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Application of Different Gypsum Sources as Soil Amendments to Improve Some Salt Affected Soils Properties

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Abstract: Salinity considered being an important limitations for agricultural production in semi-arid regions. A field experiment was conducted on saline affected soil in El-Hussania area, Egypt, during the 2019 growing season. The aim of the experiment was to study the effect of by products gypsum (phosphogypsum and sulphugypsum) and natural one applied at two rates (15 and 30 Mg ha^{-1}) on some soil properties, growth, yield and yield components of rice (*Oryza sativa* L., Giza 177*cv*) in new reclaimed soil. The obtained results showed some differences in soil bulk density, electrical conductivity (EC), pH, exchangeable Ca^{2+} and Sodium Adsorption Ratio (SAR) among the treatments in comparison with the control. Among the treatments, the highest reduction in SAR (18.75 mmol l^{-1})$^{1/2}$ and EC (7.20 dSm^{-1}) were recorded by the phosphogypsum. The obtained data reveal that the applied gypsum-rates significantly increased yield attributes of rice. However, gypsum-rate of 30 t ha^{-1} resulted in relative increase percentages for grain panicle^{-1} reached 46.8% over the control treatment. With increasing phosphogypsum levels from 15 Mg ha^{-1} to 30 Mg ha^{-1}, the yield components increased 22.3 and 30.6% for 1000-grain weight respectively, compared with the control. Among the gypsum-sources, phospho-, to sulpho- and natural gypsum gave pronounced increases in seed yield of rice 20.7, 58.6 and 77.2 %, respectively. This means that phosphogypsum is considered the best gypsum source from soil productivity point of view, followed by sulpho- and natural gypsum for rice plants. Under the current experimental conditions, it could be concluded that application of 30 Mg ha^{-1} to rice plants grown on a salt affected soil was necessary to realize an optimum productivity. As for the applied different gypsum-sources, it is noteworthy to mention that although phosphogypsum was not only promising in terms of productivity and best soil properties but also it represents a better option from the applicable point of view as compared to sulpho- and naturalgypsum, this is mainly due to its relative cheap costs.

Key words: Phosphogypsum · Sulphuregypsum · Gypsum · Salt affected soil properties

INTRODUCTION

The saline-sodic soils with high sodium content are compact and generally form ahardpan on the soil surface [1]. This compactness prevents plant root proliferation and reduces salt leaching. Thus the reclamation of such soils with simpleleaching by flooding remains ineffective. The application of gypsum enhances leachingby improving soil hydraulic conductivity [2]. The gypsum application with or without organic manures for reclamation of different sodic and saline-sodic soils has proved profitable [3]. Beside gypsum, the chemical amendments followed by leaching with canal water can reclaim saline-sodic soils [4]. The chemical amendments, being costly can be replaced successfully by organic manure which has been found effective in increasing the crop yield and good physical health of soil [5]. This research study was conducted to assess the effect of various reclamation techniques for improving soil health and crop productivity on saline sodic soils.

Rice (*Oryza sativa* L.) is one of the most important food crops in the world. Also, rice is moderately sensitive to salinity and moderately tolerant to sodicity [6, 7]. It is often recommended as a desalinization and dealkalinity crop because of its ability to grow well in standing water [8] and the above-ground parts of the rice plants could consume alkalinity in alkaline soil [9] due to its shallow rooting zone, roots are less hampered by a sodic B-horizon.

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Furthermore, rice roots release organic compounds and complex energy sources [10], which increase partial CO_2 pressure [11] as well asdecrease soil pH through proton excretion. All these processes combined favour the increased dissolution of $CaCO_3$ in the soiland the decrease of soil alkalinity and sodicity as a function of time [12]. Rice cultivation may improve percolation rates even in highly sodic soils [13]. Irrigated rice cropping is practiced to reclaim saline-sodic soils in many parts of the world [9].

Phosphogypsum is a by-product of the phosphoric acid industry, containing mainly calcium sulphate and small contents of P, is largely available in many parts of the world. More than 22 milliontons of phosphoric acid is produced annually worldwide generating in excess of 110 million tons of phosphogypsum by products [14]. Phosphogypsum, due to containing low phosphates and its acidic nature, has advantages over mined gypsum where itis applied to the predominantly slightly alkaline soils of the region. More importantly, fine-grained phosphogypsum contributes more than mined gypsum to soil electrolyte concentrations through a higher dissolution rate and therefore contributes more toelectrolytic control of clay dispersion in sodic soils [15, 16].

Thus, it is necessary to increase knowledge on the use of phosphogypsum as a soil amendment for saline soils as an alternative to dispose of a bulky by-product of the fertilizer industry. The present investigation, therefore, was undertaken too bserve the effect of different levels of phosphogypsum application on grain yields and yield components of ricecultivar under salt affected soils.

MATERIALS AND METHODS

Site Description: This study was conducted in El-Hussania area which lies in the North-Western Egypt, between longitudes 32° 35'& 32° 45'E and latitudes 31° 00' & 31° 25' N with an average elevation of 10 meters above the sea and representing new reclaimed area, is in the semi-humid and semi-arid area, the average annual temperature is 21°C. The soil of our experimental fields is classified as saline-sodic soil.

Experimental Design: Experiment was laid out as a Complete Randomized Block Design with three replications of 3 m × 5 m each plot was conducted with the following treatments:

- Saline-sodic soil (Control),
- Natural gypsum at rates of 50 and 100 gypsum (15 and 30 Mg ha^{-1}, respectively),
- Phosphogypsum at of 50 and 100 % (15 and 30 Mg ha^{-1}, respectively),
- Sulphugypsum at of 50 and 100 % (15 and 30 Mg ha^{-1}, respectively),
- Elemental sulphure at of 50 and 100 % (15 and 30 Mg ha^{-1}, respectively).

Estimation of Gypsum Requirements: Estimation of the required gypsum was made considering the cation exchange complex of the soil, exchange efficiency andthe initial and final ESP using the gypsum requirement (GR) as described in [17, 18] as follows:

$$GR = Na_{exch} \times \text{Eqwt Gypsum} / \text{Eqwt Na} \times \text{mg Na mmol}^{-1}\ \text{kg}^{-1}\ \text{soil}$$

where: GR = Gypsum requirements ($g.kg^{-1}$); Na_{exch} = Exchangeable Na ($mmol.kg^{-1}$ soil); Eqwt = Equivalent weight.

The chemical characteristics and nutrients status of the applied soil amendment were determined according to the standard methods of [19] and the obtained data are illustrated in Table (1). Following the layout of the plots, Natural gypsum, Phosphogypsum and Sulphugypsum were spread uniformly on the surface of the respective treatments and thoroughly mixed into the 0.2 m surface soil before transplanting in 2019. The rice (*Oryza sativa* L.) cultivars (Giza 177) irrigated with saline irrigation water derived from El-Salam canal (Nile water mixed with agriculture drainage water, with a ratio of 1:1) during the growing summer season of 2012, currently used in local production were grown in the field. Rice grains were sown in nonsaline soil in a nearby greenhouse on May 20, 2019 and the 40-day seedlings were manually transplanted at a density of 4 plants/hill on June 30, 2019. Spacing of the hills was 20 cm by 30 cm. All plots received nitrogen fertilizer at the rate of 240 kg ha^{-1} nitrogen as urea (46.5 % N), which were split into the basal application 7 days prior to transplanting (60% of the total N), side-dressing on 9 July (20% of the total N) and at panicle initiation on 3 August (20%). Phosphorus was added at the rate of 280 kg ha^{-1} (as single superphosphate, 15% P_2O_5), while K was added at a rate of 95 kg ha^{-1} K_2O as potassium sulphate (48% K_2O) during the preparation of soil cultivation. Rice was harvested on 25 September 2019. Three times horizontal flushing of standing water was taken during the rice grown stage.

Table 1: Some chemical characteristics and the nutrients status of the studied by-product materials and gypsum shale

Character (%)	Natural-gypsum	Phospho-gypsum	Sulphu-gypsum
SO_4^{-2}	52.8	55.5	53.2
Ca^{+2}	22.3	23.0	22.8
Cl^-	1.21	0.29	0.89
NaCl	0.22	0.12	0.15
$CaSO_4.2H_2O$	97.0	98.2	97.5
S	15.9	16.2	15.8
pH	7.70	5.31	4.45
Particle less than 2 mm	90 %		
Particle less than 1mm	50 %		
Purity	97 %		

Table 2: Some physical and chemical properties of the experimental soil.

Soil characteristics	Value		Soil characteristics	Value
Particle size distribution%:		*Soil chemical properties:*		
	Sand	14.4	pH (1:2.5 soil water)	8.6
	Silt	32.5	$CaCO_3$ %	3.17
	Clay	53.2	Organic matter %	44.2
	Textural class	Clayeyey	ECe (dSm^{-1}, soil paste extract)	10.42
		Exchangeable Ca^{2+} ($cmol_c$ kg^{-1})	10.98	
		SAR (mmol $l^{-1})^{1/2}$	20.53	

Table 3: Chemical characteristics of the used irrigation source El-Salam canal (Nile water mixed with agriculture drainage water, with a ratioof 1:1)

Water characteristics	Value	Water characteristics	Value
pH	7.23	Sodium absorption ratio (SAR)	6.89
Total dissolving salt (mgl^{-l})	1440	Irrigation water suitability degree	C2S1
ECiw (dSm^{-1})	2.25	Residual sodium carbonate (RSC)	0.00

Data Collection: Plant height was measured on the main stem for fixed 30 hills in each treatment. The yield components were separated and processed from plants by hand. The data regarding plant height, 1000-grain weight, grain panicles^{-1} and yield were recorded. Grain yield of all the plants from a one m^2patch was determined in each plot after the grains were adjusted to a moisture content of water to 0.14 g g^{-1} fresh weight as described by [20].

Soil pH was measured in a 1:2.5 soil: water/1M KCl [21]. Removal of carbonates, OM and soluble salts were determined as reported in [2]. Soil OM was determined as in [22] and carbonates by volumetric calcimeter according to [23]. Electrical conductivity of the saturated paste [24]. Determination of Ca and Mg was using atomic absorption spectrophotometry and K and Na by flame emission spectrophotometry. Cation exchange capacity was determined after [25]. Exchangeable Na was extracted with a buffered neutral 1M NH_4OAc solution and Ca and Mg by 1N NaOAc solution (pH 8.2). Sulphate contents in plant and sulphur in soil were determined by using a standard turbidity method and chlorine by silver nitrate 0.01 N [18]. Total Na was extracted by 1M NH_4OAc solution followed by flame emission spectrophotometry. Exchangeable Napercentage was estimated by direct determination of exchangeable Na and CEC and calculated as in [25] as follows:

$$ESP = Na_{exch} / CEC \times 100$$

where:

ESP = Exchangeable sodium percentage;
Na = Sodium;
CEC = Cation exchange capacity. Sodium absorption ration (SAR) was calculated as in [26] as follows:

$$SAR = Na / (Ca + Mg)^2$$

where: SAR = Sodium absorption ratio

Some physical, chemical and fertility properties of the investigated soil are presented in Table (2), which were determined according to the methods described by [25, 27, 28]. According to the water salinity and sodicity classes undertaken by [29], data in Table (3) indicated that the used irrigation water derived from El-Salam canal (Nile water mixed with agriculture drainage water) lies in the second category C2S1, where ECiw and SAR values lay within the range < 0.75 dS m^{-1} and <6.00, respectively.

Statistical Analysis: Data collected were statistically analyzed according to [30]. The treatment means were compared using LSD test.

RESULTS AND DISCUSSIONS

Effect of Gypsum-Sources and Rates on Some Soil Chemical and Physical Characteristics Cultivated Rice Plants

Soil Bulk Density: Data presented in (Table 4) show that soil bulk density generally decreased after the application of gypsum-sources in comparison with control treatment with significant differences among treatments. Continued supply of Ca^{2+} through dissolution of by-product gypsum and binding effect of the soil particles together by gypsum-sources might have improved soil structure and aggregation, which would have been the reason for decrease in bulk density in the treatments. The best treatment for bulk density reduction was the Phosphogypsum. Calcium accumulations on the exchange sites have improved soil aggregation thus reducing the bulk density. These results are in harmony with the findings outlined by [31].

Soil pH: The pH reduced to 8.40 for Phosphogypsum at 100 % gypsum requirement at rate of 30 Mg ha^{-1} and 8.44 for natural gypsym added at rate of 30 Mg ha^{-1} (Table 4). Differences between treatments control were significant. Lowest value recorded for gypsum followed by Sulphugypsum and Phosphogypsum treated soil added at rate of 15 Mg ha^{-1}. This might be due to water promoted Phosphogypsum dissolution, expediting the reclamation reactions and due to improvement of soil [32]. Natural gypsum only showed a slight decrease in the pH in the range of 8.54 and 8.46 for PH in comparison to the control. This may due to acidifying effect of acids produced during the course of reaction with water.

Soil Electrical Conductivity: Effect of gypsum sources application at 15 and 30 Mg ha^{-1} shown in Table 4. Among the treatments, Phosphogypsum at 100% gypsum requirement at rate of 30 Mg ha^{-1} was more effective in reducing the EC of the soil as compared to Natural gypsum at the same rate. The possible reason may be the improvement in porosity and hydraulic conductivity, which resulted in enhancing the leaching of salts. Application of inorganic ameliorants superior in reducing EC of soil [33]. Decrease in EC as a result of gypsum application. A substantially decreased EC of saline-sodic soils with the addition of different inorganic amendments [34]. The reduction of EC may be due to the result of excessive ions by improving the physical properties of soil [1].

Exchangeable Calcium: Table (4) shows the effect of different gypsum sources naturally or by product on the exchangeable calcium of the investigated soil. Generally, exchangeable Ca^{2+} values were clearly increased due to any amendment applied after application. This may due to addition of inorganic amendments exchanging the adsorbed Na^{+} for Ca^{2+} and in the displacement of Na^{+} [35]. High level of exchangeable Ca^{2+} was observed for Phosphogypsum at 100% gypsum requirement at rate of 30 Mg ha^{-1} treated soils. Among them Phosphogypsum had the highest exchangeable Ca^{2+} content followed by Sulphugypsum and Natural gypsum treated soil. These treatments were significantly different among them and the control. A similar trend was observed by [36].

Sodium Adsorption Ratio (SAR): A clear decrease in SAR was observed for amended soils after leaching. The decrease inSAR due to either increase in divalent cations (Ca^{2+} and Mg^{2+}), or decrease in mono valent cation (Na^{+}). The measured values of cations (Table 4) indicated that Na^{+} decreased while Ca^{2+} increased in the application rate of amendments. The relatively high mobility and leach ability of Na^{+} from soil due to the applied amendments as compared with Ca^{2+}, resulted in lower values of SAR, hence, the SAR values of the treated soil were sharply decreased with phosphogypsum at 100% gypsum requirement at rate of 30 Mg ha^{-1}. A decrease in SAR with simple leaching in control waslikely due to mineral weathering and leaching out from the soil [37]. Applied phosphogypsum was more effective in reducing the SAR than an equivalent amount of $CaCl_2$ [38].

Effect of Gypsum-Sources and Rates on Available Sulphur in the Soil: The status of available S in the soil at the maximum vegetative growth stage was greatly improved with the application of S irrespective of its source, as shown in Table (5). However, sulphugypsum and phosphogypsum left behind more S in the soil than gypsum shall at the maximum vegetative growth stage of riceplants. Data indicate that the relative increase percentages at the applied rate of 30 t ha^{-1} left behind a soil rich in available S, reached 128.9 and 155.5 % over the control treatment for rice plants, respectively.

It is noteworthy to mention that the gypsum-source at rate of 30 Mg ha^{-1} at rice crop was about half of the S-available in the soil. This means that a more addition of gypsum-source surpassed that removal by the grown plants uptake. A similar trend was also observed by [39].

Table 4: Effect of gypsum-sources and rates on some soil chemical and physical characteristics

Treatment		Soil bulk density		Soil electrical conductivity	Exchangeable calcium	
Gypsum source	*Rate, (Mg ha^{-1})	(g cm^{-3})	Soil pH	(dS m^{-1})	(cmol$_c$ kg^{-1})	SAR (mmol$_c$ l^{-1})$^{1/2}$
Control	Without	1.20	8.62	7.59	11.0	21.06
Naturalgypsum	15	1.10	8.54	7.56	12.4	20.46
	30	1.00	8.46	7.44	11.9	20.10
Sulphugypsum	15	1.14	8.52	7.34	13.2	19.85
	30	1.11	8.44	7.30	12.4	19.33
Phosphogypsum	15	1.12	8.50	7.22	14.5	18.83
	30	1.00	8.40	7.20	13.1	18.23

*added at 50 % gypsum requirement at rate of 15 Mg ha^{-1}
*added at 100 % gypsum requirement at rate of 30 Mg ha^{-1}

Table 5: Effect of gypsum-sources and rates on available S-soil under rice plant cultivated at salted affected soil

Treatment		
Gypsum source (S)	Rate, Mg ha^{-1} (R)	Available sulphur (mg kg^{-1} soil)
Control	0	2.97
Gypsum shall	15	3.00
	30	4.53
	Mean	3.50
Sulphugypsum	15	5.12
	30	6.80
	Mean	4.96
Phosphogypsum	15	6.33
	30	7.59
	Mean	5.63
Average	15	4.38
	30	5.47
L.S.D. at 0.05	R	0.11
	S	0.09
	R × S	0.12

*added at 50 % gypsum requirement at rate of 15 Mg ha^{-1}
*added at 100 % gypsum requirement at rate of 30 Mg ha^{-1}

This means that a marked improvement in rice yield as a resulted of the residual S-amount could be ascribed to enhancement of SO_4^{-2} content in the soil due to gypsum-source to rice was not fully utilized by the crop leading to residual effect. This might have modified the media, especially physical properties which positively reflected on the growth and development of crop.

Effect of Gypsum-Sources and Rates on Growth and Yield of Rice Plants: Plant is a sensitive indicator of the efficiency of reclamation. Soil salinity threshold limit (EC dS m^{-1}) for rice for 50% yield reduction is 8.3 [40]. The influence soil by products materials as gypsum-sources added to a salt affected soil on yield and yield components ofrice plants is presented in Table (5).

Rice Plant Growth Parameters: The obtained data in Table (6) indicate that gypsum-sources and rates markedly increased plant growth parameters (*i.e.,* plant height), yield attributes (*i.e.,* grain panicle^{-1} and 1000 grain) and seed yield of rice. Application of 15 Mg ha^{-1} increased the grain panicle^{-1} and 1000 grain of rice by 42.3 and 22.3 % vs 46.8 and 30.6 % for rate of 30 Mg ha^{-1} over the control treatment, respectively. Also, gypsum-source application exerted a significant increased in rice seeds at the rates of 15 and 30 Mgha^{-1} which reached 51.2 and 66.3 % over the control treatment, respectively. These beneficial effects of applied gypsum-sources and rates may be attributed to a smaller component of nitrogenase enzyme of Fe-S clusters which involved in N-biofixation achieved by either nodule bacteria or free living bacteria [41]. Further, such favored better N-fixation, thus growth, yield attributes and yield formation finally led to improve the previous plant parameters, which acts increase percentage of 36.6and 43.8 % for plant height at the rates of 15 and 30 Mg ha^{-1}, the corresponding values were 27.2 and 29.2 % over the control treatment for Stalk yield, respectively.

Thus, Phosphogypsum proved to have a promising effect for increasing rice growth, yield and its attributes than both Sulphugypsum and Natural gypsum (Table 6). This is mainly due to Phosphogypsum enhanced the grain panicle^{-1} and 1000 grain of rice by 8.1 & 12.5 % as well as 7.2 & 17.7 % as an improvement in seed yield of rice over the gypsum shall and Sulphugypsum, respectively. The performance of Sulphugypsum as a source of S to cowpea remained in between gypsum shall and Phosphogypsum and thus recorded at par yield with these two gypsum-sources. Better growth and yield with Phosphogypsum may be attributed to its smaller particle size that resulted in greater surface area which might enhanced its solubility as well as the oxidation of S to SO_4^{-2} (available form of S to plants). In addition, the better S-nutrition for plants could have contributed to better root and shoot growth as well as nodulation and ultimately higher yield [42, 43].

Table 6: Effect of gypsum-sources and rates on growth parameters and yield of rice plants

Treatment Gypsum source (S)	Rate, Mg ha^{-1} (R)	Plant height (cm)	Grain $panicle^{-1}$ (g)	1000 grain (g)	Grain yield (Mg ha^{-1})	Stalk yield (Mg ha^{-1})
Control	0	80.3	101.6	19.30	2880.5	2908.8
Gypsum shall	15	100.4	144.3	22.33	3626.8	3420.7
	30	116.4	152.3	24.41	3924.9	3658.8
	Mean	99.0	132.7	22.01	3477.3	3329.5
Sulphugypsum	15	108.0	160.1	24.54	4830.2	5115.6
	30	111.7	168.7	26.99	5995.9	5658.2
	Mean	100.0	143.5	23.60	4568.6	4560.7
Phosphogypsum	15	150.1	172.2	28.27	6079.9	5990.8
	30	152.7	174.4	30.15	6360.2	6095.5
	Mean	101.0	149.4	25.91	5106.7	4998.4
Average	15	109.7	144.6	23.61	4354.3	3698.8
	30	115.3	149.2	25.21	4790.1	3756.8
L.S.D. at 0.05	R	2.4	1.8	0.5	112.1	101.5
	S	1.1	2.1	0.3	99.6	89.9
	R × S	0.9	1.1	0.5	121.1	111.5

Table 7: Effect of gypsum-sources and rates on macronutrient content in rice plants

Treatment Gypsum source (S)	Rate, Mg ha^{-1} (R)	N	P	K
		------------- % ---------------		
Control	0	0.99	0.11	1.92
Gypsum shall	15	1.06	0.13	2.00
	30	1.15	0.16	2.11
	Mean	1.07	0.13	2.01
Sulphugypsum	15	1.24	0.18	2.1 5
	30	1.36	0.19	2.20
	Mean	1.20	0.16	1.51
Phosphogypsum	15	1.56	0.20	2.25
	30	1.67	0.22	2.29
	Mean	1.41	0.18	1.49
Average	15	1.21	0.16	2.08
	30	1.29	0.17	2.13
L.S.D. at 0.05	R	0.04	0.02	0.10
	S	0.02	0.04	0.12
	R × S	0.05	0.03	0.15

Table 8: Effect of gypsum-sources and rates on SO_4^{-2} and Cl^- content in rice

Treatment		SO_4^{-2}- Content (%)			
Gypsum source (S)	Rate, Mg ha^{-1} (R)	Grain	Stalk	Total	Total Cl^- (%)
Control	0	0.25	1.35	1.60	1.64
Gypsum shall	15	0.30	1.59	1.89	1.50
	30	0.38	1.99	2.37	1.48
	Mean	0.31	1.64	1.95	1.45
Sulphugypsum	15	0.33	2.39	2.78	1.35
	30	0.39	2.56	2.95	1.30
	Mean	0.32	2.10	2.44	1.43
Phosphogypsum	15	0.38	2.60	2.98	1.28
	30	0.41	2.79	3.20	1.20
	Mean	0.35	2.25	2.61	1.37
Average	15	0.33	1.97	2.31	1.44
	30	0.36	2.17	2.53	1.41
L.S.D. at 0.05	R	0.01	0.10	0.03	0.04
	S	0.02	0.07	0.05	0.05
	R × S	0.01	0.05	0.06	0.07

Effect of Gypsum-Sources and Rates on Macronutrients, SO_4^{-2} and Cl^- Content in Rice Plant

Macronutrients Content: Content of N, P and K in rice plants increased significantly with successive applied rates up to 15 Mg ha^1 as shown in Table (7). The increase in N, P and K content might be ascribed to the improved soil characteristics and in turn SO_4^{-2} contents in plant organs. However, the relative increase percentages at the applied rates of 15 and 30 Mg ha^{-1} were 22.2 & 30.3 % for N *vs* 45.5 & 54.5 % for P and 8.2 & 10.9 % for K over the control treatment, respectively. As for gypsum-source, Phosphogypsum recorded a markedly higher N, P and K content over both Sulphugypsum and Gypsum shall.

SO_4^{-2} and Cl^- Content: Total SO_4^{-2} and Cl^-content in rice plants increased significantly with successive applied rates up to 15 Mg ha^{-1}, as shown in Table (8).

The increase in total SO_4^{-2} and decrease in total Cl^- content might be ascribed to the increase in biological yields and in turn S-contents in plant organs. However, the relative increase percentages at the applied rates of 15 and 30 Mg ha^{-1}were 44.3 and 58.1 % for total SO_4^{-2} over the control treatment. As for gypsum- source, Phosphogypsum recorded a markedly higher total content of SO_4^{-2} and decrease in total Cl^-content over both Sulphugypsum and Gypsum shall. The relative increase percentages for SO_4^{-2} content for Phospho- Sulphu- and Gypsum shall were 21.8, 52.5 and 63.1 % and relative decrease percentages for Cl^-content were 11.6, 12.8 and 16.4 % over the control treatment, respectively. These results are in harmony with the findings outlined by [44].

CONCLUSIONS

The study revealed that addition of gypsum-sources at different rates acted as ameliorant to salt affected soils. In this study, Phosphogypsum was more effective in changing EC and SAR. Gypsum-sources added at 100 % gypsum requirement at rate of 30 Mg ha^{-1} improved the soil chemical properties by reducing the EC, SAR and pH, than the applying gypsum aloneat 100 % gypsum requirement at rate of 30 Mg ha^{-1}. Among the treatments, Phosphogypsum had a remarkable effect in reducing soil salinity/sodicity. The yield of rice from Phosphogypsum treatment was higher compared with other treatments.

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