RECLAMATION AND AMELIORATION OF SALINE-SODIC SOIL USING GYPSUM AND HALOPHYTIC GRASSES: CASE OF GOLINA-ADDISALEM IRRIGATION SCHEME, RAYA KOBO VALLEY, ETHIOPIA

M .Sc. THESIS

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HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY

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This is to certify that the thesis entitled "**Reclamation and Amelioration of Saline-Sodic Soil using Gypsum and Halophytic Grasses: Case of Golina-Addisalem Irrigation Scheme, Raya Kobo Valley, Ethiopia".** Submitted in partial fulfillment of the requirement for the degree of Master's with specialization in **IRRIGATION AND DRAINAGE** Engineering, the Graduate Program of the Department of Water Resource and Irrigation Engineering and has been carried out by Sisay Dessale, Id. No PGIDE/007/10 under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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Abraham W/Michael (PhD)	____________________	____________________
Name of co-advisor	signature	date

DEDICATION

I would like to dedicate this thesis manuscript to **my beloved mother Direb Tefera;** i always remember you with inconsolable feelings. God may rest her soul in heaven amen.

BIOGRAPHICAL SKETCH

The author, Sisay Dessale Abate was born on Jun 15, 1985 in Raya Kobo district, north Wollo zone, Ethiopia. He attended his elementary education at Robit Elementary School and his secondary and preparatory School at Kobo Secondary and Preparatory School between 1997 and 2008. He then joined Wollo University and graduated with B.Sc. Degree in Soil and Water Resource Management in July 2011. After graduation, he joined Raya Kobo wereda Bureau of Agriculture and served there as an irrigation water management expert for two years. The author then has been employed by Amhara Regional Agricultural Research Institute at Sirinka Agricultural Research Center as a junior irrigation water management researcher from Jan 26, 2014 until he joined Hawassa University, Ethiopia Postgraduate Program in 2017 to pursue his MSc Degree in Irrigation and Drainage Engineering.

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ABBREVIATION AND ACRONYMS

Ca^{2+}	Calcium
$CaSO_4$, $2H_2O$	Calcium Sulfate
cm	Centimeter
$CO_3^{\ 2-}$	Carbonate
CP	Crude Protein
dS m^{-1}	DeciSiemens per Meter
EC_e	Electrical Conductivity of Saturated Paste Extract
EC_w	Electrical Conductivity of Water
EIAR	Ethiopian Institute of Agricultural Research
ESP	Exchangeable Sodium Percentage
ETB	Ethiopian Birr
ETc	Evapotranspiration of Crop
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
$FeSO_4$	Iron Sulfate
gm	Gram
G	Gypsum Requirement
H^+	Hydrogen Ion
ha	Hectar
HCO_3^-	Bicarbonate
IRg	Gross Irrigation Requirement
Kc	Crop Coefficient
Kc adj	Adjusted Crop Coefficient
Kcb	Basal or Tabulated Crop Coefficient
KGVDP	Kobo Girana Valley Development Project
km	Kilometer
m	Meter

m.a.s.l.	Meter Above Sea Level
Na^+	Sodium
Na_2SO_4	Sodium Sulfate
OH^-	Hydroxyl Ion
pHe	Soil Reaction of the Saturated Paste Extract
pHw	Water Reaction
ppm	Parts Per Million
PG	Panikum Grass
PWP	Permanent Wilting Point
RG	Rhodes Grass
RAW	Readily Available Water
RCBD	Randomly Completely Block Design
SAR	Sodium Adsorption Ratio
SARC	Sirinka Agricultural Research Center
TAW	Total Available Water
TDS	Total Dissolve Solid
t/ha	Ton per Hectare
0H	No Halophytic Grass Plantetion

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ABSTRACT

In the Golina-Adisalem irrigation scheme, 500 ha irrigated land is becoming salt-affected. This relatively recent agricultural threat in the study area has never been comprehensively managed until now. Rehabilitation of salt-affected field into productive lands using drainage is expensive and the application of leaching by far is not feasible in shallow water table areas. The alternative way is chemical amendment and bioremediation. Therefore, the field experiment was conducted from January to May 2019 to evaluate the possibility of using gypsum soil amendment and halophytic grasses on modification of properties of saline-sodic soil, and the effects of gypsum on the performance of grasses. The gypsum levels (0%, 75%, 100%, 125% G) and halophytic grasses (0H, RG, PG) were set in factorial RCBD design with three replication. Composite soil samples before the experiment and from each treatment after 1st and 2nd harvest with 0-20, 20-40, 40-60 cm depths were collected for laboratory analysis. Deep percolated water samples (at 1.5 m depth) were collected from the gypsum received and control plots. The gypsum rates mixed to the top 20 cm soil layer 20 days prior to planting. The laboratory analysis revealed that after the 1st and 2nd harvest the soil pHe, ECe, SAR and ESP in the three soil columns were highly significantly ($P<0.01$) affected by the main effects of gypsum, grasses and by their interaction. After the 1st harvest, the lowest pHe, ECe, SAR and ESP was recorded from the soils treated with a combination of RG+125% G and PG+125% G, whereas the highest values recorded from the soil of the control plot. After the 2nd harvest, combination of RG+125% and PG+125% G in contrasting with the control treatment exhibits more pronouncedly decreased the pHe from 8.54, 8.66, 8.77 to 7.23, 7.29, 7.51, ECe from 20.1, 16.31, 11.4 to 4.62, 4.89, 4.31dS m $^{-1}$,SAR from 50.12, 54.23, 57.29 to 10.78, 15.81, 16.38 and ESP from 57.37, 66.22, 72.26 % to 8.93, 8.66, 9.47 % for 0-20, 20-40, 40-60 cm respectively. The reclamation efficiency of RG+125% G was statistically equal (≈) with PG+125% G. The highest infiltration rates were noted from soils treated with RG+125% G (6.3 cm/hr) and PG+125% G (5.92 cm/hr); while the lowest value (1.22 cm/hr) was recorded from the control treatment. After the two experimental season, the concentration of Na^{+}, Ca^{2+}, mg^{2+}, ECw and TDS in the deep percolated water does not appears much change by surface gypsum application. However, the biomass yield in the saline-sodic field had highly significantly ($p<0.01$) affected by gypsum application. The highest biomass yields (10.56 and 13.2 t/ha) with highest net benefits (187,153.47 and 255,319.44 ETB/ha) were obtained in saline-sodic soil that treated with RG+125% G for first and second harvest respectively followed by PG+125% G. Whereas, the lowest biomass yield (5.73 and 7.14 t/ha) was recorded from the normal field which treated by PG+0% G for first and second harvest respectively. From the result, it could be concluded that combined application of RG+125% G and PG+125% G was the most efficient treatment with respect to a faster decreased pHe, ECe, SAR, ESP and it enhances soil infiltration rate, reached high biomass yield with high net benefit as well as getting acceptable tissue quality for forage provision.

Keywords: Salinity and sodicity, gypsum amendment, phytoremediation, biomass yield.

1. INTRODUCTION

1.1. Background of the Study

Salinity and sodicity are a major environmental threat to soil fertility and agricultural productivity of the world. In arid and semi-arid regions, good soils are scarce with their overall productivity declining due to inadequate provision of soil and water management practices (Young *et al.*, 2015; Gebremeskel *et al*., 2018). Globally about 7 % or 831 million ha of land affected by salinity and sodicity (Mirza *et al*., 2014). Ahmed and Qamar, (2004) reported that 20 million ha of land rendered to zero productivity each year. In Ethiopia, nearly 11 million ha irrigated land has already been salt-affected, being the highest from African countries (Fantaw, 2007) and ranked as 7^{th} in the world (Qureshi *et al*., 2018). There is strong evidence and understanding that at least soil salinity has been spreading and it is recognized as being one of the greatest challenges of our world as a whole and its impacts towards several sectors have become major concerns of researchers today (Mustafa, 2007).

Prior to management and reclaiming salt-affected soils, determining the type of problem and identification of its source is the first step to select ideal mitigation measures for sustainable irrigation project (Fantahun, 2007). Hence, irrigation water quality, soil salinity and sodicity statuses of Golina-Adisalem irrigation scheme have characterized and documented before the last three years. Based on Sisay *et al.*, (2016) characterization that the soil pHe, EC_e, SAR and ESP values varied from 8 to 8.6, 4.1 to 24.4 dS m^{-1}, 41 to 45 and 48 to 55 % respectively, which classified as “saline-sodic” soil (Lamond *et al.,* 1992). On the other hand, the groundwater quality analysis of the Golina-Adisalem irrigation scheme showed EC_w values within the range of 0.37 and 0.41 dS m^{-1} respectively rated within “medium saline” range USSLS, (1954).

Previous studies indicate that the main source of salinity and sodicity in Golina-Adisalem irrigation scheme is soil parent material, the presence shallow groundwater table (at 1.5 m below the surface), inadequate provision of drainage systems, poor on-farm water management practices coupled with substantial salt buildup due to high evaporation (KGVDP, 2010; Sisay *et al.*, 2016; Merse, 2018).

The main characteristics of saline-sodic soil from the agricultural standpoint that soils degraded due to the simultaneous effect of salinity and sodicity. Plant growth in saline-sodic soil also affected by excess salinity and excess sodicity (Na^+). Excess exchangeable Na^+ has an adverse effect on soil structure, seedling emergence, root penetration and lowers the permeability of the soil to air and water (Yu *et al*., 2010). The primary effect of excess salinity is rendered less water available to plants even the water is still present in the root zone. This is because, the osmotic pressure of the soil solution increases as the salt concentration increase resulted in physiological drought (Hasegawa *et al*., 2000; Munns, 2002; Zhu, 2007).

A saline-sodic soil normally does not exhibit strong sodicity symptoms. However, the management of salinity and sodicity becomes more complicated when both occur in the same soil together. There is no straightforward solution to solve these complex problems (Makoi and Ndakidemi, 2007). There are two major approaches sustaining productivity in saline-sodic environment: 1) modifying the environment to suit the plant, 2) modifying the plant to suit the environment. Both approaches may use either singly or in combination. The first approach used more extensively for enabling the plants to respond better (Tyagi and Sharma, 2000).

The saline-sodic environment modified by, drainage, leaching, chemical amendments and bio-remediation suit for the plant. While the drainage and leaching approaches are difficult and expensive. Moreover, the leaching without subsurface drainage is applicable only in a place where the soil moisture content is low and the groundwater table is deep unless it is not feasible (Siyal *et al*., 2002; Ahmed and Qamar, 2004; Hanay *et al*., 2004). The application chemicals followed by bio-remediation is an alternative way to answer saline-sodic problems under shallow water table areas (Siyal *et al*., 2002).

Chemical amendments have a long history of usage for soil reclamation (Qadir *et al*., 2001). Gypsum ($CaSO_4$. $2H_2O$) is the most common and relatively economical amendment for replacing excess Na^+ from the soil exchangeable sites by the provision of readily available source of Ca^{2+} (FAO, 1988; Gupta and Abrol, 1990; McCauley and Jones, 2005). Because Ca^{2+} has a stronger charge than Na^+ and it replaces Na^+ on the exchange site in the form of leachable Na_2SO_4.

This Na_2SO_4 form is easy to be removed, either by downward leaching or susceptible to upward absorption by halophytic grasses (Qadir *et al*., 2001; Pitman and Läuchli, 2002; McCauley and Jones, 2005; Bennett *et al*., 2014). To avoid resodification in saline-sodic areas, replaced Na_2SO_4 should be absorbed from the root zone using salt-loving halophytic species.

Several studies including in Ethiopia indicate bio-remediation by growing halophytic grasses (Panicum and Rhodes grass) is the most cost-effective and environmentally friendly approach to bring salt-affected soils back into production (Qureshi *et al*., 2018; Ashenafi *et al.*, 2019). This approach is relatively easy for applicable in large irrigation areas to improve soil porosity, enhancing the rate of percolation of water, absorbs soil salinity and sodicity (Kushiev *et al*., 2005). Moreover, the grasses absorb Na^+ ion from soil to maintain turgor (Qadir *et al*., 2003). In addition, it can improve the livelihood of rural peoples living in arid and semi-arid climatic zones by enhancing feed and fodder production (Hameed and Ashraf, 2008; Qureshi *et al*., 2018). The Panicum and Rhodes grasses have a chance and offer a useful approach for obtaining a good biomass yield in salt-affected lands. Salinity for such species is advantageous to the crop rather than to the tolerance of the crop to soil salinity (Masters *et al.*, 2007).

In Ethiopia, many researches have done at Amibara, Melka Sedi and Melka Werner dryland irrigation areas for reclaiming saline-sodic soil either using gypsum with leaching or by halophytic species alone (Fantaw, 2018; Qureshi *et al*., 2018; Ashenafi, 2019). For a successful reclamation of saline-sodic soil by the integrated approaches of halophytic species with chemicals is a newly emerging idea for many countries like Egypt and Pakistan in recent decades, but not practiced in Ethiopia. The combined application of gypsum with halophytic species not only increases the salinity and sodicity reclamation efficiency but also reduces the time of reclamation than the single used amendments (Swarp, 2004; El-Fattah, 2011; Mahdy, 2011; Ghafoor *et al*., 2012)

1.2. Statement of Problem

The problems of salt-affected soils are long-standing, but their magnitude and intensity have been increasing fast due to the establishment of large-scale irrigated farms in recent decades. The salinity induced problems are not associated with natural resources degradation, but they do affect the country's economy as a whole (Fantaw, 2007; FAO, 2009).

Currently, there is a rapid population growth, which requires large food demand. Irrigation development is the only solution to meet the food demand of an ever-growing human population (Ladeioro, 2012). The increasing demand for food and agricultural raw materials needed for future studies to optimize the utilization of soil and water resources is very important and urgent. Besides, Tesfaye and Fassil, (2011) reports that the limited capacity of rain-fed agriculture to sustain crop production due to erratic nature of the rainfall has persuaded farmers to look for alternative ways of improving the availability of food.

In Raya-Kobo Valley, largescale irrigation infrastructure had already made and it has highly abundant resources with respect to groundwater, fertile land and livestock potential (Getahun, 2014). Nevertheless, there has been a challenge to agricultural production and 500 ha of irrigable land being entirely out of production due to salinity and sodicity effect. This coverage indicates only for Golina-Adisalem irrigation scheme, it denuded above eight years. Regarding, the salinity expansion also going up and the sustainability of irrigated agriculture in the valley as the hole threatened by salinization (Sisay *et al.*, 2016; Merse, 2018). This relatively recent agricultural threat has not received much attention yet, and there has never been a comprehensive management of the salt-affected problem in the study area. Therefore, new insight should be captured as salt-affected soils rehabilitated and managed. Transforming of salt-affected irrigated lands into agricultural purposes for economic use was a special preference for this study.

In the Golina-Adisalem irrigation area, the water table remains shallow to the surface considered as the main constraint to apply leaching experimental trial. For this study, vertical leaching was substituted by upward absorption using salt laving halophytic grasses with and without gypsum.

1.3. Objectives

1.3.1. General Objective

- To evaluate the possibility of using gypsum soil amendment and halophytic grasses on the efficiency of reclamation processes (on modification of properties of saline-sodic soil).

1.3.2. Specific Objectives

- To evaluate the effects of gypsum and halophytic grasses on chemical properties of saline-sodic soil (on soil salinity and sodicity induces)
- To evaluate the effects gypsum and halophytic grasses on infiltration rate of salin-sodic soil
- To evaluate the effects of gypsum on the performance of halophytic grasses
- To determine the effects of gypsum soil amendement on the quality of local groundwater.

1.4. Significance of the Study

This study provides lessons for salt-affected irrigation schemes in general, and particularly for irrigators in Raya Kobo Valley. The output of this study contributes to uncultivable land to make fit for cultivation for suitable agricultural production. It provides as a guideline and the bases for future research about soil salinity and sodicity management in Raya-Kobo Valley. It helps farmers to obtain acceptable yield and attaining food security by bringing back salt-affected irrigation fields into production for a better tomorrow. It has a great role in the restoration of saline-sodic soils for sustainable agriculture and conservation of environmental quality. It is imperative to find ways to ensure highly productive land-use systems for sustainable and effective utilization of scarce soil and water resources.

1.5. Scope of the Study

Contextually, the scope of the study was limited only evaluating the effects of halophytic grasses and agricultural gypsum on soil salinity and alkalinity parameters (pHe, ECe, SAR and ESP) and the effects of gypsum on the performance of halophytic grasses for two cropping seasons. Geographically, the study addresses two locations (Golina-Adisalem salt-affected irrigation project and Raya-Kobo non-saline irrigation research station) within Raya Kobo Valley.

1.6. Hypothesis of the Study

1.6.1. Null Hypothesis:

The application of experimental treatments (reclamation method and ameliorative species) have no effect on improving the salt-affected soils and performance of grasses.

2. LITERATURE REVIEW

2.1. Origin and Distribution of Salts

All soils and irrigation water whether from canals or underground pumping, those including considered in very good quality, contain some dissolved salts. Salts are common and the necessary component of the soil and many salts (e.g. nitrates and potassium) are essential plant nutrients. However, it accelerated by crop irrigation (Kotuby *et al.*, 2000).

In the world, nearly half of the irrigated surface seriously affected by salinity and/or secondary alkalinity (Flagella *et al*., 2002). Beltran *et al.*, (2005) estimate 0.25–0.50 million ha of irrigated lands had gone out of production in the world every year due to salts buildup. Munns and Tester, (2008) stated that worldwide 1.5 million ha taken out of production each year due to high soil salinity. Elderly and Garcia, (2008) indicated that the spread of salinization at a rate of up to 2 million ha a year is offsetting a good portion of the increased productivity achieved by expanding irrigation.

Salinization is recognized as the main threat to environmental resources and human health in many countries; affecting almost 1 billion ha worldwide/globally representing about 7% of a country like Venezuela or 20 times the size of France (Metternicht and Zinck, 2003). It has been predicted that damaging global effects of increased salinization of arable lands could result in a 30% loss of productive land in the next 15 years and up to 50% by 2050 (Wang *et al*., 2003). FAO, (2009) estimated that soil salinization cost the world's farmers $11 billion a year in reduced income. Similarly in the Ethiopia arid and semi-arid lowlands and Valleys of the country affected by major salinity and sodicity problems (Yonas, 2005).

The amount of such salts stored in the soil varies with the soil type, being low for sandy soils and high for soils contain a high percentage of clay minerals. It also varies inversely with average annual rainfall (Sultana *et al.,* 2001). The source of salts in salt-affected soils comes from two main sources viz; primary or natural sources and secondary or human factors (FAO, 2000; Michael and Paul, 2002; Horneck, 2007).

2.1.1. Primary salinization

Salts formed naturally in the soil and water at all the humid and arid regions of the world (Molatakgosi, 2006). Primarily salinities formed by the accumulation of salts over long periods, through natural processes, in the soil or groundwater. The first is weathering of parent materials containing soluble salts. Weathering processes break down rocks and release soluble salts of various types, mainly chlorides of sodium, calcium, magnesium and to a lesser extent sulfates and carbonates. Sodium chloride is the most soluble salt (Podmore, 2009).

The second is the deposition of oceanic salt carried in wind and rain. 'Cyclic salts' are ocean salts carried inland by wind and deposited by rainfall are mainly sodium chloride. Rainwater contains from 6 to 50 mg/kg, the concentration of salts decreases with distance from the coast (Podmore, 2009).

2.1.2. Secondary salinization

Results from human activities that change the hydrologic balance of the soil between water applied (irrigation or rainfall) and water used by crops (transpiration). Anthropogenically induced salinity is human-caused factors, mainly by improper methods of irrigation. Lack of drainage facilities, inappropriate application of fertilizer, industrial wastes and application of poor quality water for irrigation resulted in a gradual salt build up in the soil (FAO, 2000; Fantaw, 2007).

In semi-arid zones, soil salts tend to accumulate in the upper soil profile, especially when it is associated with insufficient drainage or where soluble salts move upward in the soil profile and left behind as the water evaporates (Owens, 2001). As groundwater is polluted and recharged, at about two meters below the soil surface the salts move upwards through capillary action (Podmore, 2009) making it potentially hazardous.

Sardo, (2005) has revealed that an increase in groundwater levels due to excessive irrigation has caused salinity development in these soils. In irrigated areas of arid and semi-arid regions, the upward motion of capillary water is generally greater than the downward motion and it facilitates the buildup of salt in soil profiles due to the large evapotranspiration rates.

2.2. Classes of Salt Affected Soils

2.2.1. Saline soils

Many peoples define soil salinity in different ways. Yadav *et al.,* (2011) stated that since salt injury depends on species, variety, growth stage, environmental factors, and nature of the salts, it is difficult to define saline soils precisely. Ramoliya and Pandey, (2002) defined saline soils as soil that contain sufficient salt in the root zone to impose the growth of crop plants. A saline soil also defined as having a high concentration of soluble salts, high enough to affect plant growth. It is the accumulation of salts (often dominated by sodium chloride) in soil and water that affect human and natural assets (e.g. plants, animals, aquatic ecosystems, water supplies, agriculture and infrastructure) (Yadav *et al*., 2011).

2.2.2. Sodic (Alkaline) soils

Sodic soils contain low soluble salts than saline or saline-sodic soils but relatively high in exchangeable Na^+ than other cations. These soils contain HCO^{3-} and CO_3^{2-} as the dominant anions (Qadir *et al*., 2003). Sodic soils characterized by electrical conductivity less than 4 dS m^{-1} at 25 °C and the pH readings usually range between 8.5 and 10 with ESP value greater than 15 %. In sodic soils, the presence of hydrolysis of the exchangeable Na^+ often causes a rise of pH as higher than 10 (Conway, 2001; Jim, 2002). These soils frequently occur in semi-arid and arid regions, often referred to as “slick spots”. The combination of high levels of Na^+, low total salts and high pH causes a breakdown of soil aggregates and swelling of clays. This results in poor soil structure that makes poor tilth (Conway, 2001; Denise, 2003).

2.2.3. Saline-sodic soils

These soils formed by combined processes of salinization and alkalization. It has some different properties from both saline and sodic soils (FAO, 1999 and Yu *et al*., 2010). Saline-sodic soils contained both excessive quantities of soluble salts and exchangeable Na^+ that interferes with the growth and production of most crop plants (USSLS, 1954).

Table 1. Most widely used classes of salt-affected soils

Parameters	Normal	Saline	Sodic	Saline-sodic
ECe	<4	>4	<4	>4
PHe	<8.5	<8.5	>8.5	>8.5
ESP	<15	<15	>15	>15
SAR	<13	<13	>13	>13

Source, (USSLS, 1954; Horneck *et al*., 2007)

2.3. Effect of Saline- Sodic Soils on Crops Yield and Soil Properties

2.3.1. Effect of salinity on crop yield

Salinity is one of the most serious factors limiting the productivity of crops with the adverse effects on germination, plant vigor and crop yield. High concentrations of salts have detrimental effects on plant growth and excessive concentrations kill growing plants (Munns and Tester, 2008).

Many investigators have reported that salinity affects the ability to plant growth, seed germination and revegetation (Denise, 2003). It influences the plant tissue and cells at different growth stage that the plant exhibit varying degrees of tolerance to salinity (Ashraf, 2010). Usually, germination or the early growth stages are the most sensitive stage to salinity. The shoot growth often suppressed more than the root growth by soil salinity. The general response of plants to salinity is a reduction in growth (Hasegawa *et al*., 2000; Munns, 2002; Zhu, 2007).

2.3.2. Effect of sodicity on soil structure and permeability

Certain ions negatively influence soil structure and permeability characteristics result in retarding plant growth (Joe, 2002). Moreover, Qadir *et al.,* (2005) report sodic and saline-sodic soils show structural problems created by certain physical processes (slaking, swelling and dispersion of clay) and specific conditions (surface crusting and hard setting). Such problems may affect water and air movement, plant-available water holding capacity, root penetration, seedling emergence, runoff, and erosion, as well as tillage and sowing operations (Pam, 2002).

When the sodic clay layer occurs near the surface it often acts as a barrier to roots. Hence, most roots found in the topsoil above the clay pan, because the movement of water and nutrients is restricted. Plants on sodic soils usually show a burning or drying of tissue at leaf edges and stunted growth are common (Pam, 2002).

2.4. Irrigation Water Quality

Most salinity problems in agriculture result directly from the salts carried in the irrigation water. There are numerous parameters used to define irrigation water quality, to assess salinity hazards and to determine appropriate management strategies. A complete water quality analysis includes the determination of; 1) the total concentration of soluble salts, 2) the relative proportion of sodium to the other cations, 3) the bicarbonate concentration as related to the concentration of calcium and magnesium, and 4) the concentrations of specific elements (USSLS, 1954).

2.4.1. Salinity hazard

Water with high salinity is toxic to plants and poses a salinity hazard. High concentrations of salt in the soil can result in a "physiological" drought condition. Even though, the field appears to have plenty of moisture, the plant's wilt because the roots are unable to absorb the water. Water salinity hazard usually expressed or measured by the TDS (total dissolved solids) or the ECw (electric conductivity) (Bauder *et al*., 2007). TDS is sometimes referred to as the total salinity and is measured or expressed in parts per million (ppm) or in the equivalent units of milligrams per liter (mg/L). ECw is the capacity of water to pass an electric current.

Table 2. Salinity and sodicity hazard

Types of Salinity Problems				
Salinity hazard	Affects ⟹	Plants	Can lead to ⟹	Saline soil condition
Sodium hazard	Affects ⟹	Soils	Can lead to ⟹	Sodic soil condition
Both sodium and salinity hazard	Affects ⟹	Soils and plants	Can lead to ⟹	Saline-sodic soil condition

Source, USSLS, 1954

2.4.2. Sodium hazard

Irrigation water containing large amounts of sodium that poses a sodium hazard to the soil. The sodium hazard usually expressed in terms of sodium adsorption ratio (SAR). Continued use of irrigation water develops a high SAR leads to a breakdown in the physical structure of the soil. According to Ezlit, (2009) and Dhembare, (2012), sodicity is common in soils irrigated with water containing considerable bicarbonate and carbonate which raises soil pH resulting in the precipitation of divalent cations and an increase in the relative sodium concentration.

2.5. Soil Salinity and Sodicity Induces

Electrical conductivity (ECe), soil reaction (pHe), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are the most widely used and universally accepted parameters to explain salinity and sodicity (USSLS, 1954).

2.5.1. Soil reaction (pHe)

Soil reaction (pHe) explained as a "master variable" because it regulates almost all biological and chemical reactions in soils. The pHe is a measure of soil acidity or alkalinity that indicates the activity of the hydrogen ion (H^+) and hydroxyl ion (OH^-) in soil solution (Brady and Weil, 2002). The pHe characterizes the chemical environment of the soil and may be used as a guide to the suitability of soils for various pasture and crop species (Hazelton and Murphy, 2016).

It is a very good guide to some expected nutrient deficiencies and toxic effects (Brady and Weil, 2002). The values of pHe increased with soil depth because smaller H^+ ions released from decreased OM decomposition, which caused by decreased OM content with depth (Herrera, 2005). Water pH has no direct effect on plant growth but does affect the availability of nutrient elements in irrigation water, fertilizer solutions and the growing medium (Maral, 2010). A low pHe may be a result of excess iron and manganese availability leading to toxicity, or calcium and magnesium deficiencies while a high pH may cause iron and manganese and other minor nutrients to become unavailable to plants, leading to deficiencies (Faust and Will, 2002).

2.5.2. Electrical conductivity (ECe)

The electrical conductivity of the saturation paste extract (ECe) measurement identifies soil salinity potential (Okalebo *et al*., 2002). Soil ECe correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, OM content and subsoil characteristics (Robert *et al*., 2009). Samuel, (2006) reported that ECe values below or above unity can affect the growth of most crops.

The conditions that facilitated the accumulation of salts on the surface are the absence of leaching from the surface to lower depths and high evaporation has been responsible for the increasing trend of ECe values on the soil surface. While, leaching of salts by irrigation water to the deeper layers and absence of rapid capillary rise were responsible for lower ECe value in the surface layer and higher ECe valued at the bottom layer (Sharma *et al*., 2004).

2.5.3. Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR)

Exchangeable sodium percentage (% ESP) is the amount of adsorbed Na^+ (meq/100 gm) on the soil exchange complex to the CEC (meq/100 gm) of soil. Rao, (1989) reported that the ESP increased with an increase in SAR. Exchangeable sodium percentage increase with the increase in soil depth (Yerriswamy, 1996). A trend of increase in ESP from soil surface downwards has considered indicated initiation of sodiumization process in a downward direction (Balpande *et al*., 1996).

Sodium adsorption ratio (SAR) is the ratio of soluble sodium (meq/l) compared to calcium and magnesium in the soil solution (meq/l) (USSLS, 1954). ESP and SAR increase with increasing soil depth due to the increased sodium down the profile by leaching action (Abay and Sheleme, 2012). The extent of dispersion is due to high levels of Na^+ in soil, but the complementary divalent cations like Ca^{2+} have the potential to promote flocculation (Keren and Ben-Hur, 2003).

2.6. Reclamation and Amelioration of Saline-sodic Soils

Management saline-sodic soils are more complex. However, it can be given a good crop yield if properly managed. In this respect, the development of most suitable reclamation technology or a combination of technologies important to optimize better crop yields in saline-sodic soil. The management approach of soil resources needs to be multidimensional and must take into account the biophysical and environmental conditions of the target area as well as the livelihood aspects of the associated communities (Makoi and Ndakidemi, 2007).

2.6.1. Chemical (Gypsum) as an amendment

Chemical amendments used for reclamation sodic and saline-sodic soils broadly grouped into three categories; totally soluble calcium salts, such as $CaCl_2$, acids or acid-forming substances, such as sulfuric acid, iron sulfate, aluminum sulfate, pyrite,… etc and calcium salts of low solubility (ground limestone). The suitability of amendments for the reclamation of saline or saline-sodic soil largely depends on the nature of the soil and cost consideration (FAO, 1988). Gypsum is commonly used as an amendment for the reclamation of saline-sodic and sodic soils and reduces the harmful effects of high sodium irrigation water because of its solubility, low-cost, availability and ease of handling (Abdel-Fattah, 2012).

Abou Yuossef, (2001) reported that the application of phosphogypsum in saline-sodic soil with increasing rate decreased pHe, ECe, ESP and bulk density. Many laboratory and field studies have reported improvements in both physical and chemical properties after gypsum use. The benefits include; decreased SAR or ESP due to the improvement of flocculation, soil aggregate stability and reduced surface crusting (Clark *et al*., 2007; Chi *et al*., 2012).

Ahmad *et al*., (2001) and El-Fattah, (2006 and 2011) reported that ECe, ESP, SAR, pHe and bulk density decreased with gypsum application. The application of excessive gypsum for reclamation sodic and saline-sodic soil observed a quick removal of soluble sodium with a decreased ESP and pHe (Singh and Bajwa, 1991; Khalifa *et al*., 1994).

Verma *et al*. (1985) studied the influence of five amendments on reclamation and physicochemical conditions of black sodic soils. The effects of gypsum application were more pronounced and on par with each other and were superior to pyrites and ferrous sulfate applications. Sharma *et al*. (2011) studied the effect of gypsum application and growing crops on an alkali soil. The effect of four years of reclamation showed that there was a reduction in pH, ECe, exchangeable sodium, dispersion ratio.

In a study conducted by Sharma and Gupta, (1986) for black sodic soils of Barwaha in Madhya Pradesh noted a reduction in pHe, ECe, and ESP but there was an increase in exchangeable Ca and Mg contents with an increased dose of amendments. The reduction in ESP was proportional to the dose of gypsum and pyrites application. Ali *et al*., (1991) reported that the SAR decreased significantly with the application of gypsum @ 100 percent GR.

A detailed study conducted by Kumar and Thiyageshwari, (2018) observed that the application of gypsum and pyrites to sodic soil decreased ECe, pHe and ESP. Patel and Suthar, (1993) reported that application of gypsum @ 50 percent GR reduced the ESP and ECe from 67.3 to 12.8 and 2.3 to 0.4 dS m^{-1} in the surface layer, respectively for saline-sodic soils.

Patel *et al*., (1990) observed that gypsum was superior in reducing the exchangeable sodium percentage than pyrites for few alkali soils of Ludhiana (Punjab). Similarly, Solaimalai, (2001) opined that gypsum treatments significantly reduced the pHe and ESP but increased the exchangeable Ca^{2+} and Mg^{2+}contents of soil at all levels of application than press mud and pyrites. Gypsum application decreased pHe, ECe, exchangeable Na^{+}, ESP, CO_3^{2-} and HCO_3^{-} contents but increased the organic matter content, exchangeable Ca^{2+} (María *et al*., 2018).

2.6.2. Halophyte plants as phytoremediation

Kelly, (1937), introduced phytoremediation or vegetative bioremediations of sodic and saline-sodic soils ameliorated using Bermuda grass. Since then many researchers have studied the potential of plant-based approaches in the reclamation of salt-affected soils (Qadir *et al*., 2001; Qadir and Schubert, 2002; Ahmad *et al*., 2006; Ammari *et al*., 2008). Singh, (1998) reported the farming history of the Indian Subcontinent reveals the cultivation of certain salt-resistant grasses and trees as an important step in the management of salt-affected soils.

From scientific research and farmers' feedback, sodic and saline-sodic soils of highly productive state ameliorated through a plant-assisted approach called phytoremediation (Kumar and Abrol, 1984; Mishra *et al*., 2002; Qadir *et al*., 2002). Synonymous terminology for phytoremediation includes vegetative bioremediation, phytoamelioration, biological reclamation bio-saline agriculture.

As salinity tolerance is a highly complex trait, both physiologically and genetically, it is hardly surprising that progress in crop breeding for salinity tolerance has been very modest during most of the 20th century, with no truly salt-tolerant cultivars delivered to farmers fields (Flowers, 2004). Halophytic species possess a range of highly efficient and complementary morphological, physiological and anatomical characteristics to combat and even benefit from a salt-affected environment (Flowers and Colmer, 2008; Shabala, 2011).

Qadir *et al*., (2002) reported phytoremediation as a plant-based strategy for contaminated soils, work through the cultivation of specific plant species capable of accumulating ions in their shoots, thereby removing them from the soil. Salt tolerance refers to the ability of a plant to maintain growth and metabolic function (including photosynthesis) when exposed to a high concentration of salt in the soil or irrigation water (Denise, 2003). Even though, plating of deep-rooted native vegetation used to maintain the water tables below the surface (Podmore, 2009).

The success of phytoremediation requires a greater understanding of the potential of plant species to withstand ambient salinity and sodicity levels in the soil and water (Quadir *et al*., 2007). The growth of many halophytic species is stimulated within a salinity range of 15-25 dS m^{-1} (Rozema and Schat, 2013). The grasses increase the level of CO_2 during roots and microbial respiration in the rhizosphere, which upon dissolution in water acts as a weak acid and helps in the dissolution of soil calcite (Qadir *et al*, 2002) resulted in reduction pHe.

In Ethiopian salt-affected areas, Rhodes grass (*Chloris gayana*) is the most suitable salt-tolerant forage crop as compared to other grass species (Ashenafi *et al*., 2019). Similarly, Deifel *et al*., (2006) indicated that *Chloris gayana* as the most salt-tolerant forage grass.

The growth of these grasses in salt-affected lands also results in remarkable improvement in soil quality. Soil salinity generally decreased markedly in all grass treatments from a mean ECe value of 12.3 to 3.7 dS m^{-1} in the upper 0-30 cm soil layer. Rhodes grass (*Chloris gayana*) and Blue panic (*Panikum antidotale*) were reported as promising grasses for sodic soils. There was also an improvement in soil pH and bulk density characters resulting from the growth of salt-tolerant grass species (Akhter *et al*., 2003).

The Panicum and Rhodes grasses have grown in Awash Ethiopia there is a continuous decrease in soil sodicity and an improvement in soil physical properties due to the biological action of grassroots (Qureshi *et al*., 2018). The grasses have different mechanisms to tolerate salinity. These include increased root growth, ion exclusion, osmotic adjustment, compartmentalization, glandular secretion and formation of compatible osmolytes (Marcum, 2007). Removing salt from shoot tissue through different means is associated with overall salinity tolerance. Thus, the ability to exclude Na^+ and Cl^- by their excretion glands of the abaxial as well as adaxial surfaces of the leaves (Marcum, 1999).

Marcum and Murdoch, (1994) reported that salt gland density and excretion rates of those grasses increased due to the increases soil salinity. The salinity tolerance achieved by excluding the Na^+ and Cl^- ions from the shoots with the aid of salt glands are a common trait in grass genotypes. Their excretion response increased when salinity increased up to 32.5 dS m^{-1} (Baldwin *et al.*, 2006). Bonales-Alatorre *et al*., (2013) found that grasses accumulate the harmful ions in ‘‘vacuoles’’ which account for more than 90% of the plant cell. This helps in preventing the potential damage that the ions would cause to the proper functioning of the plant.

Cynodon dactaylon has a wide range of genotypes tolerating various salt regimes hence it is wise to evaluate them up to seawater level, Ecw = 54 dS m^{-1} or 34,560 mg/L (Duncan and Carrow, 1999). Similarly, Rhodes grasses have a special preference to adsorb excess Na^+ than other ions by its “salt gland” resulted in a significantly decreased ECe, pHe, SAR and ESP (Kobayashi *et al*, 2007). All studies indicate the effectiveness of plants to help improve soil function and productivity under irrigated conditions.

2.6.3. Combined application Gypsum amendments and phytoremediation

Abdel-Fattah, (2012) studied the efficiency of gypsum, rice and their different combinations on reclamation of clay saline-sodic soils. The results indicated that all the amendments used either, singly or in combination decreased the ECe, pHe, SAR, and ESP markedly compared to control. While the combined application was more efficient than individual application.

Ilyas *et al*., (1997) indicated that, in a field experiment conducted at Jodhpur (Rajasthan) on alkali soils, treatments receiving crop rotation with gypsum application significantly decreased the pHe, ECe, SAR and chlorides in the top 20 cm soil. Salim *et al*., (2002) carried out field experiments using gypsum, calcium chloride and ameliorative rice crop to compare the relative efficiency for reclamation of sodic soils. Results showed a significant increase in crop yields and the soil salinity and sodicity decreased.

A lysimeter study was conducted to assess the impact of some crop rotations and gypsum on amelioration of a calcareous saline-sodic soil irrigated with marginal-quality water (EC =1.0 dS m-1, SAR = 4.2, RSC = 3.1 mmolc L-1). It has been observed that cropping with salt-loving rice with soil application of gypsum treatment removed greater amounts of sodium (Na^+) from the root zone leaving behind the minimum level of sodium adsorption ratio (SAR) (Ahmad *et al*., 2006).

A 3-year saline-sodic soil field experiment was conducted in Pakistan by gypsum, tile drainage and halophytic species through utilized low-quality irrigation water (EC 2.7 dS m^{-1} and SAR 8.0). The finding suggested that 100% gypsum requirement (G) + Sesbania aculeata was the most effective treatment with reducing both ECe (24 to 4.6 dS m^{-1}) and SAR (120 to 19). (Ghafoor *et al*., 2012).

2.7. Effect of Gypsum and Halophytic Grasses on Infiltration of the Soil

Gypsum application improves soil aggregates resulted in increases of infiltration rate and total porosity (Abou Yuossef, 2001). Many investigators have reported that gypsum application improves water and air permeability (Yu *et al*., 2014b) due to the decreased surface crusting, improved flocculation and aggregate stability (Clark *et al*., 2007; Chi *et al*., 2012).

Kumar and Thiyageshwari, (2018) reported that the application of gypsum to sodic and saline-sodic soils increase in hydraulic conductivity. Ahmad *et al*., (2001) and El-Fattah, (2006 and 2011) reported that hydraulic conductivity and infiltration rate increased with gypsum application. Similarly, the salinity levels in soil solution during phytoremediation maintain adequate soil structure and aggregate stability that facilitate water movement through the soil profile and enhance the amelioration process (Oster *et al*., 1999). The growing salt-tolerant Rhodes and Panicum grasses in Awash Ethiopia not only provide much-needed forage but also improve the soils resulting in increased absorption of rainwater, reducing runoff and soil losses (Qureshi *et al*., 2018).

A 3 years saline-sodic field experiment in Pakistan indicates that the application of 100% gypsum requirement (G) + Sesbania aculeata improves the infiltration rates of the soil (Ghafoor *et al*., 2012).

2.8. Performance of Forage Grasses in Salt-affected Soil (Biomass Yield and Nutrient Compositions)

Chaudhry *et al*., (2001) reported over 40 grass species from the salt range area, many of them are highly palatable and nutritious. Panicum grass (*Cynodon dactylon*), *Sporobolus arabicus*, *Imperata cylindrica*, *Aeluropus lagopoides* and *Desmostachya bipinnata* dominate the saline arid habitats. Since these grasses have been growing in the salt range, they expected to be well adapted against very high salinity. Under high saline soil conditions, planting salt-tolerant forage grasses and legume crops are more practical than field crops. Field and greenhouse studies have shown that Karnal grass (*Diplachne fusca*), Rhodes grass (*Chloris gayana*), Para grass (*Brachiaria mutica*) and Bermuda or Panicum grass (*Cynodon dactylon*) are highly salt-tolerant and can be successfully yielded in saline and sodic soils.

Karnal and Rhodes grasses grow extremely well in soils of very high ESP (80 to 90) even when no amendment is applied. In Pakistan, dry matter yields of 7.5 tons per hectare have been reported (Chang *et al*., 1994).

Studies done by Werer Agricultural Research Centre in Ethiopia during 2011-2014 have shown promising results in terms of salinity tolerance, biomass yield and ameliorative effects for four forage crop species, that is, *Cinchrus* species, *Panicum antidotal*, Sudan grass and *Chloris gayana* and 3 legume species *Desmodium triflorum*, *Sesbania sesban* and *Medicago sativa* (Alfalfa). The biomass yields obtained under saline soil conditions were closely comparable with those obtained under normal soil conditions (EIAR, 2016).

Under saline stress condition *Chloris gayana* (Rhodes grass) gave the highest mean fresh biomass yield (127 tons/ha/year), closely followed by *Cinchrus* species (118 ton/ha/year). Dry matter yield obtained under saline soil was also higher in *Chloris gayana* (36 tons/ha/year) and *Cinchrus* species (37 tons/ha/year) than both *Panikum antidotal* (30 tons/ha/year) and Sudangrass (27 tons/ha/year) (EIAR, 2016). Based on Kumar and Abrol, (1983) yield of five grasses in response to three levels of gypsum application in a highly sodic soil (ESP is 90) relative to their respective yields under normal, soil conditions; Karnal and Rhodes grass grasses gave high yield even in the control plots (no gypsum) indicated its high tolerance of sodic conditions.

Al-Khalifah, (2004) studied the response of Cynodon dactaylon grasses at two salinity levels (4.6 and 10.72 dS m^{-1}). The higher amount of biomass appeared at high salinity by tolerated the increased salt concentration in the soil and showed good forage quality with respect to color. Similarly, Pessarakli *et al*., (2008) found that the canopy color changed to lighter green for Cynodon species of (Bermuda grass) as salinity concentration increased.

Temel *et al*., (2015) studied the performance of some forage grass species in non-saline, saline and alkaline soil. Based on the result a decrease in crude protein ratio of Cynodon dactylon and under saline and alkaline soil than the non-saline soil. The higher yields of Cynodon dactylon (Bermuda grass) in saline vs non-saline soils indicates its greater salt tolerance. This higher soil salinity did not affect the chemical composition or crude protein content.

A field experiment was carried out at the University of Agriculture, Faisalabad (Pakistan) during 1988–90 to evaluate the comparative efficiency of chemical and biological methods for the reclamation of calcareous saline-sodic soil. From the result, Sesbania and kallar grass were found to be effective biotic materials for soil reclamation. These plant species produced substantial biomass and also improved the soil environment by lowering the EC and SAR of the soil (Ahmad et al., 1990).

2.9. Effect of Gypsum on the Performance of Halophytic Grasses

Gypsum application in different doses (0, 25, 50, 75, 100 and 200 % of the gypsum requirement) increased the forage yield of Rhodes grass by 9.8 to 25.3 % and that the Panicum grass by 10-80 % over control. The maximum increase occurred with the application rate of 200 % of GR in both cases (Khattak *et al.,* 2007).

A field experiment to study the effect of 5 gypsum levels (0,3,12, 6.25, 9.37 and 12.50 t/ha) on the performance of 5 forage kinds of grass NB 21 hybrid Napier, Para grass, Setaria grass, Guinea grass (Panicum maximum) and Anjan grass was conducted in saline-sodic soil having pH of 10.5. The result indicated that the survival percentage of all the grasses increased with increasing gypsum dose except for Para grass. At 12.5 t/ha gypsum level there was a significant increase in the number of tillers, forage yield and plant height compared with the control and small amount gypsum received experimental treatments (Kumar, 1988).

Ali *et al*., (2007) reported that forage biomass production mainly depends on the amount of gypsum application and seasonal climatic variation. They stated that the application of gypsum in increasing dose was more increases grass yield and yield components. On the other hand, the average cutting effect of grasses as observed in the experimental field indicates that the cuts occur during the rainy season are favorable for plant growth. Similarly, when the humidity and warm temperature exist, generally gave higher biomass yields than those obtained from cuts taken in either summer or winter.

Yilmaz *et al*., (2009) have a similar experience reported that the effect of gypsum application on forage performance was greatly influenced by time, space and season. A long term field experiment was started in 1979 to study the effect of 3 levels of gypsum, 0, 5.2 and 10.4 t/ha on the performance of 5 perennial forage grass species, Rhodes grass, Blue panic, Kamal grass, Coastal Bermuda and Panicum grass on a highly alkali soil having an initial pH 10.6 in

Gudha village of Kamal district. The result indicated that forage yield survival percentage of grasses as the application of gypsum increased (Maestre *et al*., 2001).

George *et al.*, (2004) reported that gypsum application increases grass yield (by 32-52 %) and it's quality. Repeated application of gypsum at Rhodes and Burmudagrass did not affect the growth or soil physical properties, even though appreciable Na was supplied in the irrigation water.

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The sites identified for the study are located at different irrigation schemes of Golina-Adisalem and Kobo irrigation research station Raya Kobo Wereda, Eastern Amhara Regional State. These two adjacent irrigation schemes are located at 570 km in the North of Addis Ababa and 50 km from Woldia town to the Northeast direction. It is geographically, situated between 12.03°-12.08° N latitudes and 39.28°- 39.42° E longitudes. Topographically, the area is a flat plain at an altitude of 1470 and 1368 m.a.s.l. for Kobo irrigation research experimental site (normal field) and Golina-Adisalem salt-affected field respectively. Both sites were irrigated with groundwater sources.

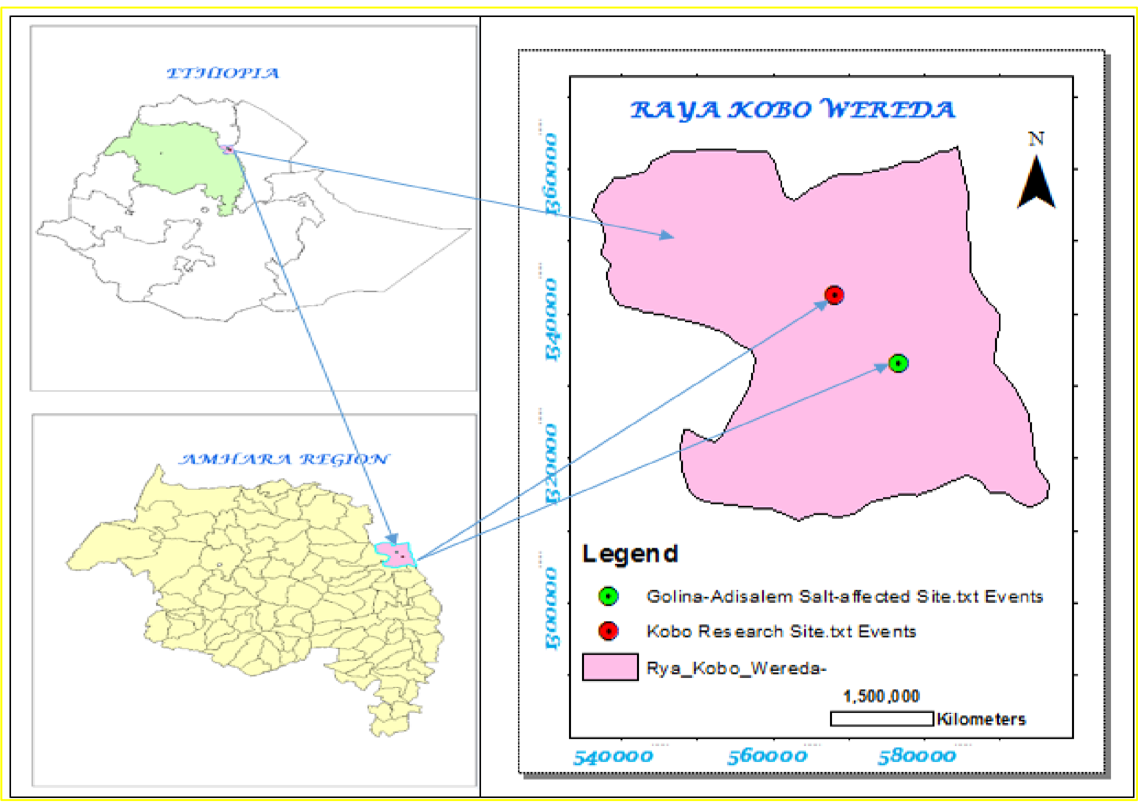

Figure 1. Location map of the study area

The Amhara region in Ethiopia; Raya Kobo Wereda in Amhara region; Golina-Adisalem (salt-affected) and Kobo irrigation research site (normal) in Raya Kobo wereda; Raya Kobo Wereda.

3.1.2. Climate

The average annual rainfall is 644.08 mm, characterized as a bimodal rainfall pattern (from Kobo Metrological Station, 2002 - 2018) with two distinct rainy seasons. The main rainy season called "Kiremt" that extends from mid-July to early September, while the short rainy season "Spring" (from March to mid-May). Due to the early secession, uneven distribution and erratic nature of rain resulted in recurrent drought and crop production mainly depends on irrigation. Surface and groundwater development is the one component to diversify the agricultural system of the area in a place where there is a good potential of groundwater (Getahun, 2014). The annual mean minimum and maximum temperatures are 8.49 °C and 36.58 °C respectively with the annual mean monthly rainfall 53.67 mm.

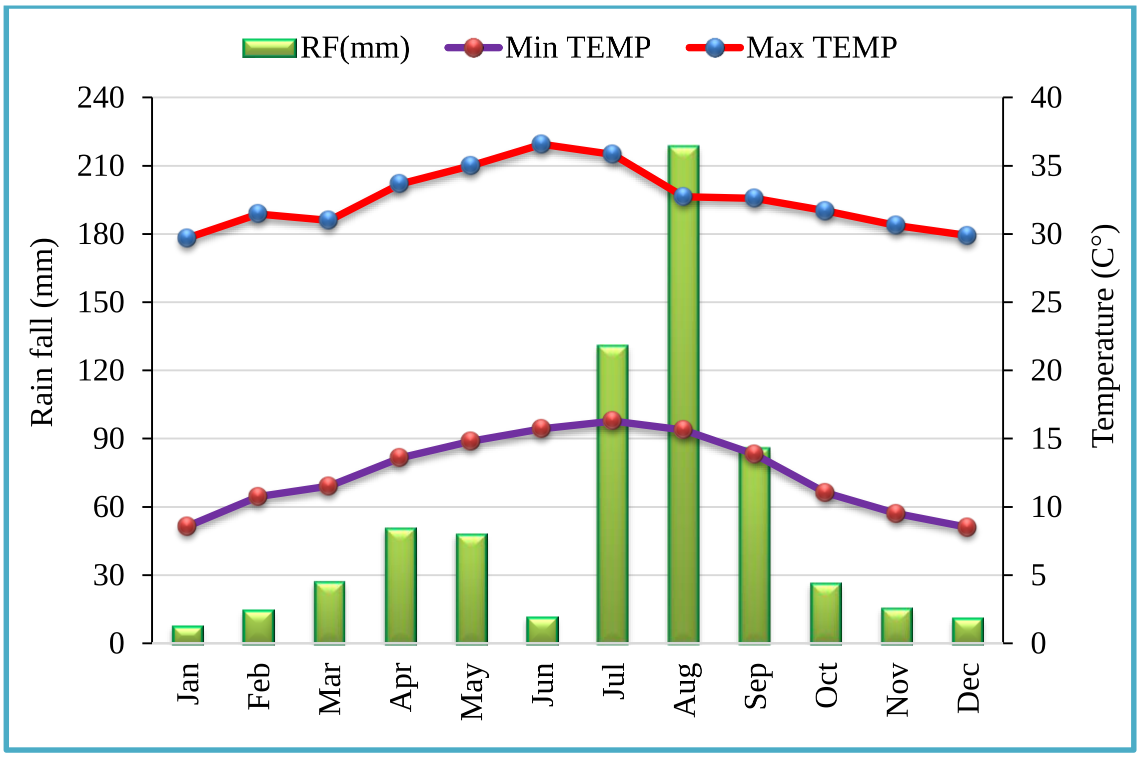

Figure 2. Mean monthly rainfall (mm), maximum and minimum temperatures (C°) of the study area (2002 – 2018)

3.1.3. Drainage systems of Golina-Adisalem irrigation scheme

The major drainage systems in Golina-Adisalem salt-affected irrigation scheme is associated with rivers within the valley plains. The rivers in the valley originate from the western mountains. There is high drainage density in the western highlands and low both in the valley floor and eastern highlands. All rivers (Golina, Hormat and Kelkelit) and streams carry large volumes of sediments from the mountains in the rainy seasons and deposit on the valley plain. The valley classified into two major sub-basins namely, Hormat- Golina and Kelikelit-Woylet sub-basins. The Hormat-Golina basin constitutes the drainage systems of Hormat and Golina. However, during rain, Woylet and Kelkelit lose their discharge in the plain before joining the Golina River that ultimately discharges through the Golina gorge to the Afar depression (Getahun, 2014; Merse, 2018).

3.1.4. Pumping well characterstics of Golina-Adisalem irrigation scheme during the design period

Based on KGVDP, (2009) report, that the well depth below the ground (117 m), Casing diameter (254 mm), Static water level (8.00 m), Dynamic water level (19.24 m), Pumping test rate (50 l/s), Draw dawn (11.24 m), Production yield (50 l/s), Pump position during pump test (51 m) and Recommended pump position (51 m).

3.1.5. Preliminary results of the hydrogeological formations of Golina-Adisalem irrigation scheme

The groundwater hydrology and geological formations of Golina-Adisalem salt-affected experimental area studied using ABEM surveying instrument, it had integrated systems of receiver and transmitter (Figure 3). Stainless steel electrodes and reels with cable used to inject an electric current into the ground and receive the required signal. Portable walkie-talkie radios for communication purposes and GPS instrument used to navigate and locate the observation points also used.

The resistivity measurements was carried out at the three VES (vertical electrical sounding) points for 1000 m length in N-S azimuth up to the depths of 400 m.

The observed resistivity data were interpreted in terms of layer parameters (depth and true resistivity) using the *IPI2WIN 2.1* software.

From the result (Figure 4), unconsolidated deposit marked by resistivity values ranging from 5.72 to 7.56 Ohm-m extending to a depth of 35 m could be attributed to silt with coarser sand. The lower margin resistivity value (5.72) is attributed to finer deposit and the resistivity value of 7.56 Ohm-m is associated with a coarser deposit. Underlying the unconsolidated deposit, a layer characterized by resistivity values ranging from 8.7 up to 13.2 Ohm-m, is the response of highly weathered and fractured basalt which extends to a depth of 130 m. The third layer revealed a relatively higher resistivity values ranged from 15.2-20.1 Ohm-m which extends to a depth of 400 m, is the responses of slightly weathered and fractured basalt.

Figure 3**.** Hydrogeology surveying using ABEM instrument

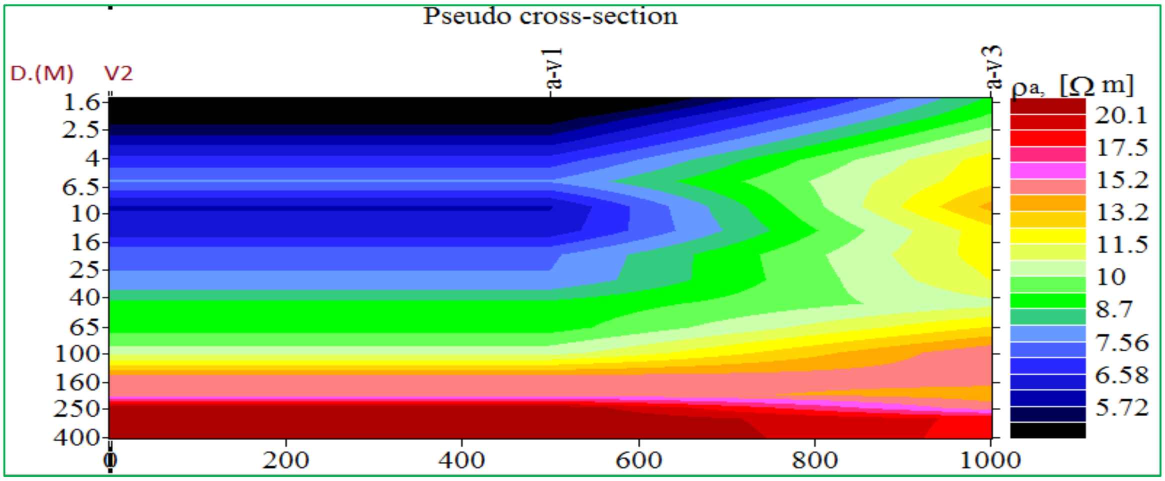

Figure 4. Interpretation geo-electrical section of the three points (VES-1, VES-2, VES-3)

The lower resistivity of geological unit even in the topsoil layer indicates the presence of sufficient moisture and the water table remains closer to the surface within 1.6 m depth (Figure 4).

3.2. Soil Sampling and Preparation

From the two experimental sites, disturbed soil samples collected using auger. At Golina-Adisalem salt-affected experimental field, soil sample collection mainly takes place for three consecutive phases as initially (before the experiment), after the first and second harvest. Thus, before experiment 20 composite soil samples collected by two-way diagonal sampling technique and at each experimental plot after the first and second harvest. In the non-saline (normal) irrigation scheme of Kobo research site, soil samples collected only once (before the start of the experiment) to describe the selected physicochemical characteristics of the site.

The sampling depths were 0-20, 20-40 and 40-60 cm for soil chemical analysis and an additional 60-100 cm depth examined for physical analysis to scheduled irrigation water up to maximum rooting (100 cm) depth of forage grasses (Allen *et al*., 1998). The subsurface soil sample (20-40, 40-60 and 60-100 cm) were collected at the same spots, in place where surface samples collected.

Most researches focused on keeping the main root zone salinity resulted, the salinity and sodicity dynamisms of Golina-Adisalem salt-affected irrigation scheme (pHe, ECe, SAR and ESP) were monitored up to the active rooting zone (60 cm) (Tyagi, 2001). Similarly, undisturbed soil samples from those depths collected using core sampler. During sample collection, dead plants, forest litter, and animal dungs excluded.

The collected samples transported to the laboratory and spread on a polythene sheet kept for air-drying at room temperature. The dried soil samples ground to pass-through 2 mm sieve and mixed thoroughly preserved for further physicochemical analysis in Sirinka Agricultural Research Center (SARC).

3.3. Soil Analysis

3.3.1. Analysis of selected soil physical properties

The soil physical properties include bulk density, texture, water retention at field capacity (FC) and permanent wilting point (PWP). Particle size distributions determined by the Bouyoucos hydrometer method using sodium hexametaphosphate for dispersing agent as pointed by Sahlemedhin and Taye, (2000).

Soil bulk density obtained from undisturbed soil samples using the oven-dry method by dried soils for 24 hrs at 105°c and weighed to calculate the dry density using the equation (Blake & Hertge, 1986).

$$\rho_b = \frac{W_d}{V_c} \qquad (1)$$

Where ρ_b= soil bulk-density (gm/ cm^3)

W_d= weight of dry soil (gm)

V_c= volume of core (cm^3)

The soil moisture content at FC and PWP measured using a pressure plate apparatus by applying suction pressures of 0.33 and 15 bar, respectively.

3.3.2. Analysis of selected soil chemical properties

Exchangeable cations (Ca^{2+} + Mg^{2+} and Na^{+}) and anions ($CO3^{2-,}$ $HCO3^{-}$ and Cl^{-}) determined from the extraction of neutral normal ammonium acetate. The water-soluble bases (Ca^{2+} + Mg^{2+} and Na^{+}) analyzed by saturated paste extract using distilled water (FAO, 1999). Both exchangeable and soluble Na^{+} determined using a flame photometer, on the other hand, exchangeable and water-soluble Ca^{2+} and Mg^{2+} measured using Atomic Absorption Spectrophotometer (AAS) by titration. The cation exchange capacity (CEC) analyzed by neutral normal ammonium acetate method followed the percolation tube procedure (Busenberg and Clemency, 1973).

The most important parameters for expressed salt-affected soils are soil reaction (pHe), electrical conductivity (ECe), exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) (USSLS, 1954; Qadir and Schubert, 2002; Gonzalez *et al.*, 2004; Horneck *et al.*, 2007). Soil reaction (pHe) and electrical conductivity (ECe) measured from saturated paste extract using digital pH-meter and conductivity meter respectively followed the methods as stated by USSLS, (1954) and FAO, (1999). Exchangeable sodium percentage (ESP) is the amount of adsorbed Na^{+} on the soil exchange complex to the CEC of soil and sodium adsorption ratio of the saturation extract (SAR) is another parameter, indicates the proportion of water-soluble sodium to calcium plus magnesium in the soil. ESP and SAR computed from the derived parameters by the equation (USSLS, 1954; Miller & Gardiner, 2007):

$$\mathrm{ESP} = \frac{\mathrm{Exchengeable\ Na^{+}}}{\mathrm{CEC}} * 100 \tag{2}$$

$$\mathrm{SAR} = \frac{\mathrm{soluble\ Na^{+}}}{\sqrt{\frac{(\mathrm{Ca^{2+}+Mg^{2+}}}{2}}} \tag{3}$$

Where $\mathrm{Exchengeable\ Na^{+}}$ = cmole (+)/kg, meq/100 gm or meq/l

CEC = cmole (+)/kg, meq/100 gm or meq/l

$\mathrm{Soluble\ Na^{+}}$ = meq/l

$\mathrm{Ca^{2+} + Mg^{2+}}$ = meq/l

ESP (%) and SAR (unitless)

3.4. Determination of Gypsum Requirement and Application Procedure

Before determining the amount of gypsum required to replace soil exchangeable sodium; the initial ESP, desired final ESP, purity, bulk density, cation exchange capacity (CEC), reclaimed depth of initial soil and its application were considered (Lamond and Whitney, 1992). Then, the upper 0.2 m soil layer tilled to break up hardpans for enhancing the downward flow of water. The amount of gypsum ($CaSO_4 . 2H_2O$) required to replace 1 meq of Na^+ per 100 gm of soil for restoring the top 0.2 m soil layer was calculated using the equations below (FAO, 1988):

$$G = \frac{\mathrm{CEC} * d * \rho b * 0.081\ (\mathrm{ESP_a} - \mathrm{ESP_f})}{f} \tag{4}$$

Where G = Amount of gypsum required in t/ha in a layer (soil depth) of d meter,

CEC = Cation exchange capacity in meq/100g or [cmole (+)/kg] of soil,

d = Reclaimed soil depth (m),

ρb = Bulk density of soil in kg/dm^3 or Mg/m^3 or ton/m^3,

ESP_a = Actual (initial) ESP of the soil as determined by analysis,

ESP_f = Final ESP or threshold arrived at after reclamation, usually (5-10%), However, 10% used for this experiment and

f = Efficiency (purity) of gypsum application in (100 %).

$$G = \frac{\mathrm{ESP_a} - \mathrm{ESP_f}}{100} * \mathrm{CEC} * yz \tag{5}$$

Where G =Amount of gypsum required in ton/ha for restoring soil structure (0.2 m layer),

ESP_a = Actual (initial) ESP of the soil as determined by analysis,

ESP_f = Permissible or final ESP arrived at after reclamation,

CEC = Cation exchange capacity in meq/100g [cmole (+)/kg] of soil and

yz = Amount of gypsum required in ton/ha to replace 1 meq of Na per 100 g soil in a 0.2 m thick.

The formula given above is only a rough approach to estimate the amount of gypsum for replacing exchangeable Na^+ (FAO, 1988). However, overall, gypsum efficiency is dependent on the rate of application, the duration of the study and the amount of water available to solubilize gypsum provide mobility of Na^{+} to lower horizons (Breker, 2016). Therefore, four gypsum levels as 0 %, 75%, 100% (calculated gypsum) and 125 % were validated under field condition.

Prior to planting 20 days before those gypsum levels mixed thoroughly for a 20 cm soil layer using local maresha and the soil moisture was monitored up field capacity to facilitate reaction.

Figure 5. Salt affected soil at Golina- Adisalem irrigation scheme

Figure 6. Gypsum application

Table 3. Properties of amendment

Gypsum ($CaSO_4 . 2H_2O$)	pH	Purity [%]
	7.8	100

*obtained as a by-product of gypsum manufacture Adigudom, (2018).

3.5. Determination the Effects of Gypsum and Halophytic Grasses on Infiltration Rate

The infiltration test was done after termination of the experimentation (after 131 days) from each experimental treatment using a double-ring infiltrometer with diameters of 30 and 60 cm. The outer and inner rings were installed into 15 cm soil depth by hammering. The tests had been started in the inner ring by ponding water up 8 cm depth. At the same time, the water added to the space between the two rings which approximated the same depth used as a buffer for preventing the lateral movement of water. During recording, the water level in the inner cylinder and stopwatch were used. The process continued until the drawdown of the water level was the same over the same time interval.

3.6. Determination the Effects of Gypsum on the Local Groundwater

Based on Lebron *et al*., (1994) stated that substitution of exchangeable Na^+ by Ca^{2+} produces soluble sodium sulfate salt (Na_2SO_4). This Na_2SO_4 is leachable by irrigation water that may affect groundwater quality (Pitman and Läuchli, 2002). After termination of the experimentation whether replaced leachable Na_2So_4 by applied Ca^{2+} source gypsum affects the quality of local groundwater or not; deep percolated water samples collected from the control plot and at each gypsum received experimental plots by excavation sampling pits with the depth of 1.5 m. The electrical conductivity (ECw), total dissolved solids (TDS), soluble Na^+, Ca^{+2} and Mg^{+2} concentration of the applied irrigation water and the deep percolated water samples were determined following the procedures outlined by the USSLS, (1954).

The TDS derived from ECw as equation below (Bauder *et al*., 2007);

$$\mathrm{TDS\ (mg/L)} = \mathrm{ECw(dS/m)} * 640 \tag{6}$$

Where the ECw < 5 dS/m

$$\mathrm{TDS\ (mg/L)} = \mathrm{ECw(dS/m)} * 800 \tag{7}$$

Where the ECw > 5 DS/m

3.7. Determination of Crop Water Requirement

All treatments have been received an equal amount of water, based on the actual soil condition, crop character and by monitoring daily climatic data.

3.7.1. Determination of reference evapotranspiration (ETo)

Throughout the experimental season, actual daily climatic data (maximum and minimum temperature, relative humidity, wind speed and sunshine hour's) and geographical locations of the experimental site (altitude, latitude and longitude) collected from Sirinka Agricultural Research Kobo sub-center metrological station. Daily ETo values determined using Penman-Monteith method Allen *et al*., (1998) with the aid of a computer-based CROPWAT 8.0 model.

3.7.2. Determination of actual evapotranspiration (ETc)

Daily actual evapotranspiration of the three growth stages, from initial up to mid-season stage determined by the equation (Allen *et al.*, 1998);

$$\mathrm{ET_c} = \mathrm{K_c} * \mathrm{ET_o} \tag{8}$$

Where, ETc= Actual evapotranspiration (mm day^{-1}),

$\mathrm{K_c}$= Crop coefficient factor and

$\mathrm{ET_o}$ = Reference evapotranspiration.

Table 4. Relevant Rhodes and Panicum grass data for first-round irrigation

Growth stage	Initial	Development	Mid	Late	Total
Stage lengths (days)	15	15	29	-	59
Basal Crop coefficient (Kcb)	0.5	>>	1.15	-	
Rooting depth (m)	0.4	0.6	1	-	
Depletion levels (P)	0.5	0.5	0.5	-	

Becauce, Rhodes and Panicum grasses were grown for forage or hay are perennial and yielded several times as once planted (Allen *et al.,* 1998). Therefore, the experiment was monitored up to two harvestings.

As indicated in Tables 4 and 5, the total growing periods of 59 and 52 days for reaching first and second cutting respectively. The amount of water applied was monitored based on allowable depletion level (p), growth stage, maximum root depth and crop coefficient factor (kc) correspondingly.

Table 5. Relevant Rhodes and Panicum grass data for second-round irrigation

Growth stage	Initial	Development	Mid	Late	Total
Stage lengths (days)	10	15	27	-	52
Basal Crop coefficient (Kcb)	0.5	>>	1.15	-	
Rooting depth (m)	1	1	1	-	
Depletion levels (P)	0.5	0.5	0.5	-	

In the second-round irrigation scheduling, the plant root maintained 1 m throughout the growing season as once reach in the first-round irrigation.

The basal crop coefficient (K_{cb}) or tabulated crop coefficient ($K_{c\ tab}$) used at the standard climatic conditions, where a daily relative humidity (RHmin ≈ 45 %) and wind speed (u_2 ≈ 2 m/s). When the daily RHmin differs from 45 % or u_2 is larger or smaller than 2.0 m/s specific adjustment had needed by monitoring actual daily aerodynamic data.

Therefore, the actual climatic data throughout the experimental season was monitored and the crop coefficient values adjusted by the equation (Allen *et al.*, 1998);

$$K_{c\ adj} = K_{c\ tab} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)](\frac{h}{3})^{0.3} \quad (9)$$

Where $K_{c\ adj}$ = Adjusted crop coefficient,

$K_{c\ tab}$ = Tabulated crop coefficient,

u_2 = Mean value for daily wind speed [m s^{-1}],

h = Plant height at each irrigation event [m], for 0.1 m $\leq$ h,

RH_{min} = Mean value daily minimum relative humidity during the growth stage [RH1].

This equation applied only when the tabulated values for $K_{c\ tab}$ exceed 0.45. The mean plant height at each irrigation event obtained by direct measurement.

3.8. Determination of Irrigation Scheduling

Irrigation scheduling indicates how much and when to apply irrigation water.

3.8.1. Determination of net irrigation requirement

For applied the net depth of irrigation water (IR), the daily rainfall data before each irrigation event was monitored. The depth of irrigation water (IR) calculated using the equation (Allen *et al.*, 1998);

$$IR = ETc - P_{eff} \tag{10}$$

Where, IR = Irrigation requirement (mm),

ETc= Crop water requirement or actual evapotranspiration (mm) and

P_{eff}= Effective rainfall (mm).

3.8.2. Determination of effective rainfall

The effective rainfall is the part of rainfall that entered the soil and makes available for crop production. It can be calculated by using the AGLAW or dependable rain formula.
Because, the dependable rainfall is the rain that can be accounted for a certain statistical probability (Allen *et al.*, 1998);

$$P_{eff} = 0.6 * p - 10/3 \text{ If } P < \frac{70}{3} \tag{11}$$

$$P_{eff} = 0.8 * p - \frac{24}{3} \text{ If } P > \frac{70}{3} \tag{12}$$

Where P = Precipitation (mm/month) and

P_{eff} = Monthly decades of effective rainfall (mm).

The readily available water (RAW) is the amount of water that crops can extract from the root zone without stress. The RAW was determined using the formula (Allen *et al*., 1998);

$$RAW = \rho * TAW \tag{13}$$

Where RAW = Readily available water (mm),

TAW= Total available water (mm) and

ρ = Allowable soil moisture depletion (fraction) for each growth stage.

Total available water (TAW) designates the amount of moisture that can be stored in the plant root zone. However, not all the available soil moisture does easily available to plants. As the water suction pressure gets closer to PWP, it becomes tightly held by the soil particles (micro-pores) and the plant suffers because it needs high energy to extract.

$$TAW = 1000\left(\frac{FC - PWP}{100}\right) * Dz \tag{14}$$

Where TAW= Total available water (mm)

FC= Moisture content at Field capacity (% on volume basis),

PWP= Moisture content at Permanent wilting point (% on volume basis) and

Dz= Maximum root zone depth (m).

Stage based irrigation interval was computed by water balance calculations using RAW and ETc from the expressions below (Allen *et al.*, 1998);

$$T = \frac{RAW}{ETc} \tag{15}$$

Where T= Irrigation interval for each growth stage (days),

RAW= Readily available water (mm) and

ETc= Daily crop water requirement (mm day^{-1})

The gross irrigation requirement, IRg, in each irrigation event computed from the expression (Allen *et al.*, 1998);

$$\mathrm{IR_g} = \frac{\mathrm{Interval} * \mathrm{IR}}{\mathrm{Ea}} \tag{16}$$

Where $\mathrm{IR_g}$= Gross irrigation requirement (mm day^{-1}),

IR = Irrigation requirement (mm) and

$\mathrm{E_a}$ = Application efficiencies of surface irrigation projects ranged from 45-60 %, for this study undertaking (60%).

3.8.3. Flow time measurement

A 3-inch standard partial flume was set near the up-stream furrows, to monitor the rate of inflowing irrigation water.

Based on the water head with the corresponded discharge gauged table (Appendix Table 15), the time required to irrigate the calculated gross irrigation depth for 3 m*3 m (9 m^2) plot area as;

$$\boldsymbol{t} = \frac{\boldsymbol{d_{rz}} * \boldsymbol{l} * \boldsymbol{w}}{\boldsymbol{6} * \boldsymbol{q}} \tag{17}$$

Where $\boldsymbol{t}$ = time in (min),

$\boldsymbol{d_{rz}}$=depth of root zone or gross irrigation depth in (cm),

$\boldsymbol{l}$= length in (m),

$\boldsymbol{w}$=width in (m) and

$\boldsymbol{q}$=discharge (L/s).

3.9. Experimental Design and Treatments

The experiment consists of two-factors. The first factor corresponded to four levels of agricultural gypsum (0 % G, 75 % G, 100 % G and 125 % G), while the second factor corresponded to two ameliorative halophytic grasses (0H, RG, PG).

Using the zero halophytes (0H) provides for constructing the control experimental plot. The treatments constructed either using the two-factor levels in single and by factorial combination. Totally 12 treatments were tested using factorial RCBD design with three replication. Each, experimental plot sizes of (3m * 3 m = 9 m^2) and the distance between blocks and plots were 2 and 1 m respectively.

The experimentation carried out phase by phase: as the two halophytic grasses (Rhodes and Panicum) transplanted after 20 days at a pre-treated with gypsum and non-gypsum experimental plots by their roots. The plant roots obtained from SARC experimental site. The spacing between rows and plants was 50 and 20 cm respectively (SARC, 2008). Each plot had six end-blocked furrows with 15 plants in each row as total plant populations of 90 plants within a plot.

The single and combined experimental treatments constructed as:

Treatment Code	Treatment Combination
T1	RG (*Chlorosis Guayana*) + 0 % G
T2	RG (*Chlorosis Guayana*) + 125% G
T3	RG (*Chlorosis Guayana*) + 100% G
T4	RG (*Chlorosis Guayana*) + 75% G
T5	PG (*Cynodo Dactaylon*) + 0 % G
T6	PG (*Cynodon Dactaylon*) + 125% G
T7	PG (*Cynodon Dactaylon*) + 100% G
T8	PG (*Cynodon Dactaylon*) + 75% G
T9	125% G + 0H
T10	100% G + 0H
T11	75% G + 0H
T12	Control (0% G + 0 H)

Where, *G- Gypsum requirement,

*0H- No halophytic or without any grasses,

*RG- Rhodes grass- Massava variety and

*PG- Panicum grass- Maxima variety

RI	P1 T_3	P2 T_4	P3 T_6	P4 T_8	P5 T_2	P6 T_7	P7 T_5	P8 T_1	P9 T_9	P10 T_{11}	P11 T_{10}	P12 T_{12}
RII	P24 T_{12}	P23 T_{10}	P22 T_9	P21 T_{11}	P20 T_6	P19 T_4	P18 T_8	P17 T_2	P16 T_7	P15 T_5	P14 T_3	P13 T_1
RIII	P25 T_8	P26 T_5	P27 T_3	P28 T_6	P29 T_1	P30 T_4	P31 T_7	P32 T_2	P33 T_{10}	P34 T_{11}	P35 T_9	P36 T_{12}

Figure 7. Randomization of treatments across the replication

Where, R (I, II and III), P and T indicates replication number, plot number and treatment number respectively

3.10. Soil Moisture Determination

During the start of stage-based irrigation interval, the initial moisture content was determined and refill up to FC for grasses establishment. At each irrigation event, the soil moisture monitored 1 day before watering the experimental plot. The wet soil samples oven-dried at 105°C for 24 hrs. It determined by the expression;

$$\theta_{dw} = \frac{W_{ws} - W_{ds}}{W_{ds}} * 100 \quad (18)$$

Where θ_{dw}= water content expressed on a weight basis in (%),

W_{ws}= weight of wet soil (gm) and

W_{ds} = weight of dry soil (gm).

The volumetric water content calculated from the gravimetric water content using the following expression;

$$\theta_v = \frac{\rho_b}{\rho_w} * \theta_{dw} \qquad (19)$$

Where θ_v= volumetric moisture content in (%)

θ_{dw}= water content expressed on a weight basis in (%)

ρ_b= soil bulk density (g/cm^3) and

ρ_w= water density g/cm^3 (1gm/ cm^3)

3.11. Evaluation of the Effects of Gypsum and Ameliorative Grasses on Saline-sodic Soil

The reclaiming efficiency of ameliorative grasses (Panicum and Rhodes) and agricultural gypsum either in single and by the combination of the two-factor levels evaluated using the analyzed soil salinity and sodicity parameters (pHe, ECe, SAR and ESP) (USSLS, 1954). In addition, their effects on soil infiltration rates were evaluated.

3.12. Evaluation of the Effect of Gypsum on the Performance of Halophytic Grasses

3.12.1. Effect of gypsum on biomass yield and yield components

Rhodes and Panicum grasses planted at two locations (saline-sodic, normal soil) which have the same climatic condition but different in soil character. In the saline-sodic field, those grasses tested at the gypsum received and non-gypsum experimental plots. Planting of grasses on the adjacent normal irrigation field mainly used as a location-specific standard to compare the obtained biomass yield and yield-related parameters under saline-sodic soil conditions with respect to those obtained in normal soil. Planting of those species for both locations carried out at the same time. The variances like, watering and weeding management practices applied homogeneously for both experimental sites.

In both experimental sites agronomic parameters like plant height, fresh and dry forage biomasses recorded from each plot of the four central rows by excluding the border rows and border plants.

Panicum grass cut out in full bloom stage (Belesky and Wilkinson, 1983; Burton, 1983; Serin and Tan, 1998) while, cutting of Rhodes grass was at the beginning of the emergence of panicles (Skerman and Riveros, 1990).

Ten plants per plot were selected randomly and measurements noted 1-2 days before harvesting by tapping the main stem height from the ground level up to the tip of the leaf using tap meter. The mean value of ten plants height recorded as plant height of each trial spot. Similarly, the fresh forage biomass obtained by harvesting the total central four rows plant population and it oven-dried at 70 C° for 24 hours and weighting using a sensitive balance instrument to get dry biomass yield (USSLS, 1954). The collected parameters changed from net plot level to ha base and encoded the data made ready for analysis.

3.12.2. Effect of gypsum on plant tissue quality

Leaf sodium

Marcum, (2007) reported that; salinity and sodicity for grasses considered as an opportunity. These species can remove soluble salts by root absorption, translocation with their shoots and transpiration to the opening stomata or absorbed by plant tissues. Whether this species really uptake ions or not, plant tissue samples collected from both locations (in saline-sodic and non-saline) and the concentration of Na^+ ion in the plant tissues been determined.

Crude protein ratio (%)

The nourishing value of forage gasses depends on their nutritional compositions such as crude protein (CP), ash and fiber contents (Ventura and Sagi, 2013). Crude protein is the most important element for animal diets that optimize their milk-producing capacity and meat quality (Al-Dakheel *et al.*, 2015).

The nitrogen content of 0.3-0.5 gm samples obtained from the dried ground plants in both first and second cutting. It determined by following the procedures outlined by USSLS (1954). The obtained nitrogen ratios multiplied with the coefficient of 6.25 to calculate crude protein ratios (Kacar, 1972 and Akyildiz, 1984).

3.13. Determination of Cost-Benefit Ratio and Net Return Analysis

The cost and benefit of each treatment analyzed partially, yield and economic data for comparing the advantages of grass varieties treated with and without gypsum. The total cost mainly includes operating and variable costs. Operating costs (labor, land preparation, and implement costs) based on the planted area. Variable costs depended on unit gypsum (Li, *et al*., 2005). According to CIMMYT, (1988) the average yield was adjusted downwards by 10 %, that the researchers have assumed the obtained yield using the same treatment in experimental plots and farmers' fields are different.

3.13.1. Determination of net return (NR)

$$\mathrm{NR} = \mathrm{Gross\ revenue} - \mathrm{Total\ cost} \qquad (20)$$

Where, gross revenue has calculated by multiplying total yield in kg ha^{-1} of forage with market price per kilogram (CIMMYT, 1988).

3.13.2. Determination of the benefit-cost ratio (BCR)

Is measures the increase in net return (NR) generated by total cost expenditure (TC). It determined by the equation (CIMMYT, 1988).

$$\mathrm{BCR} = \frac{\mathrm{NR}}{\mathrm{TC}} \qquad (21)$$

3.14. Statstical Analysis

The analysis of variance in a two-way ANOVA carried out to explore the effect of ameliorative grasses and gypsum on pHe, ECe, SAR and ESP. But, the effect of gypsum on biomass yield, plant height, crude protein content and tissue sodiums of the eight cropped treatments were analyzed by one-way ANOVA following the statistical procedure described by Gomez and Gomez, (1984) using Genstat 15.0. The mean separation performed using least significant difference (LSD) test at 1 % level and Duncan multiple range (DMRT) tests.

4. RESULT AND DISCUSSION

4.1. Physical Properties of Saline-sodic Soil at the Beginning of the Experiment

4.1.1. Soil texture

Soil analytical results showed that the textural classes of Golina-Adisalem salt-affected irrigation scheme vary from silt loam to silty clay loam (Table 6). The average proportions of clay, silt and sand percentages were 27.6, 57.4 and 15.0 % respectively. Thus according to USDA soil textural classification, the experimental site revealed as “silty clay loam” soil. The relatively highest clay content (32 %) obtained at 40-60 cm depth. The increase in clay content with depth indicates the presence of eluviation and illuviation processes or translocation of clay particles within the layers. The study in line with Lilienfein *et al*., (2000) and Buol *et al*., (2003) reported that the accumulation of clay particles in the lower layer contributed by the *in-situ* formation of secondary clays.

4.1.2. Bulk density (ρ_b)

The bulk density values ranged from 1.44 and 1.7 gm cm^{-3} for 0-20 to 60-100 cm depth respectively (Table 6). According to White, (2006) classification criteria, as indicated in (Appendix Table 11), the experimental site revealed as “compacted soil”. The increasing trend of bulk density down the depth possibly due to the relatively decreased organic matter content and the increased exchangeable sodium percentage disperses soil aggregates to promote maximum compaction. A study in agreement with the earlier findings reported that the bulk density of soil increases with profile depth, due to the reduced in organic matter and the increased compaction (Srivastava *et al.*,1987; Ahmed, 2002; Brady and Weil, 2002; Pravin *et al*., 2013). The bulk density increase with increase sodicity due to the dispersive action of exchangeable sodium (Shakir and Razzaq, 2002).

4.1.3. Soil moisture content

The moisture content at FC increased from 28.5 to 30.6 % for 0-20 to 40-60 cm depths respectively (Table 6). The increased moisture content down the profile up 40-60 cm depth had been due to the strong association of clay percentage and water retention.

The study coincided with many findings reported that soils with higher clay content had a greater water retention capacity and lower permeability than sandy soils (Gupta, 2000; Abdul-Ghafoor *et al*., 2004; Rengasamy, 2006; Mostafazadeh-Fard *et al*., 2008; Seita *et al*., 2011). The total available water (TAW) governed by the crop root zone, Fc and PWP (Allen *et al*., 1998). In this respect, the total available water (TAW) of the experimental site was 81 mm for 1 m maximum root depth of grasses.

Table 6. Selected physical properties of the Golina-Adisalem salt-affected experimental site at the beginning of the experiment.

Depth (cm)	Particle size distribution (%)			Textural class	ρ_b (gm cm^{-3})	Soil moisture content		
	Clay	Silt	Sand			FC (%v)	PWP (%v)	TAW (mm)
0-20	26.5	52	21.5	SL	1.44	28.5	22.7	11.6
20-40	30	55.5	14.5	SCL	1.58	29.8	21	17.6
40-60	32	58	10	SCL	1.68	30.6	20.5	20.2
60-100	22	64	14	SL	1.7	27.8	19.9	31.6
Average	**27.6**	**57.4**	**15**	**SCL**	**1.6**	**29.17**	**21**	$\sum 81$

Where, SCL- silty clay loam; SL- silty loam; ρ_b – bulk density; gm- gram

4.2. Selected Chemical Properties of Saline-sodic Soil at the Beginning of Experiment

4.2.1. Soil organic matter content (% OM)

The organic matter (OM) content varied within the range of 1.15 to 0.62 % for 0-20 to 40-60 cm respectively (Table 7). Based on the rating of soil organic matter content established by Takalign *et al.*, (1991) in (Appendix Table 12), the first two soil layers (0-20 and 20-40 cm) categorized within “low OM” range, while the last (40-60 cm) soil column rated as “a very low OM” content. The relatively higher organic matter content in the upper layers could be due to the presence of high livestock dung, plant debris and the relatively lower sodium concentration (Table 7) enhances soil microbial action. The study inline with other earlier findings reported as OM content decreases down the depth due to the decreased rooting effect (Brady and Weil, 2002; Pravin *et al.*, 2013).

Furthermore, the higher sodium in the lower layer affects the plant root action and active soil microorganisms resulted in decreased organic matter decomposition rate (Walpola and Arunakumara, 2010 and 2011).

4.2.2. Soil pHe

The relatively high pHe values appeared in the lower layers due to the increase of soluble and exchangeable sodium concentration (Table 7). Ann and Clain, (2005) have been similar reports as the pHe values increased down the depth due to the increased exchangeable sodium, carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions. Moreover, Tena, (2002) also revealed that high pHe values could be resulted due to the high concentration of bicarbonate (HCO_3^-). The values of pH increased with soil depth due to the decreased OM content fewer hydrogen$^+$ ions are released (Herrera, 2005). Based on Takalign *et al.*, (1991) in (Appendix Table 13) classification, that the soil pHe in all layers > 8 categorized as "strongly alkaline" soil.

4.2.3. Soil electrical conductivity (ECe)

The electrical conductivity values relatively higher at the upper (0-20 cm) soil layer and the values reduced as the profile depth increased (Table 7). It actually associated due to capillary action and poor drainage practice coupled with high evaporation results a substantial build of salts at the surface. The study coincided with other many findings they reported as capillary action and high evaporation promotes salt accumulation at the surface layer (Armstrong *et al*., 1996; Seelig, 2000; Mahmood *et al*., 2001; Owens, 2001; Murtaza *et al*., 2006; Rengasamy, 2006; Ghafoor *et al*., 2008).

The electrical conductivity values in the first two soil columns were higher than 16 dS m^{-1} rated within the "extreme saline range" resulted in only salt-tolerant plants grow, most others show severe injury (Lamond and Whitney, 1992) in (Appendix Table 13).

Table 7. Chemical properties of Golina -Adisalem salt-affected irrigation scheme at the beginning of the experiment

Concentration	**Soil depth (cm)**		
	0-20	20-40	40-60
OM (%)	1.15	0.88	0.62
CEC (meq/100 gm)	20.48	20.1	19.63
Exchangeable cation (meq/100 gm)			
Na^+	11.27	12.88	13.95
$Ca^{2+} + Mg^{2+}$	7.89	7.63	7.49
ESP (%)	**55.03**	**64.08**	**71.06**
Soluble cations (meq/l)			
Na^+	307.5	324.36	345.33
$Ca^{2+} + Mg^{2+}$	77.6	76.19	74.93
SAR	**49.37**	**52.55**	**56.42**
ECe (dS m^{-1})	20	16.4	11.49
PHe	8.5	8.65	8.77
Exchangeable anions (meq/100 gm)			
CO_3^{2-}	0	0	0
HCO_3^-	0	0.05	0.33
Cl^-	4.03	3.55	3.36

Where, OM- organic matter content.

Based on ECe, pHe, SAR and ESP values Golina-Adisalem salt-affected experimental field has characterized as “saline-sodic” (USSLS, 1954; Horneck *et al.*, 2007).

4.2.4. Exchangeable sodium percentage (% ESP)

The values of ESP appear an increasing trend as increased soil depth ranged from 55.03 to 71.06 % for 0-20 and 40-60 cm soil depth respectively (Table 7). The one reason for the increasing ESP down the profile should be due to the increases of exchangeable Na^+ by leaching from the upper soil layer. The study agreed with other findings that reported the exchangeable sodium increases with the increased depth due to the effect of leaching from upper soil layers (Saikh *et al*., 1998; Abay and Sheleme, 2012).

Besides, the higher ESP values associated with the decrease of CEC down the depth (Table 7). A similar experience has been reported by Ashenafi *et al*., (2010) as CEC tends to decreased down the depth with the decrease of organic matter content facilitates the ESP increment. Pansu and Gautheyrou, (2006) revealed that CEC is positively correlated with organic matter content and it is inversed with sodium. Based on Lamond and Whitney, (1992) classification criteria in (Appendix Table 13), the ESP values were much higher than 15 % for all soil layers rated within the "high sodium concentration" it can affect soil structure.

4.2.5. Sodium adsorption ratio (SAR)

The SAR values exhibit increased trend down the depth ranged from 49.37 to 56.42 for 0-20 and 40-60 cm depth respectively. The main reason for increased SAR values down the depth could be due to the increased proportion of soluble sodium than calcium and magnesium (Table 7). Many studies indicate that sodium absorption ratio value tends to be higher at lower depths in saline and saline-sodic soils because of groundwater is the septic tanker of soluble salt (Keren and Ben-Hur, 2003; Tsegaye, 2009; Abay and Sheleme, 2012). The SAR values >13 for all soil layers rated within the "high sodium concentration" category which affects soil aggregates (Lamond and Whitney, 1992) in (Appendix Table 13).

4.3. Physicochemical Characteristics of Kobo Irrigation Research Station (Non-saline; Normal) experimental site

The physicochemical characteristics of the non-saline experimental field indicate that the soil organic matter content ranged from 3.1 to 2.63 % and pHe from 6.75 to 6.92 for 0-20 to 60-100 cm respectively (Table 8). Based on Takalign *et al*., (1991) rating criteria, the soil had "medium" organic matter content and "neutral" in pHe (Appendix Table 12 and 13 respectively). Similarly, thus respective soil layers had the ECe ranged from 0.53 to 0.6 dS m^{-1} rated within "low salinity" class and a very little chance of injury for all plants (USSLS, 1954; Lamond and Whitney, 1992).

The total available water within the maximum rooting zone (1 m) of grasses also 131.78 mm. Hence, stage-based full ETc maintained throughout the growth stage.

Table 8. Selected physicochemical properties for Kobo (non-saline; normal) irrigation scheme

Depth (cm)	Textural class	ρ_b (gm cm-3)	OM (%)	PHe	ECe (dS m^{-1})	FC (%v)	PWP (%v)	TAW (mm)
0-20	CL	1.14	3.1	6.75	0.53	32.58	20.53	24.10
20-40	SCL	1.21	2.89	6.81	0.62	33.33	19.50	27.66
40-60	SCL	1.28	2.76	6.79	0.58	35.21	19.58	31.26
60-100	SL	1.35	2.63	6.92	0.60	32.29	20.10	48.76
					Average	**33.35**	**19.93**	$\sum \mathbf{131.78}$

Where, CL- Clay loam; SCL- silty clay loam; SL- silty loam; $\boldsymbol{\rho_b}$ – bulk density; OM- organic matter.

In considering the ECe and pHe values of the soil, the Kobo irrigation research site classified as "non-saline" soil (USSLS, 1954; Lamond and Whitney, 1992).

4.4. Gypsum Requirement

The calculated gypsum (100% G) required to amend the top (0.2 m) soil layer for decreasing initial ESP from 55.03 to 10 % using the bulk density and cation exchange capacity values 1.44 gm cm^{-3} and 20.48 meq/100 g respectively (Table 6 and 7) was 1.98 ton/ha (≈ 2 ton/ha). Most studies have been done outside of the USA and the gypsum rates have ranged from 0.9 to 71. 4 ton ha^{-1} (Breker, 2016).

Table 9. Levels or rates of applied gypsum with 100 % purity

Gypsum levels (%)	Amount (ton/ha)
0	0
75	1.5
100 (calculated)	2
125	2.5

4.5. Irrigation Water Requirements of Rhodes and Panikum Grasses

Daily climatic data collected during the growing periods from February 7 to May 27, 2019, at Kobo Meteorological Station (Appendix Table 2). The total effective precipitation during the first and second cuttings was 19.03 and 79.55 mm respectively. Based on the output, the periodic crop and irrigation water requirements were 285.58 and 266.55 mm for first cutting, while in second cutting those respective demands were 282.83 and 203.28 mm (Table 11).

At the first cutting, crop water requirement (ETc) values relatively low for the initial stage and increased gradually to development and mid-season stages. These gradual increments resulted due to the relatively high reference evapotranspiration (ETo) during February and March, the increased rooting depth and crop coefficient values (Kc). A second cutting, crop water requirement (ETc) values remain nearly similar throughout the growth stage. Because only the aerial biomass cuts at first harvest and the plant root remains constant as 1m.

Table 10. Plant height, Kc_b, Kc_{adj} and daily ETo for irrigation scheduling

Date	First-round irrigation (First cutting)			
	Daily ETo (mm/day)	Plant height (m)	Kcb	Kcaj
7-Feb	4.69	0.10	0.50	0.50
13-Feb	4.77	0.15	0.50	0.48
19-Feb	5.08	0.30	0.50	0.49
25-Feb	5.82	0.44	0.72	0.72
3-Mar	5.67	0.59	0.80	0.78
9-Mar	5.4	0.74	0.87	0.79
15-Mar	6.06	0.88	1.15	1.15
21-Mar	5.91	1.03	1.15	1.16
27-Mar	5.76	1.16	1.15	1.17
2-Apr	6.1	1.28	1.15	1.16
7-Apr	**First harvest**			
Second-round irrigation (Second cutting)				
8-Apr	6.13	0.00	0.50	0.50
21-Apr	5.89	0.40	0.69	0.67
30-Apr	5.25	0.60	0.79	0.74
9-May	6.04	0.81	1.15	1.13
15-May	5.89	1.06	1.15	1.10
21-May	5.83	1.33	1.15	1.17
27-May	6.29	1.56	1.15	1.15
30-May	**Second harvest**			

Where, Kc_b- basaltic crop coefficient; Kc_{adj-} adjusted crop coefficient and ETo-daily reference evapotranspiration.

Table 11.Crop and irrigation water requirement for Panikum and Rhodes grass

Date	Stage	ETc (mm/d)	RAW (mm)	T	ETc (mm/p)	P	P_{eff}	IR (mm)	IR_g (mm)
First-round irrigation (First cutting)									
7-Feb	Ini.	2.35	14.60	6.00	14.07			14.07	23.45
13-Feb	Ini.	2.27	14.60	6.00	13.64			13.64	22.74
19-Feb	Ini.	2.47	14.60	6.00	14.84	10.80	6.12	8.72	14.53
25-Feb	Dev.	4.19	24.70	6.00	25.15			25.15	41.91
3-Mar	Dev.	4.42	24.70	6.00	26.52			26.52	44.19
9-Mar	Dev.	4.24	24.70	6.00	25.45			25.45	42.41
15-Mar	Mid.	6.98	40.50	6.00	41.90			41.90	69.83
21-Mar	Mid.	6.85	40.50	6.00	41.08			41.08	68.47
27-Mar	Mid.	6.74	40.50	6.00	40.42			40.42	67.37
2-Apr	Mid.	7.09	40.50	6.00	42.52	22.10	12.90	29.62	49.36
7-Apr		**First harvest**		$\sum$	**285.58**		**19.03**	**266.55**	**444.26**
Second-round irrigation (First cutting)									
8-Apr	Ini.	3.07	40.50	13.00	39.85	11.70	6.66	33.18	55.30
21-Apr	Dev.	3.97	40.50	10.00	39.68	49.70	38.90	0.78	1.30
30-Apr	Dev.	3.88	40.50	10.00	38.75			38.75	64.59
9-May	Mid.	6.83	40.50	6.00	40.99			40.99	68.32
15-May	Mid.	6.50	40.50	6.00	39.00			39.00	65.00
21-May	Mid.	6.83	40.50	6.00	40.97	38.00	29.54	11.43	19.05
27-May	Mid.	7.26	40.50	6.00	43.58	8.00	4.44	39.14	65.23
30-May	**Second harvest**			$\sum$	**282.83**		**79.55**	**203.28**	**338.79**

Where, ETc (mm/d) - crop water requirement in mm per day; ETc(mm/p)- crop water requirement in mm per period; T- irrigation interval; RAW (mm)- readily available water in mm; P-precipitation; P_{eff} -effective precipitation; IR- net irrigation requirement; IRg- gross irrigation requirement.

4.6. Effect of Gypsum and Halophytic Grasses (Rhodes and Panicum) on Infiltration

Gypsum application and growth of halophytic grasses (Rhodes and Panicum) independently and by combination enhance the infiltration rates of saline-sodic soil over the control treatment. In contrast, the four gypsum levels the application of gypsum in increasing dose more increase the infiltration rates of the soil (Figures 8 and 9). It should be associated due to the replacement of excess exchangeable Na^{+} by Ca^{2+} source gypsum improves soil aggregate stability.

The study agreed with many findings reported that gypsum application restore soil aggregates, water and air permeability due to the decreased of surface crusting resulted in increases of infiltration rate (Abou-Yuossef, 2001; Clark *et al*., 2007; Chi *et al*., 2012; Yu *et al*., 2014b; Kumar and Thiyageshwari, 2018). Moreover, Ahmad *et al*., (2001) and El-Fattah, (2006 and 2011) indicated that hydraulic conductivity and infiltration rate increased with the increased gypsum application level.

The increasing infiltration rate by growings of Rhodes and Panicum grass could be due to the uptakes of excess soil Na^+ by plants and their root action enhances soil porosity for facilitating infiltration rate. Oster *et al*., (1999) reported that plantation of halophytic species maintains adequate soil structure and aggregate stability that improve water movement through the soil profile. Similarly in Awash Ethiopia growing of salt-tolerant Rhodes and Panicum grasses under salt-affected soil increases the water absorption rate and reduces runoff losses (Qureshi *et al*., 2018).

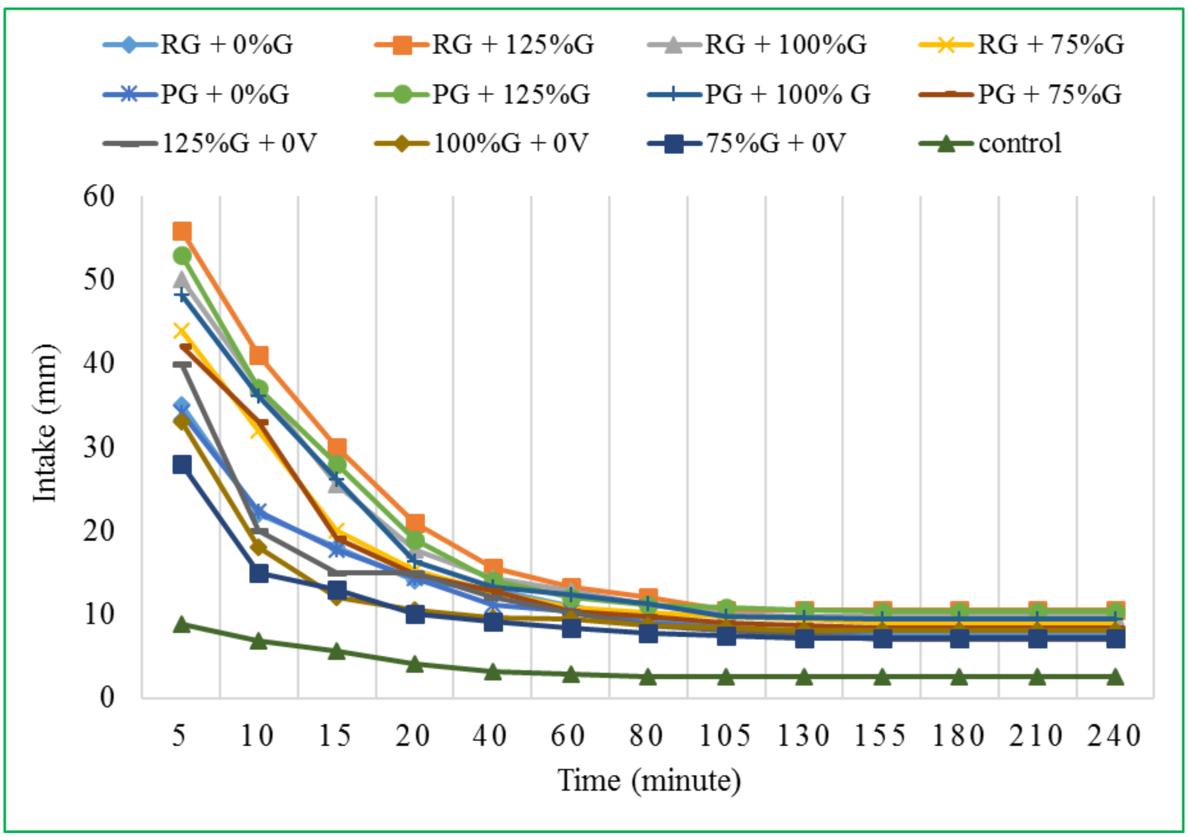

Figure 8. Infiltration (intake) vs. time

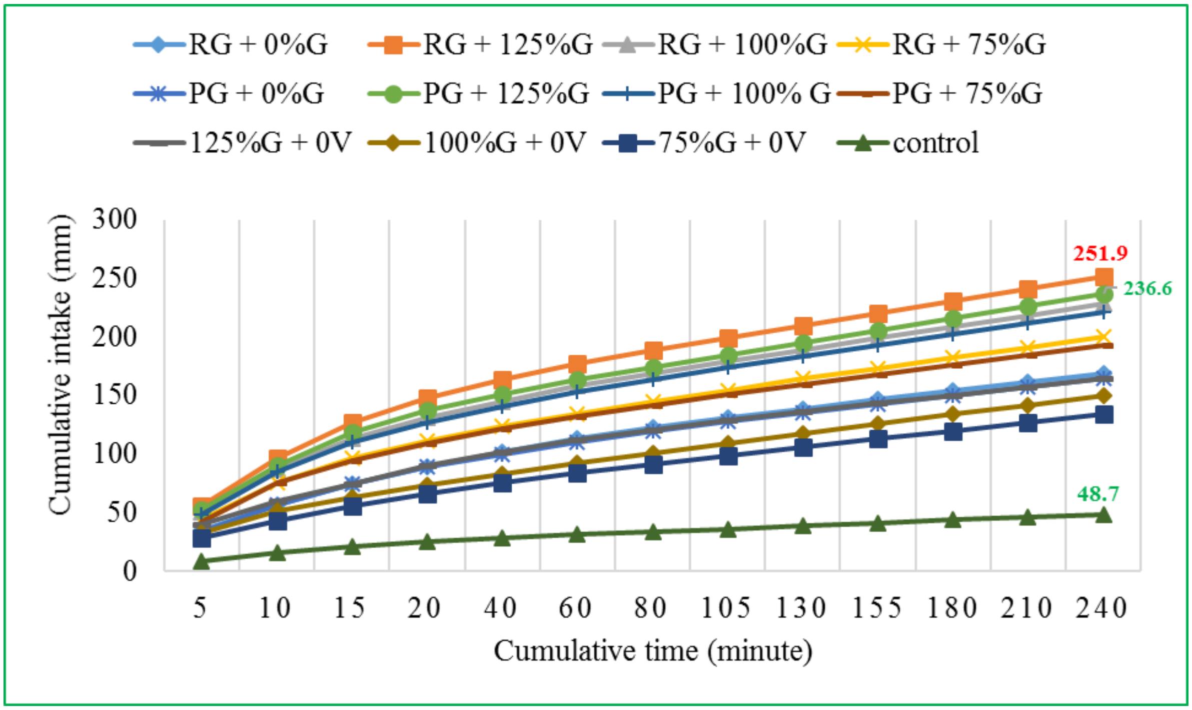

Figure 9. Cumulative infiltration vs. cumulative time

In comparing the efficiency of treatments based on their effectiveness in improving infiltration rate also approximated as "grass + gypsum treatments > plant only treatments ≈ gypsum only treatments > control". From all combined treatments, more pronounced higher infiltration rates of 6.3 and 5.92 cm/hr were recorded by treating soils with RG+125% G and PG+125% G respectively, but the lowest value (1.22 cm/hr) was recorded from the control experimental plot. A similar experience has been reported by Ghafoor *et al*., (2012) as the infiltration rate more increases through the combined application of gypsum and Sesbania aculeata than the single used treatments. Based on Miller and Donahue, (1997) classification in (Appendix Table 12), the integrated application RG+125% G and PG+125% G were the most effective treatment and improve soil infiltration rate from "low to high" compared with the control treatment.

4.7. Effects of Gypsum Amendment and Ameliorative Grasses on Soil Salinity

4.7.1. Soil reaction (pHe)

The ANOVA table showed that the soil pHe in all layers were highly significantly ($P < 0.01$) affected by the applied treatments either, in single (halophytic grasses, gypsum application) or by the interaction of gypsum with halophytic grasses (Appendix Table 3).

After the first and second harvest, all treatment exhibits a sharp falling trend of pHe in all soil columns compared with the corresponded control treatment (Table 12). In the non-plant gypsum treatments, the soil pHe decreased as the amount of gypsum increased. This study inline with Ahmad *et al*., (2001) and El-Fattah, (2006 and 2011) reported that pHe decreased with gypsum application. Moreover, Singh and Bajwa (1991) and Khalifa *et al*., (1994) reported applied excessive gypsum for reclamation was a quick reduction in pHe.

The non-gypsum grass treatments showed statistically similar in pHe reduction efficiency (Panicum garass= Rhodes grass*)*. The decrease in pHe by Rhodes and Panicum grass plantation should be associated due to the removal of soil Na^+ by the plant resulted in only minimal Na^+ remained in the soil. Researches have done in recent decades also suggests that the possible role of salt-tolerant grasses to decrease soil salinity/sodicity. In addition, it increases the level of CO_2 by their roots and microbial respiration acts as a weak acid that helps for the dissolution of soil calcite to neutralize pHe (Qadir *et al*., 2002). Moreover, the salt-tolerant grasses also absorb ions like Na^+ and Cl^- considered as food to maintain turgor resulted in decreased pHe (Ahmad *et al*., 1990; Qadir *et al*., 2003).

The efficiency among the two single used factors, 125 % G was highly decreased soil pHe than the non-gypsum Panikum and Rhodes grass treatments, especially in 0-20 cm depth. While in 20-40 and 40-60 cm soil columns the efficiency were non-gypsum halophytic grass treatments > 125 % G. This higher response of gypsum on the topsoil layer (0-20 cm) might be due to direct application of gypsum on this layer and the last two soil layers received gypsum indirectly by leaching.

Table 12. Effect of gypsum and halophytic grasses on soil pHe

Soil pHe in the three layers							
Depth (cm)		**After first harvest**			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
0-20	0%	8.52^{f}	7.83^{e}	7.85^{e}	8.54^{f}	7.70^{e}	7.70^{e}
	75%	7.76^{d}	7.65^{c}	7.65^{bc}	7.70^{e}	7.47^{c}	7.47^{c}
	100%	7.72^{d}	7.59^{b}	7.6^{bc}	7.62^{d}	7.36^{b}	7.36^{b}
	125%	7.61^{bc}	7.42^{a}	7.42^{a}	7.52^{c}	7.24^{a}	7.23^{a}
SE(±)			0.02			0.03	
LSD			0.05			0.06	
CV (%)			0.38			0.47	
		After first harvest			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
20-40	0%	8.59^{f}	7.85^{cd}	7.85^{cd}	8.66^{f}	7.61^{c}	7.61^{c}
	75%	8.15^{e}	7.74^{b}	7.76^{bc}	8.01^{e}	7.50^{b}	7.51^{b}
	100%	8.07^{e}	7.67^{b}	7.67^{b}	7.93^{e}	7.43^{b}	7.44^{b}
	125%	7.88^{d}	7.53^{a}	7.53^{a}	7.75^{d}	7.28^{a}	7.29^{a}
SE(±)			0.05			0.036	
LSD			0.10			0.075	
CV (%)			0.78			0.58	
		After first harvest			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
40-60	0	8.75^{h}	7.91^{d}	7.94^{d}	8.77^{h}	7.81^{d}	7.83^{d}
	75%	8.38^{g}	7.84^{c}	7.8^{c}	8.34^{g}	7.73^{c}	7.70^{c}
	100%	8.28^{f}	7.70^{b}	7.71^{b}	8.26^{f}	7.61^{b}	7.60^{b}
	125%	8.22^{e}	7.63^{a}	7.63^{a}	8.19^{e}	7.51^{a}	7.51^{a}
SE(±)			0.02			0.02	
LSD			0.05			0.05	
CV (%)			0.36			0.35	

Where, Mean ± SE; SE- standard error; 0H- no halophytic grasses plantation; RG- Rhodes grass; PG- Panikum grass; G- gypsum requirement; LSD- least significant difference; CV- coefficient of variation. Different letters (a, b, c, d, e and f) indicate a highly significant difference between treatments and the same letters indicate a non-significant difference between treatments at a 1% probability level. The rank of letters in ascending order.

Regardless of the amendments used, a more pronounced decrease of soil pHe was using all combined treatments compared to the control, grasses and gypsum single treatments. Among all combined treatments, application 125% G with Panikum and Rhodes grasses were substantially decreased pHe values all over other treatments in all soil layers (Table 12). A study in agreement with Swarp, (2004) and El-Fattah, (2011) findings suggested that combined application of gypsum with ameliorative plants increased the reclamation efficiency on soil salinity and sodicity parameters and markedly reduced the time of reclamation than individual amendments.

Based on the criteria established by Tekalegn *et al*., (1991) (Appendix Table 13), in 0-20 and 20-40 cm soil layers, the soil pHe changed from "strong alkaline" to "neutral" by applications of 125% G with Panikum and Rhodes grass compared with the control treatment. While in the 40-60 cm soil column, those treatments were exhibits relatively low soil pHe reduction than the top two soil layers. It might be due to the presence of relatively higher bicarbonate concentration in this soil layer inhibit the response of gypsum or act as a buffer.

4.7.2. Electrical conductivity (ECe)

From the analysis of variance (Appendix Table 4) halophytic grasses and gypsum amendment in single or interaction of halophytic grasses with gypsum in the three soil columns had a highly significant effect ($p<0.01$) on electrical conductivity (ECe).

After the first and second harvest, all treatment showed a decreased trend of ECe in all soil layers compared with the control treatment (Table 13). The salt removal efficiency between the two grasses were statistically similar (Panicum grass = Rhodes grass). Both Panicum and Rhodes grasses decreased soil salt concentration due to its high salt uptake potential. Grasses (Rhodes and Panikum) could uptake and secretion extensively excess salts in their "salt glands" have been studied (Kobayashi *et al*., 2007; Kobayashi and Masaoka, 2008; Oi *et al*., 2012; Oi *et al*., 2013).

As the rate of gypsum application increases the ECe also decreased (Table 13). The single-use of 125 % G treatment was significantly lowered the ECe than 75 and 100 % G received treatments in 0-20 cm soil column.

However, in 20-40 and 40-60 cm soil columns, 75, 100 and 125 % G did not exhibit significant response between them. It indicates the efficiency of gypsum down the depth tends to decrease.

Comparing the efficiency of amendments between the halophytic grasses and agricultural gypsum in single was, “125 % G > halophytic grasses (Panicum and Rhodes)” in 0-20 cm soil column, while in 20-40 and 40-60 cm soil columns the efficiency of grasses much higher than all gypsum rates. The decreased soil electrical conductivity including in the subsurface layers (20-40 and 40-60 cm) probably due to the improvement of soil infiltration by the applied treatments. This study coincided with Ahmad *et al*., (2001) and El-Fattah, (2006 and 2011) reported that ECe, decreased due to the increased hydraulic conductivity and infiltration rate with gypsum application. Gypsum has an effect on declining soil ECe up to the reproductive phase of commercial crops (Islam *et al*., 2017). Many researchers suggested that ECe decreased due to ion uptake by plants (Ahmad *et al*., 1990; Qadir *et al*., 2003 and 2007). Moreover, Ghaly, (2002) reported that the role of native grass species decreased the salts/ECe content within a short period.

The ECe values were highly decreased by all the combined applications of gypsum with halophytic grasses than the gypsum only (non-plant) and halophytic grasses only (non-gypsum) treatments in all soil layers. From all combined treatments, application 125 % G with Panikum and Rhodes grasses were more progressively decreases the ECe than other treatments.

Based on the rating criteria established Lamond and Whitney, (1992) (Appendix Table 13), the ECe in 0-20 and 20-40 cm depth changed from “extreme saline” to “moderately saline”, while in 40-60 cm depth it changed from “highly saline” to “moderately saline”. Swarp, (2004), Mohammed, (2011) and Ghafoor *et al*., (2012) reported that combined application of gypsum with ameliorative plants promotes reclamation efficiency and decreased soil ECe, in a short period.

Table 13. Effects of gypsum and halophytic grasses on electrical conductivity (dS m^{-1})

ECe concentration in the three layers (dS m^{-1})							
Depth (cm)		**After first harvest**			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
0-20	0%	19.92^{h}	14.9^{g}	14.59^{g}	20.1^{h}	11.92^{g}	11.9^{g}
	75%	11.87^{g}	8.18^{c}	8.37^{c}	11.05^{g}	7.28^{c}	7.34^{c}
	100%	10.63^{e}	7.2^{b}	7.17^{b}	10.39^{e}	6.38^{b}	6.33^{b}
	125%	9.11^{d}	5.55^{a}	6.00^{a}	8.73^{d}	4.13^{a}	4.62^{a}
SE(±)			0.31			0.13	
LSD			0.645			0.28	
CV (%)			3.7			3.58	
		After first harvest			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
20-40	0%	16.22^{f}	8.32^{d}	8.24^{d}	16.31^{f}	7.38^{d}	7.38^{d}
	75%	11.48^{e}	7.42^{d}	7.41^{c}	10.75^{e}	6.62^{d}	6.62^{c}
	100%	11.56^{e}	6.68^{b}	6.65^{b}	10.6^{e}	5.76^{b}	5.83^{b}
	125%	11.46^{e}	5.88^{a}	5.89^{a}	10.57^{e}	4.94^{a}	4.89^{a}
SE(±)			0.1			0.1	
LSD			0.2			0.21	
CV (%)			2.66			3.09	
		After first harvest			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
40-60	0	11.36^{f}	8.06^{d}	8.04^{d}	11.40^{f}	7.62^{d}	7.63^{d}
	75%	10.79^{e}	7.14^{d}	6.97^{c}	10.09^{e}	6.53^{d}	6.62^{c}
	100%	10.63^{e}	6.19^{b}	6.12^{b}	10.00^{e}	5.48^{b}	5.29^{b}
	125%	10.62^{e}	5.33^{a}	5.32^{a}	10.04^{e}	4.37^{a}	4.31^{a}
SE(±)			0.11			0.20	
LSD			0.23			0.41	
CV (%)			3.31			6.50	

Where, Mean ± SE; SE- standard error; 0H- no halophytes plantation; RG- Rhodes grass; PG- Panikum grass; G- gypsum requirement; LSD- least significant difference; CV- coefficient of variation. Different letters (a, b, c, d, e, f, g and h) indicate a highly significant difference between treatments and the same letters indicate a non-significant difference between treatments at a 1% probability level. The ranks of letters in ascending order.

The efficiency of treatments were, 125 % G with Panicum grass = 125 % G with Rhodes grass and significantly higher all over other treatments (Table 13).

4.8. Effects of Gypsum Amendment and Ameliorative Grasses on Soil Sodicity

4.8.1. Sodium adsorption ratio (SAR)

The analysis of variance (Appendix Table 5) shows that gypsum application, growing of halophytic grasses and the interaction gypsum with halophytic grasses had highly significantly ($p<0.01$) affect the soil SAR of the saturated paste extract.

After the first and second harvest, the SAR values in the three soil columns decreased by the application of single and combined amendments compared with the control treatment (Table 14). Among the single-use of gypsum treatments application of 125 % G was highly decreased the soil SAR than 75 and 100 % G applied treatments. As gypsum application-level increases, SAR was relatively decreasing (Table 14). The study in line with Ahmad *et a*l., (2001) and El-Fattah, (2006 and 2011) reported that SAR decreased with gypsum application. Many laboratory and field studies have indicated that the application of excessive gypsum for reclamation of sodic and saline-sodic soil observed a quick removal of soluble sodium resulted in a decreased soil SAR (Ali *et al*., 1991; Clark *et al*., 2007; Chi *et al*., 2012).

In comparing the efficiency of single used treatments independently, halophytic grasses without gypsum were lowering SAR than the single used gypsum treatments for all soil layers. This higher SAR removal efficiency of halophytic grasses compared with gypsum could be probably due to the absorption soluble Na^+ directly by grasses is the one reason. But, application gypsum in single only changes the form of soil sodium from exchangeable into soluble Na_2SO_4 form; this might be resodified for increasing SAR than the grass treatments.

Ghaly, (2002) reported that the role of native grass species decreased the salinity and soluble sodium than gypsum application. The plant's preference for adsorbing Na^+ over other ions is an important factor for decreasing SAR (Kobayashi *et al*., 2007). Many findings suggested that halophytic plant approach has much potential for the reclamation of salt-affected soils (Qadir *et al*., 2001; Qadir and Schubert, 2002; Ahmad *et al*., 2006; Ammari *et al*., 2008). In Awash Ethiopia growing of Panicum and Rhodes grasses has been a continuous decrease in soil sodicity and an improvement in soil physical properties due to the biological action of grassroots (Qureshi *et al*., 2018).

Table 14. Effects of gypsum and halophytic grasses on sodium adsorption ratio (SAR)

Soil SAR in the three layers							
Depth (cm)		**After first harvest**			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
0-20	0%	49.74^{h}	24.19^{d}	24.19^{d}	50.12^{h}	20.68^{d}	20.74^{d}
	75%	34.60^{g}	20.43^{c}	20.55^{c}	31.24^{g}	17.36^{c}	17.27^{c}
	100%	31.12^{f}	16.73^{b}	16.98^{b}	28.21^{f}	14.14^{b}	14.17^{b}
	125%	24.82^{e}	13.82^{a}	13.66^{a}	22.06^{e}	11.19^{a}	10.78^{a}
SE(±)			0.05			0.14	
LSD			0.10			0.28	
CV (%)			0.77			2.44	
		After first harvest			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
20-40	0%	53.64^{g}	27.21^{d}	27.27^{d}	54.23^{h}	24.12^{d}	24.15^{d}
	75%	38.27^{f}	23.23^{c}	23.54^{c}	35.45^{g}	23.33^{c}	23.33^{c}
	100%	34.53^{e}	19.26^{b}	19.54^{b}	30.67^{f}	19.47^{b}	19.74^{b}
	125%	27.51^{d}	15.90^{a}	15.70^{a}	25.64^{e}	16.10^{a}	15.81^{a}
SE(±)			0.05			0.37	
LSD			0.11			0.76	
CV (%)			0.76			1.72	
		After first harvest			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
40-60	0	56.36^{i}	28.08^{e}	28.05^{e}	57.29^{h}	28.43^{d}	28.29^{d}
	75%	41.02^{h}	23.54^{c}	24.24^{d}	41.66^{g}	24.02c	24.3^{c}
	100%	36.01^{g}	19.81^{b}	20.16^{b}	36.02^{f}	19.83^{b}	20.2^{b}
	125%	30.12^{f}	16.56^{a}	16.19^{a}	30.56^{e}	16.57^{a}	16.38^{a}
SE(±)			0.06			0.26	
LSD			0.13			0.53	
CV (%)			0.87			1.10	

Where, Mean ± SE; SE- standard error; 0H- no halophytic plantation, RG- Rhodes grass; PG- Panikum grass; G- gypsum requirement; LSD- least significant difference; CV- coefficient of variation. Different letters (a, b, c, d, e, f, g and h) indicate a highly significant difference between treatments and the same letters indicate a non-significant difference between treatments at a 1% probability level. The letters ranked in ascending order.

In concerning the effects of treatments, the most effective amendments were combined application of gypsum with halophytic grasses highly decreases of the SAR for all soil layers than the single use of gypsum and grass treatments.

From all combined treatments, application of 125 % G with Rhodes grass decreases SAR by, 78.49, 70.85 and 71.41 % for 0-20, 20-40 and 40-60 cm respectively compared with the control treatments of each soil layers (Table 14). Panicum grass with 125 % G has exhibited a similar SAR reduction trend of 77.67, 70.31 and 71.08 % for 0-20, 20-40 and 40-60 cm respectively compared with the corresponded control treatment. The study coincided with many findings reported that the integrated application of gypsum with ameliorative species was the most effective treatment with reducing SAR in a short period than individual amendments (Ilyas *et al*., 1997; Salim *et al*., 2002; Swarp, 2004; Ahmad *et al*., 2006; El-Fattah, 2011; Abdel-Fattah, 2012; Ghafoor *et al*., 2012).

Based on the criteria proposed by Lamond and Whitney, (1992) in (Appendix Table 13), the SAR values of the first (0-20 cm) soil layers changed from "highly alkaline" to medium alkaline using those treatments.

4.8.2. Exchangeable sodium percentage (ESP)

The application of agricultural gypsum and halophytic grasses independently and by the interaction of gypsum with halophytic grasses had highly significantly ($p<0.01$) affects soil ESP for all soil columns (Appendix Table 6).

After the first and second harvest, all treatments highly significantly reduced ESP (Table 15). At the end of experimentation (after the second harvest), the lower ESP values obtained in soils with non-plant gypsum (75, 100 and 125%) treatments than non-gypsum halophytic grass treatments especially in the first two soil columns. In the first two soil columns, the ESP values significantly decreased with an increased application rate of gypsum and the reclamation efficiency of gypsum lowers beyond the first two layers (Figure 10). It might be due to gypsum application directly in the top layer (0-20 cm) highly replaces exchangeable sodium than non-gypsum plant treatments, while the last soil layer (40-60 cm) receives a small amount of gypsum by leaching. A study agreed with previous findings indicate that applied excessive gypsum for reclamation were quick removal of exchangeable sodium resulted in decreased ESP (Singh and Bajwa, 1991; Khalifa *et al*., 1994; Abou-Yuossef, 2001;

Ahmad *et al*., 2001; Solaimalai, 2001; El-Fattah, 2006; Clark *et al*., 2007; El-Fattah, 2011; Chi *et al*., 2012; Kumar and Thiyageshwari, 2018; María *et al*., 2018).

Table 15. Effects of gypsum and halophytic grasses on soil ESP (%)

Soil ESP in the three layers (%)							
Depth (cm)		**After first harvest**			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
0-20	0%G	56.64^{g}	45.29^{f}	44.54^{f}	57.37^{j}	39.99^{i}	38.60^{h}
	75%G	39.56^{e}	26.71^{c}	25.97^{c}	36.88^{g}	18.59^{d}	17.63^{c}
	100%G	31.64^{d}	17.96^{b}	17.41^{b}	27.97^{f}	13.73^{b}	13.55^{b}
	125%G	26.06^{c}	11.99^{a}	12.41^{a}	22.23^{e}	8.94^{a}	8.93^{a}
SE(±)			0.56			0.18	
LSD			1.17			0.37	
CV (%)			2.33			0.86	
		After first harvest			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
20-40	0%G	65.47^{i}	53.48^{h}	52.33^{g}	66.22^{h}	50.1^{g}	50.35^{g}
	75%G	44.50^{f}	31.55^{d}	30.59c	40.63^{f}	22.62^{c}	22.98^{c}
	100%G	39.06^{e}	22.97^{b}	22.43^{b}	36.263^{e}	14.90^{b}	14.78^{b}
	125%G	30.39^{c}	14.86^{a}	14.76^{a}	26.00^{d}	9.14a	8.66^{a}
SE(±)			0.26			0.36	
LSD			0.54			0.74	
CV (%)			0.91			1.44	
		After first harvest			**After second harvest**		
	G levels	0H	PG	RG	0H	PG	RG
40-60	0G	72.10^{i}	57.76^{f}	57.00^{e}	72.26^{i}	50.81^{e}	49.83^{d}
	75%G	63.55^{h}	35.14^{d}	34.86^{d}	58.66^{h}	25.58^{c}	25.33^{c}
	100%G	60.84^{g}	26.32^{c}	25.69^{b}	55.73^{g}	17.27^{b}	17.19^{b}
	125%G	56.74^{e}	17.12^{a}	16.85^{a}	51.99^{f}	9.69^{a}	9.47^{a}
SE(±)			0.22			0.29	
LSD			0.46			0.6	
CV (%)			0.63			0.96	

Where, Mean ± SE; SE- standard error; 0H- no halophytic plantation; RG- Rhodes grass; PG- Panikum grass; G- gypsum requirement; LSD- least significant difference; CV- coefficient of variation. Different letters (a, b, c, d, e, f, g, h, i and j) indicate a highly significant difference between treatments and the same letters indicate a non-significant difference between treatments at a 1% probability level. The letters ranked in ascending order.

Comparing the efficiency of two independent factors in the first two soil columns were, “non-plant gypsum treatment > non-gypsum plant treatment > control”. In the last soil column “non-gypsum plant treatment > non-plant gypsum treatment > control”.

In contrasting the applied treatments, the lowest values of ESP were recorded in soils with a combined application of gypsum with halophytic grasses for all soil columns, while the control experimental plot has the highest ESP value. This study coincided with Swarp, (2004), El-Fattah, (2011) and Abdel-Fattah, (2012) reported that combined application of gypsum with salt-loving species more reduces ESP than the single used amendments.

The overall efficiency of treatments in decreasing soil ESP was ordered as “gypsum and halophytic grass combined treatments > non-plant gypsum treatments > non-gypsum halophytic grass treatments > control” in the first two soil columns. In the bottom (40-60 cm) soil column the efficiency of treatments were, “gypsum and halophytic grass combined treatments > non-gypsum halophytic grass treatments > non-plant gypsum treatments > control (without gypsum or grass)”.

Among all combined treatments, application 125% G with Panikum and Rhodes grasses substantially decrease ESP values in all soil layers. Rhodes grass with 125 % G received treatment was the most pronounced decreases soil ESP values by 84.43, 86.92 and 86.89 % for 0-20, 20-40 and 40-60 cm respectively compared with the control treatments of each soil layers. Similarly, Panikum grass with 125 % G also decreases ESP by 84.42, 89.2 and 86.59 % for 0-20, 20-40 and 40-60 cm soil column respectively contrasted with the corresponded control treatment.

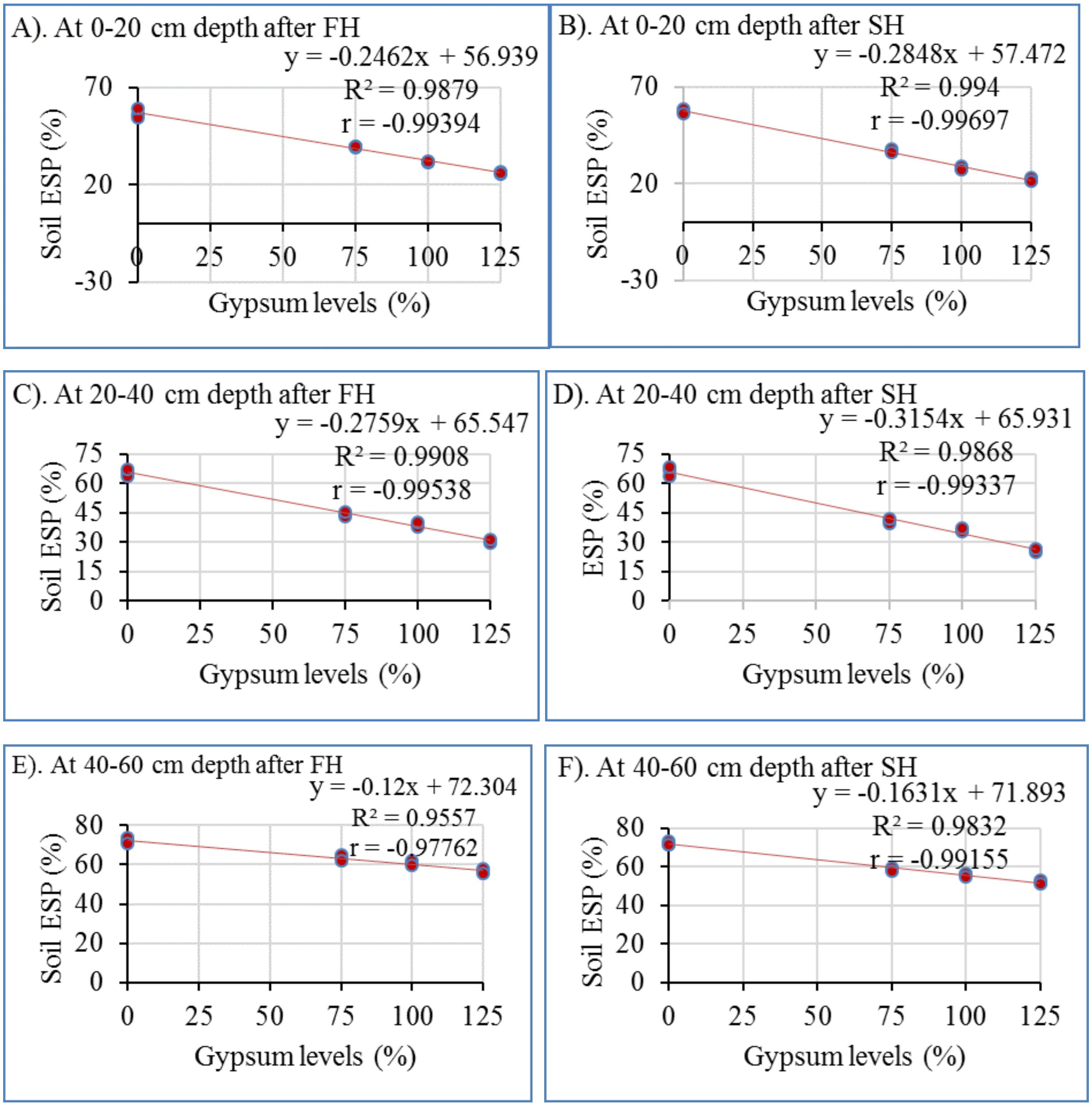

Figure 10. Relationships of gypsum levels and ESP in the three soil columns

Where, FH- first harvest; SH- second harvest

4.9. Effect of Gypsum on the Performance of Grasses

4.9.1. Plant height

From the result, (Appendix Table 7) application of gypsum in salt-affected soil had a highly significant effect ($p<0.01$) on plant height.

Gypsum application on salt-affected soils gave much higher plant height than those grown in non-saline soils in each cutting (Table 16). The study conceded with Al-Khalifah, (2004) finding reported that the height of grasses not affected by the salinity. From the first harvest result, the highest plant heights of 143.57 and 142 cm was obtained from Panicum grass with 125 and 100 % G applied treatments respectively. The lowest plant height recorded in the non-gypsum Rhodes grass treatment as 121.6 and 116.03 cm for non-saline and salt-affected irrigation fields respectively. In comparing the two kinds of grasses, Rhodes grass has relatively low plant height.

Table 16. Effects of gypsum on plant height (cm)

Experimental soil	Treatments	FH	SH
Non-saline field	RG	121.60^{ef}	147.50^{f}
	PG	129.63^{cd}	157.10^{e}
Saline-sodic field	RG	116.03^{f}	149.80^{f}
	PG	124.20^{de}	157.93^{e}
	RG+75% G	128.20^{cd}	158.50^{e}
	RG+100% G	132.50^{bc}	159.00^{de}
	RG+125% G	138.10^{ab}	163.00^{cd}
	PG+75% G	138.60^{ab}	167.02^{bc}
	PG+100% G	142.00^{a}	170.60^{ab}
	PG+125% G	143.57^{a}	172.53^{a}
SE(±)		3.04	2.07
LSD		6.39	4.34
CV (%)		2.83	1.58

Where, Mean ± SE; SE- standard error; FH- first harvest; SH- second harvest; RG- Rhodes grass; PG- Panicum grass; G- gypsum requirement; LSD- least significant difference; CV- coefficient of variation. Different letters (a, b, c, d, e and f) indicate a highly significant difference between treatments and the same letters indicate a non-significant difference between treatments at a 1% probability level. The letters ranked in descending order.

In the second harvest, all treatments gave higher plant height for both experimental sites compared with the first harvest result. The main reasons for this increment could be probably due to the increased temperature(Appendix Table2). The relatively higher plant heights of 172.53 and 170.6 cm recorded in Panikum grass with 125 and 100 % G application respectively.

4.9.2. Dry biomass yield

The ANOVA table showed Panicum and Rhodes grass cultivation in saline-sodic soil treated with gypsum had a highly significant effect ($p<0.01$) on biomass yield (Appendix Table 8).

Figure 11. Performances of grasses in the salt-affected and normal field

Figure 12. Field visit by different stakeholders

As observed in (Figures 11 and 12) the vigorous of both Panicum and Rhodes grasses sufficiently grows in saline-sodic and non-saline soils The biomass yield exhibited an increasing trend in the second harvest (Table 17); because of the relatively increased plant height, branch number and temperature. A study coincided with many findings reported that the biomass yields of Rhodes grass increase with increased temperature (Moore *et al*., 2006; Tansi, 2009). Avcioglu and Soya, (2009) had similar reports that Panicum grass was a warm climate forage.

In the two experimental sites, Rhodes grass gave much higher biomass yield than the panicum grass. The more pronounced higher yields (11.73 and 14.1 t/ha) obtained in saline-sodic soils that treated with Rhodes grass with 125 % G for first and second harvest respectively.

Ashenafi *et al*., (2019) reported that the grown of Rhodes grass under the salt-affected field gave much higher dry biomass yield than the non-saline field.

Grows of Panicum and Rhodes grass using 125 and 100 % G respectively had the next alternative regarding its comparable high biomass yield. As indicated in (Figure 13) the application of gypsum with increasing dose has positively correlated with biomass yield. The study agreed with Ahmad *et al.,* (2001) reported as all gypsum-received treatments gave a better yield compared with non-gypsum plant treatments. As the yield significantly increased when the rate of applied gypsum increased (Salim *et al*., 2002).

Table 17. Effect of treatments on dry biomass (ton/ha).

Experimental soil	Treatments	FH	SH
Non-saline field	RG	8.10^{e}	9.00^{e}
	PG	6.37^{f}	8.04^{f}
Saline-sodic field	PG	6.41^{f}	8.17^{f}
	RG	8.0^{e}	9.13^{e}
	PG+75% G	8.96^{d}	10.10^{d}
	PG+100% G	9.51^{cd}	11.35^{c}
	RG+125% G	11.73^{a}	14.10^{a}
	RG+75% G	9.71^{c}	11.56^{c}
	PG+125% G	11.13^{b}	12.91^{b}
	RG+100% G	10.85^{b}	13.20^{b}
SE(±)		0.27	0.37
LSD		0.56	0.78
CV (%)		3.58	4.21

Where, Mean ± SE; SE- standard error; FH- first harvest; SH- second harvest; RG- Rhodes grass; PG- Panicum grass; G- gypsum; LSD- least significant difference; CV- coefficient of variation. Different letters (a, b, c, d, e and f) indicate a highly significant difference between treatments and the same letters indicate a non-significant difference between treatments at a 1% probability level. The letters ranked in descending order.

In comparing each non-gypsum grass treatment independently, plants grown in salt-affected soils had statistically similar results compared with those grown in non-saline soils. The presence of high soil salinity and sodicity in saline-sodic soils probably advantageous for plants and considered as a portion of food to enhanced biomass yield.

This result inline with Hameed and Ashraf, (2008) findings reported that the application of sodium salts (NaCl) to Panikum grass (*Cynodon dactylon*) in increasing amounts that appeared non-negative effect on dry matter yield.

In this study, the treatment that efficiently reclaimed saline-sodic soil simultaneously gave a high biomass yield. Qadir *et al*., (1996b) and Qadir *et al.*, (2001) had been similar experiences reported that biomass production was directly proportional to the reclamation efficiency of salt-affected soils. Helalia *et al*., (1992) studded grows of grasses in Egypt salt-affected soils, gave higher biomass yield than a commonly cultivated fodder and at the same time it reclaims the soil better than leaching and gypsum.

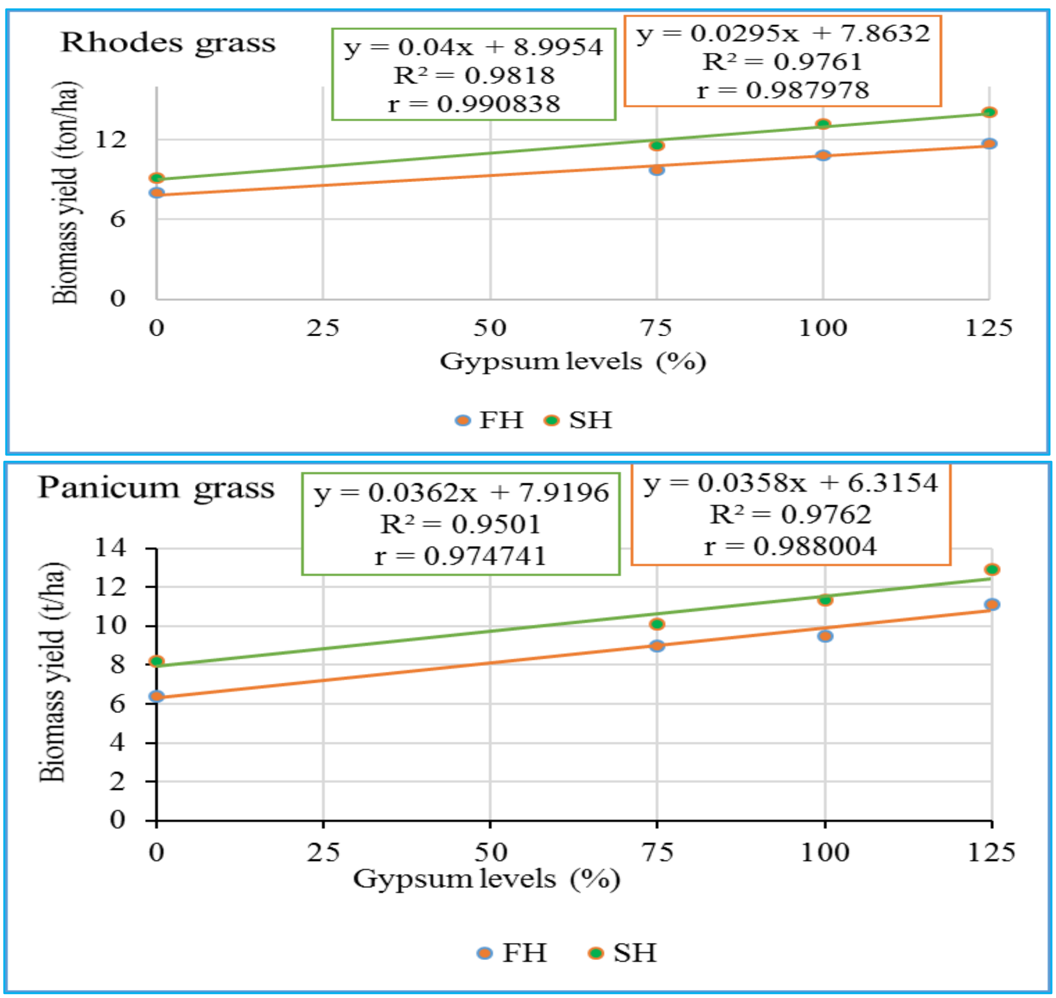

Figure 13. Relationship between the gypsum rates biomass yield

Where, FH- first harvest; SH- second harvest

4.9.3. Nutrient compositions of grasses

4.9.3.1. Sodium in plant tissue

The leaf sodium concentrations of Panicum and Rhodes grasses which grow in the saline-sodic field also highly significantly influenced ($p<0.01$) by the applied gypsum (Appendix Table 9).

The grasses planted in saline-sodic soils had much higher leaf sodium than those grown in non-affected soil (Figure 14). Even, all the non-gypsum cropped treatments in the salt-affected soil uptake excess Na^+ compared to those grown in non-affected soil.

The increased leaf sodium in place where plants grown in salt-affected soils could be due to their salt-loving potential of forage grasses was the main reason. Many researches also done in recent decades suggests that salt-tolerant forage species also absorb ions like Na^+ and Cl^- from the soil to maintain turgor (Ahmad *et al*., 1990; Ghaly, 2002; Qadir *et al*., 2003). Similar experiences have been reported by Qadir *et al*., (1996) and Batra *et al*., (1997) that the possible role of salt-tolerant species like grasses reduced soil salinity, sodicity/ Na^+. Moreover, Kobayashi *et al*., (2007) suggested that the grasses had a special preference for adsorbing Na^+ over other ions using their salt glands.

The leaf sodium's of Panicum and Rhodes grasses shows an increasing trend with increasing gypsum level. It could be due to the application of gypsum in increasing dose replaces high exchangeable sodium and improves soil structure might enhance the availability of too much sodium uptake by plants. This finding coincided with several other studies reported that the gypsum amendment improves soil structure for promoted the uptake of water and ions by plants (Gupta & Abrol, 1990; Ghafoor *et al*., 1991; Qadir *et al*., 2001).

In the first harvest, the highest leaf sodium's of 288.42 and 294.4 ppm or mg/kg was recorded in Panicum and Rhodes grass plantation at 125 % G treated soils respectively. Similarly, those respective treatments gave leaf sodium concentrations of 273.7 and 279.68 ppm or mg/kg in the second harvest. Leaf sodium concentrations of the two kinds of grass grown in salt-affected soils exhibited a falling trend in the second harvest compared with the first harvest result might be due to the decreased exchangeable Na^+ in the soil. The leaf sodium concentrations of those grasses grown in the non-affected field remain constant.

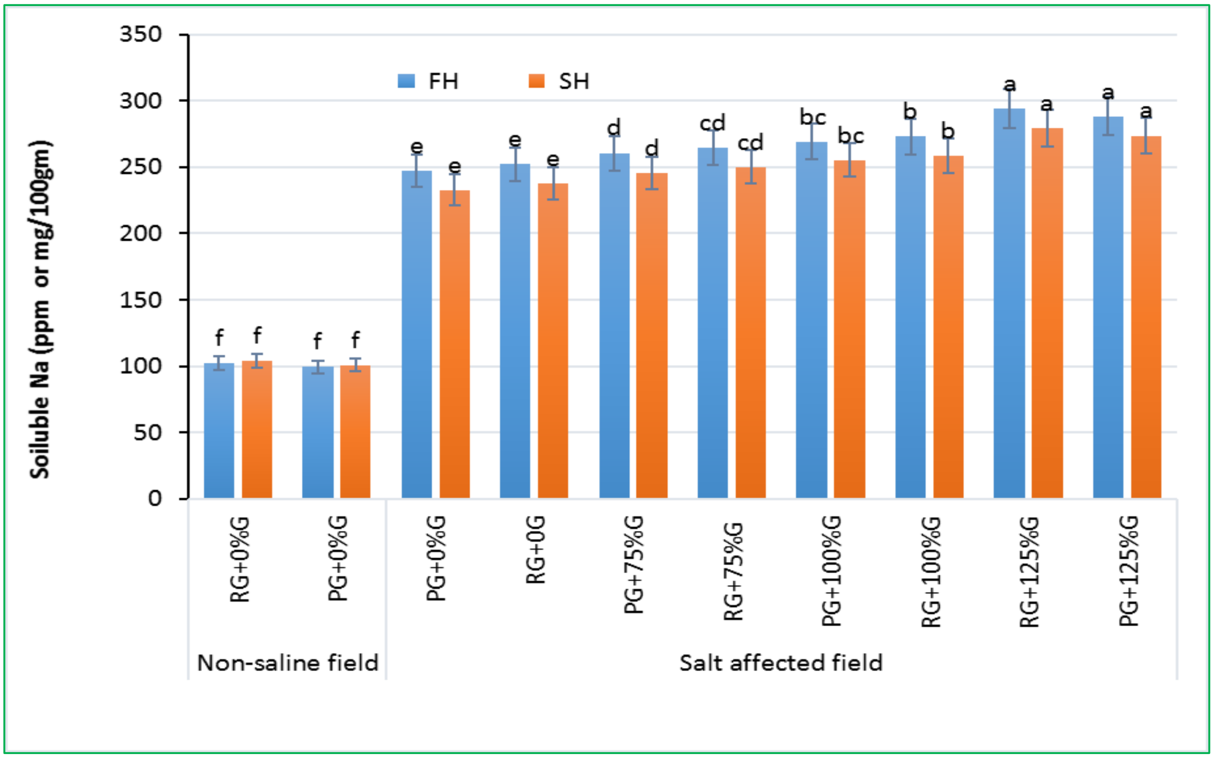

Figure 14. Leaf sodium concentrations of Panikum and Rhodes grass.

Where, Mean ± SE; SE- standard error; FH- first harvest; SH- second harvest; RG- Rhodes grass; PG- Panicum grass; G- gypsum; LSD- least significant difference; CV- coefficient of variation. Different letters (a, b, c, d, e and f) indicate a highly significant difference between treatments and the same letters indicate a non-significant difference between treatments at 1% probability level. At FH (SE= ± 0.16; LSD=0.34 and CV=1.93) and at SH (SE= ± 0.16; LSD=0.33 and CV=1.97).

4.9.1.2. Crude protein ratio (CP)

The ANOVA table showed the application of gypsum in salt-affected soil highly significantly influences ($p<0.01$) the crude portion ratios of halophytic grasses (Appendix Table 10).

Planting of halophytic grasses in saline-sodic soil had lower CP than those grown in non-saline soil. The higher CP ratios of 9.31 and 9.34 % for first and second harvest respectively obtained by Rhodes grass which planted on the non-saline soil followed by Panicum grass planted in similar soil (Figure 15).

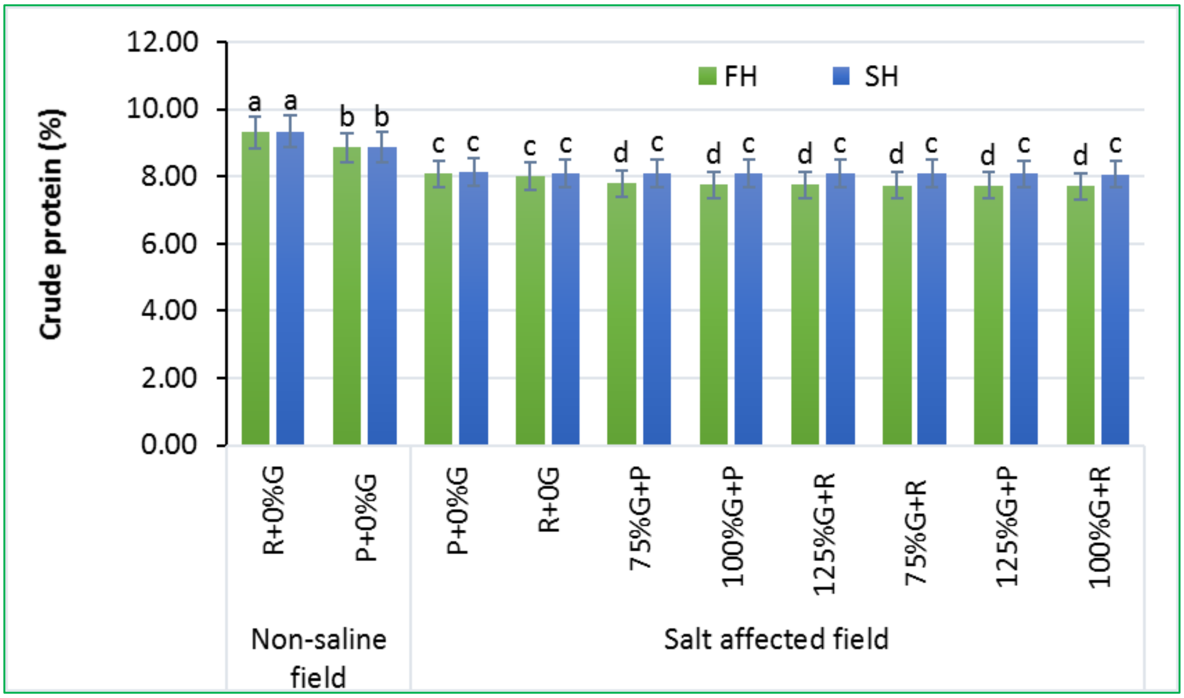

Figure 15. Crude protein ratios of Panicum and Rhodes grass.

Where, Mean ± SE; SE- standard error; FH- first harvest; SH- second harvest; RG- Rhodes grass; PG- Panicum grass; G- gypsum; LSD- least significant difference; CV- coefficient of variation. Different letters (a, b, c and d) indicate a significant difference between treatments and the same letters indicate a non-significant difference between treatments at a 1% probability level. At FH (SE= ± 0.08; LSD= 0.17 and CV=1.25) and at SH (SE= ± 0.12; LSD=0.24 and CV=1.7).

The probable reasons for relatively lower CP under saline-sodic conditions might be due to the presence of high sodium in the initial soil uptaken by plants in excess amount and simultaneously the replacement of exchangeable sodium by gypsum in the form of leachable Na_2SO_4 absorbed by plants might decrease tissue CP. This study in agreement with the earlier findings described as, the CP ratios of Panicum and Rhodes grasses which grown under saline and sodic fields gave a lower crude protein ratio than those grown under normal soil (Temel *et al*., 2015). Moreover, Suyama *et al*., (2007) and Ashenafi Worku *et al*., (2019) have been similar experiences as CP tends to decrease due to the effect of salinity. However, from ILERI, (2013) forage quality classification guidelines, this decreased crud protein still rated within the palatable feed quality range.

At the first harvest, the halophytic grasses grown in gypsum treated salt-affected soil had a lower crude protein ratio compared with non-gypsum plant treatments under similar soil. Whereas in the second harvest, it showed an increasing trend compared with the first harvest at gypsum treated salt-affected soils. This increased CP in gypsum treated salt-affected soils at second harvest could be probably due to the decrease of soil sodium than the first harvest. Plants were grown in the non-saline field and non-gypsum saline-sodic field, the CP remains relatively constant in both first and second harvest.

4.10. Partial Budget Analysis

The partial budget analysis revealed the MRR values of all treatments were exceeds 100 %. Based on CIMMYT, (1988) suggested that the minimum acceptable MRR should be between 50% and 100%, while the values higher than 100 % were more profitable. In the first harvest, grown of Panicum grass in saline-sodic and non-saline fields except it combined with 125 % G indicates a fairly similar BCR value, while non-gypsum Rhodes grass treatments which planted in saline-sodic soil had much higher BCR values (8.57) than all over other treatments. Similarly, this grass gave higher BCR (8.69) in the non-saline field (Table 18).

In the second harvest, the BCR of non-gypsum plant treatments grown in saline-sodic soils had similar results compared with those grown in non-saline soils. Plants grow in saline-sodic soil treated with gypsum gave much higher results of BCR than those grown without gypsum.

The application of gypsum in saline-sodic soil with increased dose indicates the increased BCR values. The highest net benefit (255,319.44 ETB) with the highest BCR (29.41) was recorded by combined treatments of Rhodes grass with 125 % G followed by Rhodes grass with 100 % G and Panicum grass with 125 % G combined treatments. Thus treatment combinations showed the most economically attractive for small-scale farmers with low cost of production to earn higher benefits.

Table 18. Partial budget analysis for gypsum rate and halophytic grasses

Field	Treatment	Unadjusted yield (t/ha)	Adjusted yield (t/ha)	Gross benefit (ETB/ha)	Gypsum Cost (ETB/ha)	Operation cost (ETB/ha)	Total cost (ETB/ha)	Net benefit (ETB/ha)	BCR
First harvest									
	RG	8.10	7.29	145800	0	15046.53	15046.53	130753.47	8.69
Nor.	PG	6.37	5.73	114600	0	15046.53	15046.53	99553.47	6.62
	PG	6.41	5.77	115400	0	15046.53	15046.53	100353.47	6.67
	RG	8.00	7.20	144000	0	15046.53	15046.53	128953.47	8.57
	75%G+PG	8.96	8.06	161200	5400.00	15046.53	20446.53	140753.47	6.88
Aff.	100%G+PG	9.51	8.56	171200	7200.00	15046.53	22246.53	148953.47	6.70
	125%G+RG	11.73	10.56	211200	9000.00	15046.53	24046.53	187153.47	7.78
	75%G+RG	9.71	8.74	174800	5400.00	15046.53	20446.53	154353.47	7.55
	125%G+PG	11.13	10.02	200400	9000.00	15046.53	24046.53	176353.47	7.33
	100%G+RG	10.85	9.77	195400	7200.00	15046.53	22246.53	173153.47	7.78
Second harvest									
	RG	9.00	8.10	162000	0	8680.56	8680.56	153319.44	17.66
Nor.	PG	8.04	7.14	142800	0	8680.56	8680.56	134119.44	15.45
	PG	8.17	7.27	145400	0	8680.56	8680.56	136719.44	15.75
	RG	9.13	8.23	164600	0	8680.56	8680.56	155919.44	17.96
.	75%G+PG	10.10	9.20	184000	0	8680.56	8680.56	175319.44	20.20
Saff.	100%G+PG	11.35	10.45	209000	0	8680.56	8680.56	200319.44	23.08
	125%G+RG	14.10	13.20	264000	0	8680.56	8680.56	255319.44	29.41
	75%G+RG	11.56	10.66	213200	0	8680.56	8680.56	204519.44	23.56
	125%G+PG	12.91	12.01	240200	0	8680.56	8680.56	231519.44	26.67
	100%G+RG	13.20	12.30	246000	0	8680.56	8680.56	237319.44	27.34

FH (first harvest), SH (second harvest), BCR (benefit-cost ratio), operation cost includes (land preparation cost, labor cost for planting, watering, weeding and harvesting), variable cost (gypsum cost), RG- Rhodes grass, PG- Panicum grass, Saff- salt-affected field, Nor- normal field.

4.11. Effect of Gypsum on the Quality of Local Groundwater

4.11.1. Sodium levels

Sodium in small quantities is beneficial to plant growth, however, higher concentrations are toxic to many plants and affect soil structure (Falstad, 2000; Bauder and Brock, 2001; Ezlit, 2009). Based on the result (Figure 16) shows that all samples have a sodium concentration in smaller quantities and found within FAO, (1985) permissible level. It implies that the presence of sodium in the applied irrigation water and in the deep percolated water had does not exhibit a specific ion effect or no toxicity problems in short-term usage (FAO, 1985).

At 131 days after gypsum placement, the concentrations of sodium in the deep percolated water samples obtained from in both the gypsum received and control experimental plots have relatively higher sodium than the applied irrigation water. The relatively higher sodium values in the deep percolated water samples can be due to the presence of high soil sodium (Table 7) dissolved into the shallow groundwater.

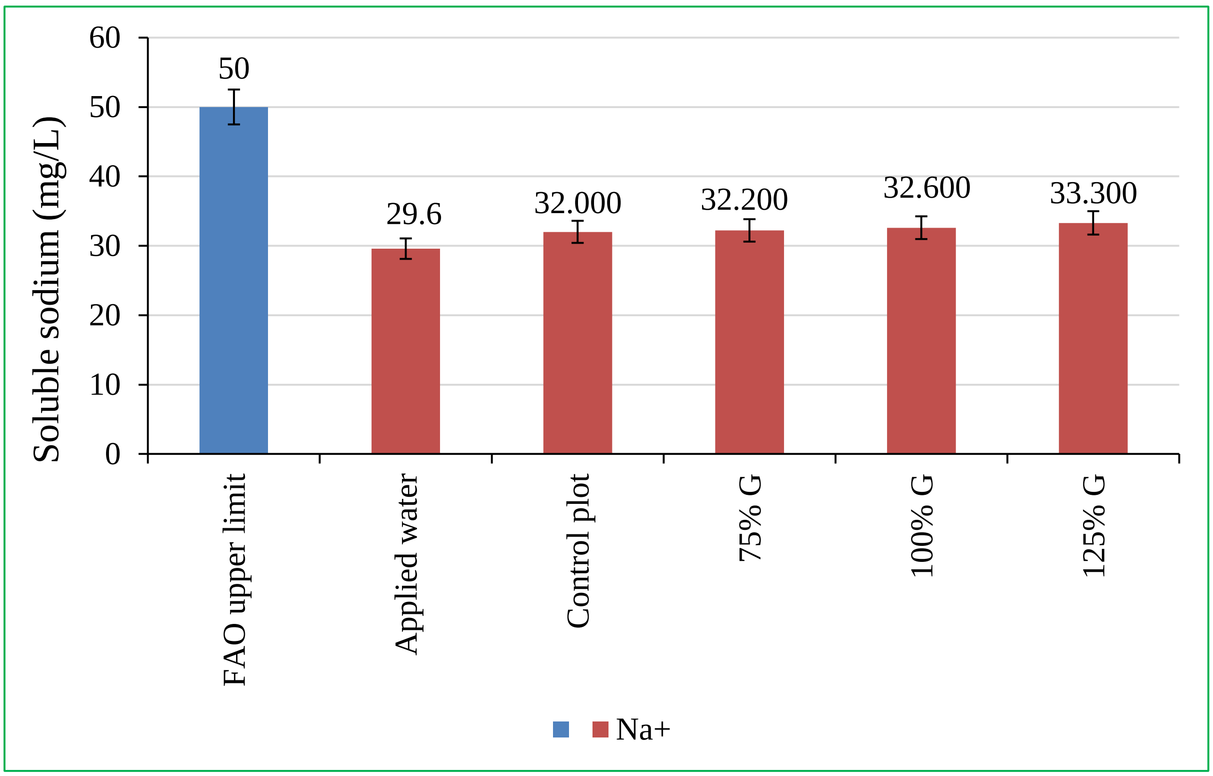

Figure 16. Sodium concentrations in water samples

The concentrations of sodium in the deep percolated water shows a little increment in all gypsum received plots compared with the control experimental plot. A relatively higher sodium concentration (33.3 mg/l) was recorded at 125% G received plot. It might be due to the application of high gypsum amount that replaces relatively high sodium from the soil exchangeable site and it joins into the soil solution. It reflects surface (0-20 cm) gypsum placement with variable rates had not much negative contribution to local groundwater quality.

4.11.2. Calcium levels

Some quantities of calcium have a positive impact by controlling the negative effects of sodium and it enhances for maintaining good soil properties (Fipps, 2004; Maral, 2010). Based on Gebauer and Ebert, (2005) calcium provides for the structural and functional integrity of plant membranes, stabilizes cell wall structure.

From the result (Figure 17), the calcium concentrations of the applied irrigation water and the deep percolated water samples fell within the FAO, (1985) permissible range. It indicates that the concentration calcium in the water samples does not inhibit the uptake of iron from the soil and induced acceptable chlorosis of plants (Attibu, 2017**.** In addition, it also not cause any nutrient imbalance (Augustine, 2009).

In comparing the concentration of calcium in the deep percolated water samples do not appear much change by surface (0-20 cm depth) gypsum application (Figure 17), however, the applied irrigation water has the highest calcium concentration (71 mg/l). The main reasons for low calcium concentrations in the deep percolated water samples were due to the presence of relatively high sodium antagonize the calcium concentration.

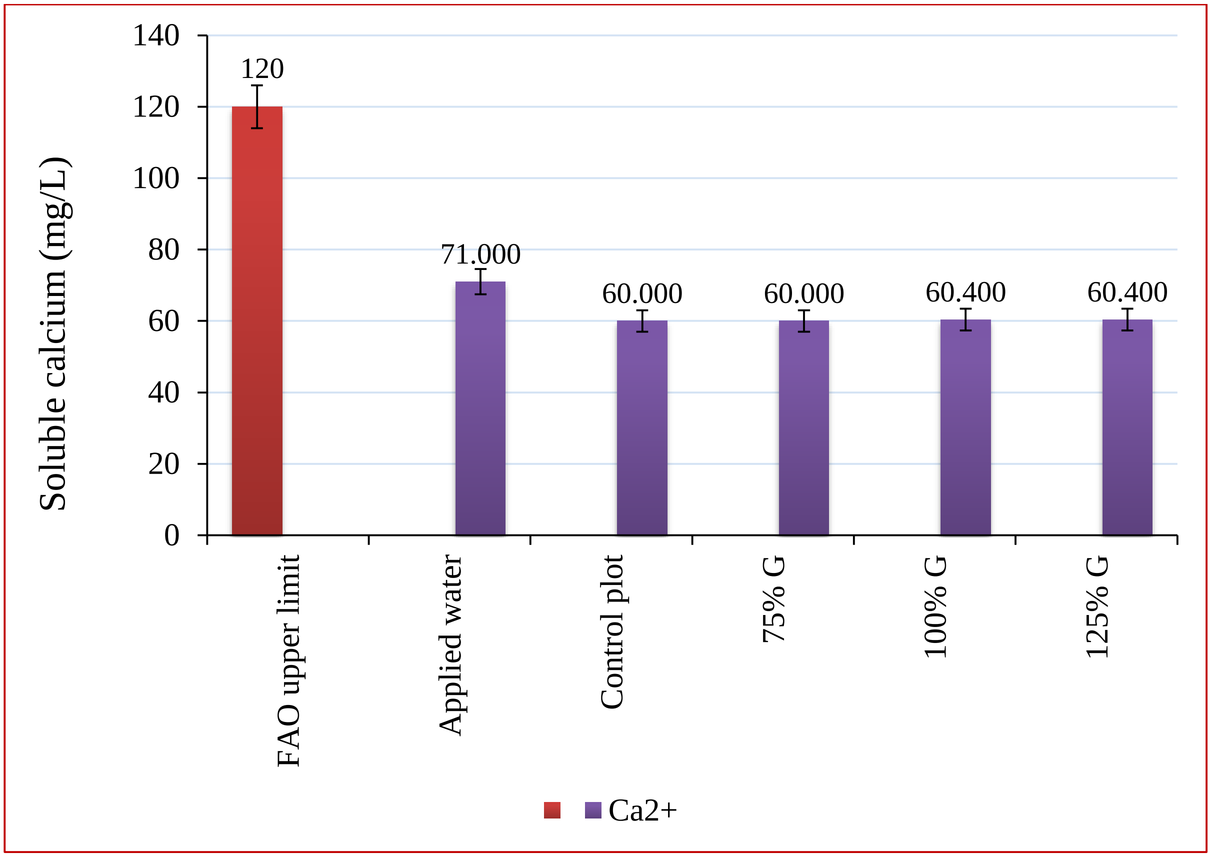

Figure 17. Calcium concentrations in water samples

4.11.3. Magnesium levels

Similar to calcium, magnesium is associated with soil aggregation and friability. Excessive magnesium in water also causes water hardness and when used for irrigation deposits mineral residues on plant surfaces (Maral, 2010; Banderi *et al.*, 2012).

From the result (Figure 18) the magnesium concentrations of the water samples ranged from 29.13 (irrigation water) to 25.5 mg/l found within the permissible range and do not affect the plant tissue (FAO, 1985). The application of gypsum with a variable rate shows a similar magnesium concentration in deep percolated water as contrasted with the control experimental treatment (Figure 18).

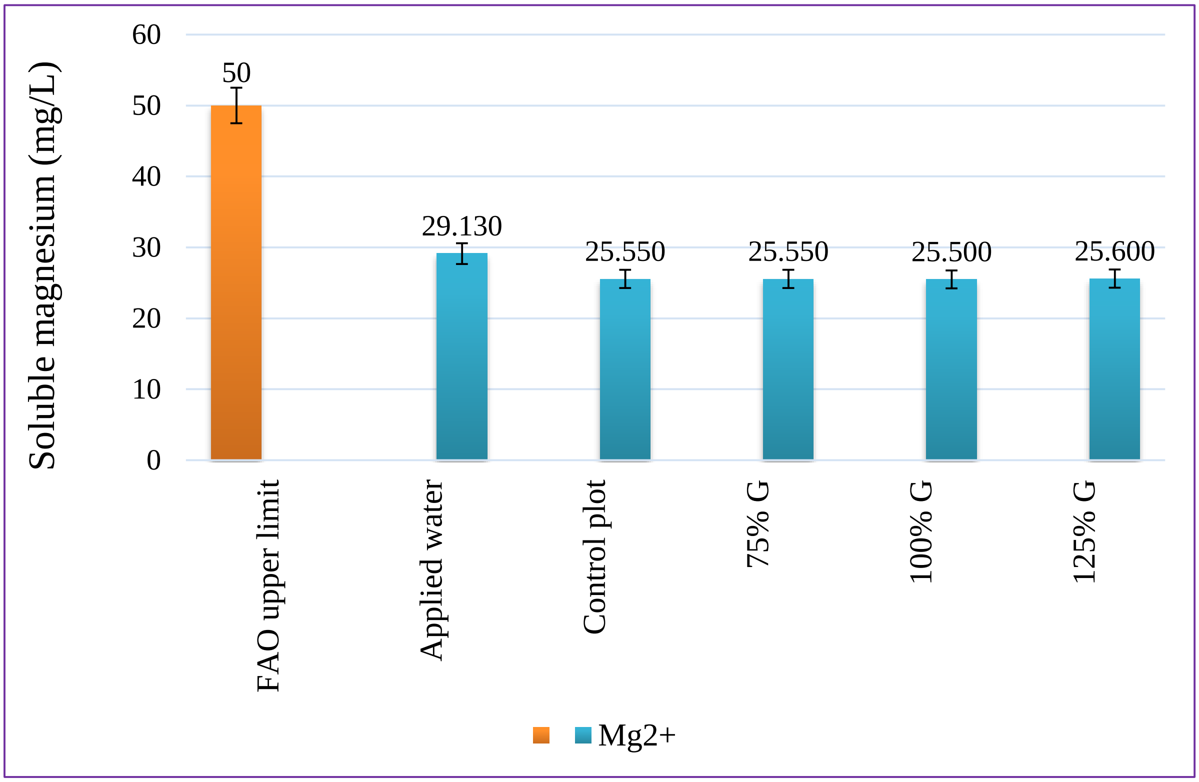

Figure 18. Magnesium concentrations in water samples

4.11.4. Total dissolved solids (TDS) and ECw concentrations

From the result (Figure 19), the ECw and TDS values of deep percolated water remain nearly similar in a comparison between gypsum applied and non-applied (control) experimental treatments; while the applied irrigation water has relatively low ECw and TDS concentrations contrasting with the deep percolated water samples.

Both the ECw and TDS concentrations in the applied irrigation water and deep percolated water samples found within the FAO, (1985) permissible range. On the other hand, the ECw values in all water samples found between 0.25 and 0.75 dS m^{-1} rated as “moderately saline” (USSLS, 1954) in (Appendix Table 14). In this respect, Golina-Adisalem shallow water table had “moderately saline” (USSLS, 1954).

The study indicates that surface (0-20 cm) application of gypsum for soil amendment has not much impact on the quality of shallow groundwater.

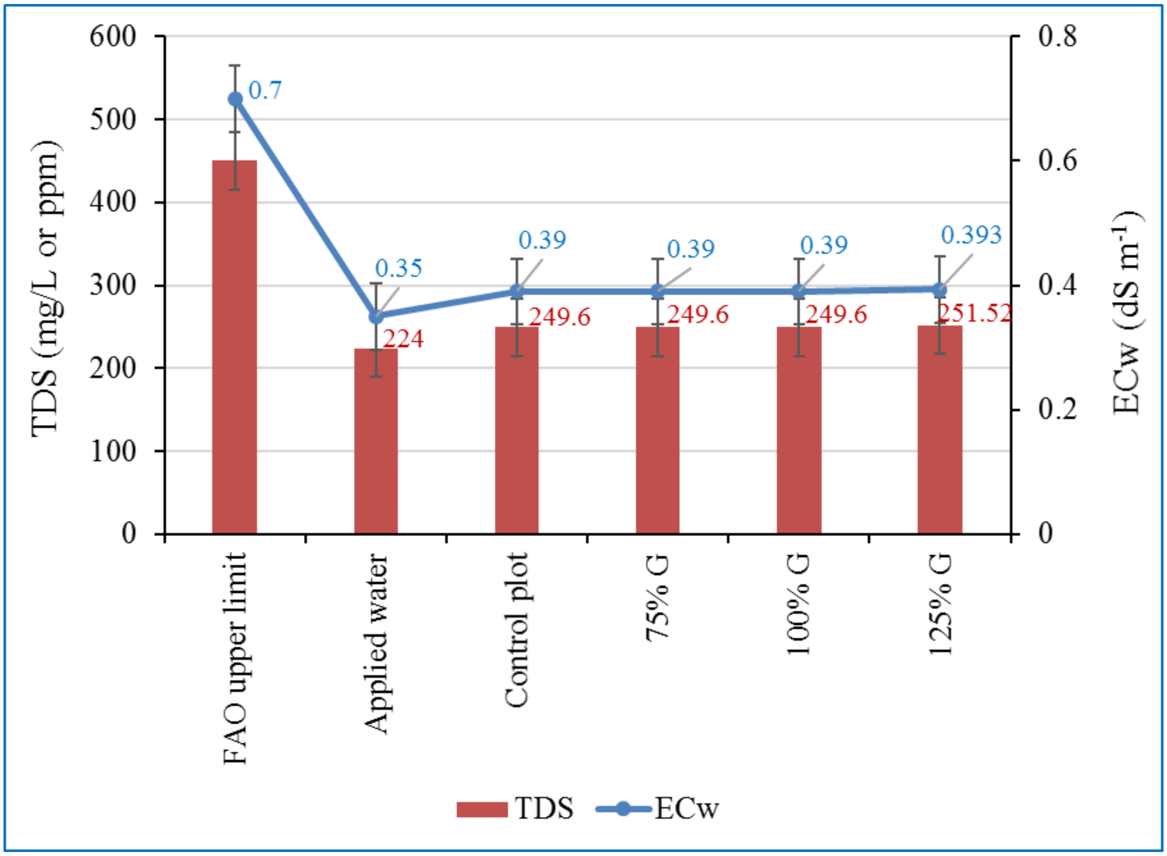

Figure 19. ECw and TDS concentrations in water samples

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Based on the research done towards reclamation and amelioration of saline-sodic soil using gypsum and halophytic grasses indicates that the application of gypsum amendment with a variable rate and plantation of ameliorative (Panicum and Rhodes) grasses enhanced the reclamation of saline-sodic soil. A combined application of gypsum with Panicum and Rhodes grasses showed relatively faster effectiveness in decreasing soil pHe, ECe, SAR and ESP for all soil layers compared with gypsum only and non-gypsum plant treatments. Those treatments (RG+125% G and PG+125% G) enhances infiltration rates of the saline-sodic soil contrasted with other treatments. The replaced sodium by applied gypsum chemical had not a considerable negative contribution to shallow groundwater quality along the two experimental season. Based on the result Panicum and Rhodes grasses were successfully grown in both saline-sodic and non-saline (normal) soils, it was important for the provision of needed forages in addition to soil improvement.

The agronomic parameters such as plant height and dry biomass have not affected by soil salinity and sodicity. In both experimental sites, those parameters more increased in the second harvest than the first harvest due to seasonal climatic variation. Application of gypsum in saline-sodic soil with increased dose increases plant height and biomass yield resulted in a better contribution to earn the highest net benefit than plants grown in the non-saline field.

The Panicum and Rhodes grasses grown in the saline-sodic field showed a lower crude protein ratio than those grown in non-saline soils. The application of gypsum in the saline-sodic field decreases the CP than non-gypsum plant treatments of those grown under the same soil condition. In the gypsum received saline-sodic experimental plots, the crude protein ratios tend to increases in the second harvest compared with the first harvest result due to the decrease of soil sodium. However, the crude protein ratios in the non-saline field and non-gypsum saline-sodic field remains nearly constant along with the two harvestings. However, thus relatively lower crude protein ratios obtained in the saline-sodic field found within a suitable forage quality range.

The halophytic grasses planted in the saline-sodic field showed much higher leaf sodium concentration than those grown in the normal field. The leaf sodium concentration in the saline-sodic field tends to decrease in the second harvest than the first harvest due to the decreased soil sodium, while leaf sodium concentrations in the non-saline (normal) field was nearly similar in both first and second harvest.

5.2. Recommendation

The present study suggested that for the Golina-Adisalem saline-sodic field combined application 125 % (2.5 t/ha) gypsum requirement with Panicum and Rhodes grasses were the most efficient treatment with respect to a better decreased pHe, ECe, SAR, ESP and it enhances soil infiltration rate, reached high biomass yield with acceptable tissue quality as well as earns highest net benefit. From the field observations of the experimental site, the following recommendations forwarded;

- As one of the difficulties of graduate research, the experiment tested in salt-affected soil was for two growing seasons in one place. Hence repeating the experiment in space and time shall improve the validity of the finding.
- Application of gypsum in an increasing rate more increases the efficiencies of the saline-sodic soil reclamation processes, as well as increased biomass yield and net benefit, which needs further research by increasing gypsum rates higher than 2.5 t/ha.
- The issue of crude protein under the saline-sodic field needs further scientific investigation about why it is getting reduced.
- The concentration of sodium and electrical conductivity in the shallow groundwater getting a little increments needs further scientific research about their long-term impact.
- Detail water table dynamics in time and space should be monitor to operationalized subsurface drainage

6. REFERENCE

Abay Ayalew and Sheleme Beyene., 2012. Characterization of soils at Angacha district in southern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 2 (1), pp. 2224-3208.

Abdel-Fattah, M.K., 2012. Role of gypsum and compost in reclaiming saline-sodic soils. *J. Agric. Vet. Sci*, **1**(3), 30-38.

Abdul-Ghafoor, B.A., Boers, T.M. and Murtaza, G., 2004. Economical use of brackish tube well waters for rice-wheat production and reclamation of saline-sodic soils. *Pak. J. Agri. Sci*, *41*, pp.1-2.

Abou-Youssef, M.F., 2001. Use of phosphogypsum fortified as a soil amendment for saline-sodic soil in El-Salhiya plain [Egypt]. *Zagazig Journal of Agricultural Research (Egypt).* 28, pp. 889-911.

Adigudom gypsum manufacturer., 2018. Chemical characteristics of gypsum, Adigudom, Ethiopia.

Ahmad N., Qureshi, R.H., Qadir, M., 1990. Amelioration of a calcareous saline-sodic soil by gypsum and forage plants. *Land Degradation and Development*, 2(4), pp. 277–284.

Ahmad, M., Hussain, N., Salim, M. and Niazi, B.H., 2001. Use of chemical amendments for reclamation of saline-sodic soils. *Int. J. Agri. Biol*, 3 (3), pp. 305-307.

Ahmad, S.A., Ghafoor, A., Qadir, M. and Aziz, M.A., 2006. Amelioration of calcareous saline-sodic soil by gypsum application and different crop rotation. *Int. J. Agric. Biol,* 8, pp. 142-146.

Ahmed Hussein., 2002. *Assessment of Spatial variability of some physicochemical properties of soils under different elevations and land use systems in the Western slopes of Mount Chilalo, Arsi* (M.Sc. Thesis, Haramaya University), Ethiopia.

Ahmed, M. and Qamar, I., 2004. Productive rehabilitation and use of salt-affected land through afforestation (a review). *Science Vision*, 9**,** pp. 1-14.

Akhter, J., Mahmood, K., Malik, K., Ahmed, S. and Murray, RS., 2003. Amelioration of a saline sodic soils through cultivation of a salt-tolerant grass Leptochloa fusca. *Environmental Conservation*, 30(2), pp. 168-174.

Akyildiz, A.R., 1984. Feed science laboratory manual. Ankara Uni. Fac. *Agric. Publ. No*. 895, Ankara.

Al-Dakheel, A.J., Hussain, M.I. and Rahman, A., 2015. Impact of irrigation water salinity on agronomical and quality attributes of Cenchrus ciliaris L. accessions. *Agricultural Water Management*, *159*, pp.148-154.

Ali, Z., Salam, A., Azhar, F.M. and Khan, I.A., 2007. Genotypic variation in salinity tolerance among spring and winter wheat (Triticum aestivum L.) accessions. *South African Journal of Botany*, *73*(1), pp.70-75.

Al-Khalifah, N.S., 2004. Response of some turfgrasses to salinity and environmental conditions of Saudi Arabia. *Emirates Journal of Food and Agriculture*, pp.9-17.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration guidelines for computing crop water requirements. *FAO Irrigation and drainage paper* 56. *FAO, Rome*, 300(9), p. Do5109.

Ammari, T.G., Tahuboub, A.B., Saoub, H.M., Hattar, B.I. and Al-Zubi, Y.A., 2008. Salt removal efficiency as influnced by phyto-amelioraion of salt-affected soils. *Journal of food Agriculture and Environment*, 6, pp. 456-460.

Ann, Mc-C. and Clain J., 2005. Soil and water management module 2. Salinity and sodicity management, Montana State University Extension Service, pp.1-13.

Armstrong, A.S., Rycroft, D.W. and Tanton, T.W., 1996. Seasonal movement of salts in naturally structured saline-sodic clay soils. *Agricultural Water Management*, 32 (1), pp. 15–27.

Ashenafi Ali, Abayneh Esayas and Sheleme Beyene., 2010. Characterizing soils of Delbo Wegene watershed, Wolaita Zone, Southern Ethiopia for planning appropriate land management. *Journal of Soil Science and Environmental Management*, 1(8), pp. 184-199.

Ashenafi Worku, Qureshi, A. and Nisaren, B., 2019. Evaluation of Some Rhodes Grass (Chloris gayana) Genotypes for Their Salt Tolerance, Biomass Yield and Nutrient Composition. *Applied Sciences,* 9(1)**,** p. 143.

Ashraf, M., Akram, M.Y., Ahmad, R., Rafiq, M., Ahmad, I. and Iqbal, J., 2010. Allometry and yield components of maize (Zea Mays L) hybrids to various potassium levels under saline conditions. *Arch. Biol. Sci. Belgrade*, 62(4), pp. 1053-1061.

Attibu, P.K., Ashun, E. and Young, G.L., 2017. Assessment of groundwater suitability for irrigation in three sub-catchments in Upper Athi River Basin, Kenya.

Augustine, A.O., 2009. Irrigation suitability assessment of effluents from West Kano rice irrigation scheme, Kisumu, Kenya. *Ethiopian Journal of Environmental Studies and Management*, *2*(2).

Avcioglu, R. and Soya, H., 2009. Bermuda grass (Cynodon dactylon L. Pers). (Avcioglu, R., Hatipoglu, R., Karadag,Y Edit.) Volume III. *Tugem, Emre Printing Office, Izmir*, pp, 727-732.

Baldwin, C.M., Liu, H., McCarty, L.B., Bauerle, W.L. and Toler, J.E., 2006. Effects of trinexapac-ethyl on the salinity tolerance of two ultradwarf bermudagrass cultivars. *HortScience*, 41(3), pp. 808–814.

Balpande, S.S., Deshpande, S.B. and Pal, D.K., 1996. Factors and processes of soil degradation in vertisols of Purna Valley, Maharashira, India. *Land Degradation and Development*, **7**(4), pp. 313-324.

Banderi, A., Mohammad, M.S., Hamdi, H., Shomeli, M. and Ali, S.D., 2012. Water quality assessment of Amir Kabir sugarcane agro-industry with respect to agricultural and drinking views. *J. Environ. Ecol*, *3*(1), pp.11-28.

Batra, L., Kumar, A., Manna, M.C. and Chhabra, R., 1997. Microbiological and chemical amelioration of alkaline soil by growing Karnal grass and gypsum application. *Experimental Agriculture*, 33(4), pp. 389–397.

Bauder, J.W. and Brock, T.A., 2001. Irrigation water quality, soil amendment, and crop effects on sodium leaching. *Arid Land Research and Management*, *15*(2), pp.101-113.

Bauder, T.A., Waskom, R.M. and Davis, J. G., 2007. Irrigation water quality criteria. Colorado State University Cooperative Extensions (USA). 7/03. No. 0.506.

Belesky, D.P. and Wilkinson, S.R., 1983. Response of ‘Tifton 44’ and ‘Coastal’ Bermuda grass to soil pH, K, and N source 1. *Agronomy Journal*, 75 (1), pp. 1–4.

Beltran, M.J., Bridze, B.J., Harch, G.R. and Orange, D.N., 2005. Physical rehabilitation of degraded krasnozems using ley pasture. *Australian Journa of Soil Research*, 35, 1093-1113.

Bennett, J.M., Greene, R.S., Murphy, B.W., Hocking, P. and Tongway, D., 2014. Influence of lime and gypsum on long-term rehabilitation of a Red Sodosol, in a semi-arid environment of New South Wales. *Soil Research*, 52(2), pp. 120-128.

Blake, G.R. and Hartge, K.H., 1986. Bulk density. *Methods of soil analysis: Part 1 Physical and mineralogical methods*, *5*, pp.363-375.

Bonales-Alatorre, E., Pottosin, I., Shabala, L., Chen, Z.H., Zeng, F., Jacobsen, S.E. and Shabala, S., 2013. Differential activity of plasma and vacuolar membrane transporters contributes to genotypic differences in salinity tolerance in a halophyte species, Chenopodium quinoa. *International Journal of Molecular Sciences*, 14(5), pp. 9267-9285.

Brady, N.C. and Weil, R. R., 2002. The nature and properties of soils, 14th edn, Prentice Hall. *New Jersey*, *USA*, p. 249.

Breker, M.C., 2016. *Influence of amendments on chemical and biological properties of sodic soils* (M.Sc. Thesis, North Dakota State University).

Buol, SW., Southard, R.J., Graham, R.C., McDaniel, P.A., 2003. Soil genesis and classification, 5th edition. *Iowa State University Press-Blackwell, Ames, IA.*

Burton, G.W., 1983. Utilization of hybrid Vigored Wood. *Crop Breeding, ASA Publ*. Madison Wisconsin, Pp. 89-107.

Busenberg, E. and Clemency, C.V., 1973. Determination of the cation exchange capacity of clays and soils using an ammonia electrode. *Clays and Clay Minerals*, *21*(4), pp. 213-217.

Chang, M.A., Mirbahar, M.B. and Marri, M.K., 1994. Comparative value of organic, inorganic, and biological method in reclaiming saline-sodic soils under tile drainage system. *Journal of Drainage and Reclamation*, 6, pp. 36-40.

Chaudhry, A.A., Hameed, M., Ahamd, R. and Hussain, A., 2001. Phyto-sociological studies in Chhumbi Surla wildlife sanctuary, Chakwal, Pakistan II. *Phytoecology International Journal of Agriculture and Biology*, 3(4), pp. 369-374.

Chi, C.M., Zhao, C.W., Sun, X. and Wang, Z.C., 2012. Reclamation of saline-sodic soil properties and improvement of rice (Oriza sativa L.) growth and yield using desulfurized gypsum in the west of Songnen Plain, Northeast China. *Geoderma*, 187, pp. 24-30.

Cimmyt, M. and Cimmyt, M., 1988. *From agronomic to farmer recommendations: an economics training manual*. CIMMY*T.*

Clark, G.J., Dodgshun, N., Sale, P.W. and Tang, C., 2007. Changes in chemical and biological properties of a sodic clay subsoil with addition of organic amendments. *Soil Biology and Biochemistry*, 39(11), pp. 2806-2817.

Conway, T., 2001. Plant materials and techniques for brine site reclamation. *Plant materials technical note*, No 25, p. 37.

Deifel, K.S., Kopittke, P.M. and Menzies, N.W., 2006. Growth response of various perennial grasses to increasing salinity. *Journal of plant nutrition*, 29(9), pp. 1573-1584.

Denise, M.W., 2003. Soil salinity and sodicity limits efficient plant growth and water use. Rio grande regional soil and water series guide A-140, *New Mexico State University*, *New Mexico*, p. 145.

Dhembare, A.J., 2012. Assessment of water quality indices for irrigation of Dynaneshwar Dam Water, Ahmednagar, Maharashtra, India. *Archives of Applied Science Research*, 4 (1), pp. 348-352.

Duncan, R.R. and Carrow, R.N., 1999. Turfgrass molecular genetic improvement for abiotic / edaphic stress resistance. *In Advances in Agronomy*, Vol. 67, pp. 233-305. Academic Press.

Eldeiry, A. and García, L. A., 2008. Mapping soil salinity using soil salinity samples and variograms: Case study in the lower Arkansas Basin.

El-Fattah, M.A., 2006. *Impact of calcium source on modification of properties of saline-sodic soils.* (M.Sc. Thesis, Fac. Of Agric., Zagazig Univ., Egypt).

El-Fattah, M.K.A., 2011. *Some biological and chemical methods for salt-affected soils reclamation* (Doctoral dissertation, Ph. D. Thesis, Department of Soil Science, Zagazig University, Zagazig, Egypt).

Ethiopian Institute of Agricultural Research (EIAR)., 2016. Annual research report. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia.

Ezlit, Y.D., 2009. *Modelling the change in conductivity of soil associated with the application of saline -sodic water* (Doctoral dissertation, University of Southern Queensland).

Falstad, J., 2000. Soil condition. Transplant status in Burger Draw. Billings Gazette. Prepared by DG Steward Page, Burger Draw Comments and Recommendations.

Fantaw Abegaz., 2007. An overview of salt-affected soils and their management status in Ethiopia. *In A paper presented in the 3rd International Workshop on Water Management project, Haramaya University, Ethiopia*.

Fantaw Abegaz., 2018. Irrigation management practices for salinity control. Lecture note, Addis Abeba, Ethiopia.

Faust, J. E. and Will, E., 2002. Irrigation water quality for greenhouse production. Agricultural Extension Service, University of Tennessee.

Fipps, G., 2004. Agriculture irrıgation. The irrıgation technology center department of biological and agricultural engineering, Texas A&M University College Station.

Flagella, Z., Cantore, V., Giuliani, M.M., Tarantino, E. and DE CARO, A., 2002. Crop salt tolerance: physiological, yield and quality aspects, *Rec. Res. Dev. Plant Biol*, 2, pp. 155–186.

Flowers, T.J. and Colmer, T.D., 2008. Salinity tolerance in halophytes. *New Phytologists*, 179, pp. 945-963.

Flowers, T.J., 2004. Improving crop salt tolerance. *Journal of Experimental Botany*, 55 (396), pp. 307-319.

Food and Agricultural Organization (FAO).,1985. Water quality for agriculture. Irrigation and drainage paper 29 rev. 1, United Nations, Rome Italy.

Food and Agricultural Organization (FAO)., 1988. *Salt-affected soils and their management*. FAO Soils Bulletin 39, Rome, Italy.

Food and Agricultural Organization (FAO)., 1999. *Soil salinity assessment: Methods and interpretation of electrical conductivity measurements*. FAO Irrigation and Drainage Paper 57, Rome, Italy.

Food and Agricultural Organization (FAO)., 2000. Global network on integrated soil management for sustainable use of salt-affected soils. *Available at: www.fao.org/agl*. Accessed on 25/05/2019.

Food and Agriculture Organization (FAO)., 2009. Advanced in the assessment and monitoring of salinization and status of bio-saline agriculture, world soil resource report, report of an expert consultation held in Dubai, 26-29 November 2007, Rome, Italy.

Gebauer, J. and Ebert, G., 2005. Comparison of the salt tolerance of the two under-utilised fruit species, baobab (Adansonia digitata L.) and tamarind (Tamarindus indica L.). In *Conference on International Agricultural Research for Development.Stuttgart Hohenheim, Alemania*, pp. 11-13.

Gebremeskel, G., Gebremicael. T.G., Kifle. M., Meresa, E., Gebremedhin, T. and Girmay, A., 2018. Salinization pattern and its spatial distribution in the irrigated agriculture of Northern Ethiopia: An integrated approach of quantitative and spatial analysis. *Agricultural Water Management,* 206, pp. 147-157.

George, M.F., Lin, C.H., Lerch, R.N. and Garrett, H.E., 2004. Incorporating forage grasses in riparian buffers for bioremediation of atrazine, isoxaflutole and nitrate in Missouri. *Agroforestry systems*, *63*(1), pp.91-99.

Getahun Wendmkun Adane., 2014. *Groundwater modeling and optimization of irrigation water use efficiency to sustain irrigation in Kobo Valley, Ethiopia* (M.Sc. Thesis, UNESCO-IHE).

Ghafoor, A., Murtaza, G., Ahmad, B. and Boers, T.M., 2008. Evaluation of amelioration treatments and economic aspects of using saline-sodic water for rice and wheat production on salt-affected soils under arid land conditions. *Irrigation and Drainage: the journal of the International Commission on Irrigation and Drainage,* 57(4), pp. 424-434.

Ghafoor, A., Murtaza, G., Rehman, M.Z. and Sabir, M., 2012. Reclamation and salt leaching efficiency for tile drained saline-sodic soil using marginal quality water for irrigating rice and wheat crops. *Land Degradation & Development*, *23*(1), pp.1-9.

Ghafoor, A., Qadir M. and Quresahi, R.H., 1991. Using brackish water on normal and salt-affected soils in Pakistan: a review. *Pak. J. Agric. Sci*, 28, pp. 273–288.

Ghaly, F. M., 2002. Role of natural vegetation in improving salt affected soil northern Egypt. *Soil and Tillage Research*, 64(3-4), pp. 173-178.

Gomez, K.A. and Gomez, A.A., 1984. Statistical procedures for agricultural research. *John Wiley and Sons, second edition, New York*.

Gonzalez, N. L., Toth, T. and Garcia, D., 2004. Integrated management for sustainable use of salt- affected soils in Cuba. *Universidad Y Ciencia,* 40 (20), pp. 86-102.

Gupta, P.K., 2000. Soil, plant, water and fertilizer analysis, 438. *New Delhi. India: Agrobios*.

Gupta, R. K. and Abrol, I. P., 1990. Salt affected soils: their reclamation and management for crop production. In *Advances in soil science* (pp. 223-288). Springer, New York, NY.

Hameed, M. and Ashraf. M., 2008. Physiological and biochemical adaptations of Cynodon dactylon (L.) Pers. from the Salt Range (Pakistan) to salinity stress. *Flora-Morphology, Distribution, Functional Ecology of Plants*, 203(8); pp. 683-694.

Hanay, A., Buyuksonmez, F., Kiziloglu, F. M. and Canpolat, M.Y., 2004. Reclamation of saline-sodic soils with gypsum and MSW compost. *Compost Science & Utilization*, 12(2), pp. 175-179.

Hasegawa, P.M., Bressan, R.A., Zhu, J.K. and Bohnert, H.J., 2000. Plant cellular and molecular responses to high salinity. *Annual review of plant biology*, 51(1), pp. 463-499.

Hazelton, P. and Murphy. B., 2016. *Interpreting soil test results: What do all the numbers mean*. CSIRO Publishing.

Helalia, A.M., El-Amir, S., Abou-Zeid, S.T. and Zaghloul, K.F., 1992. Bio-reclamation of saline-sodic soil by amshot grass in Northern Egypt. *Soil and Tillage Research*, 22(1-2), pp. 109-115.

Herrera, E., 2005. Soil Test Interpretation. Guide A-122. College of agriculture and home economics. New Mexico State University phosphorus deficiency. *Oxford Journal of Sciences, 94(3), pp. 323, 332*.

Horneck, D.A., Ellsworth, J.W., Hopkins, B.G., Sullivan, D.M. and Stevens, R.G., 2007. Managing salt-affected soils for crop production.

Ilyas, M., Qureshi, R.H. and Qadir, M.A., 1997. Chemical changes in a saline-sodic soil after gypsum application and cropping. *Soil technology* 10(3), pp. 247-260.

International Livestock Research Institute (ILRI)., 2013. Quality parameters of agricultural research commodities, *1st version*.

Islam, M.N., Islam, A. and Biswas, J.C., 2017. Effect of gypsum on electrical conductivity and sodium concentration in salt affected paddy soil. *International Journal of Agricultural Papers*, *2*(1), pp.19-23.

Jim, M., 2002. Managing salt affected soils, NRCS, outh Dakota.

Joe, S., 2002. *Salt affected soils: their causes, measure and classification* (No. 5). Plant material program technical note.

Kacar, B., 1972. Chemical analysis of plant and soil, II. Plant analysis. *Ankara Univ. Fac. Agric. Publ. No*: 453, Ankara.

Kelly, W., 1937. The Reclamation of Alkali Soils. *California agricultural experiment station Bulletin*, 617, pp. 1-40.

Keren, R. and Ben-Hur, M., 2003. Interaction effects of clay swelling and dispersion and calcium carbonate content on saturated hydraulic conductivity. *Soil Research*, 41(5), pp. 979-989.

Khalifa, M.R., Koriem, M.A., Ibrahim, M.M. and Hammad, E., 1994. Reclamation of saline-sodic soils by leaching with drainage water and gypsum application. *Monofiya Journal of Agricultural Research (Egypt)* 19, pp. 685-698.

Khattak, S.G., Haq, I., Malik, A., Khattak, M.J. and Naveedullah, M.J., 2007. Effect of various levels of gypsum application on the reclamation of salt affected soil grown under Rhodes and Panicum grass. *Sarhad Journal of Agriculture*, 23(3), p.675.

Kobayashi, H. and Masaoka, Y., 2008. Salt secretion in Rhodes grass (Chloris gayana Kunth) under conditions of excess magnesium. *Soil Science and Plant Nutrition*, 54(3), pp. 393-399.

Kobayashi, H., Masaoka, Y., Takahashi, Y., Ide, Y. and Sato, S., 2007. Ability of salt glands in Rhodes grass (Chloris gayana Kunth) to secrete Na^+ and K^+. *Soil Science and Plant Nutrition*, 53(6), pp. 764-771.

Kobo Girana Valley Development Project (KGVDP)., 2009. Well completion report. *Irrigation and Drainage Study Department*, Bahir Dar, Ethiopia.

Kobo Girana Valley Development Project (KGVDP)., 2010. Well completion report. *Irrigation and Drainage Study Department*, Bahir Dar, Ethiopia.

Kotuby-Amacher, J., Koenig, R. and Kitchen, B., 2000. Salinity and plant tolerance. *Electronic publishing*. AG-SO-03.

Kumar, A. and Abrol, I. P., 1984. Studies on the reclaiming effect of Karnal-grass and para-grass grown in a highly sodic soil. *Indian Journal of Agricultural Sciences*, 54, pp. 189–193.

Kumar, A. and Abrol, I.P., 1983. Effects of gypsum on five tropical grasses grown in normal and extremely sodic soil. *Experimental Agriculture*, *19*(2), pp.169-177.

Kumar, A., 1988. Long-term forage yields of five tropical grasses on an extremely sodic soil and the resultant soil amelioration. *Experimental Agriculture*, *24*(1), pp.89-96.

Kumar, M.S. and Thiyageshwari, S., 2018. Performance of nano-gypsum on reclamation of sodic soil. *Int J Curr Microbiol App Sci*, *6*, pp.56-62.

Kushiev, H., Noble, A.D., Abdullaev, I. and Toshbekov, U., 2005. Remediation of abandoned saline soils using glycyrrhiza glabra: a study from the Hungry Steppes of Central Asia. *International Journal of Agricultural Sustainability*, 3(2), pp. 102-113.

Ladeiro, B., 2012. Saline agriculture in the 21st century: using salt contaminated resources to cope food requirements. *Journal of Botany*.

Lamond, R.E. and Whitney, D.A., 1992. Management of saline and sodic soils. Kansas State University Agricultural Experiment Station and Cooperative Extension Service Retrieved 29.10. 2008.

Lebron, I., Suarez, D.L. and Alberto. F., 1994. Stability of a calcareous saline-sodic soil during reclamation. *Soil Science Society of America Journal*, 58(6), pp.1753-1762.

Li, J., Eneji, A.E., Duan, L., Inanaga, S. and Li, Z., 2005. Saving irrigation water for winter wheat with phosphorus application in the North China Plain. *Journal of Plant Nutrition*, 28(11), pp. 2001-2010.

Lilienfein, J., Wilcke, W., Ayarza, A., Vilela, L., Lima, C. and Zech, W., 2000. Chemical fractionation of phosphorus, sulfur, and molybdenum in Brazilian savannah Oxisols under different land uses. Geoderma, 96, pp.31-46.

Maestre, F.T., Bautista, S., Cortina, J. and Bellot, J., 2001. Potential for using facilitation by grasses to establish shrubs on a semiarid degraded steppe. *Ecological Applications*, *11*(6), pp.1641-1655.

Mahdy, A.M., 2011. Comparative effects of different soil amendments on amelioration of saline-sodic soils. *Soil and Water Research*, *6*(4), pp.205-216.

Mahmood, K., Nadeem, M.Y. and Ibrahim, M., 2001. Use of gypsum as an ameliorant of brackish ground water. *International Journal of Agriculture and Biology* (Pakistan), 3, pp. 308-311.

Makoi, J.H. and Ndakidemi, P.A., 2007. Reclamation of sodic soils in Northern Tanzania, using locally available organic and inorganic resources. *African Journal of. Biotechnology*, 6(16), 1926-1931.

Maral, N., 2010. *Soil and water analysis techniques for agricultural production* (M.Sc. Thesis. Natural and applied sciences of Middle East technical university).

Marcum, K.B. and Murdoch, C.L., 1994. Salinity tolerance mechanisms of six C4 turf grasses. *Journal of the American Society for Horticultural Science*, 119(4), pp. 779-784.

Marcum, K.B., 1999. Salinity tolerance mechanisms of grasses in the subfamily Chloridoideae. *Crop Science*, 39(4), pp. 1153-1160.

Marcum, K.B., 2007. Physiological adaptations of turfgrasses to salinity stress. *In Handbook of Turfgrass Management and Physiology* (pp. 416-426). CRC Press.

María, E., Del Carmen, M. and Victoria, M., 2018. Metodología de investigación.

Masters, D.G., Benes, S.E. and Norman, H.C., 2007. Biosaline agriculture for forage and livestock production. *Agriculture, Ecosystem and Environment*, 119(3-4), pp.234-248.

McCauley, A. and Jones, C., 2005. Salinity and Sodicity Management: Soil and water management module 2. *Montana State University, United States of America*.

Merse Mengesha, Lemma Wogi and Solomon Tamiru., 2018. *Characterization and classification of salt-affected soils of Ambo-Coba area under Golina Watershed in Raya Valley, Amhara Region* (M.Sc. Thesis, Haramaya University).

Metternicht, G.I. and Zinck, J.A., 2003. Remote sensing of soil salinity: potentials and constraints. *Remote sensing Environment*, 85(1), pp. 1-20.

Michael, P. and Paul, J., 2002. Growing turf on salt-affected sites. *Technical note*, No-519, Utah State University Extension Service.

Miller, R.W. and Gardiner, D.T., 2007. *Soils in our environment, 9th edn* (pp. 126-165). *NJ*.

Miller, S. and Donahue, T., 1997. Advances in acid drainage prediction using the net acid generation (NAG) test. In *4th International Conference on Acid Rock Drainage, Vancouver, Canada*.

Mirza Hasanuzzaman, K. N., MD. Mahabub Alam., Prasanta C. B., MD. Amzad Hossain., Motior M. Rahman., Majeti Narasimha Vara Prasad., Munir Ozturk. and Masayuki Fujita., 2014. Potential use of halophytes to remediate saline soils. *Journal List Biomed Res Intv*.

Mishra, A., Sharma, S. D. and Khan, G. H., 2002. Rehabilitation of degraded sodic lands during a decade of Dalbergia Sissoo plantation in Sultanpur district of Uttar Pradesh, India. *Land degradation and development*, 13(5), pp. 375-386.

Molatakgosi, G., 2006. Impact of infield irrigation management by Botswana cabbage farmers on soil salinity. *MPhil thesis, Cranfield University, UK.*

Moore, G.A., Sanford P. and Wiley T., 2006. Perennial pastures for Western Australia, p. 248.

Mostafazadeh-Fard, B., Heidarpour, M., Aghakhani, A. and Feizi, M., 2008. Effects of leaching on soil desalinization for wheat crop in an arid region. *Plant Soil and Environment*, *54*(1), p.20.

Munns, R. and Tester, M., 2008. Mechanisms of salinity tolerance. *Annu. Rev. Plant Biol*., 59, pp. 651-681.

Munns, R., 2002. Comparative physiology of salt and water stress. *Plant, cell and environment*, 25(2), pp. 239-250.

Murtaza, G., Ghafoor, A. and Qadir, M., 2006. Irrigation and soil management strategies for using saline-sodic water in a cotton-wheat rotation. *Agricultural Water Management*, 81(1-2), pp**.** 98-114.

Mustafa, M. A., 2007. Desertification processes. Published by UNESCO Chair of Desertification, University of Khartoum Printing Press. pp 230.

OI, T., Kanjun, H., Mitsutaka, T. and Hiroshi, M., 2013. Salt excretion from the salt glands in Rhodes grass (Chloris gayana Kunth) as evidenced by low-vacuum scanning electron microscopy. *Flora-Morphology, Distribution, Functional Ecology of Plants*, 208(1), pp. 52-57.

OI, T., Taniguchi, M. and Miyake, H., 2012. Morphology and ultrastructure of the salt glands on the leaf surface of Rhodes grass (Chloris gayana Kunth). *International Journal of Plant Sciences*, 173(5), pp. 454-463.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L., 2002. Laboratory methods of soil and plant analysis: a working manual, second edition. *Sacred Africa, Nairobi*, p.21.

Oster, J.D., Shainberg, I. and Abrol, I.P., 1999. Reclamation of salt affected soils. *Agricultural drainage*, (agriculturaldra), pp. 659-691.

Owens, S., 2001. Salt of the Earth. Genetic engineering may help to reclaim agricultural land lost due to salinization. *European Molecular Biology Organization.*

Pam, P., 2002. How to interpret if your soil is sodic, using soil physical and chemical test results, Sheet number 11, *Chrysalis Landscape Consultant*, Australia. 12p.

Pansu, M. and Gautheyrou, J., 2007. *Handbook of soil analysis: mineralogical, organic and inorganic methods*. Springer Science & Business Media.

Patel, K.P., Singh, B. and Chhibba, I.M., 1990. Crop yields and properties of a sodic soil as influenced by s-containing amendments under draining and nondraining conditions. *Arid Land Research and Management*, *4*(3), pp.173-180.

Pessarakli, M., Kopec, D.M. and Gilbert, J.J., 2008. Growth responses of selected warm-season Turfgrasses under salt stress. *Turfgrass, Landscape and Urban IPM Research Summary. January*, pp. 47- 54.

Pitman, M.G and Läuchli, A., 2002. Global impact of salinity and agricultural ecosystems. *In Salinity: environment-plants-molecules* (pp. 3-20). Springer, Dordrecht.

Podmore, C., 2009. Irrigation salinity causes and Impacts, Natural Resource Advisory Services. (*October*), 2007–2010.

Pravin, R., Dodha, V., Vidya, D., Manab, C. and Saroj, M., 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications*, 3(2), pp. 1-8.

Qadir, M. and Schubert, S., 2002. Degradation processes and nutrient constraints in sodic soils. *Land Degradation and Development*, 13(4), pp. 275-294.

Qadir, M., Noble, A.D., Oster, J.D., Schubert, S. and Ghafoor, A., 2005. Driving forces for sodium removal during phytoremediation of calcareous sodic and saline-sodic soils: a review .*Soil Use and Management*, 21(2), pp. 173–180.

Qadir, M., Oster, J.D., Schubert, S., Noble, A.D. and Sahrawat, K.L., 2007. Phytoremediation of sodic and saline-sodic soils. *Advances in agronomy*, 96, pp. 197-247.

Qadir, M., Qureshi, R.H. and Ahmad, N., 2002. Amelioration of calcareous saline-sodic soils through phytoremediation and chemical strategies. *Soil Use and Management*, 18(4), pp. 381-385.

Qadir, M., Qureshi, R.H., Ahmad, N. and Ilyas, M., 1996b. Salt-tolerant forage cultivation on a saline-sodic field for biomass production and soil reclamation. *Land Degradation and Development*, 7(1), pp. 11-18.

Qadir, M., Schubert, S., Ghafoor, A. and Murtaza, G., 2001. Amelioration strategies for sodic soils: a review. *Land Degradation and Development*, 12(4), pp.357–386.

Qadir, M., Steffens, D., Yan, F. and Schubert, S., 2003. Sodium removal from a calcareous saline-sodic soil through leaching and plant uptake during phytoremediation. *Land Degradation and Development*, 14(3), pp. 301-307.

Qureshi, A.S., Ertebo, T. and Mehansiwala, M., 2018. Prospects of alternative copping systems for salt-affected soils in Ethiopia. *Journal of Soil Science and Environmental Management*, *9*(7), pp.98-107.

Ramoliya, P.J. and Pandey A.N., 2002. Effect of salinization of soil on emergence, growth and survival of seedlings of Acacia nilotica. *Botanica complutensis*, 26(2002), pp.105-119.

RAO, B. S., 1989. Effect of quality of irrigation water on soil properties in selected soils of Karnataka (M. Sc. thsis, University of Agricultural Sciences, Bangalore). Rate and crop yield. *Journal of the Indian Society of Soil Science*, *41*(4), pp.802-803.

Rengasamy, P., 2006. World salinization with emphasis on Australia. *Journal of experimental botany*, 57(5), pp. 1017-1023.

Robert, G., Alley, W., David, H. and Thomason, W., 2009. Soil electrical conductivity. Virginia polytechnic institute and state university, USA, pp. 442-508.

Rozema, J. and Schat, H., 2013. Salt tolerance of halophytes, research questions reviewed in the perspective of saline agriculture. *Environmental and Experimental Botany*, 92, pp. 83-95.

Sahlemedhin Sertsu and Taye Bekele., 2000. Procedures for soil and plant analysis. *Technical paper*, 74, p.110.

Saikh, H., Varadachari, C. and Ghosh, K., 1998. Effects of deforestation and cultivation on soil

CEC and contents of exchangeable bases: a case study in Simplipal National Park, India. *Plant and Soil*, 204 (2), pp. 175-181.

Salim, M., Ahmad, M., Hussain, N. and Niazi, B.H., 2002. Role of soil amendments in saline agriculture. *In Prospects for Saline Agriculture* (pp. 433-438). Springer, Dordrecht.

Samuel Feyissa., 2006. *Characterization and classification of soils of Maichew agricultural technical and vocational education and training college, Tigray, Ethiopia* (M.Sc. Thesis, Haramaya University).

SARC (Sirinka Agricultural Research Center)., 2008. Recommended and released technologies. Sirinka Agricultural Research Center technical note.

Sardo, V., 2005. Halophytes and salt-tolerant glycophytes a potential resource. *The use of non-conventional water resources. Bari: CIHEAM / EU DG Research*, pp. 87-98.

Seelig, B., 2000. Salinity and sodicity in North Dakota soils, EB 57, p. 16.

Serin, Y. and Tan, M., 1998. *Forage Grasses*. Ataturk Univ. Agri. Faculty, Pub. No, 334, Erzurum.

Setia, R., Marschner, P., Baldock, J., Chittleborough, D., Smith, P. and Smith, J., 2011. Salinity effects on carbon mineralization in soils of varying texture. *Soil biology and biochemistry*, 43(9), pp. 1908-1916.

Shabala, S., 2011. Physiological and cellular aspects of phytotoxicity tolerance in plants: the role of membrane transporters and implications for crop breeding for waterlogging tolerance. *New Phytologist*, 190(2), pp. 289-298.

Shakir, M.S. and Razzaq, A., 2002. Effect of salts on bulk density, particle density and porosity of different soil series. *Asian Journal of plant sciences*.

Sharma, O.P. and Gupta, R.K., 1986. Comparative performance of gypsum and pyrites in sodic vertisols. *Indian Journal of Agricultural Sciences*.

Sharma, R.C., Mandal, A.K. and Singh, R., 2011. Delineation and characterization of waterlogged and salt-affected soils in Gandak command area of Bihar for reclamation and management. *Journal of the Indian Society of Soil Science*, 59(4), pp. 315-320.

Sharma, V.K., Sharma, P.D., Sharma, S. P., Acharya, C. L. and Sood, R. K. 2004. Characterization of cultivated soils of Neogal watershed in North-West Himalayas and their suitability for major crops. *Journal of the Indian Society of Soil Science*, 52(1), pp.63-68.

Singh, H. and Bajwa, M.S., 1991. Effect of sodic irrigation and gypsum on the reclamation of sodic soil and growth of rice and wheat plants. *Agricultural Water Management*, 20 (2), pp. 163-171.

Singh, N. T., 1998. Historical perspective. In ''Agricultural Salinity Management in India'' (N. K. Tyagi and P. S. Minhas, Eds.), pp. 9-19. *Central Soil Salinity Research Institute, Karnal, India.*

Sisay Dessale, Zeleke Belay and Samual Adisie., 2016. Assessment of salt affected soils in selected schemes of Raya Kobo Valley, Eastern Amhara. Sirinka Agricultural Research Center, Ethiopia (unpublished).

Siyal, A.A., Siyal, A.G. and Abro, Z.A., 2002. Salt affected soils their identification and reclamation. *Pakistan Journal of Applied Science*, 2(5), pp.537-540.

Skerman, P.J. and Riveros, F., 1990. *Tropical grasses* (No. 23). Food and Agriculture Org. pp. 832.

Solaimalai, A., Baskar, M., Ramesh, P.T. and Ravisankar, N., 2001. Utilization of press mud as soil amendment and organic manure–a review. *Agricultural Reviews*, *22*(1), pp.25-32.

Srivastava, A., Singh, K. and Bajpai, P., 1987, Effect of sugarcane ratooning on variability in bulk density of soil. *Journal of the Indian Society of Soil Science*, 35(3), pp. 349-352.

Sultana, N., Ikeda, T. and Kashem, M.A., 2001. Effect of foliar spray of nutrient solutions on photosynthesis, dry matter accumulation and yield in seawater-stressed rice. *Environmental and Experimental Botany*, 46(2), pp. 129-140.

Suyama, H., Benes, S.E., Robinson, P.H., Grattan, S.R., Grieve, C.M. and Getachew, G., 2007**.** Forage yield and quality under irrigation with saline-sodic drainage water: *Greenhouse evaluation. Agricultural water management*, 88(1-3), pp. 159-172.

Swarp, A., 2004, February. Chemistry of sodic soils and management. In *Advances in Sodic Land Reclamation Int. Conf. Feb* (pp. 9-14).

Tekalign Mamo, Haque, I., 1991. Phosphorus status of some Ethiopian soils, II. Forms and distribution of inorganic phosphates and their relation to available phosphorus. *Tropical Agriculture* 68(1), pp. 2-8.

Temel, S., Keskin, B., Simsek, U. and Yilmaz, I. H., 2015. Performance of some forage grass species in halomorphic soil. *Turkish Journal of Field Crops*, 20(2), pp. 131-141.

Tena Alamirew., 2002. Spatial and temporal variability of Awash River water salinity and the contribution of irrigation water management on the development of soil salinization in the Awash River Valley of Ethiopia (PhD Thesis, University of Agricultural Sciences, Vienna).

Tesfaye, M. and Fassil, K., 2011. Suitability of Koga watershed for irrigated onion production in the Blue Nile Basin, *Ethiopia. Journal of the dry lands* 4(2), pp.325-332.

Tsegaye, G., 2009. *Surface Water–Groundwater Interactions and Effects of Irrigation on Water and Soil Resources in the Awash Valley* (M.Sc. Thesis, Addis Ababa University).

Tyagi, N.K. and Sharma, D.P., 2000. Disposal of drainage water recycling and reuse. *In role of drainage and challenges in 21st century. Vol. III. Proceedings of the 8th ICID International Drainage Workshop, New Delhi, India, 31 January-4 February 2000.* (pp.199-213). International Commission on Irrigation and Drainage.

Tyagi, N.K., 2001. September. Managing salinity in northwest India: some short and long-term options. *In Proceedings International Conference on Agricultural Science and Technology, Beijing* (pp. 7-9).

U.S. Salinity Laboratory Staff (Richards, L.A)., 1954. *Diagnosis and Improvement of Saline and Alkali Soils.* USDA Handbook No. 60, Pp.160

Ventura, Y. and Sagi, M., **2013.** Halophyte crop cultivation: The case for Salicornia and Sarcocornia. *Environmental and Experimental Botany*, 92, pp. 144–153.

Verma, S.K., Gupta, R.K and Dubey, S.K., 1985. Comparative effectiveness of some chemical amendments in reclaiming a sodic Vertisol. *Journal of the Indian Society of Soil Science*, 33(4), pp. 948-950.

Walpola, B.C. and Arunakumara, K.K.I.U., 2010. Effect of salt stress on decomposition of organic matter and nitrogen mineralization in animal manure amended soils. *Journal of Agricultural Sciences–Sri Lanka*, *5*(1).

Walpola, B.C. and Arunakumara, K.K.I.U., 2011. Carbon and nitrogen mineralization of a plant residue amended soil: The effect of salinity stress. *Bangladesh Journal of Scientific and Industrial Research*, *46*(4), pp.565-572.

Wang, W., Vinocur, B. and Altman. A., 2003. Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. *Planta, 218(1), pp.*1-14.

White, E., 2006. Principles and practices of soil science: *Soil as a natural resource*, 4th ed, pp. 133-154.

Yadav, R.L. and Panyab. P.A., 2011. Fifty rears of agronomic research in India. *Indian Society of Agronomy*, p. 270.

Yerriswamy, A.N., 1996. *Studies on salt affected soils of upper Krishna project command area* (M.Sc.Thesis, University of Agricultural Sciences, Bangalore).

Yilmaz, A., Nishiyama, M.Y., Fuentes, B.G., Souza, G.M., Janies, D., Gray, J. and Grotewold, E., 2009. Bioremediation: a platform for comparative regulatory genomics across the grasses. *Plant physiology*, *149*(1), pp.171-180.

Yonas Girma., 2005. *Appraisal, spatial structure and mapping of soil salinity and irrigation water quality Yellen-Jewaha areas in North Shewa zone of Amhara Region* (M.Sc. Thesis, Haramaya University, Ethiopia. p.65).

Young, J., Udeigwe, T.K., Weindorf, D.C., Kandakji, T., Gautam, P. and Mahmoud, M.A., 2015. Evaluating management-induced soil salinization in golf courses in semi-arid landscapes. *Solid Earth*, 6(2), pp. 393-402.

Yu, H., Yang, P., Lin, H., Ren, S. and He, X., 2014b. Effects of sodic soil reclamation using flue gas desulphurization gypsum on soil pore characteristics, bulk density, and saturated hydraulic conductivity. *Soil Science Society of American Journal*, 78(4), pp. 1201-1213.

Yu, J., Wang, Z., Meixner, F.X., Yang, F., Wu, H. and Chen, X., 2010. Biogeochemical characterizations and reclamation strategies of saline-sodic soil in Northeastern China. *Clean-Soil, Air, Water*, 38(11), pp. 1010-1016.

Zhu, J.K., 2007. Plant Salt Stress: John Wiley & Sons, Ltd.

7. APPENDICES

Appendix Table 1. Long-Term Meteorological Data of the Study Area (2002 – 2018)

Month	Max Temp °C	Min Temp °C	RF (mm)	WS (m/s)	RH (%)	SS (hours)
Jan	29.69	8.56	7.28	1.60	58.41	9.20
Feb	31.47	10.75	14.20	1.87	51.95	9.80
Mar	31.00	11.52	26.74	1.93	48.36	10.30
Apr	33.67	13.59	50.47	1.76	49.65	10.20
May	35.00	14.81	47.75	1.52	42.88	10.05
Jun	36.58	15.72	11.23	1.75	34.94	9.20
Jul	35.83	16.29	130.69	1.66	49.29	8.20
Aug	32.73	15.64	218.27	1.26	57.71	8.15
Sep	32.62	13.85	85.57	0.94	56.16	8.70
Oct	31.69	11.03	26.03	1.23	48.41	9.10
Nov	30.62	9.50	15.10	1.34	46.88	10.20
Dec	29.88	8.49	10.75	1.35	51.39	9.40

Appendix Table 2. Daily Meteorological Data Throughout the Experimental Period.

Date	Min Temp (°C)	Max Temp (°C)	RH (%)	WS (m/s)	SS (hours)	RF (mm)
7-Feb	8.60	29.00	34.00	1.40	0.41	0.00
8-Feb	8.30	28.10	39.00	1.26	0.41	0.00
9-Feb	8.90	28.10	31.00	1.23	0.41	0.00
10-Feb	9.00	29.30	32.00	1.16	0.41	0.00
11-Feb	11.00	29.30	33.00	1.25	0.41	0.00
12-Feb	10.30	29.80	38.00	1.24	0.42	0.00
13-Feb	14.00	32.50	37.00	1.09	0.42	0.00
14-Feb	11.50	31.20	38.00	1.38	0.42	0.00
15-Feb	12.30	29.30	43.00	1.45	0.42	0.00
16-Feb	11.30	29.50	44.00	1.72	0.42	0.00
17-Feb	10.10	30.10	42.00	2.01	0.42	0.00
18-Feb	16.80	29.20	55.00	1.79	0.42	0.00
19-Feb	14.20	31.00	41.00	1.47	0.42	0.00
20-Feb	18.00	29.20	61.00	1.82	0.42	0.00
21-Feb	17.10	29.40	40.00	1.63	0.42	0.00
22-Feb	17.50	29.90	64.00	1.59	0.42	0.00
23-Feb	17.00	31.10	53.00	1.43	0.42	0.00
24-Feb	16.00	32.80	41.00	1.38	0.42	0.00
25-Feb	13.50	33.40	48.00	2.10	0.42	0.00

Date	Min Temp (°C)	Max Temp (°C)	RH (%)	WS (m/s)	SS (hours)	RF (mm)
26-Feb	17.00	31.60	57.00	2.18	0.42	0.00
27-Feb	15.00	32.10	53.00	1.94	0.42	0.00
28-Feb	12.40	30.30	70.00	1.97	0.42	0.00
1-Mar	14.10	29.10	60.00	1.12	0.45	0.00
2-Mar	16.00	27.00	70.00	2.38	0.45	0.00
3-Mar	16.10	29.30	61.00	2.54	0.45	0.00
4-Mar	15.00	26.80	64.00	1.77	0.45	0.00
5-Mar	15.00	28.40	53.00	1.92	0.45	0.00
6-Mar	15.00	29.40	47.00	1.65	0.45	0.00
7-Mar	14.80	30.10	49.00	1.58	0.45	0.00
8-Mar	14.00	30.00	42.00	1.43	0.44	0.00
9-Mar	15.60	35.30	61.00	0.90	0.46	0.00
10-Mar	12.20	30.60	34.00	1.53	0.44	0.00
11-Mar	11.10	30.30	27.00	1.63	0.44	0.00
12-Mar	12.80	31.30	31.00	1.69	0.44	0.00
13-Mar	15.00	29.20	60.00	1.90	0.44	0.00
14-Mar	13.90	30.10	54.00	2.03	0.44	0.00
15-Mar	15.10	29.90	54.00	2.68	0.44	0.00
16-Mar	16.00	27.20	62.00	1.67	0.44	0.00
17-Mar	12.60	27.80	70.00	1.40	0.44	0.00
18-Mar	12.60	27.00	76.00	1.31	0.44	0.00
19-Mar	13.80	28.10	54.00	1.57	0.44	0.00
20-Mar	17.20	29.40	44.00	2.09	0.44	0.00
21-Mar	15.60	30.10	43.00	2.07	0.44	0.00
22-Mar	16.00	30.20	44.00	1.57	0.44	0.00
23-Mar	14.50	31.10	34.00	1.29	0.44	0.00
24-Mar	14.00	31.20	32.00	1.83	0.43	0.00
25-Mar	13.80	34.10	35.00	2.15	0.43	0.00
26-Mar	14.60	29.00	31.00	2.09	0.43	0.00
27-Mar	13.10	31.50	35.00	1.74	0.43	0.00
28-Mar	13.00	29.80	38.00	2.04	0.43	0.00
29-Mar	14.60	32.40	39.00	2.01	0.43	0.00
30-Mar	16.00	33.00	33.00	1.42	0.43	20.50
31-Mar	15.10	31.60	39.00	1.18	0.43	0.00
1-Apr	Xx	33.00	28.00	3.15	0.41	0.00
2-Apr	14.50	31.30	42.00	2.06	0.41	1.60
3-Apr	15.20	30.00	55.00	0.64	0.41	0.00
4-Apr	13.50	31.30	50.00	1.88	0.41	0.00
5-Apr	16.00	30.60	59.00	0.90	0.45	0.00
6-Apr	16.30	34.10	46.00	1.65	0.41	11.70
7-Apr	17.50	30.00	64.00	1.47	0.41	0.00

Date	Min Temp (°C)	Max Temp (°C)	RH (%)	WS (m/s)	SS (hours)	RF (mm)
8-Apr	16.80	33.60	56.00	1.90	10.32	0.00
9-Apr	17.00	31.60	54.00	1.74	0.41	0.00
10-Apr	18.00	29.60	65.00	1.33	0.41	0.00
11-Apr	17.10	27.00	65.00	1.86	0.46	0.00
12-Apr	13.90	28.70	56.00	1.32	0.42	0.00
13-Apr	16.00	29.00	67.00	1.54	0.42	8.40
14-Apr	15.30	29.10	70.00	1.84	0.42	10.30
15-Apr	17.00	28.20	69.00	1.00	0.42	0.00
16-Apr	17.10	31.30	58.00	1.27	0.42	0.00
17-Apr	17.80	31.00	57.00	1.56	0.42	0.00
18-Apr	17.00	29.30	62.00	1.34	0.42	2.00
19-Apr	16.40	29.00	67.00	1.38	0.42	0.00
20-Apr	18.00	30.20	61.00	1.44	0.42	0.00
21-Apr	17.50	30.50	57.00	2.16	0.42	29.00
22-Apr	17.30	31.10	58.00	0.90	0.42	0.00
23-Apr	17.40	32.10	52.00	1.55	0.42	0.00
24-Apr	18.80	31.00	53.00	1.88	0.42	0.00
25-Apr	16.00	28.80	71.00	1.29	0.42	0.00
26-Apr	17.40	31.30	60.00	1.22	0.43	0.00
27-Apr	16.00	31.00	59.00	1.39	0.43	0.00
28-Apr	16.30	28.10	65.00	1.61	0.43	0.00
29-Apr	16.80	29.00	65.00	1.61	0.43	0.00
30-Apr	14.80	31.70	56.00	1.28	0.41	0.00
1-May	17.30	30.00	60.00	1.19	0.43	0.00
2-May	18.50	30.00	56.00	2.06	0.41	0.00
3-May	18.00	31.00	51.00	1.14	0.41	0.00
4-May	17.00	32.00	50.00	1.49	0.41	0.00
5-May	18.00	31.30	44.00	1.51	0.42	0.00
6-May	18.80	33.00	41.00	1.16	0.42	0.00
7-May	18.10	32.00	46.00	1.20	0.42	0.00
8-May	18.30	33.30	42.00	1.35	0.42	0.00
9-May	19.30	33.60	48.00	1.73	0.42	0.00
10-May	17.30	33.00	40.00	1.44	0.42	0.00
11-May	16.00	33.30	39.00	0.40	0.42	0.00
12-May	15.00	32.80	31.00	0.97	0.42	0.00
13-May	19.00	33.20	48.00	1.40	0.42	0.00
14-May	16.30	33.30	35.00	1.18	0.42	0.00
15-May	18.50	34.00	55.00	1.57	0.42	38.00
16-May	16.60	32.40	41.00	1.28	0.42	0.00
17-May	19.00	32.80	41.00	1.54	0.42	0.00
18-May	16.00	34.60	44.00	2.06	0.42	0.00

Date	Min Temp (°C)	Max Temp (°C)	RH (%)	WS (m/s)	SS (hours)	RF (mm)
19-May	18.80	32.00	48.00	1.40	0.42	0.00
20-May	19.00	34.00	46.00	1.93	0.42	0.00
21-May	18.00	35.10	29.00	1.28	0.42	0.00
22-May	15.00	33.00	43.00	1.71	0.42	4.50
23-May	18.00	34.00	44.00	1.51	0.42	2.50
24-May	17.80	32.00	46.00	1.72	0.42	0.00
25-May	16.80	34.00	36.00	1.49	0.42	0.00
26-May	16.30	34.10	34.00	182.00	0.42	1.00
27-May	18.80	35.00	40.00	1.71	0.43	0.00
28-May	17.20	34.70	30.00	1.81	0.42	0.00
29-May	19.80	34.20	32.00	1.24	0.41	0.00
30-May	18.50	35.60	32.00	2.04	0.42	0.00

Appendix Table 3. Factorial ANOVA Table for Soil **pHe** After Reclamation

SD (cm)	SV	After first harvest DF	SS	MS	F	P	After second harvest DF	SS	MS	F	P
		Soil pHe in the three soil layers									
0-20	Rep	2.00	0.00	0.00	1.95		2.00	0.02	0.01	6.44	
	G	3.00	1.66	0.60	643.04	<.001**	3.00	2.16	0.72	570.00	<.001**
	H	2.00	0.62	0.31	358.39	<.001**	2.00	1.32	0.66	523.37	<.001**
	G*H	6.00	0.45	0.08	86.79	<.001**	6.00	0.52	0.09	68.71	<.001**
	Err	22.00	0.02	0.00			22.00	0.03	0.00		
	Tot	35.00	2.75				35.00	4.04			
		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
20-40	Rep	2.00	0.01	0.01	1.64		2.00	0.02	0.01		
	G	3.00	0.95	0.32	84.73	<.001**	3.00	1.29	0.43	217.50	<.001**
	H	2.00	1.81	0.90	242.22	<.001**	2.00	3.15	1.58	799.70	<.001**
	G*H	6.00	0.20	0.03	8.85	<.001**	6.00	0.48	0.08	40.43	<.001**
	Err	22.00	0.08	0.00			22.00	0.04	0.00		
	Tot	35.00	3.05				35.00	4.98			
		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
40-60	Rep	2.00	0.01	0.00	3.97		2.00	0.01	0.00	3.46	
	G	3.00	0.71	0.24	288.70	<.001**	3.00	0.81	0.27	356.75	<.001**
	H	2.00	3.26	1.63	2002.10	<.001**	2.00	4.24	2.12	2794.10	<.001**
	G*H	6.00	0.10	0.02	20.53	<.001**	6.00	0.14	0.02	30.02	<.001**
	Err	22.00	0.02	0.00			22.00	0.02	0.00		
	Tot	35.00	4.10				35.00	5.21			

Where, SD- soil depth; SV- source of variation; G- gypsum; H- halophytes; G*H- interaction of gypsum and halophytes; DF- degree of freedom; SS- sum square; MS- mean square; F-f calculated; P- probability level. Tot-total variation; Err- variation due to error and **- highly significant.

Appendix Table 4. ANOVA Table for Soil **ECe** After Reclamation **(dS m^{-1})**

Soil ECe in the three soil layers (dS m^{-1})											
SD(cm)		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
0-20	Rep	2.00	0.32	0.16			2.00	0.31	0.16	1.44	
	G	3.00	488.53	162.84	1123.77	<.001**	3.00	392.83	130.94	1210.68	<.001**
	H	2.00	120.86	60.43	417.02	<.001**	2.00	206.60	103.30	955.10	<.001**
	G*H	6.00	4.98	0.83	5.73	0.00**	6.00	26.54	4.42	40.89	<.001**
	Err	22.00	3.19	0.14			22.00	2.38	0.11		
	Tot	35.00	617.88				35.00	628.66			
		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
20-40	Rep	2.00	0.06	0.03	0.54		2.00	0.22	0.11	1.74	
	G	3.00	52.45	17.48	309.37	<.001**	3.00	65.59	21.86	345.15	<.001**
	H	2.00	252.49	126.25	2234.04	<.001**	2.00	276.67	138.34	2183.99	<.001**
	G*H	6.00	16.61	2.77	49.00	<.001**	6.00	27.16	4.53	71.47	<.001**
	Err	22.00	1.24	0.06			22.00	1.39	0.06		
	Tot	35.00	322.86								
		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
40-60	Rep	2.00	2.03	1.02	14.33		2.00	1.03	0.52	2.21	
	G	3.00	21.33	7.11	100.26	<.001**	3.00	34.95	11.65	49.73	<.001**
	H	2.00	141.23	70.62	995.80	<.001**	2.00	154.95	77.47	330.71	<.001**
	G*H	6.00	4.61	0.77	10.84	<.001**	6.00	5.94	0.99	4.22	0.01**
	Err	22.00	1.56	0.07			22.00	5.15	0.23		
	Tot	35.00	170.76				35.00	202.03			

SD- soil depth; SV- source of variation; G- gypsum; H- halophytes; G*H- interaction of gypsum and halophytes; DF- degree of freedom; SS- sum square; MS- mean square; F- f calculated and P- probability level; Tot- total variation; Err- variation due to error and **- highly significant.

Appendix Table 5. ANOVA Table for Soil **SAR** After Reclamation

Soil SAR in the three soil layers											
		After first harvest					After second harvest				
SD (cm)	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
0-20	Rep	2	1.17	0.59			2	6.71	3.35	2	
	GY	3	1133.6	377.86	10715.7	<.001**	3	1214.6	404.87	1472.5	<.001**
	H	2	2112	1056	29946.5	<.00**	2	2344.53	1172.27	4263.5	<.001**
	G*H	6	244.28	40.71	1154.6	<.001**	6	414.8	69.13	251.44	<.001**
	Err	22	0.78	0.04			22	6.05	0.27		
	Tot	35	3491.8				35	3986.7			
		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
20-40	Rep	2	3.65	1.82			2	4.57	2.283		
	GY	3	1288.95	429.65	10189	<.001**	3	1101.1	367.03	1829.44	<.001**
	H	2	2319.78	1159.9	27506.3	<.001**	2	1982.18	991.09	4939.95	<.001**
	G*H	6	248.66	41.44	982.81	<.001**	6	556.15	92.691	462	<.001**
	Err	22	0.93	0.04			22	4.41	0.201		
	Tot	35	3861.96				35	3648.4			
		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
40-60	Rep	2	7.99	3.99			2	14.56	7.28	2	
	G	3	1341.11	447.04	7309.63	<.001**	3	1404.39	468.13	4749.16	<.001**
	H	2	2827.81	1413.91	23119.1	<.001**	2	2927.58	1463.79	14850.1	<.001**
	G*H	6	253.57	42.26	691.03	<.001**	6	268.26	44.71	453.57	<.001**
	Err	22	1.35	0.06			22	2.17	0.1		
	Tot	35	4431.83				35	4616.96			

SD-soil depth; SV- source of variation; G- gypsum; H- halophytes; G*H- interaction of gypsum and halophytes; DF- degree of freedom; SS- sum square; MS- mean square; F- f calculated and P- probability level; Tot- total variation; Err- variation due to error and **- highly significant.

Appendix Table 6. ANOVA Table for Soil **ESP (%)** After Reclamation

Soil ESP (%)											
		After first harvest					After second harvest				
SD (cm)	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
0-20	Rep	2	5.69	2.85	5.97		2	15.9	7.95	167.57	
	G	3	5283	1761	3694	<.001**	3	5322	1774	37400.4	<.001**
	H	2	1392.7	696.33	1460.66	<.001**	2	2081.5	1040.8	21941.7	<.001**
	G*H	6	7.78	1.3	2.72	0.004**	6	45.95	7.66	161.47	<.001**
	Err	22	10.49	0.48			22	1.044	0.047		
	Tot	35	6699.7				35	7466.4			
		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
20-40	Rep	2	25.381	12.69	123.96		2	23.454	11.727	61.96	
	G	3	6840	2280	22271.8	<.001**	3	8603	2867.7	15150.6	<.001**
	H	2	1680.9	840.43	8209.57	<.001**	2	2617.4	1308.7	6914.25	<.001**
	G*H	6	20.004	3.33	32.57	<.001**	6	33.722	5.6203	29.69	<.001**
	Err	22	2.25	0.10			22	4.1641	0.1893		
	Tot	35	8568.5				35	11282			
		After first harvest					After second harvest				
	SV	DF	SS	MS	F	P	DF	SS	MS	F	P
40-60	Rep	2	29.6	14.81			2	11.601	5.8004	45.83	
	G	3	5081	1693.7	22486	<0.001**	3	5855.3	1951.8	15421.4	<.001**
	H	2	6946	3473.1	46108	<0.001**	2	9256.9	4628.5	36570.7	<.001**
	G*H	6	706.5	117.75	1563.3	<0.001**	6	474.44	79.074	624.78	<.001**
	Err	22	1.7	0.08			22	2.78	0.1266		
	Tot	35	12765				35	15601			

SD- soil depth; SV- source of variation; G- gypsum; H- halophytes; G*H- interaction of gypsum and halophytes; DF- degree of freedom; SS- sum square; MS- mean square; F-f calculated and P- probability level; Tot-total variation; Err-variation due to error; **- highly significant and **- highly significant.

Appendix Table 7. ANOVA Table for Plant Height (cm)

	First harvest					Second harvest				
SV	DF	SS	MS	F	P	DF	SS	MS	F	P
Rep	2	17.33	8.666			2	15.3	7.648		
Tr	9	2267.05	251.895	18.18	<.001**	9	1809.03	201.003	31.44	<001**
Err	18	249.45	13.858			18	115.09	6.394		
Tot	29	2533.83				29	1939.41			

SV-source of variation; DF- degree of freedom; SS- sum square; MS- mean square; F- f calculated, P- probability level; Tot- total variation; Err- variation due to error and **- highly significant.

Appendix Table 8. ANOVA Table for Dry Biomass (Dry Matter Yield) (ton/ha)

	First harvest					Second harvest				
SV	DF	SS	MS	F	P	DF	SS	MS	F	P
Rep	2	0.47	0.24			2	0.63	0.317		
Tr	9	94.67	10.52	99.76	<0.001**	9	129.01	14.335	69.79	<0.001**
Err	18	1.90	0.11			18	3.70	0.205		
Tot	29	97.047				29	133.35			

SV- source of variation; DF- degree of freedom; SS- sum square; MS- mean Square; F- f calculated and P- probability level; Tot- total variation; Err- variation due to error and **- highly significant.

Appendix Table 9. ANOVA Table for Leaf Na^+ (mg/kg or ppm)

	First harvest					Second harvest				
SV	DF	SS	MS	F	P	DF	SS	MS	F	P
Rep	2	0.007	0.0035			2	0.018	0.009		
Tr	9	266.50	29.61	758.35	<.001**	9	219.60	24.40	665.55	<.001**
Err	18	0.703	0.039			18	0.66	0.037		
Tot	29	267.213				29	220.28			

SV- source of variation; DF- degree of freedom; SS- sum square; MS- mean Square; F-f calculated and P- probability level; Tot- total variation; Tr- variation due to treatment; Err- variation due to error and **- highly significant.

Appendix Table 10. ANOVA Table for Leaf Crude Protion (%)

	First harvest					Second harvest				
SV	DF	SS	MS	F	P	DF	SS	MS	F	P
Rep	2	0.142	0.071			2	0.16	0.081		
Tr	9	8.44	0.94	91.77	<.001**	9	6.42	0.71	35.91	<.001**
Err	18	0.18	0.01			18	0.36	0.02		
Tot	29	8.76				29	6.93			

SV- source of variation; DF- degree of freedom; SS- sum square; MS- mean Square; F- f calculated and P- probability level; Tot- total variation; Tr- variation due to treatment; Err- variation due to error and **- highly significant.

Appendix Table 11. Classes of soil bulk density

Bulk density (gm cm^{-3})	Rating
< 1	For soils high in organic matter
1 – 1.4	Well-aggregated loam soils
1.2 – 1.8	Sand and compacted horizons in clay soils

Source, White, (2006)

Appendix Table 12. Rating of Soil Organic Matter Content (%OM)

Rating or class	OM (%)	Infiltration rate mm/hr
Very low	< 0.86	<2.5
Low	0.86 - 2.59	2.5-12.5
Medium/moderate	2.59 - 5.17	12.5-25
High	> 5.17	>25
Very high	Not Given	
Tekalegn *et al.*, (1991)		Miller and Donahue, 1997

Appendix Table 13. Rating of Soil Salinity and Sodicity Parameters

Parameter	Test method	Rating
Ece (dS m^{-1})	From saturated paste extract	< 2 (non-saline) no management option needed 2 - 4 (slightly saline) 4-8 (moderately saline) 8-16 (highly saline) > 16 (extreme saline)
PHe	From saturated paste extract	6.7 - 7.3 (neutral) 7.4 - 8 (moderately alkaline) > 8 (strongly alkaline) careful monitoring of SAR and ESP recommended
ESP (%)	Derived parameter	< 5 (low) 5-15 (medium) >15 (high)
SAR	Derived parameter	<5 (low) 5-13 (medium) >13 (high)

Sources, Lamond and Whitney, (1992) for soil ECe, SAR and ESP; Tekalign, (1991) for soil pHe

Appendix Table 14. Salinity Classes of Irrigation Water

ECw (dS m^{-1} or mmhos cm^{-1})	Rating
<0.25	Low salinity
0.25 - 0.75	Medium salinity
0.75 – 2.25	High salinity
>2.25	Very high salinity

USSLS, (1954)

Appendix Table 15. Free Flow Discharge Values for 3-inch Partial Flume

Head (mm)	Discharge (l/s)
100	8.5
90	7
80	5.5
70	4.5
60	3.5
50	2.5
40	1.5
30	1
20	0.5

Appendix Table 16. Salinity and Sodicity Parameters in Golina-Adisalem Irrigation scheme at the Begning of the Experiment

Requested by: Sisay Dessale

Lab no	First bach soil analaysis							
0.001	0-20 cm							
	pHe	Ece	Ex Na	CEC	ESP (%)	sol Ca+Mg	sol Na	SAR
	8.5	20	11.27	20.48	55.03	77.6	307.5	49.37
0.002	20-40 cm							
	pHe	Ece	Ex Na	CEC	ESP (%)	sol Ca+Mg	sol Na	SAR
	8.65	16.4	12.88	20.1	64.08	324.36	76.19	52.55
0.003	40-60 cm							
	pHe	Ece	Ex Na	CEC	ESP (%)	sol Ca+Mg	sol Na	SAR
	8.77	11.49	13.95	19.63	71.06	345.33	74.93	56.42

where, ECE in DS/m
excangeable Na+ in meq/100gm
CEC in meq/100 gm
soluble Na in meq/L
soluble Ca+Mg in meq/L

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Solomon Wondatir Taye

Amhara National Regional State
Sirinka Agricultural Research Center

Appendix Table 17. Salinity and Sodicity Parameters After First Harvest in 0-20 cm Soil Layer

Requested by: Sisay Dessale

Second bach soil data

0-20 cm

lab no	pHe	Ece	Ex Na	CEC	sol Ca+Mg	sol Na	SAR	ESP(%)
1	7.58	7.12	4.15	24.10	100.20	121.00	17.09	17.22
2	7.63	8.25	5.88	23.00	99.30	147.20	20.89	25.57
3	7.43	5.13	3.44	28.75	104.10	100.25	13.90	11.97
4	7.64	8.08	6.14	22.99	98.90	144.40	20.53	26.71
5	7.45	6.32	3.42	27.30	103.80	99.20	13.77	12.53
6	7.60	7.32	4.36	23.94	99.00	118.30	16.81	18.21
7	7.80	14.63	10.10	22.30	95.10	168.00	24.36	45.29
8	7.88	14.39	9.80	22.00	95.80	168.30	24.32	44.55
9	7.61	9.33	6.33	24.00	117.90	191.39	24.93	26.38
10	7.75	11.99	9.02	22.80	98.70	244.34	34.78	39.56
11	7.71	10.96	7.52	23.50	101.30	222.64	31.28	32.00
12	8.50	20.12	11.52	20.50	78.90	309.00	49.20	56.20
13	7.81	14.89	9.65	21.80	97.30	166.80	23.91	44.27
14	7.63	7.42	4.16	24.15	101.70	119.50	16.76	17.23
15	7.85	14.96	9.95	22.10	96.60	166.40	23.94	45.02
16	7.60	6.67	4.24	23.74	100.50	116.80	16.48	17.86
17	7.38	5.96	3.25	26.80	105.30	97.60	13.45	12.13
18	7.63	8.27	5.99	22.79	100.40	142.00	20.04	26.29
19	7.65	8.06	5.87	22.80	100.80	143.30	20.19	25.75
20	7.41	6.10	3.32	28.55	105.60	98.75	13.59	11.63
21	7.74	11.34	8.87	22.60	100.20	242.84	34.31	39.25
22	7.62	8.52	6.18	24.24	119.40	189.89	24.58	25.50
23	7.73	10.51	7.37	23.70	102.80	221.14	30.85	31.10
24	8.47	19.35	11.41	21.00	80.40	316.30	49.89	54.33
25	7.69	8.19	6.29	23.19	100.40	146.70	20.71	27.13
26	7.84	15.10	10.25	22.50	96.60	168.80	24.29	45.56
27	7.59	6.97	4.32	24.30	101.70	122.00	17.11	17.78
28	7.41	5.43	3.58	28.95	105.60	101.50	13.97	12.37
29	7.86	14.50	9.95	22.20	97.30	169.60	24.32	44.82
30	7.66	8.81	6.17	23.20	100.80	148.00	20.85	26.59
31	7.58	7.62	4.30	24.14	100.50	120.00	16.93	17.81
32	7.44	5.72	3.46	27.50	105.30	99.70	13.74	12.58
33	7.72	10.41	7.67	24.10	102.80	224.14	31.26	31.83
34	7.79	12.29	9.17	23.00	100.20	245.84	34.73	39.87
35	7.61	9.47	6.48	24.64	119.40	192.89	24.96	26.30
36	8.60	20.30	11.76	19.80	81.60	320.50	50.18	59.39

Lab expert Signature

Directorate: Signature

Solomon Wondatir Taye

Soil And Water Resea

Directorate Coordin

Amhara National Regional State Sirinka Agricultural Research Center

Appendix Table 18. Salinity and Sodicity Induces After First Harvest in 20-40 cm Soil Layer

Requested by: Sisay Dessale

Second bach soil data

20-40 cm

Lab no	pHe	Ece	Ex Na	CEC	ESP (%)	sol Ca+Mg	sol Na	SAR
37	7.64	6.57	5.08	22.65	22.43	89.60	130.80	19.54
38	7.69	7.40	6.82	22.30	30.58	88.90	157.90	23.68
39	7.55	5.83	4.01	27.00	14.85	95.10	110.30	16.00
40	7.70	7.37	6.92	21.94	31.54	89.10	153.60	23.01
41	7.51	5.89	3.96	26.83	14.76	94.00	107.00	15.61
42	7.68	6.49	5.17	22.51	22.97	88.90	128.20	19.23
43	7.78	8.47	11.55	21.60	53.47	85.00	177.40	27.21
44	7.81	8.33	11.38	21.75	52.32	85.70	178.50	27.27
45	7.90	11.36	7.20	23.70	30.38	107.80	202.00	27.51
46	8.15	11.23	9.70	21.80	44.50	88.80	255.00	38.27
47	8.12	11.63	8.94	22.89	39.06	91.10	233.00	34.52
48	8.64	16.35	13.10	20.10	65.17	76.30	330.00	53.43
49	7.83	8.54	11.23	21.96	51.14	86.90	177.39	26.91
50	7.72	6.53	4.93	22.86	21.57	90.80	129.69	19.25
51	7.91	8.30	11.40	21.81	52.27	86.20	176.29	26.85
52	7.69	6.63	5.02	22.72	22.10	90.10	127.79	19.04
53	7.59	5.69	3.81	27.04	14.09	95.20	106.60	15.45
54	7.82	7.60	6.77	22.15	30.56	90.30	154.50	22.99
55	7.85	7.55	6.67	22.51	29.63	90.50	155.10	23.06
56	7.53	5.79	3.86	27.21	14.19	96.30	108.10	15.58
57	8.20	11.71	9.55	22.01	43.39	90.00	253.89	37.85
58	7.89	11.41	7.05	23.91	29.49	109.00	200.89	27.21
59	8.11	11.33	8.79	23.10	38.05	92.30	231.89	34.13
60	8.46	15.70	12.95	20.31	63.76	76.20	325.89	52.80
61	7.69	7.29	7.07	21.73	32.54	87.90	157.10	23.70
62	7.86	8.20	11.70	21.39	54.70	83.80	178.51	27.58
63	7.65	6.85	5.23	22.44	23.31	88.40	131.91	19.84
64	7.50	6.01	4.16	26.79	15.53	93.90	110.50	16.13
65	7.90	7.85	11.53	21.54	53.53	84.50	179.61	27.63
66	7.75	7.27	6.97	22.09	31.55	87.70	158.20	23.89
67	7.64	6.91	5.32	22.30	23.86	87.70	129.31	19.53
68	7.49	6.09	4.11	26.62	15.44	92.80	109.30	16.05
69	7.98	11.73	9.09	22.68	40.08	89.90	234.11	34.92
70	8.10	11.49	9.85	21.59	45.62	87.60	256.11	38.70
71	7.86	11.60	7.35	23.49	31.29	106.60	203.11	27.82
72	8.68	16.60	13.25	19.64	67.46	75.10	335.11	54.69

Lab expert Tesfaye
Signature

Directorate:
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Solomon Wondatir Taye

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Appendix Table 19. Salinity and Sodicity Induces After First Harvest in 40-60 cm Soil Layer

Requeted by: Sisay Dessale

Second bach soil data

40-60 cm

lab no	pHe	Ece	Ex Na	CEC	ESP	sol Ca+Mg	sol Na	SAR
73	7.73	6.25	5.69	22.15	25.69	90.50	135.60	20.16
74	7.79	6.94	7.40	21.23	34.86	89.70	162.30	24.23
75	7.64	5.45	4.55	26.59	17.11	96.30	114.90	16.56
76	7.80	7.21	7.49	21.32	35.13	89.90	157.80	23.54
77	7.65	5.46	4.43	26.30	16.84	95.20	111.70	16.19
78	7.73	6.32	5.79	22.00	26.32	89.50	132.50	19.81
79	7.94	8.10	12.14	21.02	57.75	83.70	181.60	28.07
80	7.93	8.24	11.97	21.00	57.00	84.50	182.30	28.05
81	8.26	10.90	11.80	20.80	56.73	97.80	210.60	30.12
82	8.45	11.08	12.93	20.35	63.54	81.80	262.30	41.01
83	8.32	11.02	12.55	20.63	60.83	89.60	241.00	36.01
84	8.77	11.49	14.10	19.58	72.01	75.60	346.00	56.28
85	7.96	8.00	12.12	20.80	58.27	82.51	183.79	28.61
86	7.68	5.60	5.84	21.95	26.61	88.51	137.09	20.61
87	7.90	7.96	12.29	20.82	59.03	81.71	183.09	28.64
88	7.69	5.67	5.94	21.80	27.25	87.51	133.99	20.26
89	7.63	5.11	4.58	26.10	17.55	93.21	113.19	16.58
90	7.86	7.06	7.64	21.12	36.17	87.91	159.29	24.03
91	7.81	7.09	7.55	21.03	35.90	87.71	163.79	24.73
92	7.62	5.17	4.70	26.39	17.81	94.31	116.39	16.95
93	8.38	10.05	13.08	20.15	64.91	79.81	263.79	41.76
94	8.21	10.10	11.95	20.60	58.01	95.81	212.09	30.64
95	8.27	9.88	12.70	20.43	62.16	87.61	242.49	36.64
96	8.72	10.84	14.28	19.37	73.72	73.50	349.80	57.70
97	7.86	7.15	7.34	21.52	34.11	91.89	156.31	23.06
98	7.88	8.13	11.99	21.22	56.50	85.69	180.11	27.52
99	7.72	6.50	5.54	22.35	24.79	92.49	134.11	19.72
100	7.64	5.36	4.40	26.79	16.42	98.29	113.41	16.18
101	7.92	7.89	11.82	21.20	55.75	86.49	180.81	27.50
102	7.80	6.88	7.25	21.43	33.83	91.69	160.81	23.75
103	7.69	6.57	5.64	22.20	25.41	91.49	131.01	19.37
104	7.60	5.40	4.28	26.50	16.15	97.19	110.21	15.81
105	8.25	10.99	12.40	20.83	59.53	91.59	239.51	35.39
106	8.32	11.23	12.78	20.55	62.19	83.79	260.81	40.29
107	8.19	10.85	11.65	21.00	55.48	99.79	209.11	29.60
108	8.76	11.74	13.98	19.81	70.57	78.00	344.20	55.12

Lab expert Signature

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Solomon Wondatir Taye

Appendix Table 20. Salinity and Sodicity Induces After Second Harvest in 0-20 cm Soil Layer

Requested by: Sisay Dessale

3rd bach soil analaysis

0-20 cm

lab no	pHe	Ece	Ex Na	CEC	ESP(%)	sol Ca+Mg	sol Na	SAR
109	7.35	6.15	3.40	25.10	13.55	101.50	101.00	14.18
110	7.42	7.14	4.21	23.89	17.62	100.00	122.00	17.25
111	7.19	4.26	2.63	29.43	8.94	105.20	81.20	11.20
112	7.44	7.24	4.38	23.57	18.58	99.80	122.50	17.34
113	7.22	4.78	2.59	29.01	8.93	104.20	77.70	10.76
114	7.35	6.26	3.48	25.35	13.73	100.50	100.10	14.12
115	7.63	11.83	9.18	22.96	39.98	94.60	142.10	20.66
116	7.65	11.73	8.81	22.83	38.59	95.20	143.00	20.73
117	7.55	8.68	5.92	26.63	22.23	118.80	170.00	22.06
118	7.70	10.79	8.68	23.54	36.87	101.00	222.00	31.24
119	7.64	10.12	7.02	25.10	27.97	101.70	201.00	28.19
120	8.52	20.00	11.61	20.24	57.36	79.80	309.30	48.97
121	7.69	11.76	8.96	22.63	39.59	97.20	141.50	20.30
122	7.38	6.50	3.55	24.90	14.26	103.50	99.50	13.83
123	7.68	12.08	9.33	22.76	40.99	96.60	140.60	20.23
124	7.37	6.42	3.63	25.15	14.43	102.50	98.60	13.77
125	7.19	4.78	2.74	28.96	9.46	106.20	76.20	10.46
126	7.46	7.46	4.53	23.52	19.26	101.80	121.00	16.96
127	7.48	7.55	4.36	23.69	18.40	102.00	120.50	16.87
128	7.25	3.61	2.78	29.23	9.51	107.20	79.70	10.89
129	7.69	11.24	8.83	23.34	37.83	103.00	220.50	30.73
130	7.53	8.86	6.07	26.43	22.97	120.80	168.50	21.68
131	7.60	10.24	7.17	24.90	28.80	103.70	199.50	27.71
132	8.49	19.35	11.76	20.04	58.68	81.80	312.00	48.79
133	7.50	7.15	4.23	23.62	17.91	97.80	124.00	17.73
134	7.78	11.85	9.03	23.16	38.99	92.60	143.60	21.10
135	7.36	6.33	3.25	25.30	12.85	99.50	102.50	14.53
136	7.27	4.51	2.48	29.63	8.37	103.20	82.70	11.51
137	7.75	12.20	8.66	23.03	37.60	93.20	144.50	21.17
138	7.50	7.33	4.06	24.09	16.85	98.00	123.50	17.64
139	7.37	6.46	3.33	25.55	13.03	98.50	101.60	14.48
140	7.29	4.30	2.44	29.06	8.40	102.20	79.20	11.08
141	7.61	10.80	6.87	25.30	27.15	99.70	202.50	28.68
142	7.72	11.12	8.53	23.74	35.93	99.00	223.50	31.77
143	7.49	8.65	5.77	26.83	21.51	116.80	171.50	22.44
144	8.62	20.96	11.46	20.44	56.07	77.80	328.00	52.59

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Directorate: Signature

Solomon Wondatir Taye

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Appendix Table 21. Salinity and Sodicity Induces After Second Harvest in 20-40 cm Soil Layer

Requested by: Sisay Dessale

3rd bach soil analaysis

20-40 cm

	pHe	Ece	Ex Na	CEC	ESP (%)	sol Ca+Mg	sol Na	SAR
145	7.39	5.73	3.48	23.55	14.78	91.10	133.20	19.74
146	7.45	6.61	5.26	22.90	22.97	90.20	159.80	23.80
147	7.25	4.97	2.64	28.90	9.13	96.20	112.40	16.21
148	7.43	5.89	5.15	22.77	22.62	90.40	156.00	23.20
149	7.26	4.54	2.52	29.12	8.65	95.70	109.20	15.79
150	7.42	5.71	3.53	23.70	14.89	90.60	131.00	19.46
151	7.53	7.53	11.01	21.98	50.09	83.80	179.70	27.76
152	7.56	7.45	11.10	22.05	50.34	84.30	180.90	27.86
153	7.70	10.56	6.63	25.50	26.00	133.20	209.20	25.63
154	7.95	10.73	9.03	22.23	40.62	109.30	262.00	35.44
155	7.92	10.62	8.35	23.03	36.26	122.00	239.50	30.66
156	8.72	16.35	13.24	19.89	66.57	75.90	334.50	54.30
157	7.60	7.22	10.95	22.27	49.17	86.29	179.41	27.31
158	7.47	6.04	3.33	23.77	14.01	93.09	131.71	19.31
159	7.65	7.36	10.86	22.20	48.92	85.79	178.21	27.21
160	7.45	5.70	3.38	23.92	14.13	92.59	129.51	19.03
161	7.32	5.10	2.37	29.34	8.08	97.69	108.10	15.47
162	7.58	6.89	5.00	22.99	21.75	92.39	155.10	22.82
163	7.53	6.66	5.11	23.12	22.11	92.19	157.20	23.15
164	7.28	4.89	2.49	29.12	8.55	98.19	108.70	15.51
165	8.05	10.68	8.88	22.45	39.56	111.29	260.51	34.92
166	7.73	10.47	6.48	25.72	25.20	135.19	207.71	25.26
167	7.97	10.51	8.20	23.25	35.27	123.99	238.01	30.23
168	8.57	15.85	13.09	20.50	63.86	77.89	328.00	52.56
169	7.50	7.07	5.30	22.55	23.50	88.41	159.30	23.96
170	7.64	7.26	11.16	21.76	51.28	81.81	181.19	28.33
171	7.46	5.72	3.63	23.33	15.56	89.11	134.69	20.18
172	7.30	4.96	2.79	28.68	9.72	94.21	113.89	16.59
173	7.68	7.47	11.25	21.83	51.53	82.31	182.39	28.43
174	7.55	6.60	5.41	22.68	23.85	88.21	158.90	23.93
175	7.43	5.87	3.68	23.48	15.67	88.61	132.49	19.90
176	7.29	5.04	2.67	28.90	9.24	93.71	110.69	16.17
177	7.90	10.66	8.50	22.81	37.26	120.01	240.99	31.11
178	8.03	10.85	9.18	22.01	41.70	107.31	263.49	35.97
179	7.81	10.69	6.78	25.28	26.82	131.21	210.69	26.01
180	8.69	16.74	13.42	19.67	68.23	72.80	336.90	55.84

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Appendix Table 22. Salinity and Sodicity Induces After Second Harvest in 40-60 cm Soil Layer

Requested by: Sisay Dessale

3rd bach soil analaysis

40-60 cm

181	pHe	Ece	Ex Na	CEC	ESP	sol Ca+Mg	sol Na	SAR
182	7.62	5.38	3.89	23.10	16.84	92.30	137.20	20.20
183	7.68	6.28	5.61	22.15	25.33	90.50	161.20	23.96
184	7.53	4.36	2.78	28.10	9.89	97.30	116.60	16.72
185	7.69	6.44	5.70	22.29	25.57	90.90	159.60	23.67
186	7.54	4.30	2.61	27.80	9.39	96.30	113.60	16.37
187	7.62	5.36	4.00	22.95	17.43	91.70	134.20	19.82
188	7.83	7.78	11.20	21.97	50.98	83.30	183.40	28.42
189	7.82	7.69	10.89	22.10	49.28	83.70	182.90	28.27
190	8.23	11.13	11.02	21.20	51.98	99.50	215.50	30.55
191	8.40	11.06	12.20	20.80	58.65	83.40	268.90	41.64
192	8.29	10.99	11.68	20.96	55.73	90.50	242.20	36.01
193	8.80	11.49	14.03	19.61	71.55	76.10	353.20	57.26
194	7.86	7.38	11.19	21.94	51.00	87.00	181.30	27.49
195	7.58	5.20	4.10	22.90	17.90	95.60	135.60	19.61
196	7.80	7.70	11.25	21.86	51.46	86.60	181.80	27.63
197	7.60	5.61	3.98	22.68	17.55	95.00	132.60	19.24
198	7.51	4.43	2.72	27.58	9.86	99.60	112.40	15.93
199	7.76	6.60	5.81	22.13	26.25	94.20	160.80	23.43
200	7.71	7.27	5.72	21.99	26.01	93.80	163.10	23.82
201	7.49	4.20	2.76	27.94	9.88	100.40	113.80	16.06
202	8.34	9.68	12.31	20.64	59.64	86.70	267.30	40.60
203	8.18	9.45	11.13	21.04	52.90	102.80	213.90	29.84
204	8.25	9.60	11.79	20.80	56.68	93.80	240.60	35.13
205	8.74	10.84	14.30	19.45	73.52	79.40	351.60	55.80
206	7.75	6.56	5.59	22.45	24.90	87.60	165.10	24.95
207	7.80	7.38	11.06	22.13	49.98	80.00	185.00	29.25
208	7.59	5.29	3.91	23.26	16.81	89.00	138.80	20.81
209	7.50	4.54	2.63	28.26	9.31	93.80	116.10	16.95
210	7.81	7.82	10.93	22.21	49.21	80.40	184.50	29.10
211	7.72	6.32	5.50	22.31	24.65	87.20	165.90	25.12
212	7.60	5.48	3.89	23.11	16.83	88.40	135.80	20.43
213	7.48	4.19	2.56	27.96	9.16	93.00	114.90	16.85
214	8.23	9.41	11.57	21.12	54.78	87.20	243.80	36.92
215	8.29	9.53	12.09	20.96	57.68	80.10	270.50	42.74
216	8.16	9.55	10.91	21.36	51.08	96.20	217.10	31.30
217	8.77	11.86	14.18	19.77	71.72	72.80	354.80	58.81

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Appendix Table 23. Sodium and Crue Proteion Concentration in Plant Tissue

Requested by: Sisay Dessale

Plant tissue analaysis

frist round			second round		
lab no	Na	crude p (%)	lab no	Na	crude p (%)
1	273	7.67	50	260	8.03
2	265	7.7	51	251	8.04
3	288	7.77	52	274	8.11
4	261	7.6	53	245	7.95
5	294	7.72	54	280	8.07
6	269	7.65	55	254	8
7	247	7.96	56	235	8.02
8	258	7.99	57	238	8.06
9	252	7.91	58	236	8.05
10	268	7.63	59	252	7.98
11	243	7.97	60	234	8.04
12	274	7.7	61	262	8
13	299	7.67	62	284	8
14	266	7.79	63	251	8.01
15	260	7.67	64	245	8.04
16	292	7.61	65	277	7.96
17	255	7.99	66	240	8.35
18	252	8.29	67	229	8.33
19	278	7.81	68	263	8.17
20	285	7.79	69	270	8.15
21	247	8.14	70	239	8.17
22	269	7.83	71	254	8.16
23	265	7.9	72	250	8.25
24	290	7.86	73	275	8.2
25	102	9.4	74	103.6	9.87
26	97	8.98	75	98.2	9.02
27	100.6	9.23	76	102.3	9.28
28	99.6	8.85	77	100.06	8.83
29	104.2	9.31	78	105.4	9.29
30	101.5	8.73	79	104.5	8.92

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Signature Signature

Date Date

Soil And Water Research Directorate Coordination

Amhara National Regional State Sirinka Agricultural Research Center

Appendix Table 24. Water Quality Analaysis ofor the Applied Irrigation Water and Deep Percolated Water Samples

Requested by: Sisay Dessale

	water quality					
lab no	Unit	1/W	2W	3/W	4/W	5/W
sol Na	mg/L	29.6	32	32	32.6	33.3
sol Ca	mg/L	71	60	60	60.4	60.4
soil Mg	mg/L	29.1	25.55	25.55	25.5	25.6
EC		0.35	0.39	0.39	0.39	0.4

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Solomon Wondatir Taye

Amhara National Regional State
Sirinka Agricultural Research Center

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Appendix Figure 1. Salt-affected Problem in Golina-Adisalem Irrigation Plain

Appendix Figure 2. Disturbed Soil Sampling Using Auger

Appendix Figure 3. Gypsum Application at Golina-Adisalem Irrigation Scheme

Appendix Figure 4. First Round Irrigation Pictures (From Establishment up to First Harvesting)

Appendix Figure 5. Second Round Irrigation Pictures

Appendix Figure 6. Field Visit by Different Stakeholders

Appendix Figure 7. Flow Measuring Device Using Parshal Flume

Appendix Figure 8. Soil Analaysis in the Laboratory