the amended soils was low.

Generally, the increase in available micronutrients was not sufficient to meet the nutrient requirement of the crop mainly because sodium concentration and pH in the soil were still high. The high pH attribute to the formation of micronutrients complexes thus, reduce their availability. The micronutrients cations are most soluble and available under acid conditions (Tisdale *et al.*, 1993). Therefore, supplement of the micronutrients from inorganic sources is inevitable.

4.6 The relationship between soil properties (pH, ECe, total nitrogen, available P and organic carbon) and grain maize yield

Regression analysis was used to identify soil parameters that had significant effect on maize grain yield at (P, 0.05). Maize grain yield was regressed against some soil variables namely: pH, ECe, total nitrogen, available phosphorous and organic carbon. The results (Table 8) show that pH significantly affected maize grain yield. This is probably due the fact that when pH increases (pH>8.5) the percent crop production decreases (Abrol *et al.*, 1988 and Landon, 1991). A strong linear relationship was observed between pH and yield. ECe shows a slight relationship with maize grain yield. The other soil variables are weakly correlated with maize grain yield. This implies that they were not linearly correlated with the maize grain yield.

Table 8: Regression relationship between soil parameters (pH, ECe, %N, P and OC) and maize grain yield

Variable	Adjusted R^2	P-Value	Regression Equation
pH	0.60	0.000	$Y = -5.534x + 49.767$
ECe (dSm^{-1})	0.49	0.001	$Y = 4.005x - 6.323$
N (%)	-0.06	0.960	$Y = 1.379x + 7.890$
P ($mgkg^{-1}$)	0.006	0.309	$Y = 0.036x + 6.346$
OC (%)	-0.05	0.701	$Y = 1.646x + 6.055$

Where: Y = Maize grain yield, x = Soil variables and R^2= Coefficient of Determination.

4.6.1 CEC, exchangeable bases and DTPA extractable micronutrients

Regression analysis results (Table 9) show that apart from Ca, which significantly affected maize grain yield ($P<0.05$), other nutrients show a weak relationship. Exchangeable Ca is positively correlated with maize grain yield probably because it was required in great quantities to replace exchangeable Na. Magnesium, K, Na, CEC and DTPA extractable micronutrients expressed weak and non linear relationship with maize grain yield.

Table 9: Regression relationship between soil parameters (Ca, Mg, K, Na, CEC and DTPA extractable micronutrients) and maize grain yield

Variable (Cmol $(+)kg^{-1}$)	Adjusted R^2	P-Value	Regression Equation
Ca	0.54	0.000	$Y = 1.638x - 3.958$
Mg	0.38	0.003	$Y = 3.856x - 9.037$
K	0.06	0.750	$Y = -0.193 + 11.86$
Na	-0.06	0.973	$Y = 0.011x + 8.002$
CEC	-0.05	0.674	$Y = -0.015x + 10.003$
DTPA extractable micronutrients($mgkg^{-1}$)			
Cu	-0.05	0.510	$Y = 1.321x - 4.823$
Fe	-0.12	0.300	$Y = 2.20x + 1.974$
Zn	0.23	0.232	$Y = -0.18 + 7.052$
Mn	-0.07	0.487	$Y = 0.647 - 8.004$

Where: Y = Maize grain yield, x = Soil variables and R^2= Coefficient of Determination.

4.7 Effect of amendments on yield parameters

4.7.1 Percentage seedling emergence

Results on the effect of soil amendments on seedling emergence are summarized in Table 10. The percentage seed emergence ranged from 44.3 to 76.4% for gypsum treated plots. The percentage seed emergence for sulphur treated plots ranged from 0.0 to 37.6%. The percentage seed emergence for FYM treatment ranged from 0% to 34.1%. With the exception of S_{25} and S_{50} there was a significant increase ($P<0.05$) of germinated seeds over control. This was probably due to the high-recorded pH (10.30), which is unfavourable for most field crops including maize. When gypsum and sulphur were combined with FYM, the percentage seed emergence ranged from 42.4 to 91.4 and 20.0 to 47.8% respectively whereby there were significant increases at $P<0.05$ in all combined treatments, except in S_{25} + FYM and S_{50} + FYM. In combined application of gypsum and FYM, G_{100} and FYM treatment recorded the highest percent of seedling emergence. There was no significant difference ($P<0.05$) between G_{75} and G_{100}. S_{100} + FYM ranked superior among sulphur treatments and it was significantly different to other sulphur amended plots at $P<0.05$. Apart from S_{25} and S_{50} the results reveal that there was an increase in seed emergence with increasing gypsum and sulphur rates compared to the control. The percentage seedling emergence increased because the amendments removed part of the exchangeable sodium and replaced the favourable calcium ions in the root zone.

4.7.2 Number of seeds per cob

Effect of soil amendments on number of seeds per cob is summarized in Table 10. The number of seeds per cob ranged from 171.2 to 215.8 for gypsum amended plots. The number of seeds per cob for sulphur treated plots ranged from zero seeds (control) to 146.2. In the FYM treated plots the number of seeds per cob ranged from 0 to 140. In the combination of gypsum and FYM the number of seeds per cob ranged from 155.3 to 249.3 while that of sulphur and FYM ranged from 92 to 153 seeds per cob. The number of seeds per cob increased significantly ($P<0.05$) over the control, except in S_{25} and S_{50} treatments. The increase was probably caused by the soil amendment after reducing soil pH and improving physical characteristics of the sodic soils. There were no significant increases in number of seeds per cob between G_{25} and G_{50} and between G_{75} and G_{100}. The same applied to S_{75} and S_{100} treatments. A combination of gypsum and FYM showed significance differences in all treatments at $P<0.05$. The combination of sulphur and FYM showed non-significance differences between S_{25} + FYM and S_{50} + FYM. While significance difference at $P<0.05$ was observed between S_{75} + FYM and S_{100} + FYM treatments. When averaged overall gypsum treatments were superior in increasing number of seeds per cob to those of sulphur. It is probably because gypsum treatments had greater effect on improving soil pH, Ca and ESP (Tables 5 and 6). However, they were much more effective when combined with FYM, whereby G_{100} + FYM treatment was the most superior. The number of seeds per cob was very important parameter since it reflected the crop yield. Generally, the results show that the number of seeds increased with an increase of sulphur and gypsum applications.

4.7.3 One hundred seed weight

Results on one hundred seed weight are presented in Table 10. The gypsum treated plots recorded one hundred seed weight ranging from 8.1 to 30.6. One hundred seed weight for sulphur treated plots ranged from 0 to 17.8. One hundred seed weight for FYM treatment was 16.4. When gypsum was combined with FYM, one hundred seed weight ranged from 17.9 to 35.3. The combination of sulphur and FYM ranged 12.03 to 24.9 of one hundred seed weight. With the exception of S_{25} and S_{50} treatments, the results show that there was a significant increase in weight of seeds with increasing levels of treatments at $P<0.05$. There were no significant increase in one hundred seed weight between G_{75} and G_{100}. The combination of gypsum and sulphur with FYM showed significance differences in all treatments at $P<0.05$. When gypsum and sulphur were compared gypsum was better in increasing seed weight. However, gypsum became more effective as it was combined with FYM. It might be that the more the sodicity was ameriolated the more the nutrients were taken up by the maize plants since the soil pH, ESP and Ca were improved (Tables 5 and 6). The same results were also observed by Singh *et al.*, (1981) that application of amendments increases the uptake of essential nutrients by safflower and linseed. The authors further noted that, besides other reasons like genetic make up of the plant, the seed weight entailed amount of nutrients taken in by plants due to effect of the treatments on ameriolating the sodic soils. Generally, except for S_{25} and S_{50} treated plots there was an increase in weight over the control.

4.7.4 Grain maize yield

Results on the grain maize are presented in Table 10. The results show that for gypsum amended plots maize grain yield increased 113% from the control. Maize grain yield for sulphur treated plots on the other hand increased by 32%. Maize grain yield for FYM treatment increased by 35%. When gypsum and sulphur were combined with FYM, maize grain yield increased significantly at $P<0.05$ by 142 and 53% of maize grain yield respectively, except in S_{25} +FYM and S_{50} + FYM.

The results show that maize grain yield increased with increasing treatment application. Maize failed in plots that did not receive gypsum, sulphur and FYM. This was expected in view of the high soil pH and high levels of ESP of the soil. Even with the application FYM alone the yield was poor. Combined application of gypsum, sulphur with FYM resulted in increasing maize grain yield whereby the highest crop yields were obtained in a combination of G_{100} and FYM. The result supports the observations reported by Dargan *et al.*, (1976); Chand *et al.*, (1977); Verma and Abrol (1980); Prasad and Verma (1987); Chauhan (1995); and Pandiyarajan and Kannaiyan (1996) who observed best crop yields when they combined gypsum and organic amendments.

There were non significant differences at ($P<0.05$) between G_{75} and G_{100} whereby their average maize grain yields were almost similar, and lower than that of the same treatment combined with FYM. Treatments S_{25} and S_{50} were not significantly different ($P<0.05$) compared to control in such a way that there was total crop failure, perhaps, because they registered high levels and intolerable soil pH and ESP for maize. The results however, indicate that with exception of S_{25} and S_{50} treatments, maize grain yield increased significantly relative to the control at ($P<0.05$).

Table 10: Effect of treatments on yield parameters

Amendment	Percentage seed emerged	Number of seed per cob	One hundred seed weight (g)	Grain yield(tonnesha^{-1})
Control	0.0^{k}	0.0^{j}	0.0^{k}	0.00^{k}
G_{25}	44.3^{fg}	171.2^{e}	9.66^{j}	0.14^{fg}
G_{50}	66.7^{e}	162.7^{ef}	18.02^{g}	1.0^{e}
G_{75}	76.5^{c}	223.3^{c}	32.75^{bc}	1.1^{c}
G_{100}	76.4^{c}	224.4^{c}	34.8^{b}	1.13^{c}
S_{25}	0.0^{k}	0.0^{j}	0.0^{k}	0.00^{k}
S_{50}	0.0^{k}	0.0^{j}	0.0^{k}	0.00^{k}
S_{75}	20.0^{j}	139.4^{h}	17.5^{g}	0.06^{j}
S_{100}	37.6^{hi}	146.2^{ch}	20.8^{cf}	0.32^{hi}
FYM	34.1^{i}	140.9^{h}	20.63^{ef}	0.35^{i}
G_{25}+FYM	42.4^{g}	155.3^{fg}	22.97^{e}	0.42^{g}
G_{50}+FYM	71.4^{d}	159.7^{d}	28.1^{d}	1.0^{d}
G_{75}+FYM	82.8^{b}	134.8^{b}	35.25^{b}	1.23^{b}
G_{100}+FYM	91.4^{a}	249.1^{a}	39.16^{a}	1.42^{a}
S_{25}+FYM	20.0^{j}	92.0^{i}	12.8^{i}	0.06^{j}
S_{50}+FYM	23.5^{j}	100.4^{i}	14.44^{h}	0.14^{j}
S_{75}+FYM	41.2^{gh}	134.5^{h}	22.56^{e}	0.39^{gh}
S_{100}+FYM	47.8^{f}	153.3^{fg}	27.9^{d}	0.53^{f}
LSD ($P<0.05$)	3.148	33.07	0.3710	0.7079
CV (%)	5.18	1.07	1.07	5.12

Means within the column followed by the same letter are not significantly different at ($P<0.05$)

*Mean of three blocks, n=54

4.7.5 Economic analysis of maize grain yield

Using the prevailing maize grain and input (amendment) prices, economic analysis of maize grain yield was carried out using "FACTOR- PRODUCT RELATIONS" and the results are presented in Table 11. The factor- product relations entail that in order to breakeven the farmer has to combine his/her resources in such a way that Marginal Revenue (MR) is equal to Marginal Cost (MC) (Johansen, 1972 and Sibuga, 1985). The MR ranged from 3.30 to 27.50 T. Shs/kg for gypsum amended plots and that sulphur treated plots ranged from 0 to 14.30 T. Shs/kg with the increasing rate of the amendments.

The MR for FYM treatment was 1.10 T. Shs/kg. When gypsum and sulphur were combined with FYM, the MR ranged from 9.90 to 35.20 T. Shs/kg and 2.20 to 24.20 T. Shs/kg respectively. The results indicate that there was a systematic trend in MR with increasing treatment levels. In gypsum treated plots G_{100} treatment had the highest MR, whereas S_{100} showed the highest MR in sulphur amended plots. S_{25} and S_{50} had zero MR meaning that economically are not recommended rates for amending the soil with sulphur. Among the combinations, of gypsum and FYM, G_{100} + FYM treatment was economically superior to all treatments. On the other hand, S_{100} + FYM had the highest MR of all treatments when sulphur was combined with FYM. This is due to the fact that they are the only treatments that had MR, which at least approaches the cost of a kg of each amendment. Therefore, the best treatment was G_{100} + FYM. Generally, the results show that the application of amendments was uneconomical due to low production levels in all amended plots.

Table 11: Marginal Rate of Return analysis for gypsum, sulphur and FYM application in maize

Treatment	X1 (kg/ha)	Y1 (kg/ha)	ΔX1	ΔY1	ΔY1/ΔX1	(ΔY1/ΔX1)x PY1 T. Shs/kg
Control	0	0	-	-	-	-
G_{25}	4500	140	4500	140	0.03	3.30
G_{50}	9000	1000	4500	1000	0.22	24.20
G_{75}	13500	1100	4500	1100	0.24	26.40
G_{100}	18000	1140	4500	1140	0.25	27.50
S_{25}	2450	0	2450	0	0	0
S_{50}	4850	0	2450	0	0	0
S_{75}	7300	60	2450	60	0.02	2.20
S_{100}	9750	320	2450	320	0.13	14.30
FYM	20000	250	20000	250	0.01	1.10
G_{25}+FYM	24500	420	4500	420	0.09	9.90
G_{50}+FYM	29000	1000	4500	1000	0.22	24.20
G_{75}+FYM	33500	1230	4500	1230	0.27	29.70
G_{100}+FYM	38000	1420	4500	1420	0.32	35.20
S_{25}+FYM	22400	60	2450	60	0.02	2.20
S_{50}+FYM	24850	140	2450	140	0.06	6.60
S_{75}+FYM	27300	390	2450	390	0.16	17.60
S_{100}+FYM	29700	530	2450	530	0.22	24.20

Footnote: Y1=Grain maize yield per ha X1=Levels of application of amendments
PYI=Price of maize grain yield per kg PX1=Price of amendments per kg

Assuming other factors constant
Price of maize grain = 110 T.Shs/kg
Price of 1 ton of gypsum including transport = 40,000 T.Shs (40.00 T.Shs/kg)
Price of 1 bag of sulphur (25 kg) including transport = 8,000 T. Shs(320.00 T.Shs/kg)
Price of 1 ton of FYM = 6000 T.Shs (6.00 TShs/kg)

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions can be drawn from the study:

1. Mto wa Mbu soils had the following characteristics: high pH, exchangeable Na and ESP; high content of clay in subsoil that might result into compaction with poor water infiltration; low DTPA extractable micronutrients (CU, Zn, Fe and Mn) and low organic carbon contents probably because of organic matter dispersion. Therefore, application of amendments in order to ameliorate the soil sodicity is inevitable.

2. Irrigation water had minimal contribution to soil sodicity because it falls under low sodium water class.

3. Gypsum was superior to sulphur in ameliorating soil sodicity and became more effective when combined with FYM. The effect of sulphur when applied in low concentrations was almost at par with the control plots; however, it became effective when combined with FYM. Gypsum treatments gave more grain maize yields than those of sulphur, but gave better yields when combined with FYM.

4. Soil pH and Ca showed strong linear relationship with maize grain yield, whereby soil pH showed negative relationship while the relationship of Ca with maize grain yield was positive. ECe showed a slight relationship with maize grain yield. The rest of the soil variables were weakly correlated with maize grain yield.

5. The economic viable amendment was G_{100} + FYM.

5.2 Recommendations

1. Gypsum in combination with FYM (G_{100}+ FYM) is recommended as an effective treatment for ameliorating soil sodicity for better crop yields. However, G_{50}, S_{100}, G_{50} + FYM and S_{75} + FYM show an attractive benefit to farmers compared to other treatments.

2. Soil amendments, use of organic materials to improve on soil physical properties, leaching and drainage should be a pre-requisite for sound and sustainable land use in sodic soils.

5.3 Future studies

1. Longterm studies on the effect of the amendments on soil properties and maize yield are required.

2. A detailed study to assess the residual effect of gypsum and sulphur in order to determine their economic returns for the second season is required.

3. More research is required to the effect of gypsum and sulphur on sodic soils in other areas of the country in order to establish general recommended rates.

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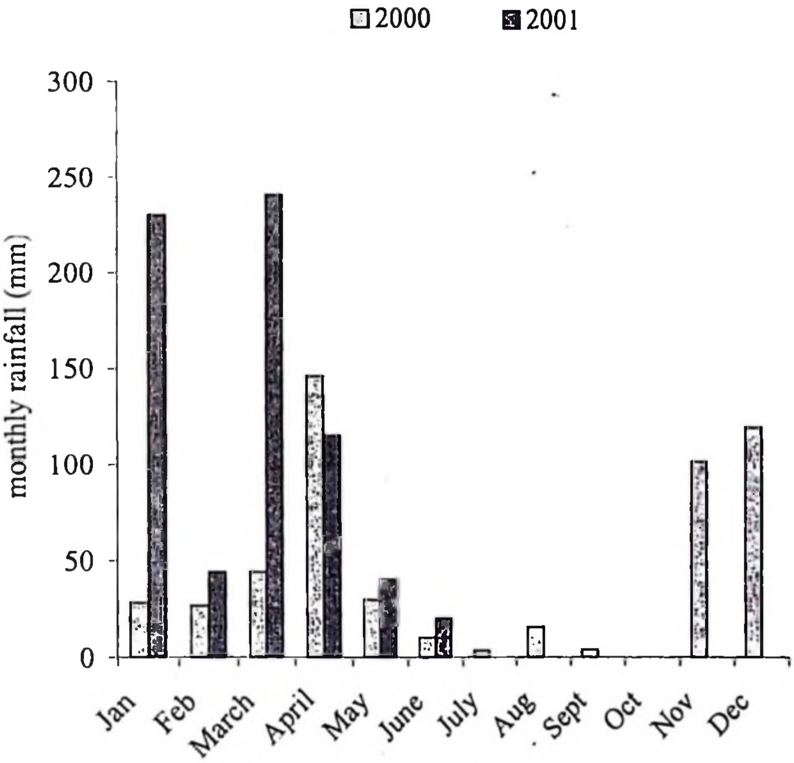
APPENDICES

Appendix 1: Monthly rainfall of Mto wa Mbu area for Jan 2000/Aug 2001



Source : **Manyara National Park Weather Station**

Appendix 2: Chemical analysis of gypsum in water

pH	EC	NH_4	K	Na	Ca	Mg	Si	NO_3	Cl	SO_4	HCO_3	H_2PO	Fe	Mn	Zn	B	Cu	Mo
	.dS/m.	.............ppm(millimol/l)..............						...........ppm(millimol/l)...............					.........ppb(micromol/l)..............					
8	2.2	1.8	16	4.6	710	2.4	2.8	6.2	7.1	1400	6.1	4.85	5.6	5.5	6.5	46	13	48

Source: Kibo Gypsum Ltd, Moshi, Tanzania.