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Impact of Gypsum and Filter Cake on Selected Physicochemical Properties of Saline-Sodic Soil of Amibara Area Central Rift Valley Ethiopia

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Abstract: Salinity and aridity are two interrelated problems rapidly expanding in Ethiopia, and soil with saline sodic property in Amibara irrigated farms threatens crop productivity. The purpose of the experiment is to evaluate saline-sodic soil using a combination of organic and inorganic amendments. A factorial experiment was laid out in Randomized Complete Block Design with three replications. A field experiment was conducted at the Werer Agricultural Research Center, to evaluate the ameliorative effects of gypsum and filter cake on saline-sodic soil. Composite surface soil samples before the experiment were collected, and after lab analysis, the soil gypsum requirement was calculated. After post-harvesting, plot-level samples were collected for laboratory analysis. The analysis result revealed that bulk density, total porosity, soil pH, exchangeable and soluble cations, and SAR (sodium absorption ratio) were reduced by the interaction of gypsum and filter cake ($P < 0.01$). The soil pH (7.76) was reduced 5.36% compared to control plots when plots treated with 75% gypsum requirement with 25 t ha^{-1} filter cakes. The interaction effect of gypsum with filter cake is also highly significant ($P < 0.01$) on wheat grain yield and biomass. An important conclusion is that the interaction of 75% gypsum with 25 t ha^{-1} filter cake can improve the physicochemical properties of saline-sodic soil.

Keywords: amelioration; exchangeable cations; salt-affected soil

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1. Introduction

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Soil salinity and sodicity are among the major land degradation problems in different parts of the world including Ethiopia (Abbas et al., 2023). According to Frew et al. (2015) in Ethiopia, soil salinity problems are increasing in all parts, and more expansion is seen in the central rift valley around the Afar region. The significant impacts of salinity are the agricultural land out of crop production (Ashenafi and Bobe, 2016; Melese et al., 2016). The identification, reclamation, and management of salt-affected soils are the main characteristics and guiding principles for using these soils for agricultural production. However, the process, scope, and speed of soil reclamation vary depending on the site due to variances in the soil, environment, water supply, farm management ability, financial capital, available inputs, and economic incentives. Different research has examined soil amendment enhancing the physicochemical parameters of saline-sodic soils (Cha-um and Kirdmane, 2011; Singh et al., 2016).

One of the materials used as an amendment to recover sodic soils is gypsum. The most emphasis has been paid to the relative effectiveness of gypsum because of its widespread usage as an amendment for the reclamation of saline-sodic soil due to its availability and low cost, albeit sluggish reaction (Ashenafi et al., 2019; Teshome, 2019; Kasahun et al., 2020). Various scientists are concentrating on employing organic materials as part of a bigger plan to utilize organic wastes in an environmentally acceptable manner and shield soils from further deterioration. The most frequent issue in dry and semi-arid soils is low organic matter content (Kasahun et al., 2020). Several Authors have also reported that benefits of using organic materials to remediate salt affected soils by improving their physical, chemical, and biological properties (Tejada et al., 2008).The addition of organic matter (OM) can accelerate the leaching of Na, decrease the ESP and electrical conductivity (EC), and increase water infiltration, water-holding capacity and aggregate stability (Tejada et al., 2008; Zaman et al., 2018).

Filter cake is one of the organic materials to amend saline sodic soil. It's the solids left after filtering the cane juice are often used as fertilizers on sugarcane farms. Therefore, organic matter and macro and micro nutrients is high in sugar industry press mud, its application improved the physicochemical characteristics of soil and also favorably influence the soil environment (kumar and Chopra, 2016; Kumar et al., 2017 ; Bethel et al., 2019). It has a substantial amount of trace minerals like Zn, Fe, Cu, and Mn, along with important plant nutrients like calcium, magnesium, phosphorus, potassium, and nitrogen (Ghulam et al., 2012; Dotaniya et al., 2016). The positive impact of this bio compost on enhancing soil fertility and crop productivity is widely established (Ghulam et al., 2012; Saleh et al., 2012; Kumar et al., 2018). 2019). Soil pH, ECe and ESP is considerable decreased with increasing of filter cake and gypsum singly and/or in combinations. Beneficial effects on physical and biological soil properties are also observed. Thus, due to its characteristics, filter cake can play a fundamental role in agricultural production in the maintenance of soil fertility and as a soil conditioner. Combined use of natural and inorganic amendment (gypsum) on saline-sodic soils helped in expanding and supporting yields and in further

developing soil wellbeing and useful capacity (Madejón et al., 2001; Tejada et al., 2006; Gedion, 2009; Clemente et al., 2012).

The area of agricultural land in Amibara is deeply affected by the problem of salt accumulation and important areas in the region are being converted into saline to saline-sodic soil at an alarming rate. This problem has adversely changed the physical, chemical, and biological conditions of the soil environment. The current farm lands approximately 2,000 hectares, which accounts for about 20% of the total area of the Amibara irrigation scheme area, has been abandoned. The ultimate cause for the occurrence of soil salinization in the area was identified to be shallow and poor-quality ground water, due to ineffective irrigation water application. The situation is reported to have been accelerated due to absence of effective drainage facilities (Heluf, 1985 ; Gedion , 2009).

The study area needs efficient and cost-effective crop production systems with appropriate management practices that minimize salinity impacts on soils and plant. Soil productive capacity and soil physicochemical properties can be improved by using organic byproducts (filter cake or press mud) and gypsum (Bethel et al., 2019 ; Kasahun et al., 2020). In Ethiopia different researchers Ashenafi et al.(2016) and Kasahun et al.(2020) have been working on saline-sodic soil reclamation using filter cake and gypsum, but not on the combination of filter cake and gypsum to reclaim saline-sodic soil. In Amibara area the research on the combined effect of filter cake and gypsum on reclamation of saline-sodic soils and on the yields of Wheat is scant. Thus, the study was initiated to investigate the effects of gypsum and filter cake on the physicochemical properties of saline-sodic soil at Amibara area, central rift valley, Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at Amibara District, located at 9°20'31" N latitude and 40°10'11" E longitude and the elevation is at about 740m. The climate is semiarid with a bimodal rainfall of 533 millimeters annually. The mean minimum and maximum temperatures are 19.0 and 34.8OC, respectively. The annual evapotranspiration rate of the Amibara district is 2829mm. The soils of the study area are predominantly Eutric Fluvents, order Fluvisols followed by Vertisols occupying about 30% of the total area (Wondimagegne and Abere, 2012). Generally, the widespread occurrence of salinity and sodicity problems in Amibara District farmlands is mainly due to the weathering of Na, Ca, Mg, and K-rich igneous rocks and poor irrigation water management (Heluf, 1985). There is also a deficiency of micronutrients Fe, Zn, and Mn which are needed to neutralize soil reaction (pH) but also minimum toxicity effect of B and Mo (Ashenafi et al., 2016). Most salinity and sodicity/alkalinity abandoned areas are covered by *Prosopis julifora*.

2.2. Soil Sampling and Preparation

Before sowing (composite soil samples) and after harvesting (plot level samples) were collected. Soil samples were taken at a depth of 0–30 cm using a soil auger and core sampler, depending on the variability of the soil.

2.3. Gypsum and filter cake application methods and chemical analysis

2.3.1. Determination of gypsum requirement

Gypsum purchased from the Yonatan Biti Gypsum Factory. A 2mm sieve was used to filter agricultural grade gypsum, which has an 80% purity level, to guarantee consistency and good solubility. A significant quantity of adsorbed sodium up to 15% or more on their exchange complex is a defining characteristic of saline-sodic soils. When applied appropriately in terms of size and quantity, gypsum ($CaSO_42H_2O$) is frequently utilized for the restoration of such soils. To lower the initial ESP, gypsum parameters (GR) for a 30 cm soil depth were measured (FAO, 2008). Zia (2006); and Yadav (2013) determined the amount of gypsum required per unit of land area of saline-sodic soils to replace exchangeable Na to attain the requisite sodicity.

$$GR = CEC * d * BD * 0.081(ESPi - ESPf)/f$$

where GR = Amount of gypsum required in t ha^{-1}, CEC = cation exchange capacity [cmol(+)/kg] of soil, d = Depth of soil (0.30 m) to be reclaimed and soil structure has to be improved, BD = Bulk density of soil (g cm-3), ESPi = Actual ESP of the soil, ESPf = Final ESP to be arrived at after reclamation (10%) and f = purity of gypsum applied (80%).

2.3.2. Filter cake chemical analysis and sources

Filter cake has beneficial effects on physical and biological soil properties are also observed. Thus, due to its characteristics, filter cake is one of the amendment materials to saline -sodic soil reclamation. Filter cake was applied in powder forms on 0-30cm soil depth. The source of the filter cake was collected Kesem Kebena Sugar Factory.

Table 1. Laboratory results of selected chemical properties of filter cake

Parameter	Units	Values
pH	---	7.57
EC	$ds.m^{-1}$	1.66
TOC	%	2.88
Av.P	mg/kg	17.94
Total Cations		
Ex Ca	cmol(+) kg^{-1}	19.84
Ex Mg	cmol(+) kg^{-1}	5.96
Ex Na	cmol(+) kg^{-1}	4.51
CEC	cmol(+) kg^{-1}	52.42
C: N	-	15.16
SAR		2.27
N	%	0.19
Soluble cations		
K	meq/l of water	4.5
Na	meq/l of water	5.69
Ca	meq/l of water	13.39
Mg	meq/l of water	6.1

Where, EC = (electric conductivity), C: N = (carbon to nitrogen ratio), CEC = (cation exchange capacity), Av.P = (available phosphorus), SAR = (sodium absorption ratio). TOC = (total organic carbon).

2.3.3 The combined application of gypsum and filter cake and application

Combined use of organic (filter cake) and inorganic amendment (gypsum) on saline-sodic soils helped in expanding and supporting yields and in further developing soil wellbeing and useful capacity (Madejón et al., 2001; Tejada et al., 2006). Addition of sugar cane by-products along with gypsum reduces the EC and ESP up to the great extents (Tejada et al., 2006; Scotti et al., 2015). After soil gypsum requirement calculation, three levels of gypsum (0%,25%,50% and 75%) calculated from 100% soil gypsum requirements, its combine with five levels of filter cake application (0,10,15,20, and 25 ton/ha). Before application Filter cake was crushed using hand tool materials. The powder forms of filter cake combine with gypsum was applied in the soil. Hand tools were utilized to incorporate gypsum and filter cake into the soil. Following a month-long treatment application, the Ga'ambo variety of bread wheat was seeded. Awash River was the source of irrigation water, was obtained through furrow irrigation methods, water applied in ten (10) day interval (The experimental site was arid area) in full doze soil water requirement. Monitory and Evaluation of River Water Quality Status for Irrigation result was indicated the properties of irrigated water were not significant impacts on the soil chemical properties (it is recommended to irrigation).

2.4. Crop planting (Wheat (Ga,ambo variety) and Management

Wheat crop by its nature needs more water for a better production therefore, unless proper measurement and soil reclamation technologies applied as early as possible, soil salinity problem cannot divert easily after once it reached at a maximum level of toxicity especially sodic soil cannot be reclaimed easily. The experiment taste crop was Wheat one of the salt resistance varieties. Weeding was done following recommend practices for weeds control at the experimental station and hoeing was carried out on a weekly basis, and all cultural practices were the same for all treatments.

2.5. Experimental Design and Treatments

Three replications and a factorial combination of two factors were employed in the Randomized Complete Block Design (RCBD). Factor one was gypsum, with four levels computed from 100% gypsum requirement: 0% (control), 25%, 50%, and 75% (GR). Factor two was filter cake (FC), with five levels: 0 (FC0), 10 (FC10), 15 (FC15), 20 (FC20), and 25 (FC25) t ha $^{-1}$. To achieve a fine till, the experimental area was disc-ploughed and harrowed two times by a tractor. Clods were broken during tilling process and the residue of the previous crop was removed. It was leveled and divided into 60 experimental plots and each gross plot has 3 m x 3 m size with a spacing of 3.60m between blocks and 2m between plots. Gypsum and filter cake were applied in one time (full doze) on each ridge (30cm soil depth) of the experimental plot and it was mixed using hand tools. The treatments applied in dry soil condition and applied irrigation water in full doze, however after one

month treatment application wheat seeds were sowing. The experiment was done in winter season (in Ethiopia dry season there is not rain water) and the source of water was irrigation.

Table 2. List of Treatment Combinations

Treatment Code	Treatment Combination	Description
1	Control	Control
2	GY0%FC10	0% Gypsum with 10 t ha^{-1} Filter cake
3	GY0%FC15	0% Gypsum with 15 t ha^{-1} Filter cake
4	GY0%FC20	0% Gypsum with 20t ha^{-1} Filter cake
5	GY0%FC25	0%Gypsum with 25t ha^{-1} filter cake
6	GY25%FC0	25% Gypsum without Filter cake
7	GY25%FC10	25%Gypsum with 10t har^{-1} filter cake
8	GY25%FC15	25% Gypsum with 15 t ha^{-1} filter cake
9	GY25%FC20	25% Gypsum with 20t ha^{-1} filter cake
10	GY25%FC25	25% Gypsum with 25t ha^{-} filter cake
11	GY50%FC0	50 % Gypsum without Filter cake
12	GY50%FC10	50 % Gypsum with10t ha^{-1} Filter cake
13	GY50%FC15	50 % Gypsum with 15 t ha^{-1} Filter cake
14	GY50%FC20	50 % Gypsum with 20 t ha^{-1} Filter cake
15	GY50%FC25	50 % Gypsum with 25 t ha^{-1} Filter cake
16	GY75%FC0	75 % Gypsum without Filter cake
17	GY75%FC10	75% Gypsum with 10t ha^{-1} Filter cake
18	GY75%FC15	75% Gypsum with 15 t ha^{-1} Filter cake
19	GY75%FC20	75 % Gypsum with 20 t ha^{-1} Filter cake
20	GY75%FC25	75 % Gypsum with 25 t ha^{-1} Filter cake

2.6. Soil Analysis

2.6.1. Analysis of Selected Soil Physical Properties

The Boycouos hydrometer method was used to determine the distribution of soil particle sizes (Bouyoucos, 1962). Blake (1965) states that to ascertain bulk density (BD), undisturbed soil samples were gathered using the core-sampler method. The formula for particle density (PD) is the mass of a solid divided by its volume. The following formula was also used to calculate total porosity using bulk and particle density (Hillel, 2004).

$$\text{Total Porosity} = \left[1 - \frac{\text{BD}}{\text{PD}}\right] \times 100$$

Where, BD = bulk density (g cm-3), and PD = particle density (g cm-3)

2.6.2. Analysis of Selected Soil Chemical Properties

A digital electrical conductivity and pH meter, respectively, was used to measure the soil paste extract of ECe and pHe potentiometrically (Richards, 1954). The methodology for determining soil organic carbon was followed by Walkely and Black (1934). Using a spectrophotometer and the Olsen extraction method, available phosphorus was measured calorimetrically (Olsen et al., 1954). The Kjeldahl digestion, distillation, and titration procedure, as detailed by Blake (1965), was used to

analyze total N. Samples saturated with 1M ammonium acetate (NH_4OAc) at pH 7 were used to calculate the soil's cation exchange capacity (CEC) (Van Reewijk, 1992). Exchangeable cations were removed from the samples in 1M ammonium acetate at pH 7 (Watanabe and Olsen 1965) and measured using Agilent 200 flame atomic absorption spectrophotometer (FAAS). The following formulas were used to calculate the percentages of exchangeable sodium (ESP) and percentage base saturation (PBS):

$$\text{ESP (\%)} = \frac{\text{Exchangeable sodium } (Na^{+})}{\text{CEC}} \times 100$$

$$\text{PBS (\%)} = \frac{\sum \text{Exchangeable cations } (Ca^{2+} + Mg^{2+} + K^{+} + Na^{+})}{\text{CEC}} \times 100$$

Where concentrations in cmol (+)/kg of soil. The other soil sodicity parameter computed was sodium adsorption ratio (SAR), from the relative concentrations of sodium, magnesium, and calcium. SAR was calculated from cation concentrations in a saturated paste extract (Richards, 1954).

$$\text{SAR} = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

2.7 Initial Soil Physicochemical Properties

The results indicated that texture of the soil of the experimental site was dominated by silt clay loam. On the basis of particle size distribution, the soil contained sand 14.57%, silt 46.6%, and clay 38.83%. The soil is saline-sodic soil based the following table result indicated. General soil properties of study area were presented in Table 3.

Table 3. Selected properties of the initial soil analysis results soil

Parameters	Units	Values	Comparing to standard level	Source
Clay	%	38.83		
Silt	%	46.6		
Sand	%	14.57		
Textural class		Silt clay loam		
Bulk density	g cm^{-3}	1.31	Moderate	
Particle density	g cm^{-3}	2.45		
Total porosity	%	42		
ECe	dS/m	4.85		
PHe	-	8.25	Moderately alkaline	Murphy, 1968
OC	%	0.90	Low	Tekalign,1991
Av.P	mg/kg	12.58	Medium	Olsen *et al.*,1954

TN	%	0.09	Low	Berhanu,1980
Exchangeable cations				
Na	cmol(+) kg^{-1}	9.5	Very high	FAO,2006
Ca	cmol(+) kg^{-1}	17.81	High	FAO,2006
Mg	cmol(+) kg^{-1}	3.61	High	Berhanu,1980
K	cmol(+) kg^{-1}	1.75	Medum	FAO,2006
CEC	cmol(+) kg^{-1}	38.34	High	Berhanu,1980
PBS	%	85.21	Very weakly leached	Hazelton, P. and B. Murphy,2007)
ESP	%	24.7	High	
Soluble cations				
Na	meq/l	24.28	High	
Ca	meq/l	5.25	Medum	
Mg	meq/l	4.22	Medum	
K	meq/l	2.88	Medum	
SAR		13.63		
SAR		13.63		

Where, PD = (particle Density), TP = (Total Porosity), TN = (total nitroge), Av.P = (available phosphorus), OC = (organic carbon), ECe = (electric conductivity), CEC = (cation exchange capacity), ESP = (exchangeable sodium percentage).

2.8. Data analysis

Analysis of variance (ANOVA) on soil physicochemical properties was using SAS version 9.4 statistical software program (SAS, 2016). Significant differences between and among treatment means were assessed using the least significant difference (LSD) at a 0.05 level of probability (Gomez and Gomez, 1984).

3. Results

Bulk density (BD): is routinely assessed to characterize the state of soil compactness in response to land use and soil management practices. The bulk density of soil reflects the mass or weight of a certain volume of soil. The addition of organic matter like filter cake can improve the infiltration, available water capacity, soil porosity, rooting depth/restrictions, soil microorganism activity, root proliferation, and nutrient availability.

Soil porosity: refers to the fraction of the total soil volume that is taken up by the pore space. Mainly, pore spaces facilitate the availability and movement of air or water within the soil environment. Gypsum and filter cake application improve the soil physical properties. However, the experiment result also indicates this fact.

Soil pH or soil reaction: is an indication of the acidity or alkalinity of soil and is measured in pH units. Soil pH is defined as the negative logarithm of the hydrogen ion concentration. The pH scale goes from 0 to 14 with pH 7 as the neutral point. The application of gypsum with filter cake reduced the soil pH levels 8.25 to 7.76.

Cation exchange capacity: The main ions associated with CEC in soils are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) and are generally referred to as the base cations. Gypsum and filter cake application improve the CEC of saline-sodic soil.

Exchangeable sodium percentage: is the most important soil factor affecting dispersion in soils and, consequently, soil crusting. The sol application of gypsum was improved the values of gypsum comparing to interaction.

Sodium absorption ratio (SAR): allows assessment of the state of flocculation or of dispersion of clay aggregates in a soil. The application of gypsum and filter cake can improve the initial SAR values.

4. Discussions

4.1. Effect of Gypsum and Filter Cake on Soil Physical Properties

Bulk density (BD): Soil BD was highly and significantly affected by the main effects of gypsum ($P < 0.05$), filter cake, and the interaction effect ($P \leq 0.01$). The highest bulk density (1.40 g cm-3) was recorded for the soil of the control plot, whereas, the lowest bulk density (1.04 g cm-3) was recorded for the treatment combination of 75% GR with 25 t ha^{-1}filter cake and 505GY and 25t ha^{-1}FC (Table 4). Mahmood *et al*. (2013) also reported a decrease in the bulk density of saline-sodic soil with the combined application of organic matter and chemical amendment. Decreasing soil BD might be the physical binding effect of organic matter and gypsum that creates aggregation of soil particles. Similarly, different authors, reported that soil BD decreased with the integrated application of filter cake with gypsum (Muhammad and Khattak, 2009; El-Sanat et al., 2017). Gharaibeh et al. (2009) also stated that gypsum amendment in saline-sodic and sodic soil can improve the physical soil properties such as BD.

According to Wang et al. (2014) application of mixture of organic wastes decreased BD by 11% and increased total porosity by 25% compared to the control. These suggest the effectiveness of the combination of amendments for reclaiming the physical properties of salt-affected soil. Bethel et al. (2019) reported positive effects of the combined application of sugar industry by-products (filter cake and bagasse) on calcareous soil physical properties. Ghulam et al. (2010) reported decreased BD of the soil and increased total porosity for increased application rates of press mud from 15 to 20 tones ha^{-1}.

Total Porosity (TP): The data also revealed that the interaction and the main effect of filter cake were highly significant ($P \leq 0.01$) on soil total porosity (table 4). However, the main effect of gypsum was not significant. The highest total porosity (48.48 %) was recorded for plots treated 75% GY with 25 t ha^{-1} filter cake, while the lowest (40.66 %) was recorded for control plots.

The most probable reason for increment of total porosity with the rates of organic matter (filter cake) might be due to the role of organic matter to create aggregates. Haq et al. (2001) reported that filter cake helped to acidify and makes soluble calcium available; and thus, improve soil structure and increase leaching of salts. Organic amendments are reportedly known to contribute to the flocculation of clay minerals, which subsequently improve soil structure, increases soil porosity and

decreases bulk density of saline sodic soil (Tejada et al., 2006 and Black 1934). Flocculated soils have better porosity as compared to dispersed soils (Qadir et al., 2006).

Table 4. Interaction effect of gypsum and filter cake on soil bulk density and total porosity

Gypsum rate (%)	**Filter cake (t ha $^{-1}$)**				
BD (g cm^{-3})	0	10	15	20	25
0	1.35a	1.29b	1.20c	1.17cd	1.13de
25	1.11efg	1.08fghi	1.06ghi	1.06hi	1.07fgh
50	1.10efgh	1.06ghi	1.05i	1.05i	1.04i
75	1.12ef	1.04i	1.11ef	1.04i	1.04i
CV			2.63		
LSD			0.04		
TP (%)					
0	40.66i	43.19h	47.93bc	49.14ab	51.10a
25	46.22cdefg	47.08bcdef	46.98bcdef	47.42bcd	47.42bcd
50	45.24defgh	47.10bcde	47.62bc	47.76bc	48.48bc
75	44.32gj	48.11bc	45.00efgh	48.03bc	48.16bc
CV			2.95		
LSD			2.13		

Mean values followed by the same letter within each column and row are not significantly Difference at α = 0.01, based on LSD test. BD = (bulk density), TP = (total porosity).

4.2. Effect of Gypsum and Filter Cake on Soil Chemical Properties

4.2.1. Soil reaction and electrical conductivity

Statistical analysis showed that the main and the interaction effects of gypsum and filter cake significantly ($P \leq 0.01$) affected soil pH. The highest pH value (8.20) was recorded at the control plot, whereas, the lowest pH (7.76) was recorded for plots treated with 75 % GR and 25 t ha^{-1} filter cakes (table 5). The result of this study agrees with the finding of Basak et al. (2021) who reported for the combined application of gypsum and filter cake. Gypsum application to the soil with the desired quantity of Ca^{2+} can neutralize the soluble HCO_3, and exchange Na^+ from the soil to reduce the soil pH (Pushparaj and Thiyagarajan 2016). Khattak et al. (2007) and Aljughaiman (2020) also reported considerably decreased soil pH with increasing levels of gypsum application to the soil. Results of soil pH values are in accordance with the confide finding of Said et al. (2010) that soil pH in the control treatment decreased to 30% in the soil receiving the highest level of filter cake. The decomposition of soil organic matter produces carbonic acid via CO_2 dissolution in water, which could decrease the pHe towards neutral point.

Soil electrical conductivity (ECe):

Analysis of soil laboratory data showed that the interactions of gypsum and filter cake were significantly ($P \leq 0.01$) affected soil electrical conductivity. After wheat harvest, the lowest ECe (3.20 $ds.m^{-1}$) was recorded for plots treated with application of 75% GR with 25 t ha^{-1}filter cake while, (the initial value) (4.85 $ds.m^{-1}$) was recorded from the control plots (Table 5), with gypsum rates reduced the soil electrical conductivity. The main effects of gypsum were greater than that of filter cake in reducing the EC of the soil. Udayasoorian et al. (2009) suggested that the combined application of organic and inorganic ameliorants was superior in reducing the electrical conductivity of soil.

4.2.2. Organic carbon and available phosphorus

Post-harvest soil organic carbon content was highly significantly ($P \leq 0.01$) affected by the main effect of gypsum and filter cake and their interaction effect. The highest OC (2.12 %) was recorded for plots treated with 75% GR + 25 t ha^{-1}filter cake followed by application of 75% GR + 20 tha^{-1}FC (1.95 %). The lowest soil organic carbon (1.17%) was recorded for plots treated with 10 t ha^{-1}filter cake and the control plots.

Basak et al. (2021) reported higher SOC due to the combined application of 100% gypsum and 15 t ha^{-1}pressmud (filter cake) (Gyp + PM). This could be ascribed to the supplementation of soluble Ca from gypsum, which initially might have neutralized the alkalinity effect of Na, and de–de-protonated carboxylic group (R–COO) leading to metal chelate formation, and subsequently facilitated in chemical recalcitrance of SOC (Deb et al., 2020).

The same was reported by Bahadur et al. (2013), OC content was improved by the conjoint use of organic manure and inorganic fertilizer. The organic residue enhanced the soil's organic carbon and accelerated the microbial activities in soil. Different researchers reported that filter cake increased the soil organic carbon content (Singh et al., 2009; Dotaniya et al., 2014).

Available phosphorus (Av. P): The main effect of gypsum and filter cake as well as their interaction effects were highly significant ($P<0.01$) on soil available phosphorus (Table 5). The highest available phosphorus (17.89 mg/kg) was recorded from the plots treated with 75% GR + 25 t ha^{-1} filter cake followed by 75% GR+20 t ha^{-1} filter cake (17.25 mg/kg). The availability of phosphorus from organic residue depends on the C: N ratio of the applied material. If it is on the lower side, it enhances the available phosphorus concentration in the soil solution. The minimum (11.21 mg /kg) was recorded for the control plot. In agreement with the findings of this study, Khosa (2017) reported that organic amendments (compost, farmyard manure, and sugarcane filter cake) significantly increased the bioavailability of phosphorus, soil respiration, and microbial biomass. Said (2010) reported that press mud at 15 to 20 t ha^{-1} would be the most suitable dose for improving the chemical properties of calcareous soil (P, S, K, Fe, Mn, Zn, and Cu). Bethel et al. (2019) reported that soil available phosphorus increased from filter cake and bagasse application compared to untreated plots.

Table 5. Interaction effect of gypsum and filter cake on soil pHe,ECe,OC, and Av.P

Interaction effect of GY (%) &FC	pH	ECe(ds/m)	OC (%)	Av.P(mg/kg)

(t ha^{-1})				
Control	8.20a	4.85a	1.17r	11.21p
GY0%&FC10	8.14a	4.81a	1.17r	11.85o
GY0%&FC15	8.06b	4.75b	1.25q	12.40n
GY0%&FC20	8.16a	4.71b	1.33o	14.00k
GY0%&FC25	8.16a	4.52dc	1.14n	16.00de
GY25%&FC0	7.96cd	4.66c	1.31p	13.00m
GY25%&FC10	7.97c	4.51d	1.43m	13.50l
GY25%&FC15	7.97c	4.41e	1.45l	14.50ij
GY25%&FC20	7.88de	4.33f	1.47k	15.20gh
GY25%&FC25	7.94cd	4.23g	1.49i	16.20cd
GY50%&FC0	7.95cd	4.20g	1.53i	13.20lm
GY50%&FC10	7.91cd	4.08h	1.57h	14.56ij
GY50%&FC15	7.93cd	3.98i	1.63g	15.69ef
GY50%&FC20	7.91cd	3.98i	1.63g	16.50c
GY50%&FC25	7.91cd	3.84j	1.67f	17.02b
GY75%&FC0	7.96cd	3.76k	1.75e	15.4fg
GY75%&FC10	7.90cd	3.65l	1.85d	14.2jk
GY75%&FC15	7.88de	3.54m	1.91c	14.85hi
GY75%&FC20	7.82ef	3.41n	1.95b	17.25b
GY75%&FC25	7.76f	3.20o	2.12a	17.89a
CV (%)	0.57	0.71	0.53	1.7
LSD (5%)	0.07	0.04	0.015	0.38

Means values followed by the same letter within each column and rows not significantly different at $\alpha = 0.05$, based on LSD test.Av.P= (available phosphorus), ECe = (soil electrical conductivity), OC = (organic carbon)

4.3. Interaction effect of GY and FC on exchangeable Ca, Mg, Na, and SAR

Exchangeable calcium (Ca): Exchangeable calcium was significantly influenced by the sole and combined application of gypsum and filter cake ($P < 0.01$). The highest exchangeable calcium (31.51 mol (+) kg^{-1}) was recorded in the plots treated with 75% GR + 25 t ha^{-1} filter cake followed by 75% GR +20t ha^{-1} filter cake (30.50 mol (+) kg^{-1}). Exchangeable Ca increased due to the addition of filter cake or gypsum which might have resulted from dissolution of gypsum and decomposition of filter cake. The minimum exchangeable calcium (17.46 cmol (+) kg^{-1}) was recorded from untreated plots. Sarwar et al. (2008 and 2010) reported increased exchangeable Calcium due to filter cake and synthetic fertilizer treatment, but filter cake significantly raised exchangeable calcium concentration in the soil.

Pushparaj and Thiyagarajan (2016) also reported higher exchangeable Ca on the soil exchange sites due to gypsum application followed by press mud (filter cake) and vermin compost which could result in higher Ca availability. Sodicity declined due to a sufficient supply of favorable cations, in particular Ca thus reducing the concentration of Na on the exchange complex.

Prapaga et al. (2012) reported that exchangeable Ca levels increased for gypsum-treated soils and combined application of gypsum and organic amendments.

Gypsum is widely accepted as a primary source of Ca to reclaim sodic soils and its use has been long studied as part of the most important remediation strategy in sodic soil. However, due to increased costs of chemical amendments and original recurrent sodicity issues, various organic amendments were also used to supplement Ca organic manure to improve the soil properties (Celis et al., 2013; Pushparaj and Thiyagarajan, 2016).

Exchangeable sodium: exchangeable sodium concentration in the soil was highly significantly ($P \leq 0.01$) affected by the main effects of gypsum and filter cake and their interaction. The highest exchangeable sodium (11.04 cmol (+) kg^{-1}) was recorded for the soil of untreated (control) plot, while the lowest was recorded for the soil of plots treated with 75%GR + 25 t ha^{-1} filter cakes (5.56 cmol (+) kg-1). Pushparaj and Thiyagarajan (2016) reported that the addition of gypsum effectively reduced the exchangeable content by 42.5% which was closely followed by the addition of filter cake (40.5%).

Generally, exchangeable sodium decreased with increasing application of gypsum and filer cake. Tajada (2006) also suggested that organic and inorganic ameliorants are superior in reducing exchangeable Na from saline-sodic and sodic soil. Sodicity declined due to a sufficient supply of favorable cations, particularly Ca, thus reducing the concentration of Na on the exchange complex (Srinivasan et al., 2010; Pushparaj and Thiyagarajan 2016).

Exchangeable magnesium: The soil analysis result showed that exchangeable magnesium concentration in soil was significantly ($P \leq 0.05$) affected by the main effect of filter cake and the interaction effect of gypsum and filter cake (Table 5). The highest exchangeable magnesium (4.41 mol (+) kg^{-1}) was recorded for plots treated with 25 t ha^{-1} FC and followed by 50% GY with 15t ha^{-1} FC, however, the lowest exchangeable magnesium was registered for control plots (Table 6). Ghulam et al. (2012) reported higher exchangeable magnesium content of the soil due to the application of organic manures such as press mud and vermin-compost than inorganic amendments like gypsum, elemental Sulphur, and ferrous materials.

Sodium adsorption ratio (SAR): the analysis of variance showed that a highly ($P < 0.01$) significant difference was observed for the main and interaction effects of gypsum and filter cake on SAR. The highest SAR (13.22) was obtained from the control plot, while the lowest (6.64) was from the application of 75% GR+25t ha^{-1}FC followed by 75% GR+20 t ha^{-1}FC (6.81). According to Muhammad and Khattak (2011); and Shaaban et al. (2013), the application of filter cake decreased SAR. The result also showed that SAR decreased as the rate of gypsum level increased from 0% to 75 % GR. The reduction in SAR can be explained by the displacement of excess exchangeable Na^{+} from the soil colloidal complex and its subsequent leaching by irrigation water.

Table 6. Interaction effect of gypsum and filter cake on exchangeable Ca,Na and Mg

Interaction effect of GY (%) &FC (t ha^{-1})	Ca (cmol (+) kg^{-1})	Na (cmol (+) kg^{-1})	Mg (cmol (+) kg^{-1})	SAR
Control	17.46o	11.04a	3.72d	13.22a
GY0%&FC10	17.89a	10.71b	3.87cd	12.30b
GY0%&FC15	18.56n	10.21d	3.96bcd	11.72c
GY0%&FC20	20.23m	9.77f	4.18ab	11.19d
GY0%&FC25	22.00j	10.04e	4.41a	10.48f
GY25%&FC0	18.65n	10.60c	3.93bcd	10.83e
GY25%&FC10	20.87l	10.12de	3.94bcd	10.89ef
GY25%&FC15	21.50k	9.51g	3.94bcd	10.10g
GY25%&FC20	23.54i	8.62h	4.06bc	9.69h
GY25%&FC25	25.12h	8.52hi	3.94bcd	9.11i
GY50%&FC0	26.12f	8.50i	3.99bcd	9.03ij
GY50%&FC10	23.50i	8.35j	3.94bcd	8.79j
GY50%&FC15	25.68g	7.89k	4.22ab	8.22k
GY50%&FC20	26.51f	7.62l	4.01bc	8.27k
GY50%&FC25	27.13e	7.54l	4.25ab	7.54l
GY75%&FC0	28.36d	7.02m	3.99bcd	7.42l
GY75%&FC10	28.87c	6.73n	3.94bcd	7.10m
GY75%&FC15	29.14c	6.61o	3.94bcd	7.03mn
GY75%&FC20	30.50b	6.44p	3.96bcd	6.81no
GY75%&FC25	31.51a	5.56q	3.94bcd	6.64o
CV (%)	1.08	0.74	1.04	1.75
LSD (0.05)	0.40	0.09	0.27	0.30

Mean values followed by the same letter within each column and row for the parameters are not significantly different at α = 0.05, based on LSD test. Exchangeable, Ca (Calcium), Na (Sodium), Mg (Magnesium).

4.4. The main effect of GY and FC on soil exchangeable K, CEC, PBS, and ESP

Exchangeable potassium (K): exchangeable potassium was not significantly (P > 0.05) affected by the main effect of gypsum and the interaction effect of gypsum and filter cake. The filter cake was also highly significant (P≤0.01) on exchangeable potassium. Relatively high exchangeable K (2.01cmol (+) kg $^{-1}$) was recorded for the soil of plots treated with 25t ha^{-1} filter cake followed by 20t ha-1 filter cake (2.0 cmol (+) kg $^{-1}$) while low exchangeable K (1.75 cmol (+) kg $^{-1}$) was for control plot. In agreement with this result, Pushparaj & Thiyagarajan (2016), reported that Exchangeable K status was higher for soil treated with filter cake (Bethel et al., 2019).

Cation Exchange Capacity (CEC): the interaction effect of gypsum with filter cake and the main case of gypsum haven't significant effect (P > 0.05) on soil cation exchange capacity. The main application of filter cake was highly significant (P ≤ 0.05) on CEC. The highest CEC (43.61 %) was

recorded for the sole application of 25 t ha^{-1} FC followed by 20 t ha^{-1} FC (43.11%). The lowest CEC (41.26%) was for soil of plots not treated with FC. These may be due to organic matter input into the soil.

Pushparaj and Thiyagarajan (2016) revealed that the application of organic amendments encourages granulation, increases CEC, and is responsible for the release of Ca, Mg, and K (Brady and Weil, 2005). Reduction of the soil sodicity by replacement of Na with Ca and Mg. Being a divalent cation Mg can also replace the Na from the soil exchangeable site (Gharaibeh et al., 2009, 2011).

Percent base saturation (PBS): The interaction effect of gypsum with filter cake and the main case of filter cake did not significantly ($P > 0.05$) affect soil percent base saturation. The main case of gypsum was significant ($P< 0.01$) on soil PBS. The highest PBS (97.58 %) was recorded for the soil treated by 75% GR. The lowest PBS (84.28%) was recorded for untreated plots (Table 8).

4.5. Exchangeable sodium percentage

Analysis of the soil data revealed that the main effects of gypsum and filter cake were highly significant ($P \leq 0.01$), and interaction effects were non-significant on ESP ($P > 0.05$). Based on the main effects of gypsum, the highest ESP (24.73%) was recorded for the soil of untreated plots. However, the lowest ESP (15.01%) was recorded for the soil of the plots treated with a 75% soil gypsum requirement. In the case of filter cake application, the highest ESP (22.92%) was recorded for the soil not treated by FC, and the lowest ESP (18.08) was measured from the soil treated by 25 t ha^{-1} FC. The possible reason might be the application of gypsum and filter cake that enhanced the chemical reaction and exchanged Na with Ca from the soil exchange complex. Then, Na^+ in soluble form might be leached down due to improved soil physical and chemical conditions.

Choudhary et al. (2004) reported that the mixture of organic matter with gypsum decreased the ESP of the sodic and saline-sodic soils. Decreased soil ESP with the addition of amendments either alone or in combination with gypsum might be attributed to increased Ca in soil solution which promotes Na displacement and its subsequent removal to lower soil layers during irrigation water application (Gharaibeh et al., 2009). According to Negim (2015), the application of filter cake and gypsum alone or in combinations considerably decrease d ESP.

Total nitrogen (TN): The main effect of filter cake was significantly affected soil total nitrogen ($P\leq0.05$) while, the interaction effect of gypsum and filter cake were non-significant (Table 7). TN increased in the soil with increasing levels of filter cake application. According to the analysis result, comparing to the control plot (0.14 %) TN was recorded from the main effect of filter cake at 20 and 25 t ha^{-1}. The minimum TN (0.11 %) was recorded for plots not treated with filter cake (Table 8). Mandal (2013) also reported increased total nitrogen contents in the soil. Due to application of press mud (filter cake). Ghulam et al. (2012) showed that the TN of the soil positively affected by the different doses of filter cake. According to Bethel et al. (2019) the combined application of sugar

cane by products like filter cake at the level of 20 t ha^{-1} improved the TN contents in the soil compared to untreated plots.

Table 7. The main effect of gypsum and filter cake on soil K, CEC, ESP and PBS, TN

GY %	Ex K cmol (+) kg^{-1})	CEC (cmol (+) kg^{-1})	PBS (%)	ESP (%)	TN (%)
0	1.86	42.40	84.28d	24.73a	0.11
25	1.90	42.06	88.71c	22.57b	0.13
50	1.95	42.67	93.36b	18.72c	0.13
75	1.97	43.12	97.58a	15.01	0.13
CV (%)	8.21	3.94	4.82	6.95	10.25
LSD (0.05)	NS	NS	3.38	1.06	NS
Filter cake in t ha^{-1}					
0	1.75b	41.26b	86.75	22.92a	0.11b
10	1.88a	42.27ab	88.91	21.30b	0.13a
15	1.95a	42.56ab	89.85	20.16b	0.13a
20	2.00a	43.11a	91.36	18.82c	0.14a
25	2.01a	43.61a	93.03	18.08cc	0.14a
CV (%)	8.48	4.20	5.03	7.14	11.33
LSD (0.05)	0.13	1.45	NS	1.17	0.012

Similar letters or no letters with column indicate that there is no significant difference among treatment levels, α= 0.05, based on LSD test. K= (Potassium), CEC = (Cation Exchange Capacity), PBS = (percent base saturation), ESP = (exchangeable sodium percentage) and TN = (total nitrogen).

4.6.3. Grain yield and Biomass

Grain yield (GYD): the main effect of gypsum and filter cake and their interaction were highly significant ($P \leq 0.01$) on wheat GYD. Based on interaction analysis the highest GYD (4.49 t ha^{-1}) was obtained from 75% GR with 25 t ha^{-1} filter cake (Table 8). However, the minimum GYD was recorded from the control plot. The study of Ghulam et al. (2014) indicates that filter cake (press mud) included both macro and micro nutrients, which increased yield and yield attributing characters of crops. The result of this study is in agreement with the findings of several researchers who reported that Gypsum application in different doses increased yield of rice by 9.8 to 25.3% and that of wheat crop by 10-80% over control treatment (Kasahun et al., (2020).

Filter cake itself is a good source of many essential plant nutrients. These nutrients are released to plants upon decomposition and thus help promote plant growth. Haq et al. (2001) showed that 60 % yield advantage after treating sodic soil with filter cake. The results agree with the findings of several researchers who reported increased yield due to integrated use of gypsum and filter cake. The study by Rao et al. (2018) and Sabah et al. (2020) showed that all organic nutritional sources improved yield of wheat, but integrated use of compost with chemical fertilizers proved superior to all other treatments under saline sodic soil.

Biomass (BM): Similarly, biological yield was significantly ($P \leq 0.01$) affected by the interaction effect of gypsum and filter cake and as well as the main effects of gypsum and filter cake (table 8). The highest BM was obtained from plot treated with 75% GR and 25t ha^{-1}filter cake (10.21t ha^{-1}), whereas the lowest biological yield (3.71t ha^{-1}) was from control plots. The next effective treatment was the combination between gypsum and farm yard manure, increasing the biomass of wheat.

Table 8. Interaction effect of gypsum and filter cake on wheat GYD and BM

Interaction effect of GY (%) & FC (t ha^{-1})	GYD (t ha^{-1})	BM (t ha^{-1})
Control	1.10k	3.71k
GY0%&FC10	1.12k	4.02k
GY0%&FC15	1.11k	4.02k
GY0%&FC20	1.31jk	4.91j
GY0%&FC25	1.53ij	5.23hij
GY25%&FC0	1.51ij	5.11ij
GY25%&FC10	1.68hi	6.02fgh
GY25%&FC15	1.97gh	5.35ghij
GY25%&FC20	2.36f	6.11fg
GY25%&FC25	3.10cd	6.74ef
GY50%&FC0	1.54ij	5.74ghi
GY50%&FC10	1.74hi	5.98fgh
GY50%&FC15	2.24fg	6.92de
GY50%&FC20	3.27c	6.92de
GY50%&FC25	2.59ef	8.03bc
GY75%&FC0	1.85hi	5.88ghi
GY75%&FC10	3.29c	7.57cd
GY75%&FC15	2.83de	7.65cd
GY75%&FC20	3.98b	8.83b
GY75%&FC25	4.49a	10.21a
CV (%)	9.77	7.92
LSD (0.05)	0.33	0.77
LSD (0.05)	0.33	0.77

Mean values followed by the same letter within each column and row are not significantly different at α 0.05, based on LSD test. GYD = (grain yield), BM = (biomass).

5. Conclusions

Therefore, based on the results of the study it can be concluded that, the interaction effect of gypsum and filter cake can improve the physical and chemical properties of saline-sodic soil. The results revealed that significant ($P \leq 0.01$) differences were observed on soil physicochemical properties due to sole and combined application of gypsum and filter cake. However bulk density, total porosity, soil pH, soil electrical conductivity; organic carbon, available phosphorous, exchangeable, and soluble cations, and SAR were significantly affected by the interaction of gypsum and filter cake. Filter cake is applicable on the sugar industry west products not cost and

easily available after sugar production process and gypsum also available any building material shop.

6. Recommendations

Soil amendments to improve wheat yield in saline-sodic soil conditions. The combination of gypsum and filter cake at the specified rates seems promising, but as you pointed out, more research is needed to optimize application rates across different environments and wheat varieties. Since the response curve for filter cake application is not well-established, future studies could focus on determining the most effective range of application, possibly exploring incremental increases beyond 25 tons per hectare. Additionally, evaluating interactions between gypsum and filter cake in various soil conditions could provide insights into their combined impact on soil structure, nutrient availability, and overall wheat productivity.

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