



Management of Zinc for Rice in Sodic Soils

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Influence of amendments on reclamation as well as the availability of plant nutrients will vary. The response of crop for the applied Zn will also vary with amendments. However, field experiment was conducted in sodic soil with various amendments viz., gypsum @ 50 % GR + green manure (6.25 t ha⁻¹), green leaf manure (12.5 t ha⁻¹) and press mud (10 t ha⁻¹) as main-plot treatments. Different levels of zinc sulphate viz., 50, 100 and 150 percent of recommended dose as basal with and without foliar spray of ZnSO₄ @ 0.5 per cent at panicle initiation (PI) and heading stage were imposed as sub-plot treatments. The rice (CO 52) was used as test crop. The results of field experiment revealed that reclamation of sodic soil with gypsum @ 50% GR + green manure @ 6.25 t ha⁻¹ and ZnSO₄ application @ 100% recommended dose (25 kg ha⁻¹) along with foliar spray of 0.5% ZnSO₄ at panicle initiation and heading stages found to be the best for getting higher yield of rice in sodic soils. For unreclaimed sodic soil, ZnSO₄ application @ 150% recommended dose (37.5 kg ha⁻¹) along with foliar spray of ZnSO₄ @ 0.5% at panicle initiation and heading stages is found to be best. The amendments application significantly improved the physicochemical properties, exchangeable cations, available NPK, DTPA-micronutrients of soil. It also increased the

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uptake of NPK and DTPA-micronutrients of soil. The growth and yield parameters also showed a significant response for reclamation and ZnSO₄ application. The application of gypsum + green manure (G+GM) or green leaf manure (GLM) or press mud (PM) can be effectively used as an amendment for the reclamation of sodic soil. The gypsum +GM exhibited its superiority over others.

Keywords: Amendments; gypsum +GM; GLM; press mud; sodic soil; zinc sulphate.

1. INTRODUCTION

Sodicity is a term given to the amount of sodium held in a soil. The problem of alkali land is being faced by a large number of farmers throughout the country [1]. These soils are generally characterized by poor physical condition, total and available (N), phosphorus (P), calcium (Ca) and magnesium (Mg). Micronutrients such as zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) also exhibit low levels of solubility in sodic soils, which may result in micronutrient deficiencies [2]. The Influence of different amendments will vary in improving the soil properties, nutrient availability and yield of rice. The response of rice will also vary for the application of zinc sulphate under different amendments. Hence this study was undertaken to investigate the influence of amendments and zinc sulphate application on physicochemical properties, nutrient availability and yield of rice.

2. MATERIALS AND METHODS

The study was conducted in sodic soil which belongs to clay loam in texture, alkaline pH (9.98), low in EC (0.35 dS m⁻¹), high in ESP (29.6%), low in organic carbon (0.46%), low in available nitrogen (221 kg ha⁻¹), medium in available phosphorus (11.2 kg ha⁻¹) and potassium (126 kg ha⁻¹). The exchangeable cations viz., Ca, Mg, K and Na content of the initial soil was 7.12, 5.65, 0.12, 5.42 (cmol (p⁺) kg⁻¹) respectively. The DTPA-micronutrients viz., Zn, Fe, Mn and Cu content of the initial soil was 0.36, 3.60, 1.69 and 0.65 mg kg⁻¹ respectively. The amendments gypsum @ 50% GR+GM @ 6.25 t ha⁻¹ (M₂), GLM @ 12.5 t ha⁻¹ (M₃) and press mud @ 10 t ha⁻¹ (M₄) were used as main-plot treatments for the reclamation of sodic soil by adopting standardized reclamation procedure and the treatments without amendments were maintained as control (M₁). Different levels of zinc sulphate viz., 50 (S₂), 100 (S₃) and 150 (S₄) percent of the recommended dose of zinc sulphate as basal with and without a foliar spray of ZnSO₄ @ 0.5 per cent at panicle initiation (PI) and heading stages (S₅, S₆, S₇) were imposed as

sub-plot treatments. Control (S₁) was maintained without ZnSO₄ application. All treatments were uniformly applied with recommended levels of NPK fertilizers (150:50:50 N, P₂O₅ and K₂O kg ha⁻¹). The growth and yield attributes of rice were recorded. Post harvest soil samples were analysed for pH, EC, ESP, exchangeable cations, available NPK and DTPA- micronutrients content. Plant samples were analysed for NPK and micronutrients uptake at the harvest stage.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Properties

pH of the soil ranged from 9.95 to 8.34 (Table 1). The application of amendments significantly decreases the soil pH. Maximum reduction in soil pH was recorded in gypsum+ GM applied plots (8.45). The reduction in soil pH on application of gypsum+ GM was attributed to the displacement of exchangeable Na by the calcium ions of gypsum which get leached out due to drainage provided [3]. The addition of GM after gypsum leads to further reduction in pH by producing organic acids during decomposition which solubilizes the native Ca. The GLM proved its superiority over press mud in reducing the soil pH. The fresh organic materials present in the GLM might have readily decomposed and released higher amounts of organic acids. Gypsum application, slightly increased the EC of the post-harvest soil.

A decrease in ESP of 14.8, 4.4 and 3.5% was noted due to gypsum+ GM, GLM and press mud application respectively over the control. In case of gypsum, the reduction in ESP was attributed to the replacement of exchangeable Na by Ca of the gypsum [4]. The application of organic amendments also reduced the soil ESP from the initial level which may be due to an increase in exchangeable Ca and Mg ions due to solubilization during the decomposition of organic matter and also due to the supply of nutrients like K, Ca and Mg from the GLM and press mud.

Table 1. Effect of amendments on physicochemical properties, exchangeable cations, available NPK and micronutrients of post-harvest soil

Treatments *	Unit	Control	Gypsum + GM	GLM	Press Mud	S Ed	CD (0.05)
pH	-	9.95	8.45	8.95	9.13	0.1	0.25
EC	dS m ⁻¹	0.35	0.41	0.37	0.37	0.006	0.01
ESP	%	29.7	14.8	25.2	26.2	0.36	0.91
Ex. Ca		7.13	9.7	7.76	7.79	0.13	0.33
Ex. Mg	cmol	5.64	5.73	5.77	5.79	0.08	0.22
Ex. Na	(p ⁺) kg ⁻¹	5.43	2.71	4.61	4.88	0.07	0.17
Ex. K		0.11	0.13	0.15	0.16	0.002	0.01
Av N		223	235	245	240	3.48	9
Av P	kg ha ⁻¹	11.4	13.3	14	13.9	0.2	0.52
Av K		130	136	142	147	2.17	5
DTPA- Fe		3.64	6.84	6.58	6.37	0.09	0.23
DTPA- Mn	mg kg ⁻¹	1.71	3.6	3.44	3.21	0.05	0.12
DTPA- Cu		0.66	1.22	1.17	1.18	0.02	0.04

*Sub plot treatments and interactions were not significant

3.2 Exchangeable Cations

Application of amendments significantly influenced the exchangeable Ca content of the soil. The exchangeable Ca content was highest in Gypsum + GM treatments (9.70 cmol (p+) kg⁻¹). The highest Ca in the Gypsum + GM applied treatments was mainly due to Ca ions from gypsum (CaSO₄.2H₂O) and solubilization of native calcium on decomposition of green manure incorporated in the fields. The application of organic amendments also considerably increased the exchangeable Ca content. The release of CO₂ during the degradation process decreased the precipitation of Ca²⁺ and CO₃²⁻ ions in the CaCO₃ form [5]. On the other hand, the organic acids released the Ca from CaCO₃. Application of amendments slightly increased the exchangeable Mg content of post-harvest soil. Swarup [6,7] reported that the application of organic matter increased the exchangeable Mg in sodic soil. The organic amendments generated more CO₂ and this could have resulted in greater solubilization of native mineral present in the soil and releases Mg. Another reason includes direct supplement of little amount of Mg by the plant materials on decomposition. Application of organic amendments showed the highest exchangeable K content followed by Gypsum+ GM. Application of amendments drastically reduced the exchangeable sodium content of soil. The exchangeable sodium declined to the tune of 2.72, 0.82 and 0.55 cmol (p+) kg⁻¹ due to Gypsum+ GM, GLM and press mud application respectively over control. The considerable reduction in exchangeable Na was attributed to replacement of exchangeable Na by Ca present in gypsum and dissolution of free lime on

decomposition of GM applied along with gypsum [8].

3.3 Soil Available NPK

Highest available N was observed in the treatments which received GLM (245 kg ha⁻¹) followed by press mud, gypsum+ GM and control. An increase in available N content was higher in organic material applied treatments. This might be due to the release of N from the plant material during decomposition and sustained N mineralization in flooded soils [9]. In gypsum+ GM applied plots also available N increased upto 11 kg ha⁻¹ over the control. This increase was because of GM application rather than gypsum application.

An increase of 2.0, 2.6 and 2.5 kg available P ha⁻¹ was recorded with the application of gypsum+ GM, GLM, and press mud respectively over the control. Organic materials increase the availability of P in sodic through the mechanisms of reduction, chelation and favourable changes in soil pH occurring in flooded soils. The organic matter serves as a carbon substrate for microorganisms which solubilize and mineralize the organic forms of P into inorganic forms [10]. In Gypsum+ GM treatment, the increase in available P status might be due to the presence of GM. The amendments viz., press mud, GLM and gypsum+ GM application showed an increased K content of 18, 12 and 6 kg ha⁻¹ respectively over the control.

3.4 DTPA- Micronutrients

The available micronutrients viz., DTPA-Zn, DTPA-Fe, DTPA-Cu and DTPA- Mn content were significantly influenced by the application of

amendments. The DTPA- Zn was significantly increased by both amendments (gypsum, organic manure and press mud) and zinc sulphate application. Among the amendments Gypsum+ GM treated plots showed highest DTPA-micronutrients content followed by GLM and press mud.

The application of gypsum+ GM decreased the soil pH. A decrease in pH, decreases the Zn precipitation as Zn(OH)₂ and hence the availability increases. Higher availability of applied Zn was observed by Dhaliwal et al. [11] in soils treated with organic amendments could be due to dissolution and greater decrease in pH of the soil besides contribution through added biomass. For every unit decrease in pH there may be a 100-fold increase in Zn concentration in soil solution [12]. Among the zinc sulphate application, DTPA-Zn content increased gradually from lower to higher doses of zinc sulphate, since it supplies an inorganic form of zinc directly to the soil solution (Table 2).

An increase in the availability of Fe and Mn following submergence, addition of organic matter and amendments in sodic soil may be attributed to 1. Conversion of higher oxides of Fe (Fe₂O₃, Fe₃O₄. nH₂O, Fe(OH)₃.nH₂O) and Mn (MnO₂, Mn₂O₃ and Mn₃O₄) to Fe²⁺ and Mn²⁺ as a result of microbial and chemical reduction. 2. Decrease in pH and ESP of sodic soils upon submergence and application of organic matter. Added organic matter accelerated the process of reduction in soil by decreasing the redox potential and increasing pCO₂ and this possibly resulted in the release of Fe²⁺ and Mn²⁺ from their oxides and hydroxides [13]. The increased available micronutrients with green manuring may be due to chemical, enzymatic and metabolic transformation of organic material, as the green manuring is continuously subject to degradation [14]. The other reason might be due to the increased chelation effect of organic matter in all the amended plots.

3.5 Effect of Amendments and Zinc Sulphate on Nutrient Uptake

3.5.1 NPK uptake

Application of amendments significantly increased the macronutrients uptake (Table 3). The highest uptake of NPK was recorded in the treatment which received Gypsum+ GM as an amendment followed by GLM and press mud applied treatments. The higher uptake of N noticed in amended plots might be due to the higher dry matter production (DMP) and also more root growth which might have increased the absorption. The significant rise in the uptake of N by rice was due to the combined effect of higher yield and increased absorption. Organic materials acting as slow- release sources of N are expected to more closely match the N supply and rice N demand. In Gypsum+ GM and GLM and press mud applied plots, the P uptake was increased due to an increase in DMP, direct supplement and also the release of native P to the available pool. Application of amendments enhanced the uptake of K due to dissolution and release of mineral K by the action of organic acids released during decomposition [15]. The application of graded doses of zinc sulphate also increased the NPK uptake due to the enhanced DMP produced by Zn.

Among the zinc sulphate applications, 150% zinc sulphate as basal + foliar spray was registered the highest NPK uptake which might be due to the higher biomass production in these treatments. As zinc is a part of various enzymes and hormones, it favoured increased synthesis of enzymes and hormones along with the metabolization of major nutrients which in turn promoted the growth components. Mazhar et al. [16] reported that the application of zinc narrowed the Na/K ratio and helped to increase the uptake of K.

Table 2. Effect of amendments and zinc sulphate on DTPA-Zn content of soil at post-harvest stage (mg kg⁻¹)

Treatments	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	Mean
M ₁	0.35	0.37	0.41	0.48	0.36	0.42	0.47	0.41
M ₂	0.73	0.89	1.26	1.39	0.86	1.25	1.40	1.11
M ₃	0.70	0.85	1.18	1.30	0.89	1.16	1.26	1.05
M ₄	0.68	0.81	1.10	1.26	0.80	0.98	1.08	0.96
Mean	0.62	0.73	0.99	1.11	0.73	0.95	1.05	0.88
	M		S		M × S		S × M	
SE d	0.01		0.02		0.04		0.04	
CD (0.05)	0.04		0.04		0.09		0.09	

Table 3. Effect of amendments and zinc sulphate on NPK (kg ha⁻¹) and micronutrients uptake (g ha⁻¹) at harvest stage of rice

Treatments	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	Mean
N uptake								
M ₁	36.9	40.6	45.5	51.0	44.6	51.8	56.0	46.6
M ₂	81.4	87.5	90.8	96.2	93.0	97.9	101.5	92.6
M ₃	73.0	80.5	84.1	87.3	84.6	92.7	92.5	84.9
M ₄	70.7	76.5	81.6	86.3	82.3	88.4	88.6	82.1
Mean	65.5	71.3	75.5	80.2	76.1	82.7	84.7	76.6
P uptake								
M ₁	2.99	3.91	4.30	4.36	3.96	4.81	4.81	4.16
M ₂	7.58	9.28	8.51	8.21	9.08	9.76	9.91	8.90
M ₃	6.28	7.86	8.85	7.82	8.38	8.94	8.28	8.06
M ₄	6.11	8.12	8.23	7.92	7.52	6.81	7.52	7.46
Mean	5.74	7.30	7.47	7.08	7.24	7.58	7.63	7.15
K uptake								
M ₁	31.2	36.1	39.3	41.8	37.7	43.6	46.9	39.5
M ₂	69.4	74.9	80.5	85.5	80.4	85.8	88.5	80.7
M ₃	62.8	67.4	72.6	74.6	73.1	79.2	78.4	72.6
M ₄	60.1	66.6	71.1	73.1	71.1	75.6	77.1	70.7
Mean	55.9	61.2	65.9	68.8	65.6	71.0	72.7	65.9
Zn uptake								
M ₁	95.0	118	142	163	145	178	207	150
M ₂	246	305	341	384	360	415	433	355
M ₃	218	269	301	333	325	372	380	314
M ₄	208	255	299	334	313	393	367	310
Mean	192	237	271	303	286	340	347	282
Fe uptake								
M ₁	207	233	250	278	251	290	312	260
M ₂	505	541	569	589	561	599	623	569
M ₃	450	496	524	529	516	554	566	519
M ₄	436	472	501	527	498	530	547	502
Mean	400	436	461	481	456	493	512	463
Cu uptake								
M ₁	25.2	27.6	31.5	34.0	31.3	34.7	37.4	31.7
M ₂	60.1	63.4	66.8	70.6	66.6	72.3	73.2	67.6
M ₃	54.5	58.3	60.3	63.2	61.9	65.9	66.8	61.6
M ₄	52.2	55.1	60.1	62.8	58.9	63.9	64.4	59.6
Mean	48.0	51.1	54.7	57.6	54.6	59.2	60.5	55.1
Mn uptake								
M ₁	224	251	274	303	280	312	333	283
M ₂	516	561	587	616	587	621	637	589
M ₃	461	507	528	544	488	563	576	524
M ₄	442	471	509	532	504	540	545	506
Mean	411	448	475	499	465	509	523	475
	M		S		M×S		S×M	
N uptake								
SE d	1.25		1.43		2.95		2.88	
CD (0.05)	3.06		2.90		6.14		5.79	
P uptake								
SE d	0.10		0.12		0.24		0.24	
CD (0.05)	0.25		0.24		0.52		0.47	
K uptake								
SE d	1.07		1.23		2.54		2.48	
CD (0.05)	2.64		2.50		5.28		4.98	

Treatments	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	Mean
Zn uptake								
SE d	4.4		4.9		10.3		10.1	
CD (0.05)	11		10		22		20	
Fe uptake								
SE d	6.77		7.75		16.1		15.7	
CD (0.05)	16.7		15.8		33.4		31.5	
Cu uptake								
SE d	0.83		0.95		1.96		1.92	
CD (0.05)	2.03		1.94		4.09		3.85	
Mn uptake								
SE d	7.72		8.84		18.3		17.9	
CD (0.05)	19		18		38		36	

Table 4. Effect of amendments and zinc sulphate on yield parameters (kg ha⁻¹) of rice

M / S	Levels of Zinc Sulphate (%)				Levels of Zinc Sulphate (%) + Foliar Spray			Mean
	0	50	100	150	50	100	150	
Grain yield								
Control	2300	2550	2800	3052	2800	3082	3340	2846
Gypsum+ GM	4900	5200	5520	5700	5450	5860	5950	5511
GLM	4360	4680	4960	5100	4990	5320	5391	4972
Press mud	4280	4590	4900	5120	4900	5250	5290	4904
Mean	3960	4255	4545	4743	4535	4878	4993	4558
Straw yield								
Control	2714	3009	3304	3632	3304	3698	4012	3382
Gypsum+ GM	5831	6188	6545	6840	6486	6973	7081	6563
GLM	5232	5616	5902	6018	5988	6384	6372	5930
Press mud	5093	5416	5880	6093	5782	6195	6266	5818
Mean	4718	5057	5408	5646	5390	5813	5933	5423
	M	S		M x S		S x M		
Grain yield								
SEd	74.1	84.8		176		171		
CD (0.05)	182	173		365		344		
Straw yield								
SE d	88.2	101		209		204		
CD (0.05)	217	206		435		410		

3.5.2 Micronutrient uptake

Amendments application significantly enhanced the uptake of micronutrients. This might be due to the increased solubility of their compounds which are present in sodic soil as higher oxides, hydroxides and carbonates and the reduction of soil pH on reclamation enabled rice to mobilize high amounts of these micronutrients. The highest total micronutrient uptake was observed in Gypsum + GM- treated plots followed by organic amendments. This is substantiated by the increased concentration of Fe and Mn in the soil after harvest of rice crop as compared to their initial values [17,18].

In zinc sulphate applied treatments, the highest uptake of zinc was noticed in the treatment which

received 150 per cent RD of zinc sulphate as basal+ foliar spray which was on par with 100 per cent RD of zinc sulphate as basal+ foliar spray. The increase in the zinc content in grain and straw might be due to the presence of increased amount of zinc in soil solution by the application of zinc sulphate. An increase in Zn content in grain and straw due to zinc fertilization was also reported earlier [19]. Suganya et al. [20]. reported that Zn uptake was increased with increased levels of zinc mainly due to the increase in dry matter production, yield and zinc concentration.

3.6 Grain and Straw Yield

Among the amendments, highest grain yield (5511 kg ha⁻¹) was recorded in the gypsum+ GM

applied treatments owing to the creation of a favourable micro climate and increased availability of essential nutrients which in turn increased the crop yields. Next to gypsum+ GM, a higher yield was noted in GLM and press mud applied treatments over the control (Table 4). The organic amendments not only reclaimed the sodic soil but also enhanced soil carbon content and biological properties. The application of zinc sulphate significantly enhanced the grain and straw yield of rice crop. Naik and Das [21] reported that soil application of zinc as ZnSO₄ increased the rice filled grain percentage, 1000-grain weight, number of panicles, grain and straw yield. Higher yield due to zinc fertilization is attributed to its involvement in many metallic enzyme systems, regulatory functions [22], enhanced synthesis of carbohydrates and their transport to the site of grain production.

A higher concentration of zinc in the grain maintained by the application of zinc in the rhizosphere with constant supply coupled with higher zinc uptake might have increased the grain yield. Zinc helps in inducing alkalinity tolerance to crops by enhancing its crop efficiency to utilize K, Ca and Mg and thus increases the crop yield [23].

Among the zinc sulphate applied treatments 100% zinc sulphate as basal+ foliar spray was superior over 150% RD ZnSO₄ as basal applications. In the treatments without any amendments (control), 100% RD+ foliar spray and 150% RD+ foliar spray are significantly different from each other. However in amendments applied treatments 100% RD+ foliar spray and 150% RD+ foliar spray are comparable with each other. The combined effect of amendments and Zinc sulphate application on grain and straw yield of rice was also found to be significant. The treatments gypsum + GM + ZnSO₄ @ 150% RD as basal + foliar spray recorded the highest yield which was on par with gypsum + GM + ZnSO₄ @ 100% RD as basal + foliar spray.

In addition to soil application of zinc sulphate, significant response was observed for the foliar spray of ZnSO₄ @ 0.5% at panicle initiation and heading stage. Though the amendments reduced the pH considerably, still the pH was maintained at higher level (8.45 to 9.13). Further the entire quantity of ZnSO₄ was applied as basal. Hence the applied some portion of applied ZnSO₄ might have been converted into insoluble form at later

stages. Hence foliar spray of ZnSO₄ at later stages (PI and heading stages) might have enhanced the uptake and yield of rice crop in sodic soils. Hence it is recommended that reclamation of sodic soil with gypsum @ 50% GR + green manure @ 6.25 t ha⁻¹ and ZnSO₄ application @ 100% recommended dose (25 kg ha⁻¹) along with foliar spray of 0.5% ZnSO₄ at panicle initiation and flowering stages found to be the best for getting higher yield of rice in sodic soils. For unclaimed sodic soil, ZnSO₄ application @ 150% recommended dose (37.5 kg ha⁻¹) along with foliar spray of ZnSO₄ @ 0.5% at panicle initiation and flowering stages is recommended to get reasonable yield of rice crop.

4. CONCLUSION

The results of the field experiment concluded that the application of amendments improved the physicochemical properties, exchangeable cations, available NPK, DTPA micronutrients and crop nutrients uptake. The highest exchangeable cations and available nutrients were observed with the gypsum @ 50% GR + green manure @ 6.25 t ha⁻¹ and ZnSO₄ application @ 100% recommended dose (25 kg ha⁻¹) along with foliar spray of 0.5% ZnSO₄ at panicle initiation and heading stages treatment followed by green leaf manure (GLM) and press mud (PM) treatments. Application of amendments to sodic soil significantly increased the yield parameters (dry matter production and grain and straw yield) of rice.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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