IRRIGATION WATER MANAGEMENT OF SODIC SOIL FOR TOMATO PRODUCTION IN BARWA-MINJIBIR IRRIGATION SCHEME, KANO NIGERIA

BY

NURADDEEN MUKHTAR NASIDI

M. Sc. /ENG/3747/2011-2012

ATHESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS OF SCIENCE DEGREE IN AGRICULTURAL ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

MAY, 2015

DECLARATION

Ideclare that the work in this thesis entitled “Irrigation water Management of Sodic Soil for tomato production in Barwa-Minjibir Irrigation Scheme” has been carried out by me in the Department of Agricultural Engineering under the supervision of Dr. M. K. Othman and Prof. M. A. Oyebode. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this Thesis was previously presented for another degree or diploma at any other institution.

NURADDEEN MUKHTAR NASIDI	_____	_____
M. Sc./ENG/3747/2011-2012	(Signature)	(Date)

CERTIFICATION

This thesis entitled IRRIGATION WATER MANAGEMENT OF SODIC SOIL FOR TOMATO PRODUCTION IN BARWA-MINJIBIR IRRIGATION SCHEME, by NuraddeenMukhtar NASIDI meets the regulations governing the award of the degree of Masters of science degree in Agricultural Engineering ofAhmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation

Dr. M. K. Othman	_____	_____
Chairman, Supervisory Committee	(Signature)	(Date)
Prof. M. A. Oyebode	_____	_____
Member, Supervisory Committee	(Signature)	(Date)
Prof. M. L. Sulaiman	_____	_____
Head of Department	(Signature)	(Date)
Prof. A. Z. Hassan	_____	_____
Dean, School of Postgraduate Studies	(Signature)	(Date)

DEDICATIONS

This work is dedicated to my parents Mal.Mukhtar A. NasidiDandago and Late MalamaMaimuna Ahmad Baffa and also to my lovely wife Hadiza Mustapha Balarabe for their sacrifice, support, love and encouragement throughout the conduct of this programme.

ACKNOWLEDGEMENT

In the name of Allah, the most beneficent and the most merciful,All Praise is to Him the Lord of the world, sustainer and supporter of life. We praise Him and seek for His aid, support and forgiveness amen.

I wish to express my profound gratitude to my supervisors Dr. M. K. Othman and Prof. M. A. Oyebode for their continued support, encouragement, constructive criticism, corrections and suggestions throughout the conduct of this research.

I feel highly delighted to extend my special regards and appreciations to my lovely parents: Mal. Mukhtar A. NasidiDandago and Late MalamaMaimunaAhmad who always guided, encouraged and helped me right from my childhood.

I am also indebted to express my appreciation to my lecturers and colleagues; Prof. A. A. Ramalan, Prof. H. E. Igbadun, Prof. D. D. Yusuf, Prof. S. Z. Abubakar,Dr. M. Gwarzo, Dr. M. S. Abubakar, Dr. M. M. Maina, Dr. M. A. Ali, Engr. H. Ismail, Engr. N. J. Shanono, Engr. M. M. Bello, Engr, B. Dalha, Engr. I. Abdusslam, Engr. I. Lawan, Engr. M. D. Zakari, Engr, H. A. Gidadoand other academic and non-academic staff of the Department of Agricultural Engineering at both Bayero University, Kano and Ahmadu Bello University Zaria. I am also extending my appreciation to Engr. Abubakar and Mal. Isah of the Minjibir Irrigation Scheme for their contribution during the conduct of the experiment. I am indeed grateful to my brothers and sister, I say thank you all.

ABSTRACT

A field experiment was conducted during 2013/2014 dry season at Minjibir irrigation scheme, along Jakara River, Kano State located at Longitude $8^{o}30$"E to 8^{o} 32"E and Latitude $12^{o}5$"N to $12^{o}20$"N at 414 m above mean sea level. The study examined soil and water management strategies on sodic soil condition for the production of tomato.The experiment consisted of four levels of gypsum application ($0g/m^2$, $200g/m^2$, $300g/m^2$ and $400g/m^2$) and three levels of leaching requirement (100%, 150% and 200%) arranged in a completely randomised design laid as treatments in plots (2m x 2m) basin and replicated three times. The irrigation water was applied to each plot through a calibrated PVC pipe. The irrigation water quality assessment was conducted for ESP, SAR, EC and pH and the results were 60.3%, 25.0, 1.4dS/m and 7.23 respectively. The Tomato seasonal water requirement was computed using CROPWAT software 8.0 and the result was 564.3mm while the leaching requirement of 1.49mm/day was also calculated. The results showed that there was statistically high significant difference on yields with respect to gypsum application and leaching requirement (LR) at 1% level of significance. The highest yield of 25 ton/ha was obtained from the plot treated with $400g/m^2$ of gypsum at 100% leaching requirement. The lowest yield of 18.75ton/ha was realised from plot treated with $200g/m^2$ of gypsum at 150% LR. However, there were no yields from plots with zero gypsum application due to high sodic condition. It was identified that to grow tomato in Minjibir irrigation farm, reclamation is necessary and the leaching requirement should be kept at 100% in order to achieve better yield and yield components. About 87.1% of tomato seedlings survived when transplanted in plot treated with $400g/m^2$of gypsum whereas only 52.75% of tomato seedlings survived in plot treated with $200g/m^2$ of gypsum.

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CHAPTER ONE

INTRODUCTION

1.1 General Background

Tomato (*Lycopersicomesculentum*) is an important vegetable crop in Nigeria. Large scale tomato production is found in the northern Guinea and Sudan Savannah zones of Nigeria where relatively high yield could be realized by planting during the dry season using irrigation method. Present world production of Tomato is about 100 million tons fresh fruit from 3.7 million ha (FAOSTAT, 2001). Depending on the variety, growing period of tomato is between 90 to 150 days. Optimum mean daily temperature for growth is 18 to 25^{o}C with night temperature of 10 to 20^{o}C. High humidity leads to greater incidence of pests and diseases and fruits rotting (FAO, 2013a). The presence of salts can drastically alter the morphological, physical, chemical and biological properties of the soil and impair its production (Brady and Weil, 1999). Under saline condition, nutrients toxicity and increasing osmotic pressure are common problems to plant (Bernstein, 1974). The adsorptionof sodium under sodic conditions usually manifests its destructive effects on the soil structure through reduced infiltration, permeability and increased surface crusting besides being toxic. Kijne and Kuper (1998) noted that the application of fertilizers and irrigation water continue to add salt to the system. A saline soil contains sufficient salt in the root zone that impair crop growth; saline soils hinder soil productivity by increasing the osmotic pressure in the soil making it more difficult for the crop to extract water needed for

evapotraspiration, such soil has an electrical conductivity of the saturated extract exceeding 4 dSm^{-1} at $25^{o}C$ and the exchangeable sodium percentage (ESP) of less than 15% (Richard, 1954). Also poor irrigation schedules can lead to the development of crop water deficit and result in reduced yield due to water and nutrients deficiency. Moreover, proper time of irrigation is essential to the production of quality of most vegetables. If water shortage occurs early in the crop development, maturity may be delayed which may reduce yields. The moisture shortage later in the growing season adversely affects the quality of produce even though total yields may not be affected.

The soil should be moist at the time of planting, the germination and initial growth stages, if necessary irrigation should take place to wet the soil during these periods. As the plant grows, moist soil is necessary for proper root development, as roots do not grow through a dry layer of soil. A dry layer results in a shallower rooting depth than desirable. Soil profile should be filled with water at each irrigation period. Shallow root systems result in plants being stressed even in short periods of water deficit (Stewart and Nelson, 1990). Early in the season when plants are small, it is beneficial to encourage roots to explore as much of the soil profile as possible. This maximizes nutrient uptake and maximize stress tolerance later in the season. The best approach to early season irrigation is to begin with a full soil profileand encourage deep rooting by not watering routinely, but rather waiting until the 20% depletion of available water is reached at the appropriate monitoring depth. Thismay take 5 to 7 days or longer between irrigation depending on the weather,the interval is less in a hot weather and the water stressed conditions encouragetomato to develop its root system at deeper soil layers which retained more water (Stewart, 1990).

1.2 Problem Statement

Several research works were conducted at Minjibir irrigation Scheme by IAR and other agencies aimed at improving of irrigation water as well as cropping systems in Barwa-Minjibir Irrigation Scheme.The research work on salts problems in the scheme conducted by Malqwi et al., (2002) showed that the Barwa–Minjibirirrigation water is sodic and has caused sodicity problems in the soils resulting in surface crusting and poor structural stability. The exchangeable sodium percentage (ESP) in surface and subsurface soils had the average value of 56.92%. The irrigation water had Electrical Conductivity (ECe), sodium adsorption ratio (SAR) and adjusted SAR values of 0.65dS/m, 13.0; and 12.17 respectively. These values of ESP and SAR were found to be above FAO standards of irrigation water. Similarly, the soil has high residual sodium carbonate and contains both negative and positive saturated index (Malgwi et al., 2002).

1.3 Aim and Objectives of the Study

The aim of this studyis to develop soil and water sodicity management strategies for optimum yield of irrigated tomato in Barwa-Minjibir irrigation scheme. The objectives are:

1. To ascertain the current sodicity level of irrigation water in Minjibir irrigation Scheme.
2. To determine the effect of calcium sulphate (gypsum) on yield and yield components of irrigated tomato in Barwa-Minjibir Irrigation Scheme.
3. To determine the effect of leaching requirement on yield and yield components of Tomato grown under sodic soil condition at Minjibir Irrigation Scheme.

1.4 Justification

Minjibir irrigation scheme was put into use since 1976 in both dry and wet seasons and the dominant crops cultivated include tomatoes, onion and pepper. The studies conducted are mostly diagnostic and problems identification, there were no detail studies on water and soil management practices to address the sodicity problems. The essential work is to finding solution to the identified problems. Thus, finding remedy on the use of sodic water for irrigation in Barwa-Minjibir is a worthwhile effort as the scheme serves farmers and two research stations; International Institute of Tropical Agriculture (IITA) and Institute of Agricultural Research Station (IAR), Ahmadu Bello University Zaria.

CHEPTER TWO

LITERATURE REVIEW

2.1 Introduction

Irrigation water containing large amount of sodium is of special concern due to sodium effect on the soil. Sodium hazard is usually expressed in terms of sodium absorption ratio (SAR) and is calculated from the ratio of sodium to calcium and magnesium. Continued use of water having a high SAR leads to a breakdown in the physical soil structure (Tanji, 1990). Sodium is absorbed and become attached to the soil particles, the soil then become hard and compacted when dry and increasingly impervious to water penetration. Calcium and magnesium if present in large quantities counter the effect of sodium and help maintain good soil properties. Soluble sodium percent (SSP) is also used to evaluate sodium hazard. SSP is defined as the ratio of sodium in equivalent per million to the total cat ionmultiply by 100. Water with SSP greater than 60 per cent may result in sodium accumulations that will cause a breakdown in soil physical structure (Roweand Abdel-Magid, 1995).

Water with high salinity is toxic to plant and poses salinity hazard (Rowe,1995). High concentrations of salt can result in a physiological drought condition. That is even when the field appears to be moist, the plant wilt because the roots are unable to absorb the water. Water salinity is usually measured by total dissolved solids (TDS) or the electrical conductivity (EC). TDS is sometimes referred to as the total salinity and is measuredor

expressed in part per million (ppm) or in the equivalent units of milligrams per litre (mg/l).

2.2 Salt-Affected Soils

Salt-affected soils may contain an excess of water-soluble salts (saline soil), excess exchangeable sodium (sodic soils) or both excess of salts and exchangeable sodium (saline-sodic soils)(Brady, 2002). Within each soil classification a range of physical and chemical characteristics can be observed (Table 2.1)

Table 2.1 Classification of salt-affected soils

Soil Quality Parameter	Electrical Conductivity (dS/m)	Soil pH	Sodium Absorption Ratio	Soil Physical Condition
Saline	>4.0	<8.5	<13	Normal
Saline-Sodic	>4.0	<8.5	>13	Normal
Sodic	<4.0	>8.5	>13	Poor

Adapted from Brady, 2002

2.3 Reclamation of Salt-affected Soils

2.3.1 Reclamation of saline soils

The first step in managing the salt-affected soils is to identify its causes or sources once the salt problem is suspected. Soil and water samples should be collected on an annual basis and analyze for EC, ESP, SAR and pH. Other parameters such as percent of organic matter, clay content and presence of lime may be useful (Schafer, 1982), identifying the cause or source of the salt problem can be somewhat difficult especially when multiple factors are involved, therefore it is useful to gather and observe as much information about the affected

area as possible. Information should include historical and recent land use, local geology, and location of problem with respect to the surrounding land slope (An McCauley, 2005).

For saline Soils with high salt level to significantly damage the plant and retard growth rate, reclamation with excess water is recommended provided there is enough good quality water available and adequate drainage. Water can be applied via sprinkling or flooding and is more effective when the soil moisture content is unsaturated than saturated to allow drainage rather than potential runoff (Balba, 1995). To maintain unsaturated conditions and ensure salts are being leached through the profile, water should be applied in a series of applications and allow to drain after each application. Thus sprinkling or intermittent ponding is usually more effective than continuous ponding becausethe quality of water needed depends upon initial and desired salt levels, application method and soil texture (Lamond and Whitney, 1992)

2.3.2 Reclamation of sodic and saline-sodic soils

Reclaiming Sodic and Saline-Sodic Soils requires a different approach than Saline Soils and can be considerably more expensive. Prior to leaching, excess sodium Na^+ needs to be replaced from the exchange site by stronger cat ion namely Calcium (Ca^{2+}) or Magnesium (Mg^{2+}). This is achieved by adding an amendment that either directly or indirectly releases exchangeable Ca^{2+} or Mg^{2+} (An McCauley, 2005). This is because Ca^{2+} and Mg^{2+} have stronger charge than $Na^+$and will be replaced from exchange sites, causing Na^+ to be released to the soil solution and susceptible to removal by leaching water.

Amendments normally used to correct sodicity include gypsum, ($CaSO_4.2H_2O$), Lime ($CaCO_3$), Calcium Chloride ($CaCl_2$), Magnesium Chloride ($MgCl_2$), and organic amendments (Wienhold and Trooies, 1995). The most common and economical amendment used in sodic soils is gypsum, which can be applied dry or with irrigation

water. Gypsum is slow reacting will react in the soil for long period of time, adding gypsum or lime to a soil that already has gypsum and/or lime present will not increase Ca^{2+} solubility, an outcome that could potentially limit their effectiveness as amendments (Wiehold and Trooien, 1995).

An effective soil amendment is achieved by applying adequate amount of water to leach the sodium ions that are pushed off exchange site by calcium ions. In sodic soils, leaching and drainage could be slow due to poor structure and limited water movement associated with sodic soils. For soils with low EC, application of saline water may be appropriate at the initial stage of reclamation to provide additional Ca^{2+} to promote flocculation and thus increase permeability (Troeh et al., 1990). Tillage may help break up surface crusts and increase infiltration in the soil. Therefore, management of salt-affected soils requires a combination of agronomic practice and socioeconomic considerations-for instance, reclamation of saline soils may begin with the provision of effective drainage and good quality of irrigation water to lower the level of soluble salts, whereas for saline-sodic and sodic conditions, soils can be reclaimed by adding gypsum ($CaSO_4.2H_2O$), followed by leaching water to remove excess sodium. Moreover, where the land is severely salt-affected, it may be more economical to take it out of production and address the salinity and sodicity impacts on the lands.

Table 2.2 Tolerance of some crops to saline conditions

Sensitive (0-4dS/m)	Moderate Tolerant (4-6dS/m)	Tolerant (6-8dS/m)	Highly Tolerant (8-12dS/m)
Almond	Corn	Fig	Barley
Beans	Tomato*	Oats	Cotton
Clover	Grain Sorghum	Pomegranate	Olive
Onion	Lettuce	Sunflower	Rye
Potato	Soybean	Wheat	Wheatgrass

Adapted from Brady, 2002 * Crop under consideration

2.3.3 Classification of salt-affected soils

Both EC_e and SAR are commonly used to classify salt-affected soils (Table 2.3). Saline soils resulting from salinity hazard normally have pH value below 8.5, and are relatively low in sodium and contain principally sodium, calcium and magnesium chlorides and sulfates. These compounds cause the white crust which forms on the surface and the salt streaks along the furrows. The compounds that cause salinity of soils is very soluble in water therefore leaching are usually quite effective in reclaiming these soils.

Sodic soils resulting from sodium hazard generally have pH value between 8.5 and 10. These soils are "black alkali soils" due to their darkened appearance and smooth, slick looking areas caused by the dispersed condition (Plate 2). In sodic soils, sodium has destroyed the permanent structure which tends to make the soils impervious to water. Thus, leaching alone will not be effective unless the high salt dilution method or amendments are used.

Table 2.3 Permissible limits for classes of irrigation water.

Water Sample	Concentration (Total dissolved solids)	
	Electrical conductivity (μmhos/cm)	Gravimetric in ppm
Class 1. Excellent	<250	<175
Class 2. Good	250-750	175-525
Class 3. Permissible	750-2,000	525-1,400
Class 4. Doubtful	2,000-3,000	1,400-2,100
Class 5. Unsuitable	>3,000	>2,000

Table 2.4 Sodium hazard of water based on SAR Values

SAR values	**Level of Sodium Hazard**	**Comments**
1-10	Low	Use on sodium sensitive crops such as avocados
10-18	Medium	Amendments (such as Gypsum) and leaching are needed.
18-26	High	Generally unsuitable for continue use
>26	Very High	Generally unsuitable for use.

(Adapted from James et al., 1982)

Table 2.5 Classification of salt-affected soils based EC and SAR

Criteria	Normal	Saline	Sodic	Saline-Sodic
ECe (mmhos/cm)	<4	>4	<4	>4
SAR	<13	<13	>13	>13

2.4 Quality of Surface Water for Irrigation

2.4.1Dissolved ions

The concentration and chemical composition of the dissolved constituents in water determine its quality. The water used for irrigation whether taken from well or river always contain certain amount of dissolved salts. The degree of adverse effect of salts on soil properties and crops productivity is mainly related to the chemical composition of the irrigation water (Richard, 1954).

Quality of irrigation water is important in accessing its suitability for irrigation. The degree of adverse effects on soil properties and crop productivity are mainly related to the chemical composition of the irrigation water. Irrespective of the nature of the source of irrigation water, soluble salts are always present while affect the physical properties of the soil and ultimately crop growth. The quality of irrigation water is generally determined by the following chemical composition.

- Total concentration of soluble salts (salinity)
- Concentration of sodium relative to other cat ions (sodicity)
- Concentration of carbonates and bicarbonates
- Toxic salts concentration (toxicity)

- Other factors.

The total amount of salts dissolved in irrigation water is a very good criterion for its quality as far as soil salinity development is concerned. In irrigation practice, a considerable quality of salt is usually left within the root zone depth even if the soil has good leaching effect. This is due to the processes of water up take plants and evapotranspiration. In general it has been found that the conductivity of a soil saturation extract, in the absence of salt contribution from ground water, usually ranges from 2 to 10 times of the applied water (Richards, 1954). The conductivity of irrigation water also determines the leaching requirements and sometimes the crops to be grown. For instance, a conductivity of 8mmhos/cm will reduce the yield of sugar beet by over 25% and the same value of electrical conductivity will determine the growth of strawberries, hence making its production impracticable.The concentration of sodium ions in irrigation water is not an adequate criterion for its potential hazards. An important consideration is the extent to which the ESP of a soil will increase as a result of the adsorption of sodium ions from the irrigation water. This increase depends on the square root of the soluble sodium ions to that of the square root of the average divalent cat ions in the solution. The higher the ratio the higher the sodicity hazard of the irrigation water.

2.4.2 Specific ion effects

Even under low concentrations of total dissolved salts, plants are known to suffer from soluble salts or salinity. When plants absorb salts from the soil system, either as a result of counter effects of decreased soil water potential or for cat ion nutrition, specific ion causes injury on specific physiological functions of the plant, such as the plant regulatory systems (Bernstein, 1975). In some cases specific ions can causes toxicity to plants by affecting the uptake of essential nutrients. The mechanism of the influence of excessive levels of specific

ions in plant growth is extremely complex. In the study reported here is simplified discussions on the effects of some specific ions have been given. Such ions existing in toxic concentrations include sodium, calcium, magnesium, chloride, sulphate, bicarbonate, borate and to lesser extent nitrogen and potassium (Richards, 1954).

Sodium ion Na^+:- The accumulation of sodium in soil water replaces calcium and magnesium from the exchange sites of the soil particle so that sodium is the main cat ion absorbed by plants (Table 2.4). This causes its accumulation in the plant tissues, which are mainly in the stems, and roots (Richards, 1974), which subsequently causes leaf burning. High proportions of exchangeable sodium can also cause the deficiency of calcium and magnesium which are essential elements in crop growth. Secondly, high sodium levels can also affect crop growth indirectly by dispersing soil clay particles, thereby destroying soil structure and causing poor aeration and low water availability.

Magnesium ion Mg^{2+}:- Is also an essential element in plant growth. It forms part of the chlorophyll molecule and helps in the mobilization of phosphates within the plant. Its deficiency causes a breakdown of the chlorophyll molecule, which gives brown streaks or sports on the leaves, which is accompanied with subsequent low yields in fruits or cereals.

Calcium ion Ca^{2+}:- Is an important plant mineral used in the formation of cell wall and neutralization of organic acids. Calcium deficiencies are indicated by light leaves coloration, disintegration of the growing tissues and a general weak and poor plant structure.

Potassium ion K^+:- Is a major plant nutrient that helps in photosynthesis by increasing the efficiency of leaves in assimilating carbon dioxide. It is also counter-balances the effect of excessive nitrogen by making the plant tissues firmer. Another important role of potassium is that it encourages luxury consumption by the plants nutrients without causing any

damage to the plant tissues (Thorne 1954). Other ions or chemical factors, which affect soil and water quality include: the concentration of Iron, Copper, Manganese, Zinc, Molybdenum, Sulphur and Phosphorus. These ions are no less important than the ones discussed above.

2.4.3 pH of irrigation water

The pH of a solution is the measure of its acidity expressed as the negative of the logarithm to base ten of the hydrogen ion concentration in the solution. Although most plants can tolerate a wide range of pH 6 to 8, it still exerts a considerable influence on nutrient availability, and hence the crop production. If the pH is less than 6 the availability of potassium, calcium, magnesium and phosphorus is greatly reduced while a pH value greater than 8, will reduce the availability of nitrogen and most micro-nutrients. The pH of a soil solution is also indicative of its alkalinity status. According to Shanonoet. al, (2012), pH values of 8.5 or more almost invariably indicate an ESP value of 15%, which is enough to cause dispersion of clay particles in most soils. The pH of irrigation water is not an accepted criterion for its quality because it tends to be buffered by the soil (Sheinberg, 1978).

2.4.4 Classification of irrigation water

The classification of irrigation water is not general because of the combined effects of other factors such as crop management practices, soil conditions and crop type upon its final effect on crop productivity. A classification developed by the United States Salinity Laboratory, which attempts to incorporate effect of these factors has been adopted for the purpose of this study. This system classifies waters according to the different factors that comprise its quality. The system as given by Richards (1954) is divided in to four parts:

Table 2.6 presents Salinity, Sodicity, Carbonates and Boron classification of irrigation water as well as its suitability for use.

Table 2.6 Standards for Irrigation Water

Class of water	TDS (mg/l)	EC (μS/cm)	ESP	Sulphates (mg/l)	Chloride (mg/l)	Boron (mg/l)	Suitability for Irrigation
1	0 - 700	0 – 1000	0 – 60	0 -192	0 – 142	0 – 0.5	Excellent
2	700-2000	1000-3000	60-75	192 – 480	142 – 355	0.5 – 2	Good to poor
3	> 2000	> 3000	>75	>480	>355	>2	Unfit

Source: FAO (1994)

2.4.5Limitations of water quality classification

The limited application of the above classifications is quite apparentbecause of the fact that crop growth is not only influenced by the chemical characteristics of the irrigation water, soil type and crop species above, but also by other factors such as the actual salt distribution in the root zone, management practices, depth of water table, soil fertilizer status and climatic conditions due to the interaction of these factors some waters which are classified to the unfit for irrigation have shown good crop growth and the good waters have resulted in poor yield (Smith et al., 2000).

2.4.6Soil and water quality effects on crop production

The productivity of a soil involves so many factors such as soil physical properties, soil management areal climatology, and the soil chemical properties. However, the discussion on the effect of the soil and water quality effects on crop production is limited to the chemical effects only.The effect of salinity upon crop growth is generally believed to be

osmotic in nature. (Bernstein and Hayward, 1958) as reported by Sheinberg (1978) it was found that when crops are grown in an iso-osmotic solution of various salts with different compositions of these salts, the crops have similar reductions in growth. This led to the conclusion that the effect of salinity is colligative, and depends only on the total mass of salts present. Salinity causes a reduction in water uptake in plants and decreases the gaseous exchange rate.

The rate of water entry into plants depends on both the water potential gradient and the root resistance. Under normal circumstances a mechanism known as the Bernstein adjustment takes place as the soil water potential is decreased, either as a result of salinity or reduction in soil moisture.

2.5 Gypsum ($CaSO_4.2H_2O$) as an Amendment toSodicor Sline-sodicSoils

Amendment of sodic soil is achieved by replacing the excess sodium (Na^+) from the exchange site with another cat-ioni.e. Ca^{2+} or Mg^{2+} and then leach. The recommended rate of gypsum is 1 to 2 tons per acre for every one to two years depending on the soil type (Jane, 20011). Gypsum takes two years' worth of application or more before the full benefit is realised, therefore growers are encouraged to leave untreated control checks in their field so they can see for themselves whether gypsum makes a difference.According to Chamberlain - founder of GYPSOIL, farmers have at least six reasons to apply gypsum to their fields (Jane, 2011) as follows;

i. Gypsum unlocks fertility. A balance biological system helps soil breakdown plant residue into available nutrients in the root zone.

ii. It helps in field's sponge water so that even tight clay soils more readily absorb water and more it move it down through the soil profile rather than having water pond or runoff.

iii. Soil organisms including earthworms benefit from applying calcium sulphate dehydrate (a by-product of the process that cleans the air from coal-burning power utilities by removing sulphur dioxide from the flue gases).

iv. Fields will work easier, and dry out quicker in the spring and between rains for a quicker start in the spring and after a rain event. Gypsum is especially helpful in no-till situations, where growers reported that they do no longer have to use in-line rippers to avoid compaction.

v. Gypsum improves plant vigour.

vi. Gypsum is easy to apply and can be broadcast with a lime or litter spreader available in the field.

2.6 Estimation of Crop Water Requirement

2.6.1CROPWAT 8.0 software

CROPWAT is a decisive support tool developed by the land and water development division of FAO. CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. There are several of programs dealing with computations of crop water requirements, mainly based on a reference evapotranspiration. These programs are either simply to estimate crop water requirement (ETREF, CRIWAR, and CRWTABLE) or embedded in scheduling programs (CROPWAT, IRSIS). These programs also formed the basis for

various irrigation scheduling programs which are in use in various countries. FAO's CROPWAT has the advantage of a wide dissemination and the latest CROPWAT version employs Penman-Monetith approach. It is extensively tested, widely accepted and also recommended by expert consultation in Rome (Lenselink et al., 1993). CROPWAT for windows is a computer program that uses the FAO (1992) Penman- Monteith method used to calculate reference evapotranspiration (ETo), crop water requirements and irrigation scheduling calculations. The model calculates percentage of reduction in crop yield due to water stress in the cropping period. The program algorithm allows for the development of irrigation schedules for different management conditions and calculation of water supply for varying cropping patterns (Shrestha, 2007). In addition, the program allows the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rain fed and irrigated conditions (FAO, 2013a).

2.6.2 Reference crop evapotranspiration (ET_O)

The reference crop evapotranspiration (ETo) was obtained from a hypothetical grass reference surface with specific characteristics of uniform height, actively growing and completely shading the ground. The grass reference crop was assumed with a crop height of 0.12 m, a fixed surface resistance of 70 s/m and albedo of 0.23 (Doorenbos and Pruitt, 1984; Allen et al., 1998). Also; The Reference Evapotranspiration (ETo) represents the potential evaporation of a well-watered grass crop. Although several methods exist to determine ETo, the Penman-Monteith Method has been recommended as an appropriate combination method to determine ETo from climatic data: minimum and maximum temperature, humidity, sunshine, and wind speed (FAO, 2013d).

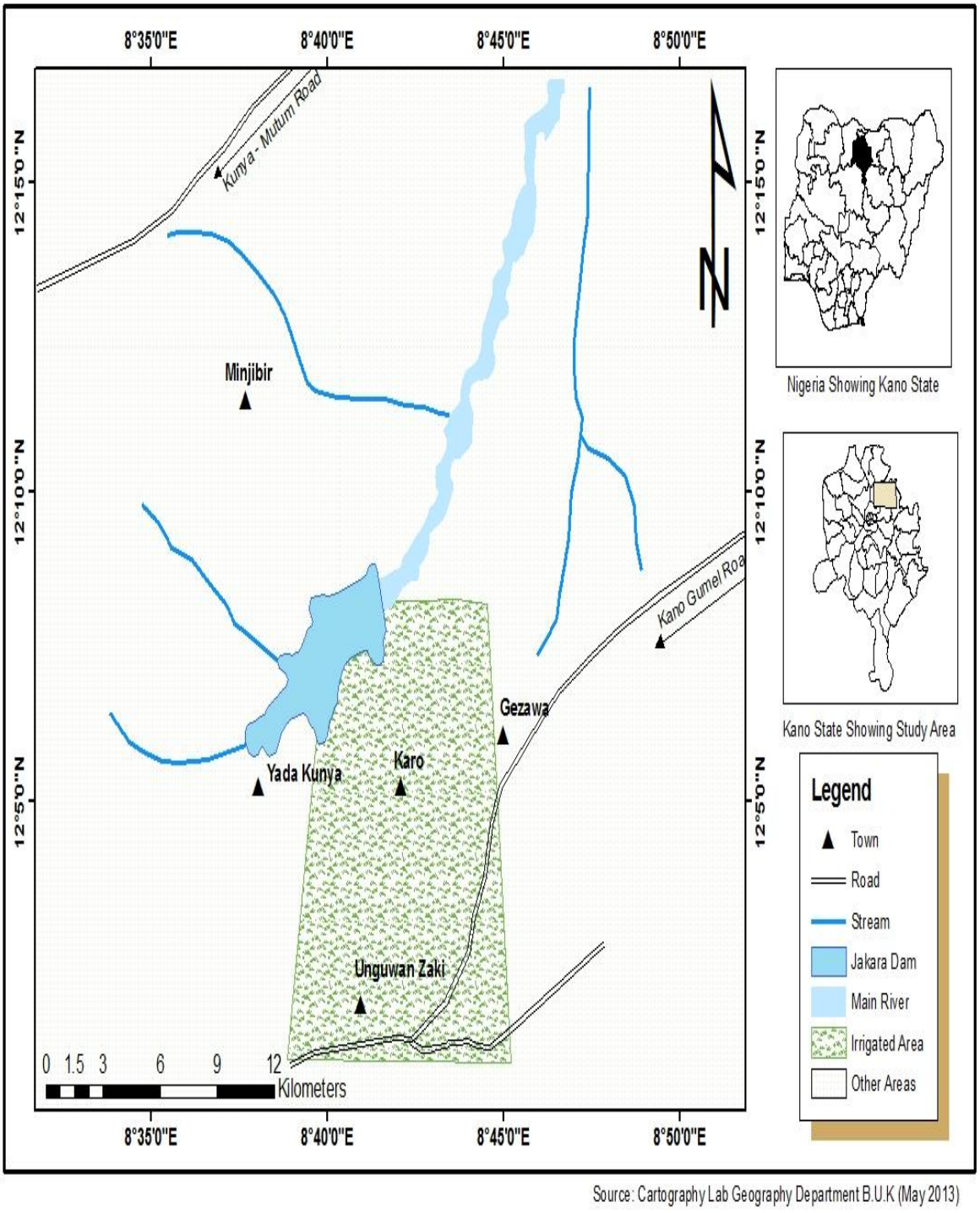
CHAPTER THREE

MATERIALS AND METHOD

3.1 Location and Description of Study Area

The study area is located at Barwa-Minjibir at Jakara irrigation project within the Kano plain (Fig.1).The irrigation scheme lies between $8^0$30”E to $8^0$52”E and $12^0$5”N to $12^0$20”N at 414 m above mean sea level covering an area of about 1,200 hectares. The soil parent materials are derived from colluvial, alluvial and/or aerolian deposits over Basement Complex (Lawes, 1962). The climate of study area is typical Sudan savannah ecological zone which divided into three distinct periods. These were; cold and dry harmattan (October to February), the hot season (March – May) and warm rainy season (June – September) Omotowuju, (1992). The mean annual rainfall is about 818 mm irregularly distributed within the rainy period of about 120 days (Kowal and Knabe, 1991). Potential evapotranspiration exceeds rainfall for greater part of the year. The mean daily temperature is 29^{o}C. The climate of the study area is gradually becoming drier (Malqwi, 2001) which favours salinization and/or sodification processes(Plate 1).

The irrigation water comes from Jakara dam through a 2.2 km canal by gravity flow to the farms. The irrigation season normally starts from November to March the main irrigation crops were pepper, Tomato, Onion, wheat, and Maize but nowadays, only moderate to highly tolerant crops are grown due to high level of salinity/sodicity for both soil and irrigation water.



(Fig 3.1)Jakara Dam andBarwa-Minjibir irrigation scheme

3.2 Selection of Field Site

Reconnaissance survey was conducted to identify locations of salt affected soils and detail study on the soil type, texture and colour were also carried out. Salt fluorescence, surface colour, hardness of soil, surface crust and report from farmers were used to assess the salt-affected soils as shown in plate 2. Featuressuch as symmetry condition of the irrigation water supply sources were examined. The plot found to be largely affected by sodium salts was selected purposely for the experiment. Some other parameters were observed such as type of irrigation practice, irrigation scheduling as practiced by the local farmers, water supply method and type of canal used for the experiment.



Plate 1: Experimental Plot at Minjibir Irrigation Scheme



Plate 2: Untreated experimental plot (all the plant perished)



Plate 3 Treated and untreated experimental plots



Plate 4: Irrigation water application through PVC Pipe



Plate 5: Some tomato yields obtained from a plot treated with gypsum

3.3 Experimental Set-up

3.3.1Experimental design and layout

.The experiment consisted of twofactors namely; Amount of gypsum (amendment) application (G_A) and leaching requirement (LR). There were four levels of gypsum; $0g/m^2$, $200g/m^2$, $300g/m^2$ and $400g/m^2$, and three level of leaching requirements; 100% LR, 150% LR and 200% LR respectively.The frequency (irrigation interval) for the experiment was seven days (7) as adopted by most farmers in the irrigation scheme. There were thirty six basins (2m x 2m) separated by 0.5m. The treatments were laid in Randomized Complete Block Design (RCBD) and the data generated analysed using statistical analysis of variance (ANOVA). Details of experimental treatments were presented in Appendix A. The control was set based on the local farmers practice (no gypsum application and no leaching requirement). (Appendix C).

3.4 Data Collection

Nine samplesof irrigation water were collected using plastic bottles from three different points (three samples each) along the conveyance system in the irrigation scheme; source (dam), main canal (MC) and field canal (FC) respectively. The plastic bottles used were washed with detergent and rinsed 3 times with distilled water and then with the sample water. The collected samples were properly labelled and taken to Agricultural Science Laboratory, Bayero University, Kanofor chemical analysis. The samples collection was repeated in three months (January 2014, February 2014 and March 2014) and the analysis was conducted over three times for each selected point. Also soil samples were collected from each experimental plot using core sampler of 5.25cm diameter with 5cm depth. The core sampler was pressed into undisturbed soil in the experimental plot and pulled out after

completely filled up with soil sample and taken to laboratory in the department of Agricultural Engineering, Bayero University, Kano for bulk density determination and soil particles size analysis.

3.5 Measurement of Irrigation Requirement (IR)

3.5.1 Determination of reference evapotranspiration (ET_o)

Reference evapotranspiration (ETo) was computed using the FAO-Penman-Monteith method incorporated in CROPWAT model. The weather data for the calculation of ETowere obtained from following sources;Geography Department Bayero University Kano, National Horticultural Research InstituteBagauda, Irrigation Research Station at Institute for Agricultural Research, Ahmadu Bello University, Zaria and Nigeria Meteorological station (NIMET) situated in Aminu Kano International Airport, Kano. Daily maximum and minimum temperatures, relative humidity, wind speed, sunshine hours and rainfall data were also collated from IITA.

Penman Montieth explicit equation incorporated in the CROPWAT model (Eq. 3.1)was used in estimating EToas adopted fromEgharevba (2009).

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_q)}{\Delta + \gamma(1 + 0.34U_2)} \quad (3.1)$$

Where;ET_o= Reference evapotranspiration (mm/day);

R_n= Net radiation at the crop surface (MJ/m^2/day);

G= Soil heat flux density (MJ/m^2/day);

T= Average temperature at 2m height (^oC);

U_2= Wind speed measured at 2m height (kPa);

Δ= Slope vapour pressure curve (kPa/^oC),

γ=psychometric constant (kPa/^{o}C),

900= coefficient for the reference crop (KJ^{-1} Kg K/day);

$(e_s - e_a)$= Vapour pressure deficit for measurements at 2m height (kPa);

0.34=wind coefficient for the reference crop and

0.408=value for λ^{-1} (reciprocal of the latent heat flux required to vaporize one unit of water).

3.5.2Actual crop evapotranspiration (ET_C)

The actual crop evapotranspiration (ETc) wasdetermined under proper management and environmental conditions when cultivating crops in fields, the real crop evapotranspiration may deviate from standard conditions due to non-optimal conditions such as the presence of pests and diseases, soil salinity, low soil fertility, water shortage or water logging. This may result in scanty plant growth, low plant density and may reduce the evapotranspiration rate below crop water requirement (Allen et al., 1998). The ETcwas calculated by using a water stress coefficient Ks and/or by adjusting Kc for all kinds of other stresses and environmental constraints on crop evapotranspiration (Allen et al., 1998; Karanja, 2006).

Water stress in the plant was quantified by the rate of actual evapotranspiration (ETc) in relation to the rate of crop evapotranspiration under standard condition. To evaluate the effect of plant water stress on yield information on actual yield (Y_a) in relation to maximum yield (Y_m) is required. In addition, it is necessary to derive the relationship between relative yield decrease and relative evapotranspiration deficit given by the empirically-derived yield response factorK_y, to quantify the effect of water stress on crop yield (Doorenbos and Kassam, 1986). The yield response factor (K_y) is a factor that describes the reduction in relative yield according to the reduction in ETc caused by soil water shortage. These values

are crop specific and may vary over the growing season (Allen et al., 1998). The crop water use between successive moisture measurements can be estimated using the soil moisture depletion method (Igbadun and Oiganji, 2012), with the expression given in (Eq. 3.2).

$$CWU = \frac{\sum_{i-1}^{n} \left(MC_{1i} - MC_{2i} \right) \times A_{si} \times D_i}{t} \qquad (3.2)$$

Where, CWU = Average daily crop consumptive use between successive soil moisture content sampling periods (mm/day);

MC_{1i}= Soil moisture content (g/g) at the time of first sampling (2 days after irrigation) in the i^{th} soil layer;

MC_{2i}= Soil moisture content (g/g) at the time of second sampling (just before irrigation) in the i^{th} layer;

A_{si} =Bulk density (g/cm^3) of the i^{th} layer;

D_i=Thickness of i^{th} layer (mm);

N = Number of soil layers sampled in the root zone depth D, and

T =Number of days between successive soil moisture content sampling.

3.5.3 Crop coefficients (K_c)

Crop coefficientKs is a property of plant used for predicting evapotranspiration (ET). The crop coefficientis simply determined by taking the ratio ofobserved ET for the crop under studyto that observed for the well calibrated reference crop under the same conditions (Allen et al., 1998; Stannard et al., 2013). AccordingIgbadun and Oiganji (2012), equations3.4 and 3.5 could be used to determine the crop coefficient (Kc).

PET = Kc x RET (mm/day) (3.3)

Where, PET = Potential Evapotranspiration

RET is the reference ET often denoted as ET_o

The Kc (Crop coefficient also known as crop evaporation rate) can be estimated

$$Kc = \frac{CWU}{ET_o} \tag{3.4}$$

$$Kc_{deficit} = \frac{CWU_{deficit}}{ET_o} \tag{3.5}$$

Where; K_c =Crop coefficient

ET_o =Reference Evapotranspiration

3.6 Irrigation Amount/Depth and Time of Application

Irrigation depth is a function of the water retentive capacity of the root zone soil and the extent of soil water depletion at time of irrigation. It refers to the depth to which the applied water would cover an area. The discharge *q*of the irrigation water was applied through the use PVC pipeand computed using (Eq. 3.6) by placing a graduated gauge at the inlet to measure the head *h*of flowing water into the pipe. Also the time of application was calculated (Eq. 3.10)

$$q = aC_d\sqrt{2gh} \tag{3.6}$$

Where; *q*=discharge from the siphon tube, m^3/s

a = cross-sectional area of the siphon tube, m^2

C_d = is coefficient of discharge for the siphon

g = acceleration due to gravity, m/s^2

h = elevation difference between the water surface and point of application

The value of C_d was therefore determined by plotting *q* against *h* using (Eq. 3.7) as detailed in Appendix B.

$$C_d = \frac{S}{a\sqrt{2g}} \qquad (3.7)$$

Where; a = cross-sectional are of PVC pipe (m^2)

g = acceleration due to gravity (m/s^2)

S = Slope of the curve

And, V = A x IR (3.8)

Where; V = Volume of water applied (m^3)

A= area of plot = 2m x m =$4m^2$

IR = Irrigation Requirement (summation of crop water requirement and leaching requirement (mm))

Also, Volume $= Q \times t$ (m^3) (3.9)

$$\therefore t = \frac{V}{Q} \qquad (3.10)$$

Where; t= time (duration for irrigation)

Q = discharge through PVC pipe in to the plot

3.7 Application of Gypsum($CaSO4.\ 2H_2O$)

Gypsum is a fine powder damp to the touch, similar to slightly damp flour giving it a tendency to bridge and nearly white in colour, normally applied after land clearing prior to planting. Gypsum could be applied any time in a field without damaging the soil or crop

(Jane, 2011). Other producers prefer to incorporate it with their fall or spring water. Applying gypsum is not difficult but new for many farmers or producers.

For the purpose of this experiment gypsum was applied in power form after the designed quantity was measured in the laboratory. The gypsum was evenly spread in the experimental unit using robber mounted with nozzle of 0.5mm diameter to ensure the particles are equally broadcasted.

3.8 Determination of Leaching Requirement (LR)

After amendment (gypsum) was applied the next essential task issupply of leaching water. This is the amount of water added in excess of crop water requirement for the purpose of remove the salt from the crop root zone and was determine using (Eq. 3.11).

$$\text{LR} = \frac{EC_w}{EC_e - EC_w} * I_c \qquad (3.11)$$

Where:

LF = fraction of applied water that must be leached through the root zone

EC_w= electrical conductivity of the irrigation water

EC_e= electrical conductivity of the saturation extract

I_c = Crop water requirement

3.9 Determination ofSodicity Level of Irrigation Water

3.9.1 Determination of sodium adsorption ratio (SAR)

Three samplesof irrigation waterwere collected in a container at each of three different locations in the irrigation scheme: source (dam), main canal and field ditch respectively for

chemical analysis in the laboratory at Agric Science Laboratory, Bayero University, Kano. The sodium adsorption ratio (SAR) was determined using (Eq. 3.12). This was achieved by taking the ratio of sodium ion concentration to the square root of the average concentration of magnesium and calcium ions in the irrigation water (Sheinberg and Oster, 1978).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (3.12)$$

3.9.2Determination of exchangeable sodium percentage (ESP)

Exchangeable sodium percentage is another important parameter used to determine the sodicity status of a soil and has a threshold of 15% (Brandy, 2002). Any soil with ESP greater than 15% is classified as sodic and will adversely affect is productivity especially for most sensitive crops. But soil in Minjibir irrigation scheme has ESP value of 60.3% and that was the reason most crops could not be grown in the scheme expect the highly tolerant crops to sodicity or else reclamation become necessary. The exchangeablesodium percentage of the soil was determined by taking the ration of sodium ions to the total ions exchangeable capacity (Eq.3.13).

$$\text{ESP} = \frac{Na^{+}}{Na^{+} + Ca^{2+} + Mg^{2+} + K^{+}}\ x\ 100\% \quad (3.13)$$

3.9.3 Determination of EC, and pH of the irrigation water

The materials used for EC measurement were conductivity meter (4071), electrodes, beaker, funnel and tissue paper. The reagents were potassium chloride and distilled water. The detailed procedure was reported by Aphaet. al, 1995.

Similarly, pH of the irrigation water was determinedusing pH meter (M200), wash bottle, funnel, flasks, beaker and tissue paper. The reagents used were buffer solutions of pH 4, 7 and 9, potassium chloride and distilled water. Also the detailed procedure of determining irrigation water pH was stated in Aphaet. al, 1995.

3.9.4 Determination of Sodium and potassium

Flame photometer model 400 was used for determination of sodium and potassium, care was taken due to flammable nature of the gas. The apparatus used include; flame photometer, volumetric flask and pipette. The reagents used were standard solution of 2ppm, 4ppm 8ppm and 10ppm of sodium and potassium distilled water.

3.9.5 Determination of magnesium and calcium

The complex-metric titration was used for the determination of calcium and magnesium. The test procedure is based on standard method for the extermination of waste water in Aphaet. al, 1995.

3.9.6Soil bulk density

The soil bulk density was determined by taking the ratio of dry soil sample weight to the total volume of core sampler (Eq. 3.14).

$$\text{Bulk density} = \frac{W_d}{V} \qquad (3.14)$$

Where; W_d = Weight of dry soil sample (g)

V = Volume of core sampler (cm^3)

3.10 Agronomic Practice

3.10.1 Land preparation

The entire site was harrowed to a depth of 40cm. Beds were prepared and plots were marked out according to the design

3.10.2Planting

The nursery sage for the tomato seedlings was carried out at IITA (Minjibir Station) where seeds of tomato variety UC82B were planted and the seedlings were raised for about four weeks. Three days before transplanting, the experimental site was prepared by harrowing up to ensure proper and conducive environment for transplanting and easy germination. A compound fertilizer NPK (15:15:15) was applied as basal application at the rate of 150kg/ha and Urea was applied thereafter when plants started flouring at the rate of 200kg/ha

3.10.3 Crop protection and harvesting

Weeds control was carried out manually using hoe and hand picking were necessary. Fertilizer (CAN 26% Nitrogen) was applied at the rate of 65kg/ha as top dressing just after second weeding. Insecticide (mixture of Vetox and Cymbush) was sprayed on the field by mixing 20g in 8 litres of water and at rate of 250g/ha using knapsack sprayer.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil and Irrigation Water Qualities Determinates

4.1.1 SAR and ESP

Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) contents in the irrigation water were analysed in the laboratory. The Sodium adsorption ratio (SAR) of the irrigation water was found to be 26.01 as per December, 2013 and increased to 38.1 in February, 2014 while a slight drop of 0.44 was observed in March, 2014. This was due to the fact that there was unusual rainfall event that occurred in Kano state in third week of February, 2014 that might have reduced the concentration of soluble substance in the irrigation water and consequently increased the potential of crop production as shown in (Fig 4.1). The exchangeable sodium percentage (ESP) of the irrigation water was 54.66% in December, 2013 which is by far greater the threshold value (15%) of ESP for good irrigation water (Brandy, 2002). However, the highest value of ESP was recorded as 60.3% in March, 2014 (Appendix I). Fig 4.2 shows ESP of the irrigation water variation from Dec,2013 to March, 2014.

The results for soil sample test also showed that the soil at Minjibir is sandy with bulk density of 1.4g/$m^2$and the soil electrical conductivity (EC) was 5.82dS/m.This value of EC

indicated that there are high dissolved chemicals that could lead to particles dispersal and poor structure of the soil as seen in plate 2.

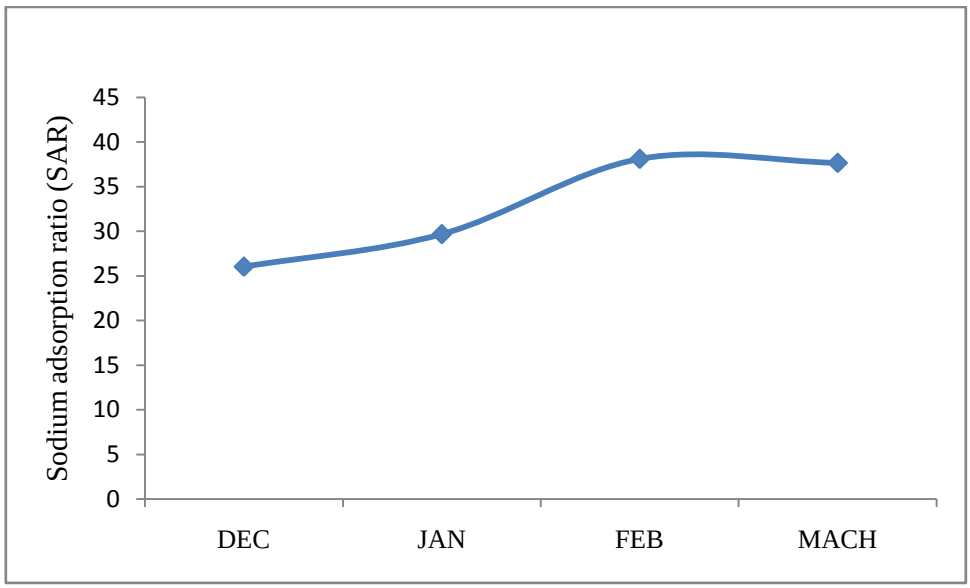


Fig. 4.1 Sodium Adsorption Ratio (SAR)

The Sodium adsorption ratio was 26.01 during December, 2013 and gradually increased to 29.66, 38.1 and 37.65 in January, February, and March, 2014 respectively (Fig. 4.1).

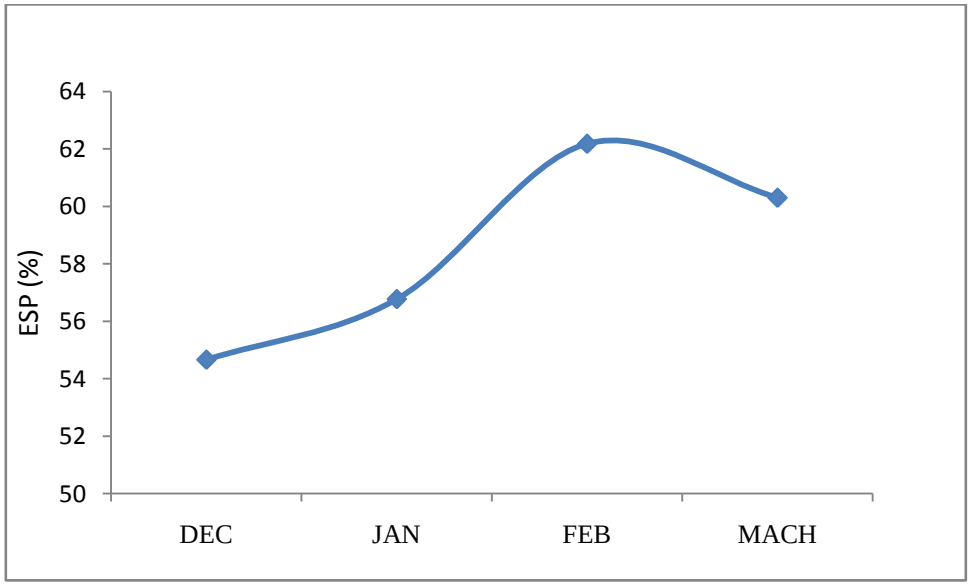


Fig. 4.2Exchangeable Sodium Percentage ESP (%)

4.1.2 EC and pH

The Electrical conductivity (EC) for irrigation water was analysed and found to be 1.4dS/m during first week of December, 2013. The maximum value of EC (1.48dS/m) was recorded in Feb., 2014 which is greater than the recommended value for irrigation water as per FAO standard (Fig. 4.3), it also increased tremendously from previous work conducted in 2001/2002 irrigation season where the soil EC was 0.65dS/m (Malqwi, et al. 2002). This large increment of water quality determinantswere as a result of continues flow of sewage water from Kano metropolitan and accumulated over time in the dam thereby raises the level of salt which renders the water unfit for both domestic and drinking purposes.

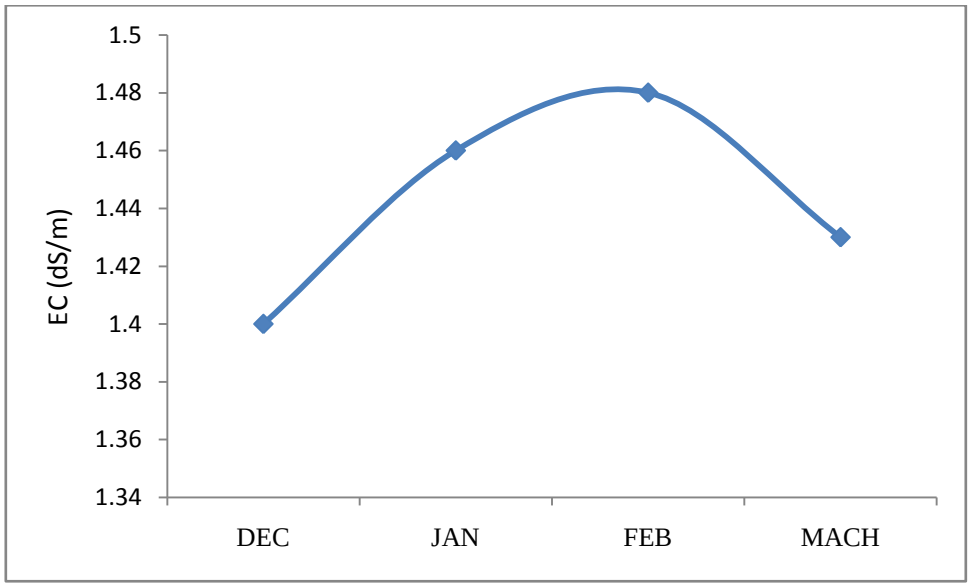


Fig. 4.3Electrical Conductivity (EC) of the irrigation water

The alkalinity (pH) of Minjibir irrigation water was found to be fluctuating from December, 2013 to March, 2014. Irrigation water pH was 7.2, 7.4, 7.26 and 7.06 in December, 2013, January, February, and March, 2014 respectively (Fig. 4.4). The pH value was 7.06 (lowest) during March which shows that the irrigation water is becoming neutral and eventually acidic when the season last longer until the beginning of rainy season.

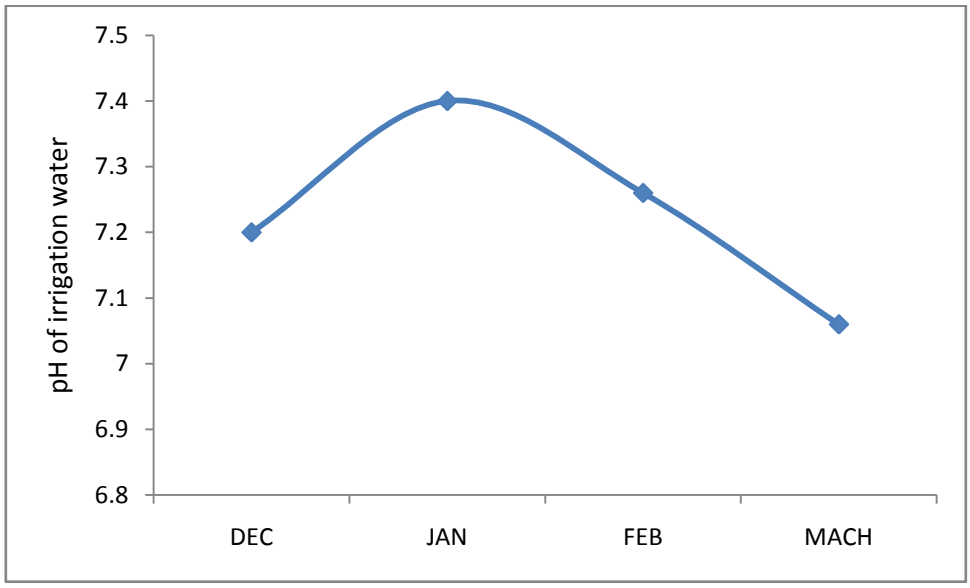


Fig 4.4 pH of the irrigation water

4.1.3Irrigation water quality changes in 12 years period

Minjibir irrigation water was assessed in 2001/2002 by soil scientist and determined the level of dissolved chemicals and the same parameters were also assessed in this work and the results obtained for ESP, SAR, EC and pH were 56.92%, 13.0, 0.65dS/m and 6.75 respectively. This work conducted about 12 years ago shows remarkable differences in all analysed parameters. The Minjibir irrigation water had pH of 6.75 in 2001/2002 irrigation season whereas in 2014 the highest level of pH was 7.23. The mount of dissolved materials indicated by electrical conductivity of the irrigation water was 0.65dS/m in 2001/2002 irrigation season and now increased by 110% (Appendix II). The same trend was observed

in sodium adsorption ratio (SAR) which was gradually increased from 13.0 in 2001/2002 to as high as 25.0 in 2013/2014 dry season (Fig. 4.5).

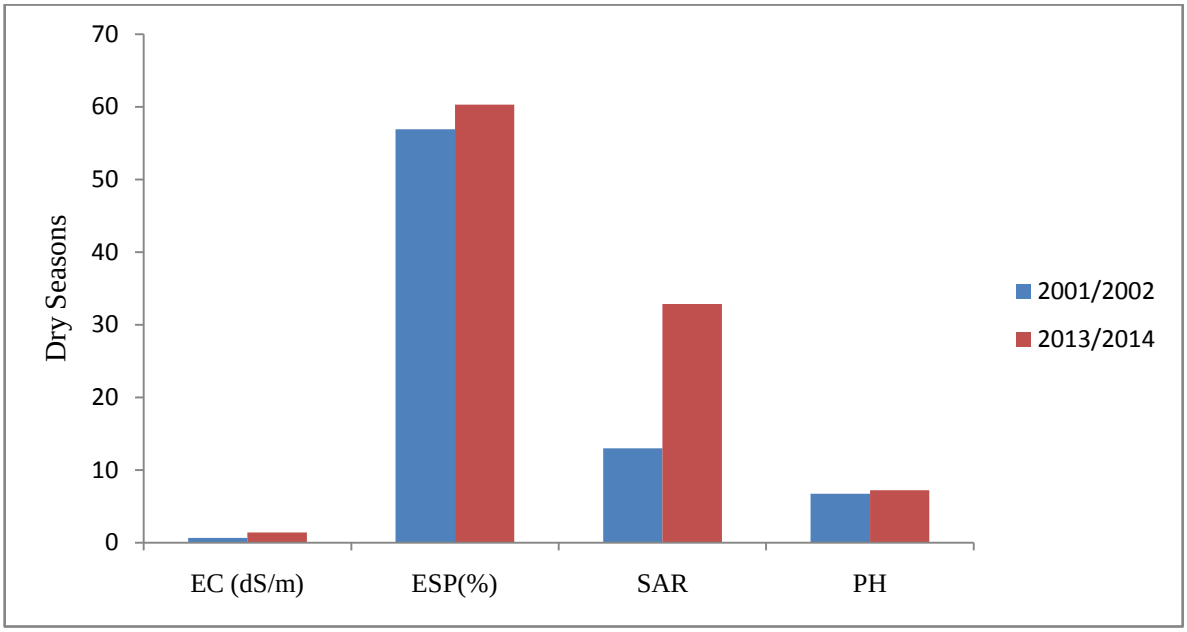


Fig.4.5 Irrigation water quality parameter in 2001/2002 and 2013/2014 dry seasons

4.2 Leaching Requirement (LR)

The leaching requirement is an amount of water applied in excess of crop ET_o for the purpose of removing the salt below the crop root zone. The electrical conductivity of irrigation water EC_w, and electrical conductivity of saturation extract EC_e were measured as 1.4dS/m and 5.82 dS/m using electrical conductivity meter respectively during 2013/2014 dry season. The leaching requirement LR was computed using (Eq. 9) as 1.49mm. Hence, the 100% LR = 1.49mm/day, 150% LR =2.24mm/day and 200% LR = 2.98mm/day.

4.3 Amount of Gypsum Applied to each Experimental Plot

The recommended rate of gypsum application depends upon the nature and type of the soil as well as the degree of salinity or/and alkalinity of a soil. For averagely light to heavier soils, the rate of gypsum application is 1 to 2 tons per acre for every two years or more (Jane, 2011). From the soil analysis, it was shown that the soil in Minjibir was slightly heavier and therefore the amount of gypsum was applied at rate of 0 g/m^2 200 g/m^2, 300g/m^2 and 400$g/m^2$and level as G0, G1, G2 and G3 for this experiment respectively.

4.4 Irrigation Water Application (ET_o and LR)

The crop water requirement was computed using CROPWAT 8.0 software as 564.3mm and leaching requirement (LR) as a factor was varied in to three levels (LR_1 = 100%LR, LR_2 = 150%LR, LR_3 = 200%LR). The highest amount of water required by the tomato was 72.1mm during late stage of April, 2014 while the least amount of 10.4mm of water was recorded from first week of January, 2014. The irrigation water applied was achieved through the use of PVC pipe with 5.0cm diameter and 45cm length. The discharge coefficient $C_d$of the PVC was determined by plotting a graph of q against square root of h which $aC_d\sqrt{2g}$becomes slope of the curve (Fig. 4.6). The value of C_d was therefore determined as 0.82 which shows that this PVC pipe could be used to apply the water to each experimental plot throughout the trials the details where shown in Appendix B. Hence, the Tomato seasonal irrigation water was computed 564.3mm using CROPWAT 8.0 and amount of leaching requirement for 100%LR, 150%LR and 200%LR were computed as 10.43mm/week, 15.68mm/week and 20.86mm/week respectively (Appendix III).

Hence, Fig. 4.7 shows the various levels of irrigation water applied to the experimental units when the treatments where imposed (after four weeks) up to the week fifteen when the harvesting was accomplished completely

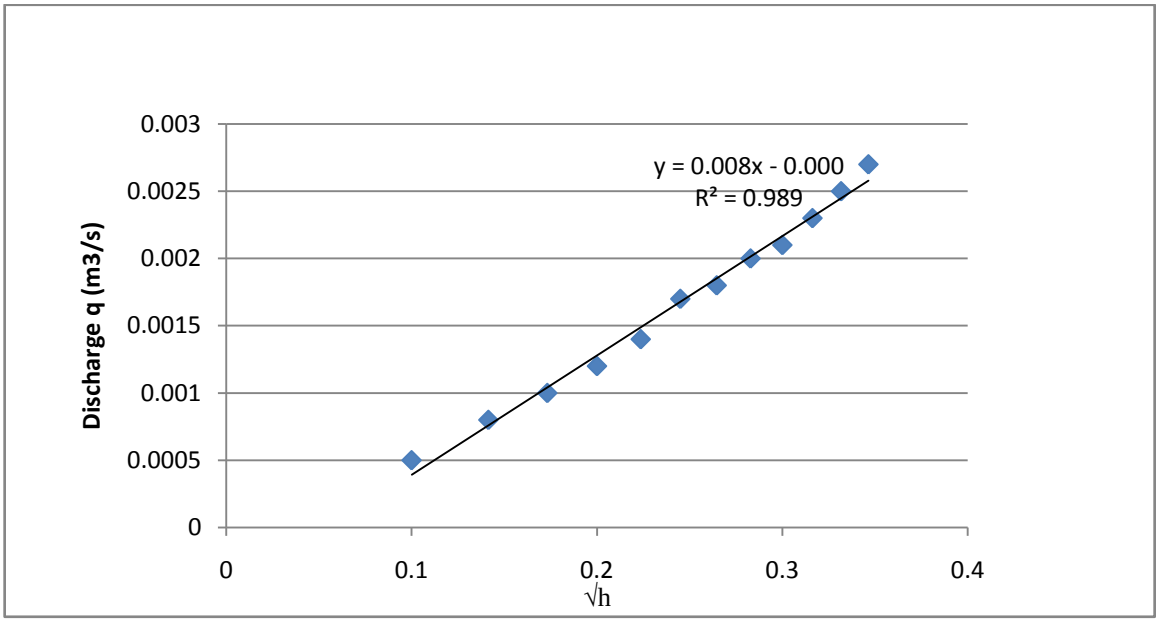


Fig 4.6 Calibration Curve of PVC Pipe

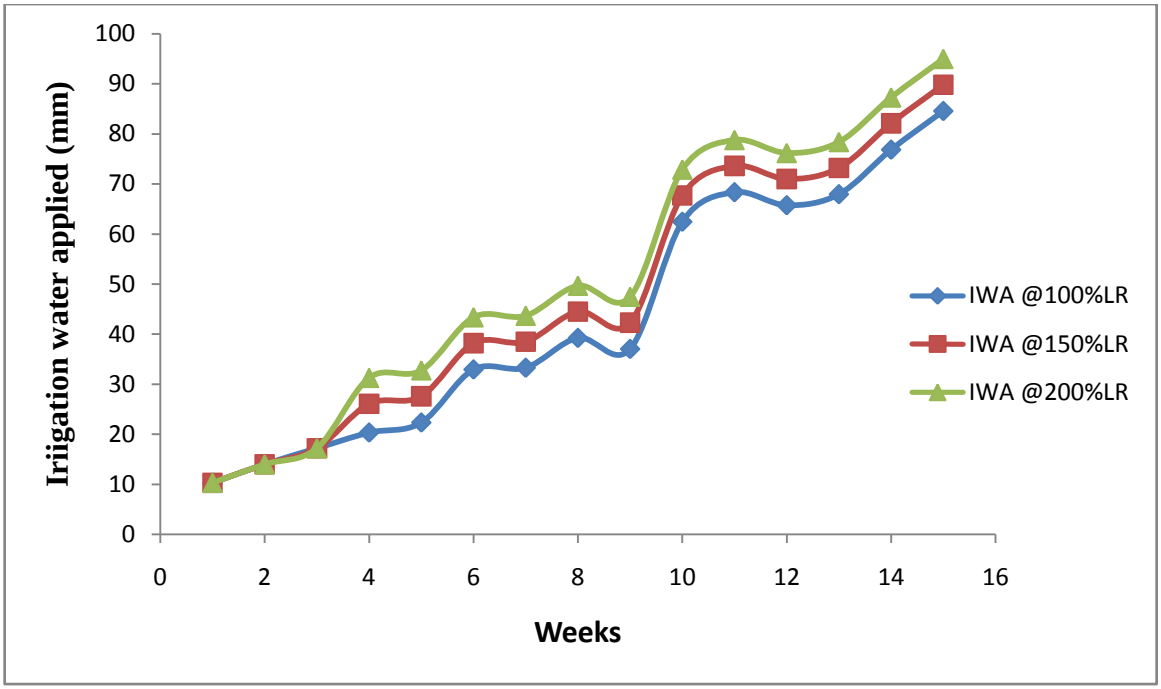


Fig 4.7 Weekly irrigation water applied at different levels of leaching requirement

4.5 Yield and Growth Parameters

4.5.1 Tomato yield in tons/ha

The total yield of tomato obtained at Minjibir irrigation farm was harvested five times on weekly basis and the result is presented in Fig. 4.8. The highest (25ton/ha) and lowest (18.75ton/ha) yields were obtained from the plot treated with 400 g/m^2 of gypsum at 100% LR and 200g/m^2 of gypsum at 150% LR respectively.Zero yieldswere obtained from untreated plots despite applying leaching requirement in accordance with experimental set up at various levels. This was because no plant (tomato) was able to withstand the current level of sodicity after two weeks of transplanting. Table 4.8 shows treated and untreated experimental plots with their corresponding yield in ton/ha. It was observed that the total yields obtained from each plot at Minjibir irrigation scheme ranged from zero yields to 25ton/ha yield. These were not found to be satisfactory when compared with 30ton/ha for the same variety under favourable conditions as reported by IAR, 1999. However, the plots treated with 400g/m^2 at 100% LR, 400g/m^2 at 150% LR and 300g/m^2 at 100% LR recorded significant amount of yields as 25 ton/ha, 24.5 ton/ha and 23 ton/ha respectively. All other plots could be described as under treated with amendment likewise for the untreated plots where no yield was obtained at all as well as the control (local farmer practice). This shows that the amount of gypsum applied for the amount of sodium to be replaced was inadequate,which affected the crop physiologic processes that led to the reduction in the yield potential. Details of tomato yield in ton/ha were presented in Appendix V.

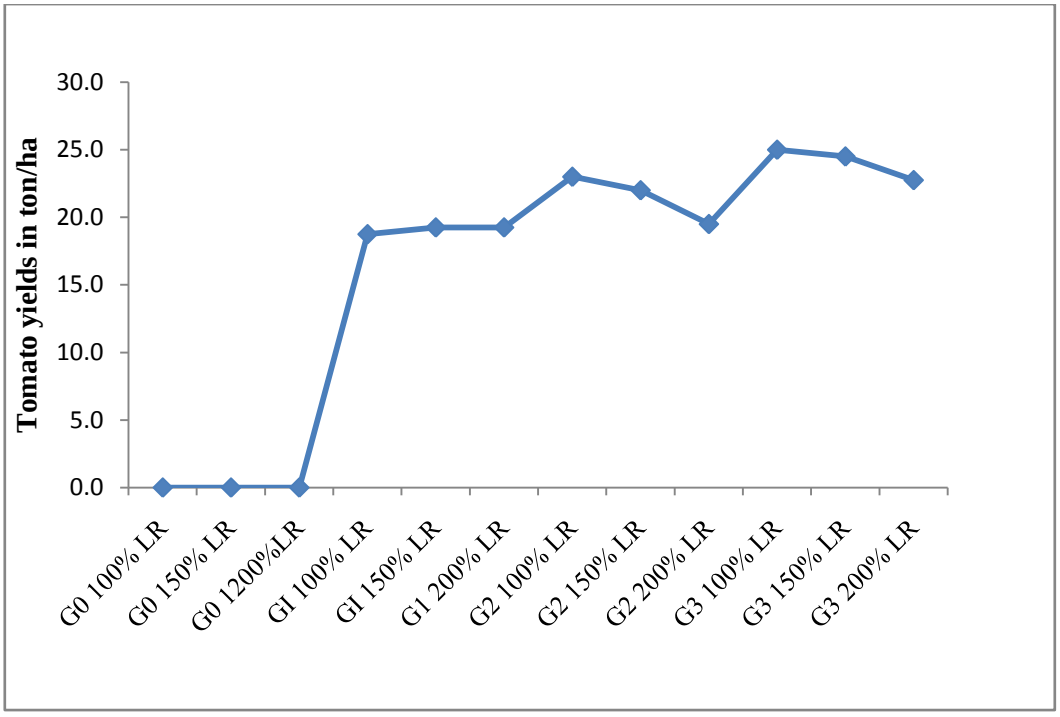


Fig 4.8Tomato yields in ton/ha

Table 4.1 shows the statistical means of tomato yields in ton/ha as affected by gypsum application and level of applied leaching requirement. The results showed that there was highly significant difference among the treatments in terms of both gypsum application and leaching requirement at 5% and 1% levels of significance. The statistically highest yield of 24.044ton/ha was obtained from plots treated with 400g/m^2 of gypsum at 100% LR while zero yields were obtained from untreated plots due to the fact that no single tomato plant was able to grow in the present saline-sodic soil condition. This showed that to produced significant amount of tomato yields at Minjibir irrigation farmland, application of amendment (gypsum) is necessary and of correct quantity followed by optimum amount of leaching requirement. The results also indicated that increasing the leaching requirements above optimum had no significant improvements on yields.

Table 4.1 Statistical means of yields and number of fruits as affected by gypsum application rate and leaching requirements.

Treatment	WT (ton/ha)	N
Gypsum (GYP)		
G3	12.044a	652222a
G2	22.356b	545278b
G1	19.067c	447222c
G0	0.000d	0.0000d
Significant	**	**
LSD @ 5%	1.712	35463
R2	0.9803	0.98766
CV	10.7159	8.8221
Leaching Requirement (LR)		
LR3	15.875a	372083b
LR2	16.033a	410833b
LR1	17.117a	450625a
Significant	NS	**
LSD @ 5%	1.4325	30712
Interaction		
G*LR	NS	NS

Means followed by the same letter (s) in a column of any treatment group are not significantly different at 5% level.
*** = highly significant difference*
** = significant difference*
NS = No significant difference
WT = Weight of tomato yield in ton/ha
N = Number of tomato fruits obtained from the experimental plots

4.5.2 Number of tomato fruits/ha

The total number of tomato fruits was obtained from each experimental plot and The highest number of fruits (687,500 fruits/ha) was obtained from tomato planted in the plots treated with 400g/m^2 of gypsum at 100%LR whereas the least number of the fruits (380,000 fruits/ha) was obtained from plots treated with 200g/m^2 at 200% LR respectively. Similarly, the untreated plots produced no yield as the crops did not survive in the unfavourable of soil condition. Fig 4.9 shows the distribution tomato fruits per hectare with respect of treatment combinations. Details on number of fruits/ha for each experimental unit was presented in Appendix VI.

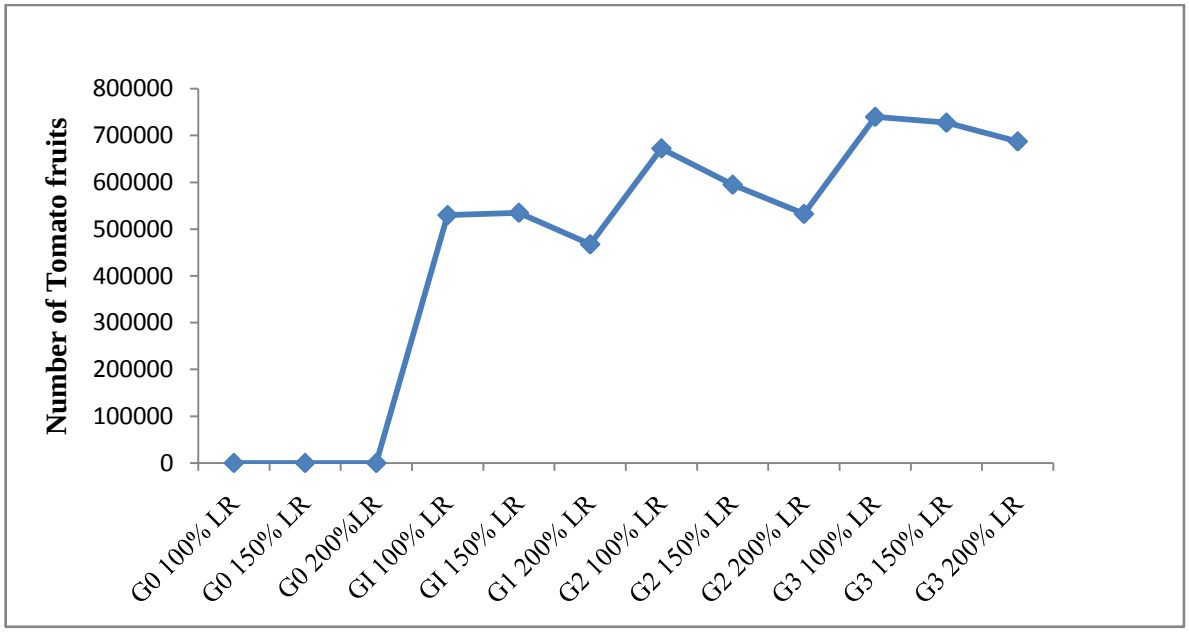


Fig 4.9 Number of tomato in fruit/ha

Similarly, the results showed that there was highly significant difference in terms of number of tomato fruits with respect of leaching requirements at 5% and 1% level of significance. Plots treated with 100% leaching requirement produced statistically higher number of tomato fruits of 450,625 fruits/ha while the least number of 300,000 fruits/ha was obtained from plots treated with 200% leaching requirements. It was observed that the

more leaching fraction is added in excess of required amount the less yield potential of the crop. This could be seen as a result that Minjibir irrigation water is sodic and might have deposited more salts to the soil thereby declining the crop yields potential. Therefore, effort should be intensified to keep the leaching fraction at 100 per cent for the benefit of achieving high yield and economically conserving the irrigation water.

The statistical means of tomato fruits as affected by gypsum application and leaching requirement was presented in Table 4.2. The result shows that there was highly significant difference among the treatments for both amount of gypsum applied and leaching requirement at 5% and 1% level of significance. Tomato seedlings planted at plots treated with 400g/m^2 of gypsum produced statistically highest number of tomato fruits of 652,222 fruits/h while statistically least number of tomato of 380,000 fruits/ha was obtained from the plots treated with 200g/m^2 of gypsum whereas no yields was obtained from untreated plots. However, the results showed no significant difference on the treatments with respect of leaching requirement. Tomato plants grown in the plots treated 150% and 200% leaching requirements were statistically produced similar amount of yields (410833 fruit/ha and 372083 fruit/ha) respectively. This indicated that application of 100% leaching requirements is just sufficient to produce high yield at Minjibir irrigation farmland when treated with required amount of gypsum (amendment). Therefore increasing water in excess of required amount will not improve on yields and thus should be avoided.

The results showed that the interactive effect of the treatments has statistically no significant difference on tomato yields (ton/ha) at both 5% and 1% levels of significance while the interactive effect has significant difference on number of tomato at 5% level of significance.

Table 4.2 Statistical means of growth parameters

Treatment	H (cm)	B	S (%)
Gypsum (G)			
G3	30.899a	9.333a	87.111a
G2	30.700a	8.333b	75.111b
G1	30.060a	7.667b	55.556c
G0	0.000b	0.000c	0.000d
Significant	**	**	**
LSD @ 5%	0.9048	0.7431	9.2291
R^2	0.9967	0.9854	0.9541
CV	4.0394	9.2191	17.339
Leaching Requirement (LR)			
LR3	23.483a	6.250a	52.75a
LR2	23.100a	6.666a	55.25a
LR1	22.150b	6.083a	55.33a
Significant	**	NS	NS
LSD @ 5%	0.7836	0.4943	7.9927
Interaction			
G*LR	NS	NS	NS

Means followed by the same letter (s) in a column of any treatment group are not significantly different at 5% level.
*** = highly significant difference*
** = significant difference*
NS = No significant difference
WT = Weight of tomato yield in ton/ha
N = Number of tomato fruits obtained from the experimental plots

4.5.3 Tomato plant heights (cm) and number of branches

Fig. 4.10 presents the average plant height (cm) of tomato at Minjibirirrigation scheme. The observation was started and recorded immediately after the treatments were imposed (four weeks of transplanting). The highest average plant height (33.5cm) was recorded from the plot treated with 400g/m^2 of gypsum at 100% LR where the least (29.6cm) was obtained from the plot treated with 200g/m^2 with 100% LR. There were no much differences in crop height for all the treatments. While for the untreated plots, no crop survived after two weeks of transplanting. That is why we have zero height for all treatments. The tomato plant heights for various treatment combinations were presented in Appendix VII.

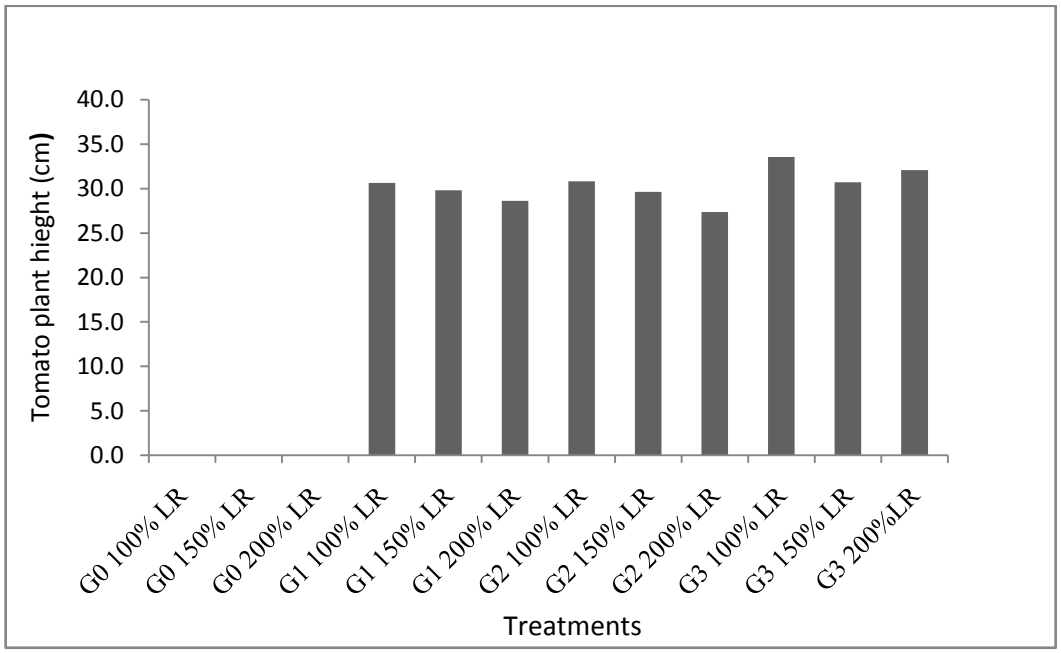


Fig. 4.10 Average tomato plant height (cm)

The statistical means of tomato plant height, number of plant branches and percentage of survived plants were obtained as affected by gypsum application and level of leaching fraction (Table 4.2). These results indicated that there was statistically no significant

difference in terms of plant heights. The highest and least plants height of 33.5cm and 29.6cm were obtained from plots treated with 400g/m^2 and 200g/m^2 of gypsum respectively. It was noted that there was highly statistical difference on the plant's height since plants do not survived in the untreated plots. Similarly, the results showed that there was highly statistical difference on plant's height with respect to leaching requirement for both 5% and 1% levels of significance.

Interactive effect between gypsum application rate and levels leaching requirements on plants heights indicated statistically no significant difference for all the treatments at 5% level of significance.

4.5.4 Survived plants (%)

Sixteen (16) seedlings of Tomato (*Lycopersicomesculentum*) were transplanted in each experimental plot by first week of January, 2014 at Minjibir Irrigation farmland. While ensuring that the treatments were fully imposed, certain number of the tomato plants begun to wilt and eventually died after two to three weeks of transplanting whereas some plants continued developing up to period of harvesting. Fig. 4.11 shows the total number of plants that survived up to period of harvesting expressed in percentage of total plants transplanted. This indicated that required amount of gypsum (amendment) was not met for all plots except 400g/m^2 which was to some extent achieved.

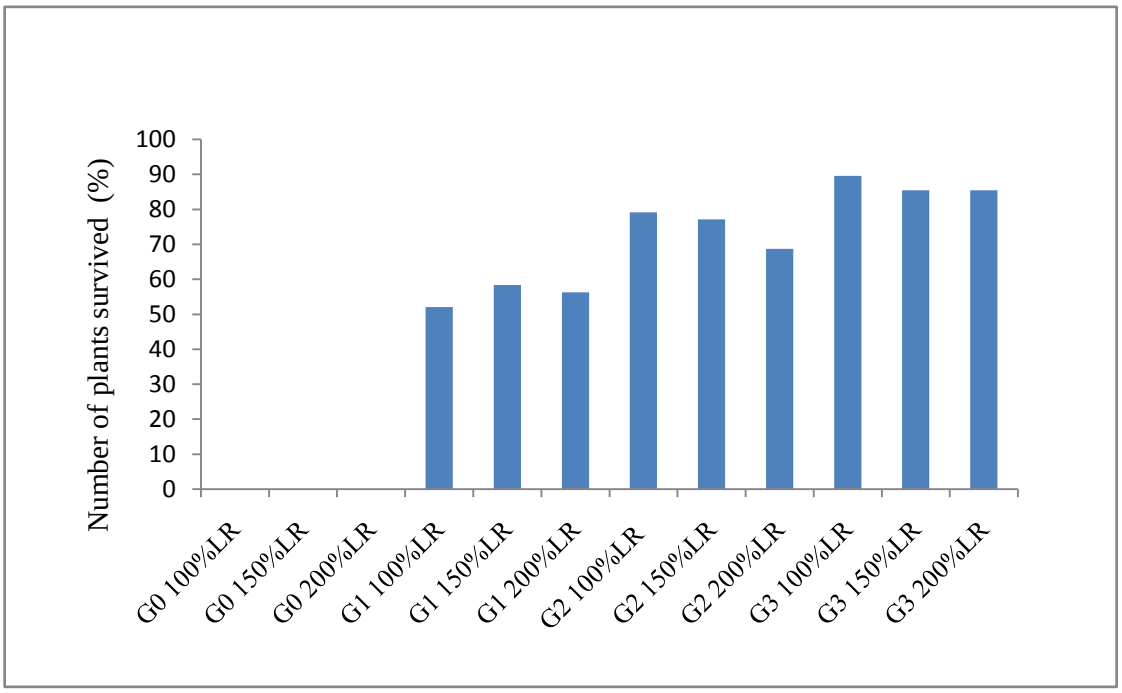


Fig 4.11 Number of survived plant at harvesting period (%)

However, the results showed that there was highly significant difference in percentage of survived plants at 5% and 1% level of significance. About 87.11% of plants were survived when planted in the plots treated with 400g/m^2 of gypsum, followed by 75.11% of survived plants at plots treated with 300g/m^2 of gypsum. Only 55.56% of tomato plants were survived when planted in the plots treated with 200g/m^2 of gypsum whereas no single plant was able to survive when planted in the untreated plots (control). This could simply show the level of necessity of applying an amendment at Minjibir irrigation farm where no tomato plant can be developed without prior treated with amendment. Optimum gypsum application was not yet achieved since only 87.11% of plant survived even though the soil was treated with 400g/m^2 of gypsum (Appendix VII). Therefore, amount of gypsum should be slightly above 400g/m^2 to achieved 100% survival of tomato plants thereby increasing

soil productivity potential through total replacement of sodium ions and properly leached afterwards.

Similarly, the results in table 4.2 showed no significant differences on percentage of survived tomato plants with respect of leaching requirement at 5% level of significance. Tomato plants survival rate was 55.33%, 55.25% and 52.75% out of total number of tomato trees planted in plots treated with 100%, 150% and 200% leaching requirements under the same amount of gypsum application. It could be observed that 100% leaching requirement gave more chance of plant survival and therefore should be maintained.

The interactive effect of gypsum application and leaching requirement had no significant difference on number of survived plants at 5% level of significance.

4.5.5Tomato plant branches

Fig. 4.12 shows the number of plant branches of tomato at Minjibir Irrigation Farmland grown under different treatments. The observation was started from the time of imposing the treatments (week 4 of transplanting). The highest number of plant branches (10 branches) was recorded from the plot treated with 400g/m^2 of gypsum at 150% LR, also the same number of branches was found from the plot treated with 300g/m^2 of gypsum and 150% LR respectively. Similarly, the least number of branches was obtained from the plots treated with 200g/m^2 of gypsum at 100% LR, 100% LR and 200% LR while for the untreated plots the plants died after two weeks of transplanting due to unfavourable soil condition. Also more details on the number of tomato plant branches under different treatments were displayed in (Appendix VIII).

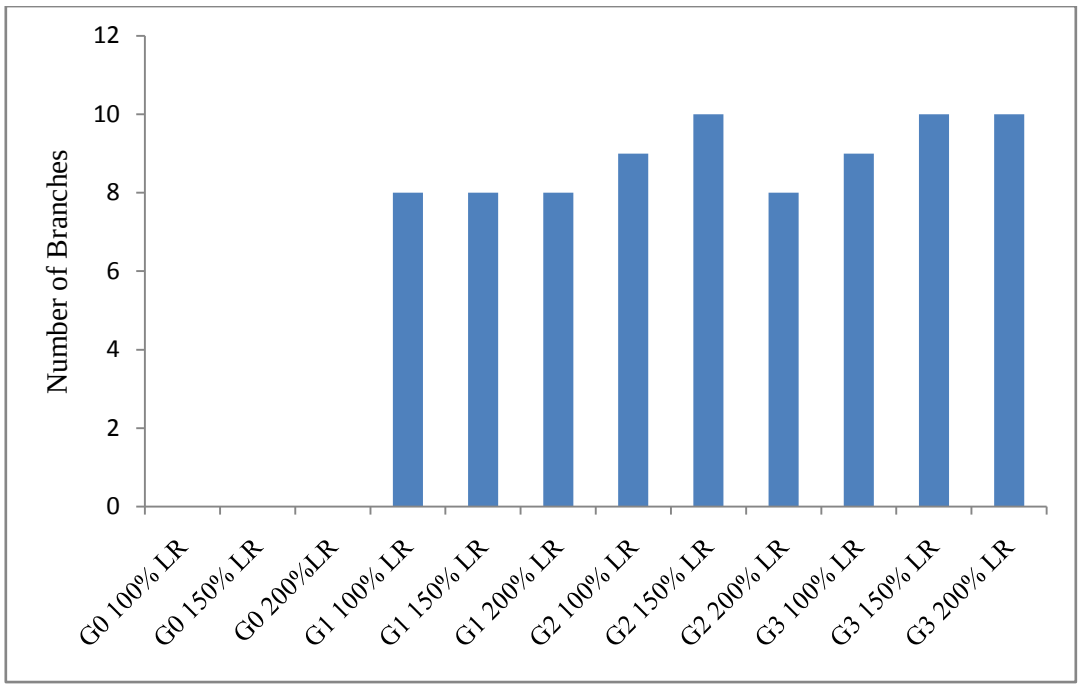


Fig. 4.12 Number of Tomato Branches at Minjibir Irrigation Farm

However, it was observed that there was highly statistical difference in number of plant branches with respect of gypsum application for 5% and 1% levels of significance. Plots treated with 400g/m^2 of gypsum produced plants with statistically highest number of branches (10 branches) whereas plots treated with 300g/m^2 and 200g/m^2 of gypsums produced statistically no differencenumber of branches (8branches and 7.67branches) respectively. Similarly, the result indicates that there was no significant difference on the treatments with respect of leaching requirements at 5% level of significance. Tomato plants treated with 100%, 150% and 200% leaching requirements developed 6.083branches, 6.25branches and 6.66branches respectively.

Also the interaction between gypsum application and leaching requirement has statistically no significant effect for all the treatments at 5% level of significance

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

A field experiment was conducted at Minjibir irrigation scheme during 2013/2014 dry season to determine the soil and irrigation water management strategy on irrigated tomato under saline-sodic soil condition at the mentioned irrigation scheme above. The results indicated a gradual increase in water quality parameter from beginning to the end of growing season of tomato crop. The exchangeable sodium percentage (ESP) in December (2013), January, February, and March 2014 has value of 54.7%, 56.8%, 62.1 and 60.3% respectively. Similarly, there was increase in sodium adsorption ratio (SAR) with highest value of 38.1dS/m in February, 2014. The results also indicated that there was a remarkable increase in the evaluated quality parameters compared with what was obtained 12 years ago. The values for ESP, SAR, EC and pH in 2001/2012 and 2013/2014 dry seasons were 56.92%; 60.3%, 13.0; 25.0, 0.65dS/m; 1.40dS/m and 6.75; 7.23 respectively.

Seasonal crop water requirement of tomato at Minjibir was estimated using CROPWAT 8.0 software and the leaching requirement was computed as 1.49mm/day. Therefore, the total irrigation water applied for irrigating the tomato at 100% LR 150% LR and 200% LR were 628.13 mm, 691.56 mm, and 753.72 mm respectively. However, the results indicated significant difference on tomato yields in terms of both gypsum application and leaching requirement at 5% and 1% level of significance.

Furthermore, the results showed that there was no statistically significant difference in terms of plant height among the treatments at 5% level of significance. The highest tomato plant (33.5cm high) was observed at plot treated with 400g/m^2 while the corresponding least height (29.6cm high) was observed at plot treated with 200g/m^2. The number of plant branches showed significant difference as the plant in plot treated with 400g/m^2 developed more number of branches. There was highly significant difference in the percentage of plants survived with respect of gypsum application at 5% and 1% level of significance. A statistically highest number plant survived was 87.11% and was obtained from plot treated with 400g/m^2 of gypsum whereas the least number was recorded from plot treated with 200g/m^2 of gypsum.

5.2 Conclusion

In this study,the sodicity level was determined to be higher than the results obtained in a previous works. Hence, there was significant increase in sodicity problem in Minjibir irrigation water with respect of the quality determinant analysed; ESP, SAR, EC and pH for the irrigation water were evaluated as 60.3%, 25.0, 1.4dS/$m^2$and 7.23 respectively. If this water would be continuously used for irrigation, there would be a time when even most tolerant crops would not survive the situation as the sodocity and/or salinity level would have become too high unless soil reclamation is carried out.

It was found that application of gypsum has great influence in managing soil in the study area and allowed for the growth and development of tomato. Applying 200g/m^2, 300g/m^2 and 400g/m^2 of gypsum at Minjibir farm was not adequate though appreciable amount of

yields was obtained when the soil was treated with 400g/m^2 but yet additional amount is required for full reclamation to be achieved.

The application of leaching requirement was found to be effective in removing the replaced sodium in the soil. Even if the sodium is replaced by applying a correct amendment it will still remain effective in the soil unless adequate amount of leaching requirement is supplied in order to wash away the sodium out of the crop rooting depth.

5.3 Recommendations

The following recommendations were drown;

i) A large scale soil reclamation exercise should be conducted by government/NGOs in order to rehabilitate the soil structure and restore its functionality.

ii) Research should be conducted to find out locally available materials that can be used as an amendment instead of gypsum.

iii) Similar research should be conducted using crops with different tolerance to salinity and sodicicy to know the crop that could survive the soil condition without any damage or reduction in yields.

iv) The management should intensify their effort in educating the farmers on the effect of over-irrigating their crop and how to avoid it.

v) Basin of different sizes should be used as to know whether there is a significant difference on the results.

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Appendix I: SAR, ESP, EC and pH of Minjibir irrigation water

Parameters	DEC 2013	JAN, 2014	FEB, 2014	MACH, 2014
ESP (%)	54.66	56.77	62.18	60.3
SAR	26.01	29.66	38.1	37.65
pH	7.2	7.4	7.26	7.06
EC(dS/m)	1.40	1.46	1.48	1.43

Appendix II: Water quality parameters in 2001/2002 and 2013/2014 irrigation seasons

Parameters	Dry Season	
	2001/2002	**2013/2014**
EC(dS/m)	0.65	1.40
ESP (%)	56.92	60.3
SAR	13.0	25
PH	6.75	7.23

Appendix III: Crop water requirement of Tomato during 2013/2014 dry season using CROPWAT 8.0

Month	Decade	stage	Kc	ETc (mm/day)	ETc (mm/dec)	Effective Rain (mm/day)	Crop water Requirement (mm/dec)
January	1	Initial	0.30	1.49	10.4	0.0	10.4
January	2	Initial	0.30	1.70	11.9	0.0	11.9
January	3	Initial	0.30	2.06	22.6	0.1	22.5
February	1	Development	0.30	2.30	23.0	0.3	22.8
February	2	Development	0.35	2.92	29.2	0.4	28.8
February	3	Development	0.42	3.36	26.9	0.3	26.6
March	1	Middle	0.50	5.22	52.2	0.1	52.0
March	2	Middle	0.57	5.79	57.9	0.0	57.9
March	3	Middle	0.57	5.02	55.3	0.0	55.3
April	1	Late	0.57	5.75	57.5	0.0	57.5
April	2	Late	1.23	14.44	61.4	0.0	61.4
April	3	Late	1.30	14.83	74.1	0.0	74.1
				Total =	**565.4**	**1.1**	**564.3**

AppendixIV: Weekly Irrigation Water Applied (mm) at theExperimental Plots

PLOT	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13	WK14
G0 100% LR	10.3	14.0	17.2	20.33	22.33	32.93	33.28	39.23	37.03	62.43	68.33	65.73	67.93	76.83
G0 150% LR	10.3	14.0	17.2	26.08	27.58	38.18	38.48	44.48	42.28	67.68	73.58	70.98	73.18	82.08
G0 200% LR	10.3	14.0	17.2	31.26	32.76	43.36	43.66	49.66	47.46	72.86	78.76	76.16	78.36	87.26
G1 100% LR	10.3	14.0	17.2	20.33	22.33	32.93	33.28	39.23	37.03	62.43	68.33	65.73	67.93	76.83
G1 150% LR	10.3	14.0	17.2	26.08	27.58	38.18	38.48	44.48	42.28	67.68	73.58	70.98	73.18	82.08
G1 200% LR	10.3	14.0	17.2	31.26	32.76	43.36	43.66	49.66	47.46	72.86	78.76	76.16	78.36	87.26
G2 100% LR	10.3	14.0	17.2	20.33	22.33	32.93	33.28	39.23	37.03	62.43	68.33	65.73	67.93	76.83
G2 150% LR	10.3	14.0	17.2	26.08	27.58	38.18	38.48	44.48	42.28	67.68	73.58	70.98	73.18	82.08
G2 200% LR	10.3	14.0	17.2	31.26	32.76	43.36	43.66	49.66	47.46	72.86	78.76	76.16	78.36	87.26
G3 100% LR	10.3	14.0	17.2	20.33	22.33	32.93	33.28	39.23	37.03	62.43	68.33	65.73	67.93	76.83
G3 150% LR	10.3	14.0	17.2	26.08	27.58	38.18	38.48	44.48	42.28	67.68	73.58	70.98	73.18	82.08
G3 200% LR	10.3	14.0	17.2	31.26	32.76	43.36	43.66	49.66	47.46	72.86	78.76	76.16	78.36	87.26

Appendix V: Tomato yields in ton/ha

Treatment	Wk10 (Kg)	Wk11 (Kg)	Wk12 (Kg)	Wk13 (Kg)	Wk14 (Kg)	Yield (Kg)	Yield (ton/ha)
G0 100% LR	0	0	0	0	0	0	0
G0 150% LR	0	0	0	0	0	0	0
G0 200% LR	0	0	0	0	0	0	0
G1 100% LR	1.5	2	2	1.5	0.5	7.5	18.75
G1 150% LR	1.1	1.3	2.3	2	1	7.7	19.25
G1 200% LR	0.6	1.6	2	2.5	1	7.7	19.25
G2 100% LR	1	2	2.7	2.5	1	9.2	23.00
G2 150% LR	1	2.3	3	2	0.5	8.8	22.00
G2 200% LR	1.2	1.5	2.2	1.4	1.5	7.8	19.50
G3 100% LR	1.5	2	3	2.5	1	10	25.00
G3 150% LR	1.1	2.2	2	3	1.5	9.8	24.50
G3 200% LR	0.5	0.6	3	4	1	9.1	22.75

Appendix VI: Number of tomato (fruits/ha)

Treatments	Wk10	Wk11	Wk12	Wk13	Wk14	Total	No. of Fruit/ha
G0 100% LR	0	0	0	0	0	0	0
G0 150% LR	0	0	0	0	0	0	0
G0 200%LR	0	0	0	0	0	0	0
G1 100% LR	27	44	35	51	26	183	457500
G1 150% LR	17	35	65	23	33	173	432500
G1 200% LR	26	30	51	24	21	152	380000
G2 100% LR	13	59	68	50	37	227	567500
G2 150% LR	21	30	45	57	41	194	485000
G2 200% LR	19	31	76	30	7	163	407500
G3 100% LR	42	72	88	43	30	275	687500
G3 150% LR	22	57	53	56	34	222	555000
G3 200% LR	33	46	56	50	25	210	525000

Appendix VII: Average Tomato plant height (cm) and survived plant (%)

TREATMENT	Average Tomato plant Height (cm)	Plants survived up to Harvesting (%)
G0 100% LR	0.0	0
G0 150% LR	0.0	0
G0 200% LR	0.0	0
G1 100% LR	30.6	52
G1 150% LR	29.8	58
G1 200% LR	28.6	56
G2 100% LR	30.8	79
G2 150% LR	29.6	77
G2 200% LR	27.4	69
G3 100% LR	33.5	90
G3 150% LR	30.7	85
G3 200%LR	32.1	85

Appendix VIII: Number of plant branches

Treatment	Wk4	Wk5	Wk6	Wk7	Wk8	Wk9	Wk10	Wk11	No. of Branches
G0 100% LR	0	0	0	0	0	0	0	0	**0**
G0 150% LR	0	0	0	0	0	0	0	0	**0**
G0 200% LR	0	0	0	0	0	0	0	0	**0**
G1 100% LR	4	4	5	8	8	10	11	10	**8**
G1 150% LR	3	4	4	6	9	12	12	11	**8**
G1 200% LR	4	5	5	7	8	10	12	12	**8**
G2 100% LR	5	5	7	8	10	12	12	22	**9**
G2 150% LR	6	7	7	9	11	12	12	13	**10**
G2 200% LR	5	6	6	7	8	10	11	12	**8**
G3 100% LR	5	5	8	9	10	11	12	13	**9**
G3 150% LR	6	6	9	11	11	13	13	14	**10**
G3 200% LR	5	7	7	10	10	12	13	13	**10**

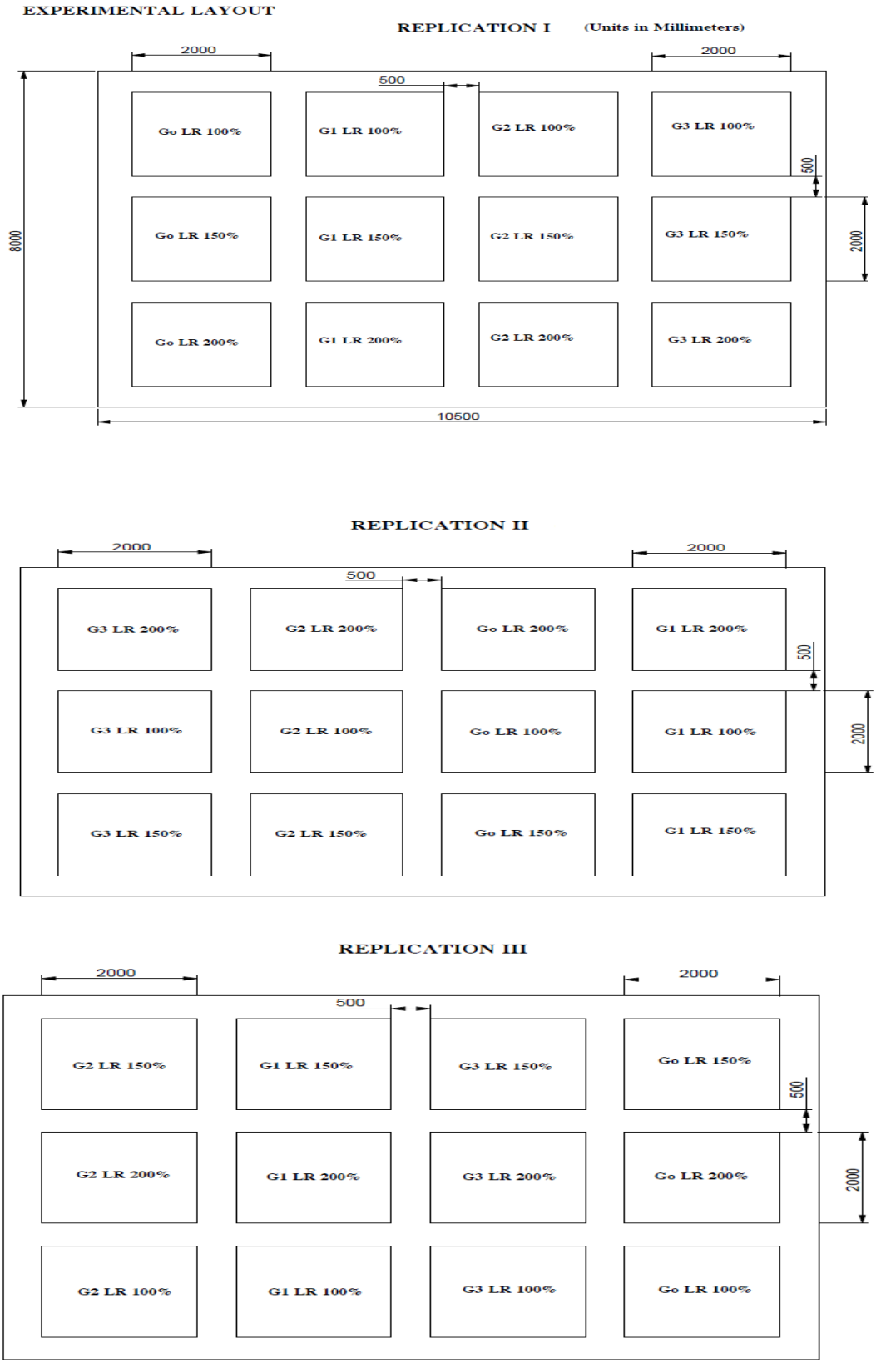
Appendix A: Description of the Experimental Treatments

Treatment No.	Treatment combination	Description
1	G0 100% LR	0g/m^2 of gypsum at 100% leaching requirement
2	G0 150% LR	0g/m^2 of gypsum at 150% leaching requirement
3	G0 200% LR	0g/m^2 of gypsum at 200% leaching requirement
4	G1 100% LR	200g/m^2 of gypsum at 100% leaching requirement
5	G1 150% LR	200g/m^2 of gypsum at 150% leaching requirement
6	G1 200% LR	200g/m^2 of gypsum at 200% leaching requirement
7	G2 100% LR	300g/m^2 of gypsum at 100% leaching requirement
8	G2 150% LR	300g/m^2 of gypsum at 150% leaching requirement
9	G2 200% LR	300g/m^2 of gypsum at 200% leaching requirement
10	G3 100% LR	400g/m^2 of gypsum at 100% leaching requirement
11	G3 150% LR	400g/m^2 of gypsum at 150% leaching requirement
12	G3 200% LR	400g/m^2 of gypsum at 200% leaching requirement

APPENDIX B: The discharge through PVC pipe

h (cm)	**h (m)**	**√h**	**q (l/s)**	**q (m^3/s)**
1	0.01	0.1	0.5	0.0005
2	0.02	0.14142	0.8	0.0008
3	0.03	0.17321	1.0	0.001
4	0.04	0.20000	1.2	0.0012
5	0.05	0.22361	1.4	0.0014
6	0.06	0.24495	1.7	0.0017
7	0.07	0.26458	1.8	0.0018
8	0.08	0.28284	2.0	0.002
9	0.09	0.30000	2.1	0.0021
10	0.10	0.31623	2.3	0.0023
11	0.11	0.33166	2.5	0.0025
12	0.12	0.34641	2.7	0.0027

APPENDIX C: Experimental Layout



APPENDIX D:Deign of the Basin

The design of basin as specified in the study is based on treatment and Experiment designas detailed below:

Width of each basin = 2 m

Number of basin in each plot = 1

Width of each plot = 2 m x 1 m = 2 m

Number of plot in each replication = 4

Width for four plots = 2 m x 4 = 8 m

Spacing = 5 m

Total width = 8 m +5 m = 13 m

Length of each basin = 2 m

Number of plots in each replication = 3

Number of plots for three replications = 9

Length for nine plots = 2 m x 9 = 18 m

Spacing = 5 m

Total length = 18 m + 5 m = 23 m

Total area = length x width = 23 m x 13 m = 299 m^2 =0.0299hectares

APPENDIX F: Statistical Analysis of Variance (ANOVA)

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL
10:17 Thursday, July 29,2014

The ANOVA Procedure

Class Level Information

Class	Levels	Values
GYP	4	G0 G1 G2 G3
LR	3	L1 L2 L3
REP	3	1 2 3

Number of observations 37

NOTE: All dependent variables are consistent with respect to the presence or absence of missing
values. However only 36 observations can be used in this analysis

The ANOVA Procedure

Dependent Variable: WT WT

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	13	3349.122500	257.624808	84.01	<.0001
Error	22	67.465000	3.066591		
Corrected Total	35	3416.587500			

R-Square	CoeffVar	Root MSE	WT Mean
0.980254	10.71597	1.751168	16.34167

Source	DF	Anova SS	Mean Square	F Value	Pr> F
REP	2	1.901667	0.950833	0.31	0.7366
GYP	3	3319.043056	1106.347685	360.77	<.0001
LR	2	10.961667	5.480833	1.79	0.1909
GYP*LR	6	17.216111	2.869352	0.94	0.4895

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL

The ANOVA Procedure

Dependent Variable: N N

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	13	2.317745E12	178288074252	135.49	<.0001
Error	22	28948611111	1315845959.6		
Corrected Total	35	2.3466936E12			

R-Square	CoeffVar	Root MSE	N Mean
0.987664	8.822059	36274.59	411180.6

Source	DF	Anova SS	Mean Square	F Value	Pr> F
REP	2	42022222222	21011111111	15.97	<.0001
GYP	3	2.2180644E12	739354803241	561.89	<.0001
LR	2	37014930556	18507465278	14.07	0.0001
GYP*LR	6	20643402778	3440567129.6	2.61	0.0456

The ANOVA Procedure

Dependent Variable: H H

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	13	6325.592778	486.584060	568.11	<.0001
Error	22	18.842778	0.856490		
Corrected Total	35	6344.435556			

R-Square	CoeffVar	Root MSE	H Mean
0.997030	4.039382	0.925467	22.91111

Source	DF	Anova SS	Mean Square	F Value	Pr> F
REP	2	6.117222	3.058611	3.57	0.0454
GYP	3	6302.464444	2100.821481	2452.83	<.0001
LR	2	11.308889	5.654444	6.60	0.0057
GYP*LR	6	5.702222	0.950370	1.11	0.3884

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL

The ANOVA Procedure

Dependent Variable: B B

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	13	506.5000000	38.9615385	114.29	<.0001
Error	22	7.5000000	0.3409091		
Corrected Total	35	514.0000000			

R-Square	CoeffVar	Root MSE	B Mean
0.985409	9.219066	0.583874	6.333333

Source	DF	Anova SS	Mean Square	F Value	Pr> F
REP	2	6.5000000	3.2500000	9.53	0.0010
GYP	3	494.0000000	164.6666667	483.02	<.0001
LR	2	2.1666667	1.0833333	3.18	0.0613
GYP*LR	6	3.8333333	0.6388889	1.87	0.1308

The ANOVA Procedure

Dependent Variable: S S

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	13	41426.27778	3186.63675	35.76	<.0001
Error	22	1960.61111	89.11869		
Corrected Total	35	43386.88889			

R-Square	CoeffVar	Root MSE	S Mean
0.954811	17.33927	9.440269	54.44444

Source	DF	Anova SS	Mean Square	F Value	Pr> F
REP	2	1012.72222	506.36111	5.68	0.0102
GYP	3	40136.88889	13378.96296	150.13	<.0001
LR	2	51.72222	25.86111	0.29	0.7509
GYP*LR	6	224.94444	37.49074	0.42	0.8573

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL

The ANOVA Procedure

t Tests (LSD) for WT

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	3.066591
Critical Value of t	2.07387
Least Significant Difference	1.712

Means with the same letter are not significantly different.

t Grouping	Mean	N	GYP
A	24.0444	9	G3
B	22.2556	9	G2
C	19.0667	9	G1
D	0.0000	9	G0

The ANOVA Procedure

t Tests (LSD) for N

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	1.3158E9
Critical Value of t	2.07387
Least Significant Difference	35463

Means with the same letter are not significantly different.

t Grouping	Mean	N	GYP
A	652222	9	G3
B	545278	9	G2
C	447222	9	G1
D	0	9	G0

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL

The ANOVA Procedure

t Tests (LSD) for H

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.85649
Critical Value of t	2.07387
Least Significant Difference	0.9048

Means with the same letter are not significantly different.

t Grouping	Mean	N	GYP
A	30.8889	9	G3
A			
A	30.7000	9	G1
A			
A	30.0556	9	G2
B	0.0000	9	G0

The ANOVA Procedure

t Tests (LSD) for B

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.340909
Critical Value of t	2.07387
Least Significant Difference	0.5708

Means with the same letter are not significantly different.

t Grouping	Mean	N	GYP
A	9.3333	9	G3
B	8.3333	9	G2
C	7.6667	9	G1
D	0.0000	9	G0

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL

The ANOVA Procedure

t Tests (LSD) for S

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	89.11869
Critical Value of t	2.07387
Least Significant Difference	9.2291

Means with the same letter are not significantly different.

t Grouping	Mean	N	GYP
A	87.111	9	G3
B	75.111	9	G2
C	55.556	9	G1
D	0.000	9	G0

The ANOVA Procedure

t Tests (LSD) for WT

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	3.066591
Critical Value of t	2.07387
Least Significant Difference	1.4826

Means with the same letter are not significantly different.

t Grouping	Mean	N	LR
A	17.1167	12	L1
A			
A	16.0333	12	L2
A			
A	15.8750	12	L3

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL

The ANOVA Procedure

t Tests (LSD) for N

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	1.3158E9
Critical Value of t	2.07387
Least Significant Difference	30712

Means with the same letter are not significantly different.

t Grouping	Mean	N	LR
A	450625	12	L1
B	410833	12	L2
C	372083	12	L3

The ANOVA Procedure

t Tests (LSD) for H

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.85649
Critical Value of t	2.07387
Least Significant Difference	0.7836

Means with the same letter are not significantly different.

t Grouping	Mean	N	LR
A	23.4833	12	L3
A			
A	23.1000	12	L2
B	22.1500	12	L1

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL

The ANOVA Procedure

t Tests (LSD) for B

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.340909
Critical Value of t	2.07387
Least Significant Difference	0.4943

Means with the same letter are not significantly different.

t Grouping	Mean	N	LR
	A	6.6667	12	L2
	A		
B	A	6.2500	12	L3
B			
B		6.0833	12	L1

The ANOVA Procedure

t Tests (LSD) for S

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	89.11869
Critical Value of t	2.07387
Least Significant Difference	7.9927

Means with the same letter are not significantly different.

t Grouping	Mean	N	LR
A	55.333	12	L1
A			
A	55.250	12	L2
A			
A	52.750	12	L3

ANALYSIS OF EFFECT OF GYPSUM AND LEACHING REQUIREMENT ON SODIC SOIL

The ANOVA Procedure

Level of GYP	Level of LR	N	WT Mean	WT StdDev	N Mean	N StdDev	H Mean	H StdDev
G0	L1	3	0.0000000	0.00000000	0.000	0.0000	0.0000000	0.00000000
G0	L2	3	0.0000000	0.00000000	0.000	0.0000	0.0000000	0.00000000
G0	L3	3	0.0000000	0.00000000	0.000	0.0000	0.0000000	0.00000000
G1	L1	3	19.0333333	0.87368949	470000.000	58789.8801	29.5333333	0.95043850
G1	L2	3	18.8666667	0.75055535	460000.000	65717.1971	31.1666667	0.85049005
G1	L3	3	19.3000000	3.50000000	411666.667	48498.2818	31.4000000	0.30000000
G2	L1	3	23.1666667	1.25830574	628333.333	54447.9874	29.0333333	1.48436294
G2	L2	3	21.7666667	1.86100331	533333.333	56199.0510	30.6000000	0.88881944
G2	L3	3	21.8333333	2.51661148	474166.667	62915.2870	30.5333333	1.22202019
G3	L1	3	26.2666667	1.25033329	704166.667	31057.7419	30.0333333	1.41539158
G3	L2	3	23.5000000	1.00000000	650000.000	87571.3994	30.6333333	1.36503968
G3	L3	3	22.3666667	2.67644042	602500.000	81509.2019	32.0000000	1.55241747

Level of GYP	Level of LR	N	B Mean	B StdDev	S Mean	S StdDev
G0	L1	3	0.00000000	0.00000000	0.0000000	0.0000000
G0	L2	3	0.00000000	0.00000000	0.0000000	0.0000000
G0	L3	3	0.00000000	0.00000000	0.0000000	0.0000000
G1	L1	3	7.33333333	0.57735027	52.0000000	3.4641016
G1	L2	3	7.66666667	0.57735027	58.3333333	21.5947524
G1	L3	3	8.00000000	1.00000000	56.3333333	16.4418166
G2	L1	3	8.00000000	1.00000000	79.3333333	9.6090235
G2	L2	3	9.33333333	0.57735027	77.0000000	3.4641016
G2	L3	3	7.66666667	0.57735027	69.0000000	22.6053091
G3	L1	3	9.00000000	1.00000000	90.0000000	3.4641016
G3	L2	3	9.66666667	1.52752523	85.6666667	9.7125349
G3	L3	3	9.33333333	0.57735027	85.6666667	4.0414519