

## Comparative Effects of Different Methods of Gypsum Application for Amelioration of Salt-Affected Soil

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### ABSTRACT

Soil degradation due to salinity and sodicity poses a significant challenge to the sustainable agriculture on a global scale. Gypsum has global importance for reclamation of sodium affected soil. Therefore, a study was planned to evaluate positive impacts of different methods of gypsum application on physicochemical properties of salt-affected soil and growth performance of rice crop. The treatments applied were: T<sub>1</sub> = Control (without gypsum), T<sub>2</sub> = Gypsum @ 100 % GR before transplanting, T<sub>3</sub> = Top dressing of gypsum @ 100 % GR, 15 days after transplanting, T<sub>4</sub> = Top dressing of gypsum @ 100 % GR, 30 days after transplanting, T<sub>5</sub> = Top dressing of gypsum @ 50 % GR, 15 days after transplanting + Top dressing of gypsum @ 50 % GR, 30 days after transplanting, T<sub>6</sub> = Application of gypsum @ 100 % GR, 15 days after transplanting in dissolved form, T<sub>7</sub> = Application of gypsum @ 100 % GR, 30 days after transplanting in dissolved form, T<sub>8</sub> = Application of gypsum @ 50 % GR, 15 days after transplanting in dissolved form + Application of gypsum @ 50 % GR, 30 days after transplanting in dissolved form. Results of the study revealed that (T<sub>1</sub>) where gypsum was applied 30 days before rice transplanting was more advantageous method for amelioration of saline-sodic soil, decreasing soil pH from (6.60 to 8.44%), EC (35.09 to 49.31%), SAR (35.95 to 49.55%), HC (7.31 to 13.15%) and BD (2.38 to 2.94%) and also showed the highest value for most of the studied parameters of rice crop.

**Keywords:** Gypsum, Salinity, Sodicity, Rice, Amelioration.

### INTRODUCTION

Salt induced land degradation in dry regions is a major prevalent environmental issue, scouring soil health and negative impact on agriculture productivity. Globally, salt induced land degraded area is approximately 424 million hectares of topsoil (0–30 cm) and 833 million hectares of subsoil (30–100 cm) (FAO, 2021) and is expected to increase under scenario of climatic change with rise in temperature and shifts in rainfall patterns. Consequently, rehabilitation of such problematic soil is of global and prime importance to secure food security and sustain agricultural system. Numerous amendments like gypsum, green manure, press mud, biochar, animal

manures are extensively used to modify and improve poor physicochemical soil qualities. The most common and recognized amendments used for saline-sodic soil is gypsum that replace Na with Ca at exchange site and improve soil conditions for plant growth. Gypsum application at 50% to 75% of the soil moisture contents of the water holding capacity is an effective strategy for reclamation of saline-sodic soils (Zhao *et al.*, 2020).

Rashmi, *et al.* (2024) studied the reclamation efficiency of gypsum in combination of organic amendments under oil seed cropping system in saline-sodic soils. They reported that gypsum (2.5 t ha<sup>-1</sup>) in conjunction with crop residue (1.5 t ha<sup>-1</sup>) is the best strategy to achieved higher yield of soybean (1.23 ha<sup>-1</sup>) and mustard (1.43 Mg ha<sup>-1</sup>) by improving soil quality index (0.93), bulk density (3-6 %) and drop exchangeable sodium percentage (45-48 %). Hamoud, *et al.* (2024) evaluated the effect of gypsum (5 t and 10 t ha<sup>-1</sup>) in combination of cotton stick biochar, lime and farm manure on growth and physiological parameters of rice grown in pots under artificially developed salt stresses. They opined that gypsum (10 t ha<sup>-1</sup>) in conjunction with cotton stick biochar (20 t ha<sup>-1</sup>) was more superior treatment leading to significant increase in membrane stability index, chlorophyll content and biomass yield of rice crop.

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Gypsiferous material at rate of 7.85 t ha<sup>-1</sup> has been shown to reduce the soil adsorption ration from 22 to 5, improved aggregate stability and increased fruit oil content, trunk expansion and fruit yield of olive plants grown in sodic soil (Ziskin *et al.*, 2024). Phosphogypsum in combination with other organic amendments is an effective strategy that relieved the salinity stress by promoting anti-oxidative enzymes system in the oilseed rape plant and ameliorated soil properties by reducing soil EC from 1.51 % to 33.49 % and soluble Na<sup>+</sup> contents from 39.47 % to 63.20 % (Xu *et al.*, 2023a). Gypsum in combination with biochar promoted the germination and growth of rice seedlings in pot and improved soil salinity indices by decreasing SAR (68.77%), EC (77.24%) and pH (20.74%) (Xu *et al.*, 2023b). Zhang, *et al.* (2021) conducted an experiment to find out efficient method of gypsum application for amelioration of saline sodic soils. They concluded that band application is a more efficient and better method for long term long-term amelioration of sodic soil due to slow release Ca<sup>2+</sup> which ameliorated salinity indices mor uniformly as compared to blend application. Wang, *et al.* (2021) evaluated the effect of gypsum on productivity and quality of 59 different types of saline-sodic soils across China. They found that gypsum improved soil quality by reducing ESP (37.4%), soil pH (8.1%), bulk density (7.3%) and improved seedling emergence (63.2%), and crop yield (91.2%). Yong-gan, *et al.* (2021) concluded after seventeen years reclamation of sodic soil that gypsum treatments increased nutrient pools and biological activity by increasing contents of organic carbon and available K. Positive effects of gypsum were contributed due to reduction in ESP, pH and EC consequently alfalfa yield increased significantly. Similarly, Sundha, *et al.* (2020) stated that gypsum @ 50% gypsum requirement in conjunction with compost @ 10 t/ha is a viable strategy for decrement of soil pH and leaching of soluble salts. Zhao, *et al.* (2019) asserted that gypsum application (0.75 t ha<sup>-1</sup>) with rice straw (18 t ha<sup>-1</sup>) is an effective practice for improving physicochemical properties of saline-alkali soils and substantially increased the sunflower yield by 20.4%. Gypsum is a safe and viable strategy for rehabilitation of saline-sodic soil (Zhao *et al.*, 2018). After two years of reclamation via gypsum they observed a reduction

of 87.8%, 38.6%, 14.6% in SAR, EC and pH respectively, whereas paddy yield increased was 80%. In field study, Patro and M. Ray (2016) applied gypsum @ 200, 400, 600 and 800 kg/ha with two times of application i.e., 100% at sowing and 50% at sowing + 50% at 30 days after sowing. They reported, split application of gypsum @ 600 kg/ha was most effective and economical method that significantly increased the number of pods/plant, dry pod weight per plant, shelling% and pod yield of ground nut. While gypsum is widely recognized for ameliorating sodic and alkaline soils, limited studies systematically compare the effects of different application timings (e.g., pre-sowing vs. split doses during growth) and methods (e.g., deep incorporation vs. surface broadcasting) on crop performance and soil health. Most research focuses on gypsum's general benefits rather than optimizing application protocols for varying soil types, climatic conditions, and cropping systems. Additionally, long-term studies assessing the timing and method of gypsum application strategies are scarce.

The timing and method of gypsum application significantly influence its effectiveness in improving soil properties, reducing sodicity, and enhancing nutrient availability and final crop yield. Proper and timely application, maximizes gypsum's benefits by ensuring optimal calcium release while minimizing its losses through leaching. In our knowledge, due to shortage of good quality water and to save time farmers usually top dress gypsum in standing crops. Therefore, this study aims to identify the most efficient gypsum application strategies for sustainable soil management and improved crop yields.

## MATERIALS AND METHODS

### Experimental Site

A three years study was carried out at farm of Soil Salinity Research Institute, Pindi Bhattian Pakistan (latitude 31.8950° N and longitude 73.2706° E) from 2018 to 2021. During the period of (2016-20), the mean weather conditions were: sunshine hours ranging from 14h and 8 min to 7 h and 36 min, relative humidity ranges from 36.2 ± 2.8% to 73.2 ± 4.8% and temperature 14.5 ± 2.5°C minimum temperature and 42.6 ± 3.5°C maximum temperature. Three different sites were selected during each study year and pre-experiment soil properties are given in Table 1.

Table 1. Initial soil analysis of three different field

Parameter	Site 1	Site 2	Site 3
pH of soil saturated paste (pH <sub>s</sub> )	9.33	9.23	9.47
Electrical conductivity of soil extract (ECe) (dS m <sup>-1</sup> )	7.55	7.34	8.30
Sodium absorption ratio (SAR)	58.5	63.43	66.20
Gypsum Requirement (GR) (t acre <sup>-1</sup> )	4.20	4.70	3.52

Hydraulic conductivity (HC) (cm hr <sup>-1</sup> )	0.41	0.39	0.38
Bulk density (BD) (Mg m <sup>-3</sup> )	1.65	1.68	1.70

### Experimental Design and Treatment Details

The experiment was laid out in a randomized complete block design with three replications having the plot size of 6m x 4m. The treatments applied were:

T1 = Control (without gypsum),

T2 = Gypsum @ 100 % GR before transplanting,

T3 = Top dressing of gypsum @ 100 % GR, 15 days after transplanting,

T4 = Top dressing of gypsum @ 100 % GR, 30 days after transplanting,

T5 = Top dressing of gypsum @ 50 % GR, 15 days after transplanting + Top dressing of gypsum @ 50 % GR, 30 days after transplanting,

T6 = Application of gypsum @ 100 % GR, 15 days after transplanting in dissolved form,

T7 = Application of gypsum @ 100 % GR, 30 days after transplanting in dissolved form,

T8 = Application of gypsum @ 50 % GR, 15 days after transplanting in dissolved form + Application of gypsum @ 50 % GR, 30 days after transplanting in dissolved form.

In T2, Gypsum (30 mesh size, 80% pure) was applied 30 days before transplanting of rice seedling followed by leaching with canal water. Twenty-five days old seedlings of rice variety ‘‘Kainat 1121’’ was transplanted during 1st week of July and required gypsum was applied according to treatment plan. Fertilizers at the rates of N 110, P 90, and K 60 kg ha<sup>-1</sup> in the form of urea, single superphosphate and sulphate of potash were used. All the agronomical practices and plant protection measures were conducted uniformly.

### Data collection

At physical maturity, data about plant height, No. of tillers plant-1, panicle length, paddy yield, straw yield and 1000 grain weight were documented. Composite

soil samples were collected, air dried, ground, sieved and stored in bottles after the harvest of every crop and analyzed for pH, ECe, SAR, hydraulic conductivity and bulk density using (US Salinity Lab. Staff, 1954). Statistical analyses

Recorded crop data was subjected to analysis of variance. Treatment means comparison was calculated by LSD Test at 5% probability level (Steel et al., 1997) using STATISTIX 8.1 package software.

### RESULTS

#### Effects of different methods of gypsum application on rice growth

Different gypsum application methods led to a significant effect on plant height during three seasons (Table 2). Average data of three season showed that maximum plant height was 112.67 cm for treatment where gypsum was applied 30 days before transplanting (T2), however, it was non-significant ( $P \leq 0.05$ ) from T3 where gypsum was top dress 15 days after transplanting. Top dressing of gypsum was more effective than dissolved form of gypsum. Plant height value was the lowest (99.67 cm) in control (T1) where gypsum was not applied. Average number of tillers were the highest (220) in T2, where gypsum was applied 30 days before transplanting followed by (T3) where top dressing was done 15 days after transplanting (Table 2). Top dressing gave better results than dissolved form of gypsum application. Minimum number of tillers (178.33) were observed in treatment without any amendments. Panicle length was also significantly influenced by gypsum application methods. Panicle length was the highest (21.66 cm) in T2 followed by T3. On contrary, minimum panicle length of 15 cm was recorded in T1 (control).

Table 2. Effect of gypsum application methods on rice growth (Average of three seasons)

Treatments	Plant Height (cm)	Number of tillers (m <sup>-2</sup> )	Panicle length (cm)
T1	99.67 D	178.33 E	15.00 E
T2	112.67 A	220.00 A	21.66 A
T3	110.67 AB	211.00 B	20.66 AB
T4	106.67 BC	202.33 BCD	18.33 CD
T5	109.33 AB	203.33 BC	19.00 BC
T6	102.67 CD	198.67 CD	18.00 CD
T7	101.33 D	194.00 D	16.66 DE
T8	102.33 CD	197.33 CD	17.33 CD

Different letters in the same column indicate significant differences by LSD at  $p \leq 0.05$

Paddy yield is a crucial trait for commercial rice crop growing and different methods of gypsum application significantly affected this yield attribute. Pool data exhibited that full dose of gypsum application 30 days before transplanting (T2) significantly influenced paddy yield and produced maximum yield of 3.36 t ha<sup>-1</sup> (Table 3). Top dressing of gypsum performed better than dissolved form of gypsum application. Control treatment without any amendment divulged minimum paddy yield of 1.60 t ha<sup>-1</sup>. Gypsum

application method also positively affected the straw yield and the highest straw yield (6.83 t ha<sup>-1</sup>) was recorded in T2 which was non-significant from T3. On contrary, minimum yield of 3.20 t ha<sup>-1</sup> was observed in T1 (no amendment). Results in Table 3 also depicted that maximum 1000 grain weight of 30.66 g were produced in treatment where gypsum was applied 30 days before transplanting (T2), whereas, minimum 1000 grain of 24 g was produced by T1 where no amendment was applied.

Table 3. Effect of gypsum application methods on rice growth (Average of three seasons)

Treatments	Paddy yield (t ha <sup>-1</sup> )	Straw yield (t ha <sup>-1</sup> )	1000-grain weight (g)
T1	1.60 D	3.20 E	24.00 G
T2	3.36 A	6.83 A	30.66 A
T3	3.00 AB	6.33 A	29.66 AB
T4	2.43 BC	4.60 BC	27.66 CD
T5	2.53 BC	5.26 B	28.66 BC
T6	2.46 BC	4.66 BC	27.33 DE
T7	2.38 C	3.63 DE	25.33 F
T8	2.34 C	4.03 CD	26.33 EF

Different letters in the same column indicate significant differences by LSD at  $p \leq 0.05$

#### Effects of different methods of gypsum application on soil properties

Data in Table 4 revealed that gypsum application methods substantially decreased the soil pH after harvesting of rice crop at each site. Gypsum application 30 days before transplanting (T2) was more effective methods to decrease soil pH at three

sites, corresponding reduction was 8.36%, 6.60%, 8.44% at site 1, site 2 and site 3 respectively as compared with initial value. On other hand, minimum reduction in pH was observed in control (without gypsum) with reduction of 2.46%, 0.54%, 2.63% at site 1, site 2 and site 3 respectively over its initial value.

Table 4. Effect of gypsum application methods on soil pH<sub>s</sub>

Treatment	Site 1	%Decrease over initial value	Site 2	%Decrease over initial value	Site 3	%Decrease over initial value
T1	9.1	2.46	9.18	0.54	9.22	2.63
T2	8.55	8.36	8.62	6.60	8.67	8.44
T3	8.68	6.96	8.74	5.30	8.76	7.49
T4	8.78	5.89	8.84	4.22	8.86	6.44
T5	8.79	5.78	8.82	4.44	8.84	6.65
T6	8.66	7.18	8.83	4.33	8.73	7.81
T7	8.88	4.82	8.89	3.68	8.91	5.91
T8	8.77	6.00	8.82	4.44	8.84	6.65

EC of soil in three different sites also showed variation with gypsum application methods and maximum depreciation in soil EC over initial value was observed in T2 with reduction of 35.09%, 49.31%, 41.92% at site 1, site 2 and site 3 respectively. On contrary,

lowest reduction of 9.93%, 14.57%, 14.69% in soil EC at site 1, site 2 and site 3 respectively was noted in control.

Table 5. Effect of gypsum application methods on soil EC (dS m<sup>-1</sup>)

Treatment	Site 1	%Decrease		Site 2	%Decrease		Site 3	%Decrease	
		over value	initial		over value	initial		over value	initial
T1	6.80	9.93		6.27	14.57		7.08	14.69	
T2	4.90	35.09		3.72	49.31		4.82	41.92	
T3	5.38	28.74		4.56	37.87		5.52	33.49	
T4	6.30	16.55		5.40	26.43		6.10	26.50	
T5	5.55	26.49		4.92	32.97		5.10	38.55	
T6	5.40	28.47		4.74	35.42		5.20	37.34	
T7	6.40	15.23		5.48	25.34		6.32	23.85	
T8	6.30	16.55		5.06	31.06		6.18	25.54	

Soil SAR was also improved in response to gypsum application and T2 was most effective methods for improving soil SAR of salt affected field. SAR was decreased by 38.80%, 49.55%, 35.95% at site 1, site 2 and site 3 respectively with gypsum application 30 days before transplanting (T2). In general, top

dressing was more effective methods of improving soil SAR than dissolved form of gypsum application. Whereas, minimum reduction of 8.71%, 8.24%, 5.74% was observed in control (without gypsum) at site 1, site 2 and site 3 respectively.

Table 6. Effect of gypsum application methods on soil SAR

Treatment	Site 1	%Decrease		Site 2	%Decrease		Site 3	%Decrease	
		over value	initial		over value	initial		over value	initial
T1	53.4	8.71		58.20	8.24		62.4	5.74	
T2	35.8	38.80		32.00	49.55		42.4	35.95	
T3	43.8	25.12		38.55	39.22		49.8	24.77	
T4	45.6	22.05		45.26	28.64		56.16	15.16	
T5	44.2	24.44		40.34	36.40		52.42	20.81	
T6	44.5	23.93		40.80	35.67		56.12	15.22	
T7	48.2	17.60		48.36	23.75		58.16	12.14	
T8	46.7	20.17		42.58	32.87		58.20	12.08	

Changes in HC value of three different sites with application of gypsum are shown in Table 7. Data depicted that maximum increase in soil HC was observed in T2 with increase of 7.31%, 10.25%,

13.15% at site 1, site 2 and site 3 respectively as compared with initial value. On other hand no pronounced effect was observed in T1, T7 and T8 on this physical parameter of soil.

Table 7. Effect of gypsum application methods on soil HC (cm hr<sup>-1</sup>)

Treatment	Site 1	%Increase		Site 2	% Increase		Site 3	% Increase	
		over value	initial		over value	initial		over value	initial
T1	0.41	0.00		0.39	0.00		0.39	2.63	
T2	0.44	7.31		0.43	10.25		0.43	13.15	
T3	0.43	4.87		0.41	5.12		0.42	10.52	
T4	0.42	2.43		0.41	5.12		0.42	10.52	
T5	0.42	2.43		0.40	2.56		0.42	10.52	
T6	0.42	2.43		0.40	2.56		0.40	5.26	
T7	0.41	0.00		0.40	2.56		0.39	2.63	
T8	0.41	0.00		0.39	0.00		0.39	2.63	

Data in Table 8 referred that gypsum application 30 days before transplanting (T2) was most effective method of decreasing soil bulk density with reduction

of 2.42%, 2.38%, 2.94% at site 1, site 2 and site 3 respectively. Whereas T1, T6, T7 and T8 remained almost ineffective to decreased soil bulk density.

Table 8. Effect of gypsum application methods on soil BD ( $\text{Mg m}^{-3}$ )

Treatment	Site 1	%Decrease over initial value	Site 2	%Decrease over initial value	Site 3	%Decrease over initial value
T1	1.65	0.00	1.67	0.59	1.70	0.00
T2	1.61	2.42	1.64	2.38	1.65	2.94
T3	1.63	1.21	1.65	1.78	1.66	2.35
T4	1.63	1.21	1.66	1.19	1.66	2.35
T5	1.63	1.21	1.66	1.19	1.67	1.76
T6	1.65	0.00	1.67	0.59	1.69	0.58
T7	1.65	0.00	1.67	0.59	1.70	0.00
T8	1.65	0.00	1.67	0.59	1.70	0.00

## DISCUSSION

Salinity and sodicity induced land degradation is a serious concern in arid and semi-arid regions of the world, scouring soil health and crop productivity. The utilization of soil amendments like gypsum, green manure, press mud, biochar and animal manure has a high potential to reduce soil salinity/sodicity and improve poor physicochemical properties of degraded salt-affected soils. Of these, most cost effective, efficient and most extensively used amendment is gypsum. For efficient rehabilitation of saline-sodic soil gypsum is usually broadcasted and mix with upper soil surface followed by irrigation (Liao et al., 2019). In our knowledge, due to shortage of good quality water and to save time farmers usually top dress gypsum in standing crops. Therefore, this study was conducted with specific objective to compare efficiency of conventional gypsum application method with farmer practice and their effects on soil qualities and rice yield. Results of the study demonstrated that rice crop showed positive response to gypsum application relative to control (no gypsum), however, top dressing or application of gypsum in dissolve form were less effective in improving rice yield and soil properties as compared to gypsum application 30 days before transplanting.

Gypsum after dissolution release large amount of Ca that replace Na at exchange site and reduce salinity-sodicity. In treatment gypsum application 30 days before transplanting provide sufficient time to complete chemical reaction and duration for amelioration of saline-sodic soil is large enough. Therefore, improved soil qualities after amelioration positively impact plant growth conditions. So, better growth performance of rice crop with gypsum application before transplanting may be attributed with increased soil organic matter (Wang et al., 2017) improved nutritional status and microbial activity (Zhao et al., 2019), these factors promote plant growth and subsequently final grain yield. Similarly, (Yonggan et al., 2021) stated that gypsum application increased soil organic carbon, microbial biomass

nitrogen and available potassium by 18, 194, and 51% respectively compared with the no-gypsum. Gypsum with organic amendments lowered hydrogen peroxide levels, increased non-enzymatic activity thus making plant cells more stable which in turn improved physiological traits of rice plants under salt stress (Hamoud et al., 2024). Phosphogypsum relieved salinity stress in the oilseed rape plant by improving microbial activity, soluble sugars, proline and soil nutrient content and activating anti-oxidative enzymes (Xu et al., 2023a). All these findings strengthen the results of current study. Evidently gypsum application 30 days before transplanting caused substantial improvement in soil physical and chemical properties (Table 4-8). Consequently, rice crop took the advantages of improved soil conditions in this treatment and produced more yield than other treatments. On contrary, top dressing of gypsum or its application in dissolved form did not cause significant changes in soil physicochemical properties that resulted little impact on rice growth and yield.

Soil properties were also improved with gypsum application as expected as it is known rich source of Ca and ameliorate salinity indices. Initial value pH value in all three selected field was 9.23 to 9.47 at onset of study and reduced substantially after gypsum application regardless of its application method as compared to no gypsum. However, gypsum application 30 days before transplanting was more efficacious method for improving unfavorable pH as compared to top dressing and dissolved form application of gypsum. The possible reason for the improvement in this treatment may be early release of large amount of Ca which replaced Na to lower soil pH (Koralegedara et al., 2019; Zhang, et al., 2021). Gypsum 30 days before transplanting was also the best ameliorated treatment with lowest value of EC and SAR. The prolong improvement time and fastest removal of Na with Ca render it more advantageous methods for amelioration of saline-sodic soil (Zhang, et al., 2021).

Gypsum application 30 days before transplanting followed by irrigation leaches soluble ions and Na contents into the deeper soil layer prompting formation of stable soil aggregates, enhanced soil flocculation and improved the soil structure (Zhao et al., 2019a; Tirado-Corbal et al., 2019). All these factors increased permeability of salt-affected soil and consequently physicochemical properties of saline-sodic soil are ameliorated (Liao et al., 2019; Zhao et al., 2019b). Similar findings were described by Rashmi, et al (2024) that gypsum (2.5 t ha<sup>-1</sup>) in conjunction with crop residue (1.5 t ha<sup>-1</sup>) decreased bulk density (3-6 %) and drop exchangeable sodium percentage (45-48 %). Wang et al. (2021) also stated that gypsum improved soil quality by reducing ESP (37.4%), soil pH (8.1%), bulk density (7.3%) and improved seedling emergence (63.2%), and crop yield (91.2%). Gypsum @ 5 t ha<sup>-1</sup> (Amezketta et al., 2005) or 4 t ha<sup>-1</sup> (Yu et al., 2003) improved the infiltration rate as compared with a control which reinforced the finding of current study.

### CONCLUSION

In current study we evaluated the effect of three different modes of gypsum application on soil physicochemical properties and growth performance of rice crop in saline-sodic soil. Results of study concluded that gypsum application 30 days before rice transplanting was more advantageous method for saline-sodic soil amelioration and also showed the highest value for most of the studied parameters of rice crop.

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