SOIL & CROP SCIENCES | RESEARCH ARTICLE

Reclamation and amelioration of saline-sodic soil using gypsum and halophytic grasses: Case of Golina-Addisalem irrigation scheme, Raya Kobo Valley, Ethiopia

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Abstract: In Golina-Adisalem irrigation scheme, 500 ha becoming salt-affected. Rehabilitation of salt-affected fields using drainage is expensive and leaching by far not feasible in shallow water table areas. The alternative way is chemical amendment and bioremediation. Therefore, the field experiment was conducted to evaluate the possibility of using gypsum soil amendment and halophytic grasses on modification properties of saline-sodic soil, and their effects on infiltration. The gypsum levels (0%, 75%, 100%, 125% gypsum requirement) and halophytic grasses (Chlorosis Guayana and Cynodon Dactylon) were set in factorial RCBD design with three replications. After the 2nd harvest, the highly significantly (P < 0.01) lowest pH (7.23, 7.29, 7.51), ECe (4.62, 4.89, 4.31 dS m⁻¹), SAR (10.78, 15.81, 16.38), and ESP (8.93, 8.66, 9.47%) were recorded from Chlorosis Guayana+125% gypsum requirement (G) and Cynodon Dactylon +125% gypsum requirement (G) applied treatment, whereas the highest pH (8.54, 8.66, 8.77), ECe (20.1, 16.31, 11.431 dS m⁻¹), SAR (50.12, 54.23, 57.29) and ESP (57.37, 66.22, 72.26%) was obtained from the control treatment for 0–20, 20–40, 40–60 cm depths.

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PUBLIC INTEREST STATEMENT
Our study contributes to uncultivable land to make fit for cultivation for suitable agricultural production. The local farmers can be obtained acceptable yield and attaining food security by bringing back salt-affected irrigation fields into productive purpose. The study investigates reclamation and amelioration of saline-sodic soil using gypsum and halophytic grasses (Rhodes and Panicum grass) provides for effective utilization of scarce soil and water resources. Therefore, this technology can improve salt-affected irrigation schemes.
respectively. The reclamation efficiency of Chlorosis Guayana+125% G was statistically equal with Cynodon Dactaylon+125% G. The highest infiltration rates were noted from soils treated with Chlorosis Guayana+125% G (6.3 cm/hr) and Cynodon Dactaylon+125% G (5.92 cm/hr); while the lowest value (1.22 cm/hr) was recorded from the control treatment. Therefore, the combined application of Chlorosis Guayana (Rhodes grass massava variety)+125% G and Cynodon Dactaylon (Panicum grass maxima variety)+125% G was the most efficient treatment for improving saline-sodic soil.

Subjects: Land Reclamation Pedology; Vegetation; Agronomy

Keywords: Soil salinity and sodicity; gypsum amendment; phytoremediation

1. Introduction

1.1. Background and justification

Globally about 7% or 831 million ha of land affected by salinity and sodicity (Mirza Hasanuzzaman 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 (Abegaz, 2007) and ranked as 7th 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).

Specifically, in Golina-Adisalem irrigation scheme, 500 ha of land has denuded above 8 years. Regarding, the salinity expansion also going up and the sustainability of irrigated agriculture in the Raya Kobo valley as the hole threatened by salinization (Dessale et al., 2016; Mengesha et al., 2018). This relatively recent agricultural threat has not received much attention yet, and there has never been a comprehensive management of the salt-affected problems. Therefore, new insight should be captured as salt-affected soils rehabilitated and managed.

Previous studies indicate that the main source of salinity and sodicity in Golina-Adisalem irrigation scheme is due to the deposition of runoff from the upper mountainous area coupled with inadequate provision of drainage systems rises the groundwater table (<1.5 m below the surface), poor on-farm water management practices and substantial salt buildup due to high evaporation (Kobo Girana Valley Development Project [KGVDIP], 2010; Dessale et al., 2016; Mengesha et al., 2018).

Normally a saline-sodic soil does not show strong sodicity symptom. However, the management of sodicity and salinity becomes more complex when both occur in the same soil together. Thus, complicated problems do not need a straightforward solution (Makoi & n.d. akidemi, 2007). For sustaining productivity in the saline-sodic environment, two major approaches are common: (1) modifying the environment to suit the plant and (2) modifying the plant to suit the environment. Both tactics may use either singly or in combination. The first approach has practiced more extensively for enabling the plants to respond better (Tyagi & 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 (Ahmed & Qamar, 2004; Hanay et al., 2004; Siyal et al., 2002). The application chemicals followed by bio-remediation are 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\(_2\)O) is the most common and relatively economical amendment for replacing excess Na\(^+\) from the soil exchangeable sites by the provision of the readily available source of Ca\(^{2+}\) (Food and Agricultural Organization [FAO], 1988; Gupta & Abrol, 1990; McCauley & 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\(_2\)SO\(_4\). This Na\(_2\)SO\(_4\) form is easy to be removed, either by downward leaching or susceptible to upward absorption by halophytic grasses (Bennett et al., 2014; McCauley & Jones, 2005; Pitman & Läuchli, 2002; Qadir et al., 2001). To avoid resodification in saline-sodic areas, replaced Na\(_2\)SO\(_4\) should be absorbed from the root zone using salt-loving halophytic species.

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 (Abegaz, 2018; Ashenafi Worku & Nisaren, 2019; Qureshi et al., 2018). 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 (M.K.A. El-Fattah, 2011; Ghafoor et al., 2012; Mahdy, 2011; Swarp, 2004).

The presence of a shallow water table on the Golina-Adisalem irrigation area considered as the main constraint to apply leaching experimental trial. For this study, vertical leaching was substituted by upward absorption using salt loving halophytic grasses with and without gypsum. Therefore, the experiment was conducted to evaluate the possibility of using gypsum soil amendment and halophytic grasses on modification of properties of saline-sodic soil and their effects on infiltration rate of saline-sodic soil to contribute uncultivable land to make fit for cultivation for suitable agricultural production.

![Figure 1. Mean monthly rainfall, maximum and minimum temperatures (2002–2018).](image-url)
2. Material and methods

2.1. Description of the study area
The field experiment was conducted at Golina-Adisalem irrigation scheme Raya Kobo Wereda, Eastern Amhara Regional State for two irrigation seasons (2018). The site is found at about 570 km in the North of Addis Ababa (Capital city of Ethiopia). Geographically, it is situated between 12.03°–12.08° N latitudes and 39.28°–39.42° E longitudes and an altitude of 1368 m. a.s.l. The average annual rainfall, minimum temperature, and maximum temperature are 644.08 mm, 8.49°C, and 36.58 °C, respectively, with the annual mean monthly rainfall 53.67 mm (Figure 1).

2.2. Soil sampling and preparation
Disturbed soil sample collection mainly takes place for three consecutive phases as initially (before the experiment), after the first and second harvests using an auger.

Thus, before experiment 20 composite soil samples collected by two-way diagonal sampling technique and at each experimental plot after the first and second harvests..

The soil sampling depths were 0–20 (surface), 20–40, and 40–60 cm. The subsurface soil samples (20–40 and 40–60 cm) were collected at the same spots, in a 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 (pH, Ece, SAR, and ESP) were monitored up to the active rooting zones of experimental grasses (60 cm) (Tyagi, 2001). Similarly, undisturbed soil samples 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).

2.3. Soil analysis
Particle size distributions determined by the Bouyoucos hydrometer method using sodium hexametaphosphate for dispersing agent as pointed by Sertsu and Bekele (2000) and soil infiltration rate determined by double ring infiltrometer. Soil bulk density obtained from undisturbed soil samples using the oven-dry method by dried soils for 24 h at 105°C and weighed to calculate the dry density using the equation (Blake & Hartge, 1986).

\[
\rho_b = \frac{W_d}{V_c}
\]  

where \(\rho_b\) = soil bulk-density (gm/cm\(^3\))

\(W_d\) = weight of dry soil (gm)

\(V_c\) = volume of core (cm\(^3\))

Exchangeable cations (Ca\(^{2+}\) + Mg\(^{2+}\) and Na\(^+\)) are 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 & 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) (U.S. Salinity Laboratory Staff (Richards, L.A.), 1954; Qadir & 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 (Miller & Gardiner, 2007; USSLS, 1954):

\[ \text{ESP} = \frac{\text{ExchangeableNa}^+}{\text{CEC}} \times 100 \quad (2) \]

\[ \text{SAR} = \frac{\text{solubleNa}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \quad (3) \]

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

\[ \text{CEC} = \text{cmole (+)/kg, meq/100 gm or meq/l} \]

\[ \text{SolubleNa}^+ = \text{meq/l} \]

\[ \text{Ca}^{2+} + \text{Mg}^{2+} = \text{meq/l} \]

\[ \text{ESP} \% \text{ and SAR (unitless)} \]

2.4. 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 & 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 (CaSO₄, 2H₂O) 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):

\[ G = \frac{\text{CEC} \times d \times b \times 0.081(\text{ESP}_0 - \text{ESP}_f)}{1} \quad (4) \]

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

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

\[ d = \text{Reclaimed soil depth (m)}, \]

\[ b = \text{Bulk density of soil in kg/dm}^3 \text{ or Mg/m}^3 \text{ or ton/m}^3, \]

| Gypsum (CaSO₄, 2H₂O) | pH | Purity [%] |
|----------------------|----|-----------|
|                      | 7.8| 100       |

*Obtained as a by-product of gypsum manufacture Adigudom, (2018).*
\[
\begin{align*}
\text{ESP}_a &= \text{Actual (initial) ESP of the soil as determined by analysis}, \\
\text{ESP}_f &= \text{Final ESP or threshold arrived at after reclamation, usually (5–10%). However, 10% used for this experiment and} \\
f &= \text{Efficiency (purity) of gypsum application in (100)}. \\
G &= \frac{\text{ESP}_a - \text{ESP}_f \times c_{\text{EC}} \times \text{yz}}{100} \\
\text{where } G &= \text{Amount of gypsum required in ton/ha for restoring soil structure (0.2 m layer),} \\
\text{ESP}_a &= \text{Actual (initial) ESP of the soil as determined by analysis}, \\
\text{ESP}_f &= \text{Permissible or final ESP arrived at after reclamation}, \\
\text{CEC} &= \text{Cation exchange capacity in meq/100 g [cmole (+)/kg] of soil and} \\
\text{yz} &= \text{Amount of gypsum required in ton/ha to replace 1 meq of Na per 100 g soil in a 0.2 m thick.}
\end{align*}
\]

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 the reaction. The selected chemical properties of the gypsum chemical as indicated below (Table 1)

2.5. 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 halophytes grasses (0 H, RG, PG).

Using the zero halophytes (0 H) 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 replications. Each of the experimental plot sizes of (3 m \(\times\) 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 spacing between rows and plants was 50 and 20 cm, respectively (Sirinka Agricultural Research Center [SARC], 2008).

The single and combined experimental treatments constructed as:

2.6. 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.

2.7. 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) (USSL5, 1954). In addition, their effects on soil infiltration rates were evaluated.

2.8. Statistical 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 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. Effects of gypsum and ameliorative grasses on infiltration rate also analyzed by microsoft excel using a graphical representation. Table 2 and 3

3. Result and discussion

3.1. Selected physical properties of Golina-Adisalem saline-sodic soil at the beginning of the experiment

Table 2. Selected physical properties of the Golina-Adisalem salt-affected experimental site at the beginning of the experiment

| Depth (cm) | Particle size distribution (%) | Textural class | \( \rho_b \) (gm cm\(^{-3}\)) | Source |
|------------|-------------------------------|---------------|-------------------------|--------|
|            | Clay  | Silt | Sand  |                      |        |
| 0–20       | 26.5  | 52   | 21.5  | SL                    | 1.44 (compacted soil) | White (2006) |
| 20–40      | 30    | 55.5 | 14.5  | SCL                   | 1.58 (compacted soil) |
| 40–60      | 32    | 58   | 10    | SCL                   | 1.68 (compacted soil) |
| Average    | 29.5  | 55.17| 15.33 | SCL                   | 1.57 (compacted soil) |

SCL: silty clay loam; SL: silty loam; \( \rho_b \): bulk density.

3.2. Selected chemical properties of Golina-Adisalem saline-sodic soil at the beginning of the experiment
3.3. Determination of 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 4), 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).

3.4. Effect of gypsum and halophytic grasses (Rhodes and Panicum) on infiltration
Gypsum application and growth of halophytic grasses, viz., Chlorosis Guayana (Rhodes grass) and Cynodo Dactylion (Panicum grass) 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
Table 3. Chemical properties of Golina-Adisalem salt-affected irrigation scheme at the beginning of the experiment

| Concentration | Soil depth (cm) | Source |
|---------------|----------------|--------|
|               | 0–20           | 20–40  | 40–60   |
| Organic matter (OM %) | 1.15 (low) | 0.88 (low) | 0.62 (very low) | Tekalign Mamo (1991) |
| CEC (meq/100 g) | 20.48 | 20.1 | 19.63 |
| Excha. cation (meq/100 g) | 11.27 | 12.88 | 13.95 |
| Na⁺ | 7.89 | 7.63 | 7.49 |
| ESP (%) | 55.03 (high) | 64.08 (high) | 71.06 (high) | Lamond and Whitney (1992) |
| Soluble cations (meq/l) | 307.5 | 324.36 | 345.33 |
| Na⁺ | 77.6 | 76.19 | 74.93 |
| Ca²⁺ + Mg²⁺ | 49.37 (high) | 52.55 (high) | 56.42 (high) | Lamond and Whitney (1992) |
| SAR | 20 (extreme saline) | 16.4 (extreme saline) | 11.49 (highly saline) | Lamond and Whitney (1992) |
| ECe (dS m⁻¹) | 8.5 (strongly alkaline) | 8.65 (strongly alkaline) | 8.77 (strongly alkaline) | Tekalign Mamo (1991) |

Based on ECe, pHe, SAR, and ESP values, the Golina-Adisalem salt-affected experimental field has characterized as “saline-sodic” (Horneck et al., 2007; USSLS, 1954).
Table 4. 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             |

Figure 2. Infiltration (intake) vs. time.

Figure 3. Cumulative infiltration vs. cumulative time.
2 and Figures 3). 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 restores soil aggregates, water and air permeability due to the decreased of surface crusting resulted in increases of infiltration rate (Abou-Youssef, 2001; Chi et al., 2012; Clark et al., 2007; Kumar & Thiyageshwari, 2018; Yu et al., 2014b). Moreover, M. Ahmad et al. (2001), M.A. El-Fattah (2006), and M.K.A. El-Fattah (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).

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 criteria, 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.

3.5. Effects of gypsum amendment and ameliorative grasses on soil salinity

3.5.1. Soil reaction (pHe)

The ANOVA table showed that the soil pH in all layers was 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.

After the first and second harvests, all treatment exhibits a sharp falling trend of pHe in all soil columns compared with the corresponded control treatment (Table 5). In the non-plant gypsum treatments, the soil pH decreased as the amount of gypsum increased. This study inline with M. Ahmad et al. (2001), M.A. El-Fattah (2006), and M.K.A. El-Fattah (2011) reported that pHe decreased with gypsum application. Moreover, Singh and Bajwa (1991) and Khalifa et al. (1994) reported that applied excessive gypsum for reclamation was a quick reduction in pHe.

The non-gypsum grass treatments showed statistically similar in pHe reduction efficiency (Panicum grass = Rhodes grass). The decrease in pHe by Chlorosis Guayana (Rhodes grass) and Cynodo Dactyylon (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 (N. Ahmad et al., 1990; Qadir et al., 2003).
The efficiency among the two single-used factors, 125% G was highly decreased soil pH\textsubscript{e} 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 was 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.

Regardless of the amendments used, a more pronounced decrease of soil pH\textsubscript{e} 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 was substantially decreased pH\textsubscript{e} values all over other treatments in all soil layers (Table 5). A study in agreement with Swap (2004) and M.K.A. 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.

| Table 5: Effect of gypsum and halophytic grasses on soil pH\textsubscript{e} |
|---|
| **Soil pH\textsubscript{e} in the three layers** |
| Depth (cm) | After first harvest | After second harvest | After first harvest | After second harvest | After first harvest | After second harvest |
|---|---|---|---|---|---|---|
| 0–20 | G levels | O H | PG | RG | O H | PG | RG | O H | PG | RG | O H | PG | RG |
| 0% | 8.52 \(\text{f}\) | 7.83 \(\text{a}\) | 7.85 \(\text{a}\) | 8.54 \(\text{f}\) | 7.70 \(\text{a}\) | 7.70 \(\text{a}\) | | | | | | | |
| 75% | 7.76 \(\text{a}\) | 7.65 \(\text{a}\) | 7.65 \(\text{bc}\) | 7.70 \(\text{a}\) | 7.47 \(\text{c}\) | 7.47 \(\text{c}\) | | | | | | | |
| 100% | 7.72 \(\text{a}\) | 7.59 \(\text{b}\) | 7.6 \(\text{bc}\) | 7.62 \(\text{a}\) | 7.36 \(\text{a}\) | 7.36 \(\text{a}\) | | | | | | | |
| 125% | 7.61 \(\text{c}\) | 7.42 \(\text{a}\) | 7.42 \(\text{a}\) | 7.52 \(\text{c}\) | 7.24 \(\text{a}\) | 7.23 \(\text{a}\) | | | | | | | |
| SE(\(\pm\)) | | | | | | | | 0.02 | | | 0.03 | | | |
| LSD | | | | 0.05 | | | | | 0.06 | | | | |
| CV (%) | | | | 0.38 | | | | | 0.47 | | | | |
| 20–40 | G levels | O H | PG | RG | 0% | 8.59 \(\text{f}\) | 7.85 \(\text{cd}\) | 7.85 \(\text{cd}\) | 8.66 \(\text{f}\) | 7.61 \(\text{c}\) | 7.61 \(\text{c}\) | | | | | | |
| 75% | 8.15 \(\text{e}\) | 7.74 \(\text{a}\) | 7.76 \(\text{cd}\) | 8.01 \(\text{e}\) | 7.50 \(\text{d}\) | 7.51 \(\text{d}\) | | | | | | | |
| 100% | 8.07 \(\text{d}\) | 7.67 \(\text{a}\) | 7.67 \(\text{a}\) | 7.93 \(\text{a}\) | 7.43 \(\text{b}\) | 7.44 \(\text{b}\) | | | | | | | |
| 125% | 7.88 \(\text{a}\) | 7.53 \(\text{a}\) | 7.53 \(\text{a}\) | 7.75 \(\text{a}\) | 7.28 \(\text{a}\) | 7.29 \(\text{a}\) | | | | | | | |
| SE(\(\pm\)) | | | | 0.05 | | | | | 0.036 | | | | |
| LSD | | | | 0.10 | | | | | 0.075 | | | | |
| CV (%) | | | | 0.78 | | | | | 0.58 | | | | |
| 40–60 | G levels | O H | PG | RG | 0% | 8.75 \(\text{h}\) | 7.91 \(\text{a}\) | 7.94 \(\text{a}\) | 8.77 \(\text{h}\) | 7.81 \(\text{e}\) | 7.83 \(\text{e}\) | | | | | | |
| 75% | 8.38 \(\text{g}\) | 7.84 \(\text{c}\) | 7.8 \(\text{c}\) | 8.34 \(\text{g}\) | 7.73 \(\text{c}\) | 7.70 \(\text{c}\) | | | | | | | |
| 100% | 8.28 \(\text{f}\) | 7.70 \(\text{c}\) | 7.71 \(\text{b}\) | 8.26 \(\text{f}\) | 7.61 \(\text{b}\) | 7.60 \(\text{b}\) | | | | | | | |
| 125% | 8.22 \(\text{e}\) | 7.63 \(\text{a}\) | 7.63 \(\text{a}\) | 8.19 \(\text{e}\) | 7.51 \(\text{a}\) | 7.51 \(\text{a}\) | | | | | | | |
| SE(\(\pm\)) | | | | 0.02 | | | | | 0.02 | | | | |
| LSD | | | | 0.05 | | | | | 0.05 | | | | |
| CV (%) | | | | 0.36 | | | | | 0.35 | | | | |

Mean \pm SE; SE: standard error; O H: no halophytic grass 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.
3.5.2. Electrical conductivity (ECe)
From the analysis of variance showed that 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 harvests, all treatment showed a decreased trend of ECe in all soil layers compared with the control treatment (Table 6). The salt removal efficiency between the two grasses was statistically similar (Panicum grass = Rhodes grass). Both Panicum (Cynodon Dactylon) and Rhodes (Chlorasis Guayana) 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 & Masaoka, 2008; Kobayashi et al., 2007; OI et al., 2013, 2012).

As the rate of gypsum application increases, the ECe also decreased (Table 6). 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

| Table 6. 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 | 0 H | PG | RG | 0 H | PG | RG |
| 0–20 | 0% | 19.92 \( ^{b} \) | 14.9 \( ^{g} \) | 14.59 \( ^{g} \) | 20.1 \( ^{b} \) | 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 \( ^{a} \) | 7.2 \( ^{b} \) | 7.17 \( ^{b} \) | 10.39 \( ^{a} \) | 6.38 \( ^{b} \) | 6.33 \( ^{b} \) |
| | 125% | 9.11 \( ^{a} \) | 5.55 \( ^{a} \) | 6.00 \( ^{a} \) | 8.73 \( ^{a} \) | 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 | 0 H | PG | RG | 0 H | PG | RG |
| 20–40 | 0% | 16.22 \( ^{f} \) | 8.32 \( ^{a} \) | 8.24 \( ^{a} \) | 16.31 \( ^{f} \) | 7.38 \( ^{a} \) | 7.38 \( ^{a} \) |
| | 75% | 11.48 \( ^{a} \) | 7.42 \( ^{d} \) | 7.41 \( ^{c} \) | 10.75 \( ^{a} \) | 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 |

| **40–60** | **G levels** | 0 H | PG | RG | 0 H | PG | RG |
|---|---|---|---|---|---|---|---|
| | 0 | 11.36 \( ^{f} \) | 8.06 \( ^{a} \) | 8.04 \( ^{a} \) | 11.40 \( ^{f} \) | 7.62 \( ^{d} \) | 7.63 \( ^{d} \) |
| | 75% | 10.79 \( ^{f} \) | 7.14 \( ^{a} \) | 6.97 \( ^{c} \) | 10.09 \( ^{f} \) | 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 |

Mean ± SE; SE: standard error; 0 H: no halophyte 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.
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 M. Ahmad et al. (2001), M.A. El-Fattah (2006), and M.K.A. El-Fattah (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 (N. Ahmad et al., 1990; Qadir et al., 2003, 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 Panicum and Rhodes grasses were more progressively decreases the ECe than other treatments.

Based on the rating criteria established by Lamond and Whitney (1992), 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) 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. The efficiency of treatments was 125% G with Panicum grass = 125% G with Rhodes grass and significantly higher all over other treatments (Table 6).

3.6. Effects of gypsum amendment and ameliorative grasses on soil sodicity

3.6.1. Sodium adsorption ratio (SAR)

The analysis of variance 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 harvests, the SAR values in the three soil columns decreased by the application of single and combined amendments compared with the control treatment (Table 7). 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 7). The study in line with M. Ahmad et al. (2001), M.A. El-Fattah (2006), and M.K.A. El-Fattah (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 (Chi et al., 2012; Clark et al., 2007).

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 Na₂SO₄ form; this might be resolified 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
Table 7. 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 |
|-----------------------------|------------|---------------------|----------------------|
|                             | 0–20       | 20–40               | 40–60                |
| G levels                    |            |                     |                      |
|                             | 0 H        | PG                  | RG                   | 0 H        | PG                  | RG                   |
|                             | 0%         | 49.74 h             | 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              |
|                             | 100%       | 31.12 f             | 16.73 b             | 16.98 b     | 28.21 f             | 14.14 b              |
|                             | 125%       | 24.82 e             | 13.82 a             | 13.66 a     | 22.06 e             | 11.19 a              |
| SE(±)                       |            | 0.05                | 0.14                |            |                     |
| LSD                         |            | 0.10                | 0.28                |            |                     |
| CV (%)                      |            | 0.77                | 2.44                |            |                     |
|                             |            |                     |                      |
|                             | 0 H        | PG                  | RG                   | 0 H        | PG                  | RG                   |
|                             | 0%         | 53.64 g             | 27.21 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              |
|                             | 100%       | 34.53 e             | 19.26 h             | 19.54 b     | 30.67 f             | 19.74 b              |
|                             | 125%       | 27.51 d             | 15.90 h             | 15.70 a     | 25.64 e             | 16.10 a              |
| SE(±)                       |            | 0.05                | 0.37                |            |                     |
| LSD                         |            | 0.11                | 0.76                |            |                     |
| CV (%)                      |            | 0.76                | 1.72                |            |                     |

Mean ± SE; SE: standard error; 0 H: no halophytic plantation; RG: Rhodes grass; PG: Panicum 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.

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 (Ammari et al., 2008; S.A. Ahmad et al., 2006; Qadir & Schubert, 2002; Qadir et al., 2001). 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).

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 (Chlorosis Guayana) 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 7). Panicum grass (Cynodo Dactylon) with 125% G has exhibited a similar SAR reduction trend of 77.67%, 70.31, and
Table 8. 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     | 0 H | PG | RG | 0 H | PG | RG |
| 0–20         |     |    |    |     |    |    |
| 0%G          | 56.64 <sup>g</sup> | 45.29 <sup>f</sup> | 44.54 <sup>f</sup> | 57.37 <sup>j</sup> | 39.99 <sup>h</sup> | 38.60 <sup>h</sup> |
| 75%G         | 39.56 <sup>e</sup> | 26.71 <sup>c</sup> | 25.97 <sup>c</sup> | 36.88 <sup>g</sup> | 18.59 <sup>d</sup> | 17.63 <sup>c</sup> |
| 100%G        | 31.64 <sup>d</sup> | 17.96 <sup>b</sup> | 17.41 <sup>b</sup> | 27.97 <sup>f</sup> | 13.73 <sup>b</sup> | 13.55 <sup>b</sup> |
| 125%G        | 26.06 <sup>c</sup> | 11.99 <sup>a</sup> | 12.41 <sup>a</sup> | 22.23 <sup>e</sup> | 8.94 <sup>d</sup> | 8.93 <sup>d</sup> |
| SE(±)        |     |    |    |     |    |    |
| 1.17         |     |    |    |     |    |    |
| CV (%)       |     |    |    |     |    |    |
| 2.33         |     |    |    |     |    |    |
| After first harvest | After second harvest |
| 20–40         |     |    |    |     |    |    |
| 0%G          | 65.47 <sup>i</sup> | 53.48 <sup>h</sup> | 52.33 <sup>g</sup> | 66.22 <sup>h</sup> | 50.1 <sup>g</sup> | 50.35 <sup>g</sup> |
| 75%G         | 44.50 <sup>f</sup> | 31.55 <sup>d</sup> | 30.59 <sup>c</sup> | 40.63 <sup>f</sup> | 22.62 <sup>c</sup> | 22.98 <sup>c</sup> |
| 100%G        | 39.06 <sup>e</sup> | 22.97 <sup>b</sup> | 22.43 <sup>b</sup> | 36.26 <sup>g</sup> | 14.90 <sup>b</sup> | 14.78 <sup>b</sup> |
| 125%G        | 30.39 <sup>c</sup> | 14.86 <sup>a</sup> | 14.76 <sup>a</sup> | 26.00 <sup>e</sup> | 9.14 <sup>a</sup> | 8.66 <sup>a</sup> |
| SE(±)        |     |    |    |     |    |    |
| 0.26         |     |    |    |     |    |    |
| LSD          |     |    |    |     |    |    |
| 0.54         |     |    |    |     |    |    |
| CV (%)       |     |    |    |     |    |    |
| 0.91         |     |    |    |     |    |    |
| 40–60         |     |    |    |     |    |    |
| 0%G          | 72.10 <sup>i</sup> | 57.76 <sup>f</sup> | 57.00 <sup>e</sup> | 72.26 <sup>i</sup> | 50.81 <sup>e</sup> | 49.83 <sup>d</sup> |
| 75%G         | 63.55 <sup>h</sup> | 35.14 <sup>d</sup> | 34.86 <sup>d</sup> | 58.66 <sup>h</sup> | 25.58 <sup>c</sup> | 25.33 <sup>c</sup> |
| 100%G        | 60.84 <sup>g</sup> | 26.32 <sup>c</sup> | 25.69 <sup>c</sup> | 55.73 <sup>g</sup> | 17.27 <sup>b</sup> | 17.19 <sup>b</sup> |
| 125%G        | 56.74 <sup>e</sup> | 17.12 <sup>a</sup> | 16.85 <sup>a</sup> | 51.99 <sup>f</sup> | 9.69 <sup>c</sup> | 9.47 <sup>c</sup> |
| SE(±)        |     |    |    |     |    |    |
| 0.22         |     |    |    |     |    |    |
| LSD          |     |    |    |     |    |    |
| 0.46         |     |    |    |     |    |    |
| CV (%)       |     |    |    |     |    |    |
| 0.63         |     |    |    |     |    |    |

Mean ± SE; SE: standard error; 0 H: no halophytic plantation; PG: Rhodes grass; RG: 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.

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 (Abdel-Fattah, 2012; S.A. Ahmad et al., 2006; M.K.A. El-Fattah, 2011; Ghafoor et al., 2012; Ilyas et al., 1997; Salim et al., 2002; Swarp, 2004).

Based on the criteria proposed by Lamond and Whitney (1992), the SAR values of the first (0–20 cm) soil layers changed from “highly alkaline” to medium alkaline using those treatments.

3.6.2. 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.

After the first and second harvests, all treatments highly significantly reduced ESP (Table 8). 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 (Table 8). 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 (Abou-Youssef, 2001; M. Ahmad et al., 2001; Chi et al., 2012; Clark et al., 2007; M.A. El-Fattah, 2006; M.K.A. El-Fattah, 2011; Khalifa et al., 1994; Kumar & Thiyageshwar, 2018; Maria et al., 2018; Singh & Bajwa, 1991; Solaimalai et al., 2001).

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), M.K.A. 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 was, “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 of 125% G with Panikum and Rhodes grasses substantially decreases ESP values in all soil layers. Rhodes grass with 125 % G applied 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.

4. Conclusion and recommendation

4.1. 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 (Cynodon Dactylon) and Rhodes grasses (Chlorosis Guayana) 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) enhance infiltration rates of the saline-sodic soil contrasted with other treatments. Furthermore, 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.

4.2. Recommendation
The present study suggested that for the Golina-Adisalem saline-sodic field combined application 125% (2.5 t/ha) gypsum requirement with Panicum (Cynodon Dactylon) and Rhodes grasses (Chlorosis Guayana) were the most efficient treatment with respect to a better decreased pHe,
ECe, SAR, and ESP, and it enhances soil infiltration rate. 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, which needs further research by increasing gypsum rates higher than 2.5 t/ha.

- Detail water table dynamics in time and space should be monitored to operationalized subsurface drainage.

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Contributions
Sisay Dessale Abate performed the experiments; collected, analysed, and interpreted the data; and wrote the manuscript. Moltate Zewdie Belayneh advised valuable comments and edited the paper throughout the manuscript work. Fantaw Abegaz Ahmed provided a guidance for laboratory data management and gave comments for detailed structure and coherency of the manuscript.

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