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Optimizing Gypsum Levels for Amelioration of Sodic Soils to Enhance Grain Yield and Quality of Rice (*Oryza sativa* L.)

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Field experiment was conducted on a fine loamy, mixed, hyperthermic, highly sodic soil having pH (10.5), electrical conductivity (EC) (2.42 dS m^{-1}), exchangeable sodium percentage (ESP) (89.0), organic carbon (OC) (0.80 g kg^{-1}) and available nitrogen (94 kg ha^{-1}) to determine the response of two rice (*Oryza sativa* L.) varieties (CSR 13 and Pant 4) to gypsum levels [(control, 15, 25 and 50% gypsum requirement (GR)]. The study revealed that all the growth parameters (plant height, number of tillers, dry matter accumulation, number of leaves/hill, leaf weight/hill and leaf area index), yield attributes (length of panicle, number of grains/panicle, test weight) and yields (biological yield, straw yield and grain yield) significantly increased with increasing doses of gypsum. Application of gypsum at 50% GR (15.4 t ha^{-1}) was significantly superior over the control and 15% GR doses but at par with that of 25% GR. Significant reduction in soil pH (10.50 to 8.91), EC (1.43 to 0.48 dS m^{-1}) and ESP (89 to 28.5) and increment in OC (0.8 to 1.2 g kg^{-1}) and available N (94 to 190 kg ha^{-1}) were recorded after three years of study with 50% GR level. Grain quality of rice in terms of N content in grain, grain length, length:breadth ratio, brown rice recovery, milled rice recovery, head rice recovery and gel consistency were higher with 50% GR as compared to control but statistically at par with that of 25% GR. There were significant varieties × gypsum interactions on number of effective tillers, dry matter accumulation, number of leaves/hill, leaf weight, number of panicles m^{-2}, length of panicle, number of grains/panicle, test weight and grain yield indicating that the varieties responded to gypsum differently. Variety 'CSR 13' showed significant increase over 'Pant 4' in all the growth parameters and yield attributes except length of panicle.

Key words: Gypsum levels, grain yield and quality, sodic soils, soil amelioration

Salinity is a global problem reducing plant growth and productivity worldwide, and affects about 7% of the world's total land area (Flower *et al*. 1997). In the world about 1200 million hectare (Mha) of land is affected with salinity and, therefore, poses a challenging task of taking up agriculture and enhancing productivity in these areas (Poonamperuma 1984; Tanji 1990). Some of the most severe problems in soil salinity are reported in arid and semiarid regions of the world (Pesarrakli 1999), where limited rainfall, high evapo-transpiration and high temperature play an important role in increasing the salt concentration in the root zone. There could be two possible ways to overcome salt stress (i) either improve the soil environment for the normal plant growth through leaching of salts from the profile through chemical amendment like gypsum ($CaSO_4 . 2H_2O$) (Meri 1984; Al-Nabulsi 2001) or (ii) improve the plant itself which can be grown in that environment (Jardat *et al.* 2004; El-Hendawy *et al.* 2005). The first approach is resource costly and the second is based on the development of salt tolerant varieties. There could be a third approach, *i.e.* hybrid approach, based on exploitation of synergies between gypsum and salt tolerant varieties (Singh *et al.* 2009). Although million of hectares of salt-affected soils are potentially suitable for crop production with appropriate improvement measures, they are left uncultivated or are grown with crops with very low yields because of salinity problem.

Rice (*Oryza sativa* L.) is one of the most important cereal crops grown in wide range of climatic zones to nourish the mankind. Rice varieties suited to normal conditions may rarely or mostly not adapt under salt stress conditions. Few screening studies have been reported based on stability of rice

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genotypes across sodicity stress and non-stress environments (Zapata *et al.* 1991; Shylaraj *et al.* 1994) while no such study has been reported for sodicity stress. Sodicity being a specific agroedaphic environment spread over about 3.8 Mha area of the country (NRSA and Associates 1996) for which gypsum ($CaSO_4.2H_2O$) is generally recommended for the reclamation. Cultivation of rice is generally recommended as first crop after application of gypsum because continuous submergence improves soil properties. Gypsum application markedly decreased the soil pH, exchangeable sodium percentage (ESP) and significantly increased the yield and nutrient uptake by rice (Singh *et al*. 2008).

More than 70% farmers in the region of sodic soils belong to small and marginal categories and the initial cost of reclamation is beyond the reach of this category of farmers because of heavy investment on account of gypsum (Dutta *et al*. 1996). Earlier studies revealed that judicious and proper use of gypsum can markedly increase the yield and nutrient uptake of rice. However, little information is available on the combined effect of gypsum and varieties on soil amelioration, grain yield and quality of rice. Therefore, given the importance of gypsum on sodic soil amelioration and grain yield of rice, it is necessary to know the extent of benefit a rice variety, which can confer to increase yield and associated components. Therefore, a three years study was undertaken to have a detailed account of the response of rice varieties and soil amelioration to gypsum.

Materials and Methods

Site Characterization

A field experiment to find out the response of gypsum on growth, yield and quality of rice and soil health was conducted in barren sodic soil at ICAR-Central Soil Salinity Research Institute, Regional Research Station, Lucknow (Shivri Farm), Uttar Pradesh for 3 years from 2001 to 2003. It is situated at an elevation of 120 m above mean sea level extending from 26°47′ to 26°48′ N latitude and 80°46′ E longitude. The mean annual rainfall is 817 mm and more than 80% generally occurs during monsoon season (July to September). Mean annual soil temperature varies from 18.6 °C during winter to 32 °C during summer. The soil of the experimental field was highly sodic with pH (1: 2 soil: H_2O) 10.5, electrical conductivity (EC) 2.42 dS m^{-1} and ESP 89, having low organic carbon (OC) (0.80 g kg^{-1}) and available N (94 kg ha^{-1}), medium available P (25 kg ha^{-1}) and rich in available K (388.8 kg ha^{-1}) at 0-15 cm soil depth. The GR of the experimental soil determined by Schoonover (1952) method at the time of initiating the experiment (2001) was 30.8 t ha^{-1}.

Experimental Details

A four-times replicated experiment was laid out in a split plot design with four gypsum levels (control, 15% GR, 25% GR and 50% GR) as main plot treatment and two varieties 'CSR 13' and 'Pant 4' as sub-plot treatment in an elementary plot of 50 m^2 size. Both the varieties were planted randomly in each gypsum plot covering 25 m^2 area. As per treatments, gypsum was incorporated once in surface soil up to 10 cm depth in the month of June and about 10 cm water was ponded in the plots for 10 days to displace the reaction products of Ca-Na exchange down the root zone. Thirty-days-old seedlings of two rice varieties 'CSR 13' and 'Pant 4' were transplanted at 20 cm row to row and 15 cm plant to plant spacing during first week of July every year. The recommended doses for sodic soils of N (150 kg ha^{-1}) and zinc sulphate ($ZnSO_4$) (25 kg ha^{-1}) were applied uniformly in all the treatments. Basal fertilizer schedule consisted of half dose of N (75 kg ha^{-1}) and full dose of zinc sulphate (25 kg ha^{-1}) were applied uniformly in all the treatments. The remaining half the dose of N (75 kg ha^{-1}) was applied in two equal splits at 30 and 60 days after transplanting. Plots received identical cultural treatments in terms of ploughing, cultivation, transplanting method and disease control, *etc*.

Plant Growth and Yield Parameters

Five hills in each plot were randomly selected and tagged for recording growth parameters like plant height, numbers of effective tillers/hill, number of leaves/hill, leaf weight and leaf area index. Dry matter accumulation was recorded at 30 days interval from 3 hills/plot harvested from outside the net plot area. Days to 50% flowering was recorded from the number of panicles emerged in a unit area. The net plots area (20 m^2 for each variety) was harvested and the biological yield was recorded. Yield attributes *viz*., length of panicle, grains/panicle and 1000 grain weight were recorded from tagged plants. The grain and straw yields were recorded after threshing, cleaning and drying of produce and straw yield was obtained by subtracting grain yield from total biomass yield. The benefit:cost (B:C) ratio was computed on the basis of prevailing market price of produce and local cost of inputs.

Grain Quality Analysis

Nitrogen content in grain was analyzed following Kjeldahl method using block digestion and steam distillation method (Foss Analytical 2003). Length: width ratio of grain with and without husk, length: width ratio of cooked rice, brown rice recovery, milled rice recovery, head rice recovery and gel consistency at 30 and 60 min after cooking were analyzed as per standard methods.

Soil Analysis

Soil samples (0-15 cm) were taken every year after harvesting of rice crop and analyzed to monitor the changes in soil properties due to gypsum doses and rice varieties. Air-dried soil samples were ground to pass through 2-mm sieve and analyzed for pH and EC using a glass electrode. The OC content was determined by Walkley and Black method (Jackson 1973). Available N was determined by distillation of soil with $KMnO_4$ and NaOH (Subbiah and Asija 1956). Exchangeable Na^+ percentage (ESP) was calculated by the formula ESP = [exchangeable Na^+ (cmol(p^+)kg^{-1}) × 100/CEC (cmol(p^+)kg^{-1})] (Richards 1954).

Statistical Analysis

A two-way analysis of variance (ANOVA) was used to test the effect of gypsum doses and varieties as well as their interaction on growth, yield and quality of rice. The data were analyzed using the statistical package MSTAT C. The differences between the gypsum mean effects were compared using the least significant differences (*LSD*) at the probability level *P*= 0.05.

Results and Discussion

Effect of Gypsum on Soil Amelioration

After three years of rice, the pH of surface soil (0-15 cm) treated with gypsum at 50% GR declined from 10.5 to 9.10 whereas, it decreased to 9.34 in the treatment receiving gypsum at 25% GR for the 'Pant 4' variety (Table 1). In control plot, it declined to 10.01. Growing the 'CSR 13' variety and applying 25 and 50% GR doses of gypsum reduced the soil pH to 9.21 and 9.00 whereas, growing the 'Pant 4' variety declined it to 9.34 and 9.10, respectively. There was no significant difference in soil pH due to varieties. It may be because sodic soils contain measurable amount of $NaHCO_3$ and Na_2CO_3 which under normal conditions react with added gypsum ($CaSO_4.2H_2O$) to neutralize and precipitate soluble Ca before it can be used to replace exchangeable Na.

The ESP of the surface soil declined from 89 to 45.4 and 45.7 at 25% GR for CSR 13 and Pant 4, respectively; however, it reduced to 32.0 and 34.4 at 50% GR after three years. There was no significant difference in ESP due to varieties but combined effect of gypsum and varieties plays a significant role in ESP levels (Singh *et al*. 2008). One possible reason may be because of cultivation of rice crop which has capacity to solubilize soil native $CaCO_3$ to further reduce soil exchangeable sodium. Chhabra and Abrol (1977) have also reported the changes in ESP and

Table 1. Improvement in soil properties due to the combined effect of gypsum and rice varieties

Soil properties	Control		15% GR		25% GR		50% GR		*LSD*
	CSR 13	Pant 4	CSR 13	Pant 4	CSR 13	Pant 4	CSR 13	Pant 4	*(P≤0.05)*
First year									
pH (1:2)	10.18	10.24	9.95	9.98	9.50	9.58	9.22	9.40	0.48
EC (1:2) (dS m^{-1})	0.97	1.01	0.64	0.88	0.67	0.69	0.65	0.69	0.08
ESP	82.1	87.21	72.62	75.43	60.00	63.67	45.50	52.76	6.34
OC (g kg^{-1})	0.84	0.81	1.04	0.86	1.08	0.90	1.10	1.00	0.02
Alkaline $KMnO_4$-N (kg ha^{-1})	96.4	97.10	104.52	100.25	128.60	124.30	146.62	140.50	8.92
Second year									
pH (1:2)	10.01	10.04	9.61	9.75	9.30	9.40	9.12	9.22	0.33
EC (1:2) (dS m^{-1})	0.82	0.82	0.63	0.74	0.59	0.63	0.53	0.67	0.04
ESP	80.0	82.6	62.5	66.6	52.6	54.8	42.6	45.4	8.12
OC (g kg^{-1})	0.86	0.84	1.06	0.88	1.10	0.95	1.15	1.16	0.04
Alkaline $KMnO_4$-N (kg ha^{-1})	102.3	100.2	120.5	118.4	150.2	144.6	171.4	167.5	7.68
Third year									
pH (1:2)	9.88	10.01	9.46	9.51	9.21	9.34	9.00	9.10	0.64
EC (1:2) (dS m^{-1})	0.76	0.82	0.60	0.66	0.56	0.62	0.48	0.54	0.06
ESP	72.2	75.1	55.2	57.3	45.4	45.7	32.0	34.4	7.68
OC (g kg^{-1})	0.90	0.86	1.06	0.90	1.18	1.00	1.20	1.20	0.03
Alkaline $KMnO_4$-N (kg ha^{-1})	110.2	110.1	143.5	142.5	172.6	168.5	190.2	190.2	4.63

improvement in soil properties with gypsum doses and cultivation of rice. Combined effect of gypsum and rice cultivars has generated more organic acids, which mobilize the soil calcium to leach down the salts from the root zone. Addition of gypsum increased the OC content of the soil. After three years of rice with 'CSR 13' and 'Pant 4' at 25 and 50% GR levels, the OC content of the surface soil increased significantly to 1.18, 1.04, 1.00 and 1.20 g kg^{-1}, respectively over the initial value of 0.80 g kg^{-1}. After one year of study *i.e.* after first year, available N content with 15, 25 and 50% GR increased by 8.4, 33.4 and 42 per cent over the control for the 'CSR 13' variety. Available N content after three years increased significantly to 190 kg ha^{-1} with 50% GR which is about 72.6 per cent over the control. However, difference between the varieties in this character was not significant. There may be one possible reason that enhanced organic matter in soil and total biomass generated with respect to gypsum levels and growing of rice which indirectly facilitates the removal of exchangeable Na^+ by increasing the cross sectional area of conducting pores, resulting in increased permeability and generation of more organic acids that mobilize the soil calcium. Rice roots provide channels for the movement of water, which increased permeability (Chhabra and Abrol 1977).

Effect of Gypsum on Plant Growth

Plant height was significantly (*P=0.05*) increased by increasing doses of gypsum. The increment in plant height was 50.3, 58.1 and 67.8 per cent at 15, 25 and 50% GR doses compared with the control treatment, respectively. A non-significant interaction between gypsum and varieties on plant height was observed (Table 2). The increase in plant height in response to gypsum levels is due to reduction in soil pH and exchangeable sodium and increase in OC and available N (Table 1) which might have enhanced more leaf area resulting into higher photo assimilates and thereby resulted in more dry matter accumulation. The growth reduction in sodic soils could also be the result of toxic effects related to the accumulation of Na^+ ions (Ehert *et al.* 1990; Brugnoli and Lauter 1991; Saneoka *et al.* 1999; Akhtar *et al.* 2001).

Number of effective tillers/hill at harvests (95-100 days after transplanting) increased significantly with increasing doses of gypsum (Table 2). Gypsum at 50% GR produced the maximal number of effective tillers/hill (9.86) but the difference between 25 and 50% GR levels was not statistically significant. However, there was no significant difference between varieties in this character. Numbers of green leaves/hill were significantly higher with 50% GR but statistically at par with that of 25% GR. A similar pattern was also registered with respect to leaf weight/hill. The increase in leaf count as well as leaf weight/hill with increasing levels of gypsum may be because of reduction in soil pH and exchangeable sodium and increasing OC content and available N in soil system (Table 1) which, in turn, increased photosynthesis and assimilates the photosynthates. Singh *et al.* (1983) have reported that addition of gypsum increased leaf count, leaf weight as well as leaf area which increased nutrient availability in the plants as a result of better root development and increasing N use efficiency. Application of gypsum at 50% GR recorded maximum leaf area index (2.21) while the minimum (1.22) was observed in the control plot. It might be due to improved soil health with increasing levels of gypsum,

Table 2. Response of growth parameters of rice varieties to gypsum (3 years pooled data)

Treatments	Plant height (cm)	No. of effective tillers/hill	Dry matter (g/hill)	No. of leaves/ hill	Leaf weight (g/hill)	Leaf area index	Number of panicle/ m^2	Days to 50% flowering	Days to maturity
Gypsum levels (% GR)									
0	62.1	3.80	19.7	33.3	22.2	1.22	95.4	90	122
15	93.3	6.96	44.1	51.5	32.5	1.54	170.4	101	132
25	98.2	8.16	57.6	72.2	39.6	1.88	386.5	105	140
50	104.2	9.86	61.8	82.1	43.5	2.21	435.2	108	145
SEm ±	5.24	0.34	1.67	3.12	0.02	0.021	7.10	0.87	1.46
LSD (P=0.05)	16.5	1.09	5.29	9.12	0.08	0.06	21.2	2.63	4.52
Varieties									
CSR 13	94.2	8.36	55.8	64.8	36.84	1.84	324.5	102	135
Pant 4	84.6	6.02	47.9	51.4	31.43	1.62	312.2	108	142
SEm±	1.70	1.20	0.87	1.46	0.54	0.01	2.25	0.76	1.01
LSD (P=0.05)	4.70	3.60	2.69	4.52	1.64	0.04	6.74	2.12	2.63
Interaction	NS	NS	*	*	*	*	*	*	*

*Significant at the 0.05 probability level, SEm±: Standard error of means, LSD: Least significant difference higher nutrient availability and enhanced plant growth.

The data presented in table 1 revealed a statistically significant increase in dry matter due to increasing levels of gypsum. Significantly higher dry matter accumulation (61.8 g/hill) was obtained from 50% GR at harvest of crop. These results were statistically at par with that of 25% GR because of almost similar vegetative growth due to non significant difference in soil pH, OC and available N status of the soil (Table 1). The higher dry matter yield from higher levels of gypsum could be due to more availability of N to the plants (Obrejanu and Sandhu 1971). These differences were statistically significant over the control for which the lowest dry matter accumulation (19.7 g/hill) was obtained.

Days to 50% flowering and days to maturity were also affected with increasing levels of gypsum. 50% flowering in control plot was recorded about 10-18 days earlier than the gypsum treated plots. It might be due to physiological stress in the plant. Similar trend was also observed in days to maturity**.** This result is consistent with the findings of Kingsbury and Epstein (1986) and Houshmand *et al*. (2005). All the growth parameters of 'CSR 13' were significantly superior over the 'Pant 4'.

Effect of Gypsum on Yield Attributes

Panicle length in rice increased with increase in gypsum rates (Table 3) up to 50% GR level but significant difference in this character was recorded only up to 25% GR level. However, a non significant effect of variety × gypsum interaction was observed. Number of grains/panicle differed significantly with the levels of gypsum. A significant interaction was also exhibited between varieties × gypsum levels (Table 3). Again in terms of test weight, 25 and 50% GR were at par between themselves but significantly superior over control and 15% GR levels with a non significant variety × gypsum interaction. Variety 'CSR 13' gave significantly higher panicle length over the 'Pant 4'. This might be due to more root proliferation and increasing N use efficiency of CSR 13 in the gypsum treated plots (Kumar *et al.* 1994). Similarly, the test weight of 'CSR 13' was significantly higher than the traditional variety 'Pant 4' because of bolder grain size (Table 3). It appears that the application of gypsum, which contains sulphur, increased the protein percentage, which in turn increased the grain weight (Kadamdhad *et al*. 1996).

Effect of Gypsum on Grain, Straw and Biological Yields

The grain yield data (Tables 3 and 4) indicate a positive response to gypsum application. The pooled data revealed that application of gypsum at 50% GR gave the maximal grain yield of rice (4.75 t ha^{-1}), which was statistically at par with that of 25% GR (4.35 t ha^{-1}) understandably because of the similar trend in yield attributing characters like length of panicle, number of grains/panicle and test weight. Chhabra *et al.* (1989) have also reported non-significant difference in rice grain yield between 25 and 50% GR levels. Similarly, Arora *et al.* (2015) recorded highest grain and straw yield of CSR36 paddy with gypsum @ 50% GR compared to 25% GR

Table 3. Response of yield attributes, yields, harvest index and benefit: cost ratio of two rice varieties to gypsum (3 years pooled data)

Treatments	Length of panicle (cm)	No. of grains/ panicle	Test weight (g)	Biological yield (t ha^{-1})	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Harvest index	B:C ratio
Gypsum levels (% GR)								
0	15.8	29.6	17.6	2.71	2.35	0.36	13.2	0.39
15	21.9	92.3	22.8	9.86	6.87	2.99	30.3	1.37
25	24.3	126.2	24.8	13.03	8.68	4.35	33.3	1.76
50	25.6	137.3	25.7	14.19	9.44	4.75	33.4	1.78
SEm±	1.06	1.76	0.67	0.42	0.32	0.16	0.007	0.02
LSD (P=0.05)	3.36	5.72	1.91	1.30	1.05	0.50	0.026	0.07
Varieties								
CSR 13	21.8	103.0	24.8	10.8	7.47	3.40	31.2	1.60
Pant 4	22.2	89.7	20.7	9.0	6.22	2.82	31.1	1.49
SEm±	0.53	1.54	0.60	0.42	0.16	0.07	0.004	0.02
LSD (P=0.05)	NS?	4.71	1.65	1.23	0.51	0.23	0.017	0.06
Interaction	NS	*	NS	NS	NS	*	NS	*

* Significant at the 0.05 probability level, ns: non-significant at P=0.05.

Table 4. Analysis of variance for the response of plant height, number of effective tillers, dry matter accumulation, days to 50% flowering, days to maturity, length of panicle, test weight , biological, straw and grain yields to gypsum and varieties

Characters	Replication (3 d.f.)	Gypsum (3 d.f.)	Varieties (1 d.f.)	Gypsum × varieties (3 d.f.)
Plant height	1.925	12.976*	15.513*	0.250
No. of effective tillers/hill	1.068	55.180*	55.086*	1.500
Dry matter accumulation	0.152	128.798*	37.534*	4.628*
Days to 50% flowering	0.630	9.681*	12.631*	3.102*
Days to maturity	0.320	14.342*	9.861*	4.130*
Length of panicle	0.224	16.064*	0.351	0.640
Test weight	1.143	22.835*	22.844*	0.497
Biological yield	0.463	158.445*	38.457*	8.312*
Straw yield	0.625	92.250*	22.957*	6.851*
Grain yield	0.170	471.646*	101.626*	5.134*

*Significant at the 0.05 probability level.

in sodic soils. The decrease in yield under control might have occurred due to retarded growth of the plants as a result of the low uptake of water and nutrients as well as the ion-toxic effects of Na^+ (Yeo and Flower 1986; Flower *et al.* 1990; Akhtar *et al.* 2001). The variety 'CSR 13' gave significantly higher grain yield than 'Pant 4' and a significant interaction between varieties × gypsum on grain yield was observed. It indicates that varieties responded to sodicity levels differently. The mean increase in grain yield of 'CSR 13' was 21 per cent over traditional variety 'Pant 4'. Sridhar *et al*. (1985) reported higher response to gypsum in respect of grain yield which might be due to readily available S in gypsum. Straw yield with 50% GR was significantly higher over control and 15% GR levels because of higher plant height (Table 1) and dry matter accumulation (Table 2) but it was at par with that of 25% GR. It was observed that 50% GR gave the maximal straw yield (10.2 t ha^{-1}) while the lowest straw yield (2.70 t ha^{-1}) was obtained from the control treatment. Cultivar 'CSR 13' gave significantly higher straw yield over 'Pant 4' but the interaction between varieties × gypsum was non-significant. Similar trend was also observed in biological yield. The mean increase in straw and biological yields of 'CSR 13' was 20.1 and 20.2 per cent, respectively, over the traditional variety 'Pant 4'. The interaction between varieties × gypsum for straw and biological yields was non-significant.

Effect of Gypsum on Harvest Index and B: C Ratio

The harvest index was significantly increased by increasing levels of gypsum. Application of gypsum at 50% GR recorded the maximal harvest index which was statistically at par with that of 25% GR because of similar trend in biological and grain yields (Table 3). Variety 'CSR 13' was significantly superior over 'Pant 4' in this character. A non-significant interaction between gypsum and varieties on harvest index was observed. Numerically highest benefit: cost (B:C) ratio (1.78 based on pooled data) was recorded with 50% GR; however, it was statistically at par with the application of gypsum at 25% GR (1.76) (Table 3). The benefit: cost ratio observed from variety 'CSR 13' was significantly higher over traditional variety 'Pant 4'. The interaction between gypsum and varieties on B:C ratio was non-significant.

Effect of Gypsum on Grain Quality

Nitrogen content in rice grain is markedly influenced by the sodicity levels (Table 5). The significantly lower N content for control could be due to high volatilization losses of N at high pH resulting in slow transformation of N from amide to ammonia and nitrate and its less availability to the plants resulting in less N uptake. Nitant and Bhumbla (1974) reported that complete hydrolysis of urea, the most commonly used nitrogenous fertilizer, delayed due to high soil pH than that in soil of low pH. The reduced N content in grain in control plots could be due to impaired availability of N at higher pH which reduced nitrogen uptake to the plants. High pH and high amount of $CaCO_3$ also favour volatilization losses of applied N (Rao and Batra 1983).

Application of gypsum improved the quality of rice in terms of rice grain length and width, grain length: breadth ratio with and without husk, length: breadth ratio of cooked rice, brown rice recovery, milled rice recovery, head rice recovery and gel consistency (Table 5). Data revealed that application of gypsum at 50% GR, recorded maximum rice grain length and breadth of 9.30 and 2.77 mm, respectively. These results were statistically at par with that of 25%

Table 5. Response of grain quality of rice varieties to gypsum

Treatments	Grain N (%)	Grain length with husk (mm) (L)	Grain breadth with husk (mm) (B)	L:B ratio with husk	L:B ratio without husk	L:B ratio of cooked rice	Brown rice recovery (%)	Milled rice recovery (%)	Head rice recovery (%)	Gel consistency after 30 minutes	Gel consistency after 60 minutes
Gypsum level (% GR)											
0	1.14	8.98	2.69	3.33	2.81	2.45	77.95	73.16	57.80	5.50	5.26
15	1.25	9.09	2.73	3.32	2.82	2.47	78.02	75.10	57.80	5.82	5.36
25	1.32	9.20	2.77	3.32	2.85	2.51	78.26	76.00	57.92	5.83	6.40
50	1.35	9.30	2.77	3.35	2.85	2.62	78.87	76.60	61.67	5.85	6.65
SEm±	0.10	0.012	0.013	0.01	0.003	0.006	0.56	0.48	0.51	0.006	0.012
LSD (P=0.05)	0.03	0.04	0.04	0.03	0.01	0.02	1.75	1.44	1.56	0.02	0.04
Varieties											
CSR 13	1.26	9.15	2.73	3.35	2.82	2.46	78.50	75.20	57.20	5.84	5.75
Pant 4	1.28	9.16	2.71	3.38	2.81	2.50	78.85	77.20	58.10	5.84	6.10
SEm±	0.04	0.004	0.005	0.01	0.005	0.05	0.07	0.21	0.17	0.005	0.003
LSD (P=0.05)	0.14	NS	0.02	0.03	NS	0.16	NS	0.64	0.53	NS	0.011
Interaction	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS

GR giving corresponding figures of 9.20 and 2.77 mm. The significantly lowest length (8.98 mm) and breadth (2.69 mm) of grain were recorded with the control. The rice recoveries in terms of brown rice, milled rice and head rice were also increased with increasing levels of gypsum. Head rice recovery was higher for 50% GR over the control, 15% GR and 25% GR. However, milled rice recovery and brown rice recovery were statistically at par with that of 25% GR. This might be due to the increase in availability of S and Ca from applied gypsum to the plant and its subsequent utilization for grain development. Variety 'CSR 13' was significantly superior over 'Pant 4' in terms of grain N, grain length, grain breadth with husk, length: width ratio with husk, length: breadth ratio of cooked rice, milled rice recovery, head rice recovery and gel consistency after 60 min. The interaction effect of gypsum × varieties on grain quality was non-significant in most of the rice recovery quality parameters (Table 5).

The present study concluded that the application of gypsum at 50% GR gave maximum yield advantage but it was at par with that of 25% GR. Study also revealed that application of gypsum at 50% GR was highly ameliorative in terms of physicochemical properties of sodic soil. Grain quality of rice with application of gypsum @ 50% GR was superior over the treatments where no gypsum was applied but it was at par with 25% GR.

References

Akhtar, J., Naseem, A., Mahmood, K., Nawaj, S., Quareshi, R.H. and Aslam, M. (2001) Response of some selected wheat genotypes to salinity: growth and ionic relations. *Pakistan Journal of Soil Science* **19**, 1-7.

Arora, Sanjay, Singh, Y.P., Mishra, V.K., Singh, A.K. and Sharma, D.K. (2015) Integrated effect of pressmud, chemical amendments and microbial bio-inoculant on sodic soil reclamation and productivity of rice-wheat. In *Advances in Soil and Water Resource Management for Food and Livelihood Security in Changing Climate* (S. Bhan and S. Arora, Eds.), SCSI, New Delhi, pp. 519-528.

Al-Nabulsi, Y.A. (2001) Saline drainage water, irrigation frequency and crop species effects on some physical properties of soils. *Journal of Agronomy and Crop Science* **186**, 15-20.

Brugnoli, B. and Lauter, M. (1991) Effect of salinity on stomatal conductance, photosynthetic capacity and carbon isotope discrimination of salt tolerant cotton and *Phaseolus vulgaris*. *Plant Physiology* **95**, 628-635.

Chhabra, R., Singh, N.T. and Hansen, A. (1989) Interaction between type of amendment and P availability. Annual Report. Central Soil Salinity Research Institute, Karnal, India, p.38.

Chhabra, R. and Abrol, I.P. (1977) Reclaiming effect of rice grown in sodic soils. *Soil Science* **124**, 49-55.

Dutta, K.K., Mishra, B., Singh, R.K., Singh, K.N. and Singh, Y.P. (1996) Technological options for reclamation of salt affected soil under resource constraint environment in Uttar Pradesh. *Agricultural Situation in India*. April 1996, pp.17-21.

Ehert, D.L., Redman, R.E., Harvey, B.L. and Cipywnyk, A. (1990) Salinity induced calcium deficiency in wheat and barley. *Plant and Soil* **128**, 143-151.

El-Hendawy, S.E., Hu, Y., Yakout, G.M., Awad, A.M., Hafiz, S.E. and Schmidhalter, U. (2005) Evaluating salt tolerance of wheat genotypes using multiple parameters. *European Journal of Agronomy* **22**, 243-253.

Flower, T.J., Hajbagheri, M.A. and Yeo, A.R. (1990) Ion accumulation in the cell wall of rice plants growing under saline conditions. *Plant Cell Environment* **14**, 319-325.

Flower, T.J., Garcia, A., Koyama, M. and Yeo, A.R. (1997) Breeding for salt tolerance in crop plants – the role of molecular biology. *Acta Physiologia Plantarum* **19**, 427-433.

Foss Analytical (2003) The determination of nitrogen according to Kjeldahl using block digestion and steam distillation. FOSS Analytical AB, Hoganas, Sweden. AN 300.

Houshmand, S., Arzani, A., Maibody, S.A.M. and Feizi, M. (2005) Evaluation of salt tolerance genotypes of durum wheat derived from in vitro and field experiment. *Field Crops Research* **91**, 345-354.

Jackson, M.L. (1973) *Soil Chemical Analysis*. Prentice Hall of India Private Limited, New Delhi.

Jardat, A.A., Shahid, M. and Al-Maskri, A. (2004) Genetic diversity in the Batini barley landrace from Oman: II. Response to salinity stress. *Crop Science* **24**, 310-315.

Kadamdhad, G.R., Babhulkar, V.P. and Banhulkar, P.S. (1996) *Annals of Plant Physiology* **10**,153.

Kingsbury, R. and Epstein, E. (1986) Selection of salt resistant spring wheat. *Crop Science* **24**, 310-315.

Kumar, Ashok, Sharma, D.K. and Sharma, H.C. (1994) Growth, yield and water use efficiency of wheat as influenced by irrigation and nitrogen levels in sodic soils. *Indian Journal of Agronomy* **39**, 220-224.

Meri, A. (1984) Plant response to salinity: Experimental methodology and application to the field soil salinity under irrigation process and management. Springer Verleg, Berlin.

Nitant, H.C. and Bhumbla, D.R. (1974) Transformation and movement of nitrogen fertilizers in sodic soils. Annual Report, Central Soil Salinity Research Institute, Karnal, India. p.24.

NRSA and Associates (1996) Mapping of salt affected soils of India, 1: 250,000 map sheets, Legend. NRSA Hyderabad.

Obrejanu, G. and Sandhu, G.A. (1971) Amelioration of solonetz and solonetzized soils in the socialist Republic of Romania. In *European Solonetz Soils and their Reclamation* (Szabolcs, Ed.), Akademias Kiado, Budapest, pp. 99-130.

Pesarrakli, M. (1999) *Handbook of Plant and Crop Stress*. Marcel Dekker Inc., New York.

Ponnamperuma, F.N. (1984) Role of cultivar tolerance in increasing rice production on saline lands. In *Salinity Tolerance in Plants: Strategies for Crop Improvement* (R.C. Staples and G.H. Toenniessen, Eds.). Wiley, New York, pp. 255-271.

Rao, D.L.N. and Batra L. (1983) Ammonia volatilization from applied nitrogen in alkali soils. *Plant and Soil* **70**, 219-228.

Richards, L.A. (1954) *Diagnosis and improvement of saline and alkali soils*. USDA (Washington) Handbook No.60, pp.112.

Saneoka, H., Shlota, K., Kurban, H., Chaudhary, M., Premchandra, G.S. and Fujita, K. (1999) Effect of salinity on growth and solute accumulation in two wheat lines differing in salt tolerance. *Soil Science Plant Nutrition* **45**, 873-880.

Schoonover, W.R. (1952) Examination of soils for alkali. University of California, extension Service, Berkely, California, USA.

Shylaraj, K.S., George, K.M., Shashidharan, N.K. and Nair, K.C. (1994) IR 4630 derived lines are stable high yielder under saline conditions in Kerala, India, IRRN **19**, 21.

Singh, G., Sharma, D.P. and Mehta, K.K. (1983) Effect of sources, levels and methods of nitrogen application on yield attributes, yield and N uptake of rice in a highly sodic soil. *46th Annual Convention of Indian Society of Soil Science*. Hisar, India.

Singh, Y.P., Singh, R., Sharma, D.K., Nayak, A.K., Mishra, V.K. and Singh, G. (2009) Synergy of reduced gypsum and salt tolerant varieties: A low cost sodic soil reclamation technology. *Technical Bulletin*: CSSRI / Lucknow/2009/03.

Singh, Y.P., Singh, R. and Kumar, Neeraj (2008) Response of rice and wheat to Gypsum rates in sodic soils. *Indian Journal of Agricultural Sciences* **78**, 362-365.

Sridhar, V., Soundarajan, M.S., Sudhakar Rao, R. and Stree Amula, C. (1985) Response of groundnut to rates, time and methods of gypsum application. *Madras Agricultural Journal* **72**, 47-53.

Subbiah, B.V. and Asija, G.L. (1956) A rapid procedure for estimation of available nitrogen in soils. *Current Science* **25**, 259-263.

Tanji, K.K. (1990) In *Agricultural Salinity Assessment and Management* (K.K. Tanji, Ed.), American Society of Civil Engineers, New York, pp. 619.

Yeo, A.R. and Flower, T.J. (1986) Salinity resistance in rice and a pyramiding approach to breeding varieties for saline soils. *Australian Journal of Plant Physiology* **13**, 161-173.

Zapata, F.J., Alejar, M.S., Torrizo, L.B., Novero, A.U., Singh, V.P. and Senadhira, D. (1991) Field performance of anther culture derived lines from F1 crosses of indica rice under saline and non saline conditions. *Theoretical and Applied Genetics* **83**, 6-11.

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