Effect of Application of Farmyard Manure and Gypsum on Saline Sodic Soils of Raya Alamata District, Northern Ethiopia

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Abstract
A field experiment was conducted in Raya Alamata district, northern Ethiopia to investigate the effect of sole and combined application of FYM and gypsum on saline sodic soils on yield of sorghum by supplying different rates of farmyard manure (FYM) and/or gypsum (CaSO4.2H2O) application alone or both mixtures using a randomized complete block design for three consecutive years. The treatment used included: control, three FYM rates alone, two gypsum rates alone and six combination of FYM and gypsum with a total of 12 treatments. Each treatment was replicated three times to yield 36 experimental plots. The result indicated that, there was no significant difference between treatments in the first and second year of cropping season. However, the effect the amendments were shown in the third year of the cropping season, and hence, the treatment effect of the combined application of FYM and gypsum were more effective and improved soil properties and increased the yield of sorghum. In addition, compared to all other treatments, the combined application of 4 tha^{-1} FYM + 100% GR followed by 8 tha^{-1} FYM + 100% GR resulted the highest grain yield of sorghum and reduced the sodium induced hazards than all other treatments. Hence, it is recommended as the best treatment in the improvement of saline sodic soils of the district.
Keywords: Gypsum; Farmyard manure; Sorghum; Soil amendment; Soil properties
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1. Introduction

Salt affected soils are characterized by excessively high levels of water-soluble salts, including sodium chloride, sodium sulfate, calcium chloride and magnesium chloride (Suriyan *etal*.,2011). Saline sodic soils are a major environmental issue and a great concern in the modern world as they significantly limit plant growth and development (Qadir *et al.,* 2008; Sadiq *et al.,* 2007). Saline sodic soils are containing both excessive quantities of soluble salts and exchangeable Na and interfere with the growth and production of most crop plants (USSLS, 1954). These soils form as a result of the combined processes of salinization and alkalization. Such accumulation of salts in the soils may alter its physical and chemical properties, including soil structure and hydraulic conductivity (Birhane, 2018; Mullins *et al*., 1990). If attempts are made to leach out the soluble salts of saline-sodic soils with good quality irrigation water, the exchangeable Na levels and also pH would increase and, therefore, the soil would change to adverse characteristics of sodic soils. Therefore, attention must first be given to reducing the levels of exchangeable Na and then to the problem of excess soluble salts (Cheraghi *et al*., 2006).

There are many procedures that can be used to improve salt affected soils, such as, water leaching, chemical remediation and phytoremediation. The remediation of saline sodic soil using gypsum (CaSO4 2H2O) and farmyard manure (FYM) is a fruitful topic of investigation, being low cost, effective and simple to implement (Makoi and Verplancke, 2010). The physical, chemical and biological properties of salt affected soils are improved by the application of gypsum and/or FYM as remediation for sustainable land usage and crop productivity, leading to enhanced plant growth and development (Suriyan *etal*., 2011). Different findings (FAO,1988; Makoi and Ndakidemi, 2007) showed that, a combination of FYM and gypsum on saline sodic soils was found to be most important on improving cereal yields and effective tools for maintaining soil productivity. The concentration of exchangeable Na, which was an indicator of sodic soil in raya Alamata district was higher in the soil and hence, continuous assessment and monitoring should be implemented to avoid the occurrence of soil sodicity and selection of suitable plants that can tolerate soil salinity/sodicity in necessary (Birhane *et al*., 2019).

In Ethiopia sorghum is grown in almost all regions occupying an estimated total land area of 1.83 million ha and its national average productivity of 2.37 tha^{-1} (CSA, 2015). However, the productivity of sorghum is low due to biotic and edaphic factors affecting directly and indirectly (Tekle and Zemach, 2014). Hence, the aim of the present study was to investigate the effect of sole and combined application of FYM and gypsum on saline sodic soils on yield of sorghum and to remediate saline sodic soil using gypsum and/or farmyard manure.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Location

The study was conducted at Raya Alamata district in southern zone of Tigray, Regional State, northern Ethiopia.

It is located 600 Km north of Addis Ababa and about 182 Km south of Mekelle, the capital city of the National Regional State of Tigray. Geographically, the experimental site is located between 12°25' to 12°55'N latitude and 39°33'to 39°53'E longitude with an altitude of 1522 meters above sea level. From the hydrological point of view, the site is located within the Afar drainage basin.

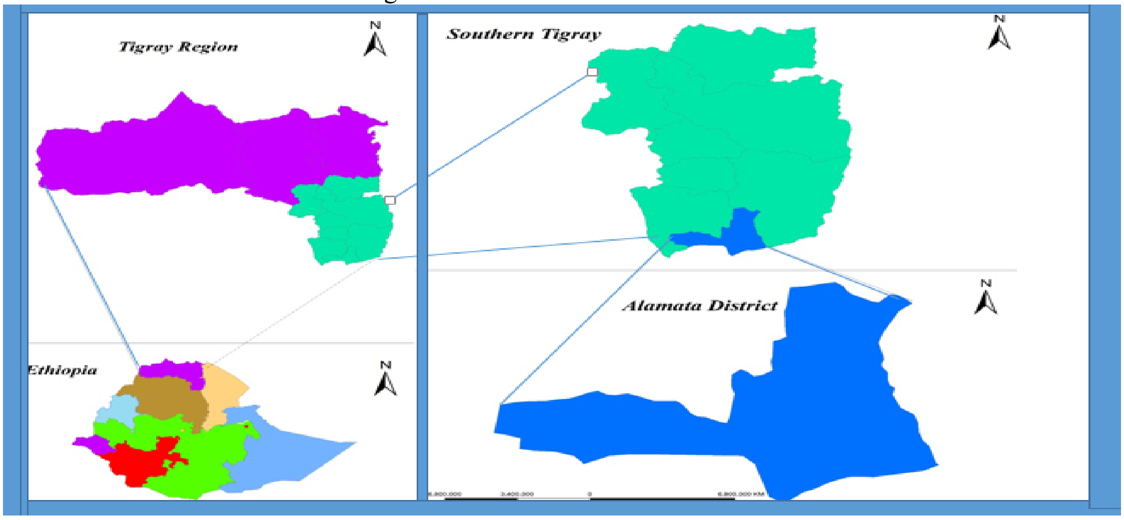

Figure 1. Location map of the district area.

2.1.2. Climate

The district is characterized as semi-arid climate region. The mean monthly minimum and maximum temperatures during the study period were 14.34 ºC and 30.04 ºC, respectively. The district has also unevenly distributed and erratic annual rainfall amount which ranges between 450 and 600 mm with most of the rain falling in July – August. Hence, recurrent drought and long dry spell, especially in the main season. The combined effect of high temperature and strong solar radiation caused the potential evapotranspiration to be very high and significantly exceeds the rainfall in all months (RVLZ, 2007).

2.1.3. Soil and hydrogeology

The major soil types found in the district are Cambisols, Fluvisols, Leptosols and Vertisols. Soil distribution follows the landscape configuration, where on the level land plain Vertisols and Fluvisols are the dominant and found extensively in farmlands (Amanuel *et al.,* 2015). The valley of the study area is a flat plain dominated by deep to very deep undifferentiated alluvial, lacustrine and beach sediments. The valley floor is bounded on both west and the east directions characterized by highly fractured and weathered basaltic rocks, alkaline and transitional basalt flows mainly Ashange basalt (Nata *et al.*, 2015). A groundwater resource is believed to be the huge water resource in the area. The dominant groundwater flow directions are north-south and west-east. The depth of groundwater varies from about 20 m in Waja and 60 m in Adis-Kigni (south) areas in the northern part of the project area. The quaternary sediments vary widely in grain size and dominantly deposited as fluvial processes (Tenalem *et al.*, 2013).

2.2. Soil Samples collection and Laboratory Analysis

Soil samples from the surface (0-30cm) were collected before the application of the amendments. Similarly, samples were collected after the application of the treatments from each experimental plots using auger in each cropping season for the determination of selected soil salinity/sodicity indicators. The collected soil samples were analyzed using the proper laboratory procedures.

2.3. Experimental Design, Treatment Combinations and Agronomic Operations

The experiment consisted of two factor amendments involving two gypsum rates (50% GR and 100% GR), three rates of FYM (4 tha^{-1}**,** 6 tha^{-1} and 8 tha^{-1}), and farmer practice as a control treatment were used (Table 1).

Table 1. Treatment combinations of the experiment

Treatments	Treatment combinations
Treatment 1	Control
Treatment 2	50% GR
Treatment 3	100% GR
Treatments 4	4 tha^{-1} FYM
Treatment 5	4 tha^{-1} FYM +50% GR
Treatment 6	4 tha^{-1} FYM +100% GR
Treatment 7	6 tha^{-1} FYM
Treatment 8	6 tha^{-1} FYM +50% GR
Treatment 9	6 tha^{-1} FYM +100% GR
Treatment 10	8 tha^{-1} FYM
Treatment 11	8 tha^{-1} FYM +50% GR
Treatment 12	8 tha^{-1} FYM +100% GR

GR = Gypsum requirement; FYM = Farm yard manure, tha^{-1} = ton per hectare.

Gypsum was calculated according to the soil test value of gypsum requirement. Farmyard manure and gypsum alone and in various combinations were applied to the soil well before planting so as mix with the soil. Each treatment replicated three times to yield 36 experimental plots, assigned in randomized complete block design (RCBD). Sorghum (*Sorghum bicolor* **L.**) (Meko) variety was planted as a test crop by early June for three consecutive cropping seasons. Except the experimental treatment differences all the necessary management activities were carried out uniformly to all experimental plots. Finally when the crop was fully matured sorghum yields were harvested and trashed after the harvesting period and yield of sorghum was measured.

2.4. Data collection and Statistical Analysis

The collected data were analyzed using Statistical Analysis System (SAS) software version 9.1. Analysis of variance (*ANOVA*) was assayed. Mean differences were also tested using Fisher's Protected LSD test at $P \leq 5\%$ level**.**

3. RESULTS AND DISCUSSIONS

3.1. Selected chemical characteristics of soils prior to the application of treatments

Soil samples were collected before the application of treatments and were analyzed in the laboratory for their selected soil salinity/sodicity indicators. Analytical results of soil reaction (pHe), electrical conductivity of the saturation paste extract (ECe), exchangeable cations and exchangeable sodium percentage (ESP) were used as important parameters to explain salinity/sodicity characteristics of the soils. Three classes of salt affected soils were defined based on their chemical properties, accounting for changes in ECe, pHe and ESP. Accordingly, a threshold value of 4 dS m^{-1} ECe was used to differentiate between saline and non-saline soils. Similarly, a threshold value 15 % for ESP and 8.5 for pHe were used as criteria for grouping the soils in to different classes of salt affected soils (USSLS, 1954). Accordingly, the experimental site was classified as saline sodic soil (Table 2).

Table 2. Selected soil chemical characteristics prior to the application of treatments

	Soil parameters						
Values	pHe	ECe	Ca + Mg	Na	K	ESP (%)	CEC (cmol (+) kg^{1})
			(cmol (+) kg^{1})				
	8.53	4.18	39.96	9.89	0.99	20.16	49.06

pHe= soil reaction, ECe= soil electrical conductivity, ESP= exchangeable sodium percentage, CEC= cation exchange capacity.

3.2. Effect of FYM and Gypsum on Yield and Yield Components of Sorghum

The statistical analysis of the first and second year data showed non-significant difference in all yield and yield components of sorghum. This showed that, all the amendments used either applied singly or in combination have not considerably increased the yield and yield attributes of sorghum. Indeed, this revealed that, the effect of treatments were not significantly effective in maintaining soil physical and chemical properties better than that of the control. The relatively no response of sorghum to FYM application may be attributed to its slow release of nutrients which decomposes over time (Haq *et al. 2001*) and that of gypsum to its low solubility (Ghafoor & Muhammad, 1990). The decomposition of FYM was further aggravated due to dry spell prevailed during most part of the crop season (Haq *et al. 2001*).

In contrary to the first and second year, the treatment effect of the applied FYM and gypsum were more effective and decreased the adverse effects of sodium and exchangeable sodium percentage in the third year and showed significant difference ($P \leq 0.05$) on panicle length, biomass yield and grain yield. This response may be attributed to release of nutrients from FYM through decomposition and due to solubility of gypsum over the three years. Accordingly, the combined treatment of 4 t ha^{-1} FYM + 100% GR followed by 8 t ha^{-1} FYM + 100% GR had responded the highest sorghum grain yield (48.25 and 47.28 qt ha^{-1}) respectively, compared to all other treatments specifically in the third year cropping season. On the other hand, the control treatment (without treatment with gypsum and FYM), had week effect and resulted in lowest (24.56 qt ha^{-1}) grain yield (Table 3). It is evident from the data that, the amendments applied in combination have considerably increased the yield of sorghum compared to the sole application of FYM and gypsum.

Table 3. Third year yield and yield component results

Treatments	DE	SC	DH	MD	PH (cm)	PL(cm)	By (qt ha^{-1})	Gy (qt ha^{-1})
Control	10	47	66	115	151	23	74.53	24.56
50% GR	9	54	67	120	158	24	94.90	32.20
100% GR	10	48	67	120	155	22	100.27	34.58
4 tha^{-1} FYM	9	51	69	125	154	24	98.43	34.25
4 tha^{-1} FYM +50% GR	8	52	67	122	158	22	105.11	38.04
4 tha^{-1} FYM +100% GR	8	48	67	133	158	29	153.81	48.25
6 tha^{-1} FYM	8	49	70	134	153	22	102.64	35.11
6 tha^{-1} FYM +50% GR	8	50	67	120	153	22	152.84	45.88
6 tha^{-1} FYM +100% GR	9	48	68	126	149	25	172.43	47.17
8 tha^{-1} FYM	7	51	68	118	157	22	162.84	44.80
8 tha^{-1} FYM +50% GR	10	47	68	121	155	24	172.86	46.74
8 tha^{-1} FYM +100% GR	9	51	60	125	157	27	177.38	47.28
LSD<0.05	NS	NS	NS	NS	NS	1.87	4.68	1.30
CV %	19.05	9.47	2.49	8.48	3.22	4.79	2.11	1.92

DE = Days to emergency, SC = Stand count, DH= Days to heading, MD = Maturity date, PL = panicle length, PH = Plant height, By = Biomass yield and Gy = Grain yield, qt ha^{-1} = quintal per hectare, NS= no significance, LSD= least significant difference, CV= coefficient of variance.

Results recorded from the three consecutive years of combined analysis showed that, there were statistically significant difference among the treatments for the major parameters of both biomass yield and grain yield. Compared to all the other treatments considering the agronomic data 8 tha^{-1} FYM +100% GR followed by 4 tha^{-1} FYM +100% GR resulted the highest biomass as well as grain yield of sorghum (Table 4). However, considering the amount of FYM which was applied within the difference of 4 tha^{-1}, had its own value of economic analysis even if the value of FYM was not measured in terms of Ethiopian birr (ETB) and FYM is not easily accessible to the farmers of the district. In addition to this, 4 tha^{-1} FYM+ 100% GR was by far lowered (best amendment) the value of sodium and exchangeable sodium percentage compared to 8 tha^{-1} FYM+ 100% GR (Table 4). These results suggested that combined amendments of FYM and gypsum treatment were superior to all other treatments in their effect on increased sorghum yield and effectively remedy the saline sodic soil condition.

It is evident from the data that, the amendments applied in combination have considerably increased the yield of sorghum compared to the sole application of FYM and gypsum. Of all the treatments, combined application of the two amendments i.e. FYM @ 4 t ha^{-1} + gypsum @ 100% of GR and FYM @ 8 t ha^{-1} + gypsum @ 100% of GR out yielded all others where 27.58% and 33.60% increase in yield over that of control were recorded respectively. This treatment was followed by a combination of FYM @ 8 t ha^{-1} + gypsum @ 100% of GR.

Table 4. Three years combined analysis results of yield and yield components

Treatments	DE	SC	DH	DM	PH (cm)	PL(cm)	By (qt ha^{-1})	Gy (qt ha^{-1})
Control	8	43	67	110	157	23	114.27	28.91
50% GR	9	43	68	115	157	24	114.16	34.34
100% GR	9	44	67	119	159	23	122.51	36.75
4 tha^{-1} FYM	8	42	68	120	158	24	122.23	36.84
4 tha^{-1} FYM +50% GR	8	45	68	119	160	23	129.42	35.61
4 tha^{-1} FYM +100% GR	8	42	68	129	160	26	146.89	39.92
6 tha^{-1} FYM	8	45	68	123	157	23	136.47	37.27
6 tha^{-1} FYM +50% GR	7	41	67	119	156	23	146.23	38.43
6 tha^{-1} FYM +100% GR	8	42	68	120	158	24	141.31	38.23
8 tha^{-1} FYM	7	39	68	113	158	23	146.42	37.47
8 tha^{-1} FYM +50% GR	9	43	67	120	162	23	147.24	41.58
8 tha^{-1} FYM +100% GR	9	45	65	120	161	25	161.68	**42.89**
LSD<0.05	NS	NS	NS	NS	NS	NS	6.38	2.43
CV %	7.27	4.21	5.46	11.18	10.54	4.79	5.18	2.35

DE = Days to emergency, SC = Stand count, DH= Days to heading, MD = Maturity date, PL = panicle length, PH = Plant height, By = Biomass yield and Gy = Grain yield, qt ha^{-1} = quintal per hectare, NS= no significance, LSD= least significant difference, CV= coefficient of variance.

The FYM @ 4 t ha^{-1} + gypsum @ 100% of GR yielded 28.33% and 29.02% more than the yield obtained from the separate application of gypsum @100% GR and FYM @4 tha^{-1} respectively. The results are in agreement with that of Tiwana *et al*. (1997) who reported that combined application of FYM and gypsum has significantly increased sugarcane yield. In addition, the present result showed that as general, individual applications of gypsum or FYM are ineffective compared to combined applications in remediating sodic soils for the production of sorghum. The result concurs with earlier results of (Amanullah, 2008; Suriyan *etal*., 2011; Makoi and Ndakidemi, 2007).

3.2. Effect of FYM and Gypsum on saline sodic soil characteristics

A significant change in soil pH was observed due to the combined application of FYM and gypsum. This showed that, the combination of the two amendments have considerably decreased soil pH value. It was lowered from 8.53 to 7. 71 by the combined application of 100% Gypsum + 4 tha^{-1} FYM and to 7.84 by the application of 100% gypsum + 8 tha^{-1} FYM respectively. The reduction in soil pH observed due to combined application of gypsum either with FYM was in agreement with earlier findings of Haynes and Naidu (1998) who reported reductions in soil pH due to combined application of gypsum with farmyard manure.

The combined application of FYM and gypsum lowered the value of exchangeable sodium and exchangeable sodium percentage of the soil. Accordingly, exchangeable sodium was decreased from the initial value of 9.89 to 7.19 at the combined application of FYM@ 4 tha^{-1} + gypsum@100% and to 7.24 at the combined application of FYM@ 8 tha^{-1} + gypsum@100% in the soil system (Table 5). ESP was reduced tremendously with the application of FYM, whereas it decreased slightly with other treatments. The best ameliorative response of gypsum compared to other treatments may be attributed to its rich calcium content which also help in the management of sodium saturated soils as reported by (Suriyan *etal*., 2011).

This may be due to the fact that gypsum provided Ca^{2+} to replace the sorbed Na^{+} and the manure would have further boosted the process by producing organic acids and CO_2 to dissolve native $CaCO_3$ to liberate more Ca^{2+} for replacement of Na^{+}. This is in line with the findings of Singh (1985) and Tiwari and Jain (1992). The combined application of FYM@ 4 tha^{-1} + gypsum@100% and FYM@ 8 tha^{-1} + gypsum @100% were also decreased the amount of exchangeable sodium percentage of the soil as compared to the other treatments (Table 5). Electrical conductivity of the soil was raised by gypsum application while decreased with other treatments. The highest EC was recorded in the treatment receiving sole application of gypsum @100% GR (Table 5). Increase in EC could be attributed to the higher amount of salts contributed by the inorganic NPS fertilizers which was uniformly added through soil application. The addition of organic amendments also influenced the electrical conductivity of soil. It was observed that the application of FYM was more effective than gypsum in reducing soil EC. This is in line with Singh *et al.* (2015).

Table 5. Effect of FYM and gypsum amendments on saline sodic soil characteristics

Treatments	**pHe**	**ECe**	**Ca+Mg**	**Na**	**K**	ESP (%)	CEC (cmol (+) kg^{1})
			(cmol (+) kg^{1})				
Control	8.53	4.20	42.21	9.87	1.02	20.10	49.12
50% GR	8.47	4.28	42.59	9.51	0.94	19.19	49.45
100% GR	8.17	4.34	43.15	9.42	0.88	18.45	51.01
4 tha^{-1} FYM	8.19	4.03	41.04	9.38	0.82	17.90	52.41
4 tha^{-1} FYM +50% GR	8.13	4.17	41.21	9.04	0.85	17.22	52.49
4 tha^{-1} FYM +100% GR	7.71	4.24	41.28	7.19	0.89	12.87	55.87
6 tha^{-1} FYM	8.13	3.84	41.18	9.33	0.97	18.30	51.00
6 tha^{-1} FYM +50% GR	8.13	4.18	41.27	9.02	0.85	17.20	52.49
6 tha^{-1} FYM +100% GR	8.07	4.20	42.07	7.84	0.94	14.76	53.13
8 tha^{-1} FYM	8.19	3.51	41.08	9.12	0.88	17.15	53.18
8 tha^{-1} FYM +50% GR	8.07	4.20	41.30	8.18	0.89	15.73	52.01
8 tha^{-1} FYM +100% GR	7.84	4.22	41.32	7.24	0.97	13.18	54.94
Mean	**8.14**	**4.11**	**41.64**	**8.76**	**0.91**	**16.84**	**52.26**

pHe= soil reaction, ECe= soil electrical conductivity, ESP= exchangeable sodium percentage, CEC= cation exchange capacity

The results of the present study showed that regardless of the grain yield and yield components of sorghum, the importance of the amendments to physical and chemical properties of the saline sodic soils tested were used. Accordingly, taking in to consideration to both the yield of sorghum and the value of the amendments to saline sodic characteristics, 4 tha^{-1} FYM +100% GR followed by 8 tha^{-1} FYM +100% GR were recommended for yield and yield component maximization and reclaiming of the saline sodic soils in Raya Alamata district.

4. Conclusion and Recommendation

Soil salinity/sodicity is an increasing problem in the world and main obstacle to agricultural productivity. The increasing distribution of salt affected soils in all continents minimizes the productivity of soil resources. Therefore, developing a strategy to amend those soils to attain food self-sufficiency and reverse ecological degradation for agricultural sector is mandatory. The findings confirmed that soil salinity/sodicity significantly limit crop production and the consequences are damaging in both socioeconomic and environmental terms. Therefore, combined application of farmyard manure with gypsum (4 tha^{-1} FYM +100% GR) followed by 8 tha^{-1} FYM +100% GR as amendment were the best compared to the others in improving of soil properties and yield and yield attribute of sorghum in saline sodic soils of Raya Alamata district. More beneficial influences were noticed by extending the applications to the last year of cropping system. However, the research was conducted for a specific site and hence, repeating the experiment in space and time is necessary so as to improve the validity of this finding and acceptance for agricultural producers.

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