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Bio-chemical amelioration effects on physico-chemical dynamics of sodic soils under rice (*Oryza sativa*) –wheat (*Triticum aestivum*) cropping system

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ABSTRACT

The effect of *dhaincha* (*Sesbania aculeata*) as first crop on physico-chemical dynamics and productivity of "B" class sodic soils was assessed on farmer's field under rice-wheat cropping system to generate the knowledge of sodic soil management for increasing the soil and crop productivity for sustainable crop production in sodic soil environment. The experiment was laid out in randomized block design at ten sites having six treatment combinations of different doses of gypsum and green manuring with sesbania under two cropping sequences, i e sesbania-rice (*Oryza sativa* L.) -wheat (*Triticum aestivum* L.) and rice-wheat. Cultivation of sesbania with gypsum significantly decreased the surface soil pH from 9.3 to 8.6 and increased the hydraulic conductivity from 0.3×10^{-3} to 3.7×10^{-3} cm/hr and buildup of soil organic matter by increasing organic carbon content from 0.20 % to 0.22 % through growing of sesbania. Sesbania green manure also increased the available water content in the soil system, which enhanced soil moisture availability for longer period. As a result, rice crop yield increased by 16.2 % in sesbania-rice- wheat cropping system in comparison to rice–wheat cropping sequence because of synergistic effect of sesbania with gypsum. Consequently, residual effect of sesbania green manuring alone and in combination with gypsum significantly enhanced the wheat grain yield by 42.5 % and 72.5 % and 80% in T_4, T_5 and T_6 treatments respectively during first year in sesbania–rice-wheat cropping sequence as compared to control. In consecutive second year, rice and wheat grain yields further enhanced by 8.1 % and 2.71% respectively, under sesbania –rice -wheat than that of rice –wheat cropping sequence. Under sesbania-rice- wheat and rice-wheat-sesbania cropping sequence, rice and wheat grain yield were similar. Hence, inclusion of *Sesbania aculeata* as green manure either before or after rice-wheat cropping sequence is equally better to improve the soil physical dynamics and crop productivity of 'B' class sodic soils in Indo-Gangetic region of Uttar Pradesh.

Key words: Green manuring, Physico-chemical dynamics, Reclaimed sodic soils, Rice, Sesbania, Wheat

Salt-affected soils are becoming a serious challenge for food and nutritional security in the developing world. As per FAO/UNESCO soil map of the world, a total of 953 m ha covering about 8 per cent of the total land surface is suffering from salinity/sodicity (Szabolcs 1979). Rice-wheat cropping systems of the Indo-Gangetic plains (IGP) are of immense importance for food security in South Asia. Rice–wheat cropping sequence is most suitable in partially reclaimed sodic soils. A large area in sodic soils has declined in their productivity in the IGP. This is the emerging threats to the sustainability of rice-wheat systems in sodic soil environment. Recent estimates indicate that 6.73 m ha (NRSA, CSSRI, NBSSLUP 2006) area is affected by soil salinity and sodicity in India. In IGP of Uttar Pradesh, owns approximately 1.37 million hectares of sodic lands, which is about 36% of the sodic land of the country in India (CSSRI 2007-08).

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Soil containing excessive salts of sodium carbonate and having sufficient exchangeable sodium to interfere with growth of most crops are called sodic soils/alkali soils. These have pH of the soil saturated paste more than 8.5, ESP 15 or more and ECe limitless if resulting from salts capable of alkaline hydrolysis. Small, marginal and resource poor farmers own sodic soils the growth of crop plants is adversely affected because of impairment of physical conditions, disorder in nutrient availability and suppression of biological activity due to high pH and sodium percentage. The sodic soils of the Indo-Gangetic plains are generally gypsum ($CaSO_4$. $2H_2O$) free, but are calcareous, with $CaCO_3$ increasing with depth, which is present in amorphous form in concretionary form, or even as indurate bed at about 1 m depth. The accumulation of $CaCO_3$ generally occurs within the zone of fluctuating water table. The dominant clay mineral is illite. The processes which target the dissolution of $CaCO_3$ have significant role in reclaimation of sodic soils. Crops like rice helps in reclaiming sodic soils (Chhabra and Abrol 1977).

The reclamation of sodic soil is being under taken through adoption of recommended reclamation technologies successfully at different stages of restoration. The chemical amendment based technology has been developed to reclaim the sodic soils (Singh *et al.* 2003). By adopting this technology about 1.3 m ha area has been reclaimed in the states of Punjab, Haryana and western UP (Singh *et al.* 2007). The reclaimed area is contributing about 8-10 m tones additional food grains to the national food grain pool. In addition to food production and employment generation, the reclamation programmes have helped in minimizing flood hazards, increasing ground water recharge, reducing incidence of malaria and water borne diseases, growth in agro-based and auxiliary industries and increasing forest cover. Some of the constraints being experienced in further adoption of this technology include increased cost of amendments and withdrawal of subsidy, requirement of repeat application of gypsum in areas with high residual sodium carbonate water or with shallow brackish water.

Keeping in view the large area (36% of the total sodic soils), which needs economic and easily available alternative intervention for sodic soil reclamation and to mitigate food requirement and sustainable production, the present investigations were essential. Addition of crop residues and other organic materials in the soil is beneficial as these help in narrowing C:N ratio to improve and maintain soil structure, supply needed plant nutrients, prevent soil erosion and help in the reclamation process. The information on the effect of sesbania green manuring alone and in conjunction with different doses of gypsum on the reclamation of B-class sodic soils as well as improvement in their physico-chemical characteristics was lacking. Therefore, present study was undertaken with the objectives to study the ameliorating impact of green manuring alone and in combination with gypsum under rice-wheat cropping sequence on physico-chemical dynamics and productivity of 'B 'class sodic soils in Indo-Gangetic plains.

MATERIALS AND METHODS

The field experiment was conducted on 'B' type sodic soils during 2005-07 for the improvement of highly degraded sodic soils. The experimental site is located in eastern plain agro-climatic zone of Uttar Pradesh (India) situated at 26° 13' 0'' N longitude, 81° 14' 0'' E latitude with an elevation of 120.4 m asl. The average annual rainfall of the zone is 863 mm and the temperature ranges from 5.5°C to 45°C. Monthly mean relative humidity ranges from 33% to 86% (annual mean 67%). 'B' type sodic soils varied from clay to clay loam, mono cropped and have poor crop yield. Before the execution of experiment, the soil samples from 0-15 and 15-30 cm depths were collected for the analysis of pH, EC, organic carbon and GR values. The experimental soil had Initial (0-15 cm) pH_2 9.1-9.46, EC_2 0.41-0.60 dS/m, organic carbon 0.20%, ESP 48.8-58.3 and SAR 44.52-56.26. The gypsum requirement (GR) was observed to be 6.0-7.8 tonnes/ha (at 50% GR) and 3.0-3.9 tonnes/ha (at 25% GR). These values of pH_2 and EC_2 varied from 9.69 to 9.88 and 0.260 to 1.18 dS/m, respectively in subsurface soil layer (15-30 cm). The experiment was laid out in split plot design with three replications at ten sites having with four cropping sequences, i e the experiment was laid out in randomized block design with three gypsum levels (G_0 = Control, G_1= 25% of gypsum requirement, G_3 = 50% of gypsum requirement) and four cropping sequences (CS_1 = Rice-wheat; CS_2 = Sesbania-rice-wheat; CS_3 = Rice-wheat-sesbania and $CS_{4\,=}$ Sesbania-rice-wheat-regular) in three replications at ten sites having 12 treatment combinations (Table 1). The size of the experimental plot at each site was kept as 100 m^2. Gypsum was applied uniformly on the leveled fields and leached as per the recommendation. Rice (Cv Narendra 359) nursery was raised at each site in the second week of June. Sesbania was sown in the last week of May at all the 10 sites. Three irrigations were applied for proper growth of sesbania. It was incorporated *in situ* with the help of bullock drawn harrow/power tiller fifty days after sowing. Transplanting of rice was done in the third week of July after one week of sesbania incorporation. Thirty days old seedlings were used for transplanting at 20 × 15 cm spacing with uniform dose of nitrogen (150 kg/ha), phosphorus (60 kg/ha) and zinc (25 kg/ha), were applied in the form of urea, DAP and zinc sulphate. The $1/3^{rd}$ of the recommended dose of nitrogen and full doses of phosphorus and zinc was applied at the time of transplanting. Remaining doses of nitrogen was applied in two equal splits of 30 and 60 days after transplanting as top dressing. Manual weeding was done twice. Continuous submergence was maintained throughout the crop season. The rice crop was harvested in the last week of October. The residual effect of green manure and gypsum on the succeeding wheat was studied.

Wheat (Cv PBW 343) was sown in the second week of November. Recommended dose of nitrogen and phosphorus (120:60) was applied. Full dose of phosphorus and half dose of nitrogen were applied as a basal application. Remaining half dose of nitrogen was applied in two equal

Table 1 Effect of gypsum levels and cropping sequence on sesbania dry- biomass production

Cropping sequence	Dry biomass (tonnes/ha)			
	Control	25% GR	50% GR	Mean
T_1 (Rice –Wheat)				
T_2 (Sesbania-Rice-Wheat)	4.08	4.50	4.89	4.49
T_3 (Rice-Wheat-Sesbania)	4.23	4.98	5.17	4.79
T_4 (Sesbania-Rice-Wheat-Regular)	4.38	5.04	5.24	4.89
Mean	3.17	3.63	3.83	
CD (P=0.05)	Cs=0.0056, Gl=0.0049, Cs×Gl=0.010			

R-W= Rice-wheat; S-R-W = Sesbania-rice-wheat; R-W-S = Rice-wheat-sesbania; S-R-W-Regular =Sesbania-rice-wheat-regular

Table 2 Effect of gypsum and cropping sequence on soil pH, electrical conductivity and organic carbon contents

Treatment	Soil properties											
	pH_2				EC_2				%OC			
	Gypsum levels											
	Control	25%GR	50%GR	Mean	Control	25%GR	50%GR	Mean	Control	25%GR	50%GR	Mean
Soil depth 0-15 cm												
T_1 (R –W)	9.18	9.01	8.89	9.02	0.54	0.50	0.48	0.507	0.205	0.209	0.210	0.208
T_2 (S-R-W)	9.14	8.82	8.65	8.83	0.52	0.41	0.39	0.44	0.211	0.215	0.219	0.216
T_3 (R-W-S)	9.12	8.81	8.63	8.82	0.55	0.44	0.42	0.47	0.209	0.213	0.218	0.214
T4 (S-R-W-Regular)	9.04	8.62	8.55	8.71	0.48	0.42	0.39	0.43	0.212	0.223	0.231	0.222
Mean	9.12	8.82	8.68		0.523	0.443	0.420		0.209	0.217	0.220	
CD (P=0.05)	Cs=0.029, Gl=0.025, CsxGl=0.051				Cs=0.041, Gl=0.036, CsxGl=0.071				Cs=0.046, Gl=0.040, CsxGl=0.079			
Soil depth 15-30 cm												
T_1 (R –W)	9.68	9.69	9.75	9.71	0.71	0.76	0.86	0.77	0.117	0.116	0.127	0.120
T_2 (S-R-W)	9.81	9.86	9.83	9.83	0.75	0.82	0.91	0.82	0.118	0.117	0.128	0.121
T_3 (R-W-S))	9.71	9.41	9.86	9.45	0.78	0.88	0.99	0.881	0.117	0.117	0.128	0.121
T4 (S-R-W-Regular)	9.78	9.53	9.98	9.66	0.88	0.98	1.09	0.98	0.118	0.119	0.130	0.124
Mean	9.74	9.62	9.86		0.78	0.86	0.96		0.118	0.117	0.128	
CD (P=0.05)	Cs=0.043, Gl=0.037, Cs×Gl=0.075				Cs=0.048, Gl=0.042, Cs×Gl=0.084				Cs=1.030, Gl=1.13, Cs×Gl=2.26			

Cs, Cropping system; Gl, Gypsum level

splits at 30 and 60 days after sowing. Four irrigations were given at crown root initiation, tillering, jointing and milking stages. 2, 4-D and isoproturan weedicides were applied for the control of broad leaved weeds and *Phalaris minor*. The wheat crop was harvested in the first week of April.

Soil samples (0-15 cm and 15-30 cm) were taken before execution of the experiment in 2005 and after the harvest of wheat in 2007. Air dried soil samples were grinded to pass through 2 mm sieve and were analyzed for pH and EC using glass electrode; organic carbon was estimated by Walkley and Black (1934) method. Measurements of soil physical parameters, viz. soil bulk density, hydraulic conductivity carried out by the methods described by Singh (1980) and Richards (1954). Percent available soil water content at field capacity (soil moisture at (1/3 bar) – (- 15bar soil moisture) difference, was calculated by using pressure plate apparatus (Jalota *et al.* 1998).

The data were analysed statistically to test the level of significance by adopting factorial randomized block design. Analysis of variance was performed with SPSS Version 10.0 (SPSS 2002) to test the effects of treatments and interactions.

RESULTS AND DISCUSSION

Sesbania biomass

The average dry mass production of sesbania was maximum under 50% GR treatment after 50 days of sowing, which was significantly higher than 25% GR and control treatments (Table 3). The production of sesbania increased significantly with increasing doses of gypsum during both the years. Under CS_2 treatment sesbania biomass production raised by 10.30 and 19.60 percent, respectively under 25 and 50% of GR as compared to control treatment. Maximum sesbania biomass production was recorded in CS_4 treatment in which the respective increment was 15.06 and 19.63 percent. Results indicate that during both the years sesbania productivity was significantly higher in comparison to control treatment. Hence, it may be inferred from the data that 'B' class sodic soil having pH 9.1 to 9.4, under rice – wheat cropping sequence, sesbania should be grown during both the years either before or after the crop.

Soil physico- chemical dynamics

Soil pH(1:2)

The pH of soil was found to be influenced significantly by green manuring and different doses of gypsum in surface and subsurface soil layers under all the cropping sequences (Table 4). The pH of surface soil decreased with increasing dose of gypsum. A synergistic effect of sesbania in combination with gypsum on further reduction of pH was observed in all the treatments. Maximum reduction in pH (0.51) was recorded under S-R-W- regular followed by S-R-W and R-W-S (0.48) and R-W (0.29) cropping sequence.

Results indicates that pH in subsoil layer of 15-30 cm (Table 4) was higher in all the cropping sequence with and without sesbania insertion. This may be because of leaching of salts from surface layer to lower layer where subsoil having poor water transmission, which promotes the accumulation of salts owing due to lower hydraulic conductivity (Table 6) in comparison to surface soil layers.

Table 3 Effect of gypsum and cropping sequence on soil ESP and SAR

Treatment	Soil properties							
	ESP				SAR			
	Gypsum levels							
	Control	25%GR	50%GR	Mean	Control	25%GR	50%GR	Mean
	Soil depth 0-15 cm							
T_1 (R –W)	44.13	30.19	25.87	33.39	38.75	21.52	16.18	25.48
T_2 (S-R-W)	37.22	28.41	23.01	29.55	30.21	19.32	12.65	21.39
T_3 (R-W-S)	35.73	20.91	20.02	25.55	28.37	10.05	8.94	15.79
T4 (S-R–W-Regular)	32.28	22.53	19.92	24.24	24.10	9.58	8.83	14.17
Mean	37.34	25.51	22.21		30.36	15.12	11.65	19.04
CD (P=0.05)	Cs = 0.041, Gl = 0.036, Cs×Gl = 0.071				Cs = 0.046, Gl = 0.040, Cs×Gl = 0.079			
	Soil depth 15-30 cm							
T_1 (R –W)	53.89	54.39	57.35	55.37	50.82	51.43	55.09	52.45
T_2 (S-R-W)	60.31	62.78	61.30	61.46	58.75	61.80	59.98	60.18
T_3 (R-W-S)	55.37	40.55	62.78	52.90	52.65	34.33	61.80	49.59
T4 (S-R –W-Regular)	58.83	46.48	64.71	56.67	56.92	41.66	64.19	54.26
Mean	57.10	51.05	61.54		54.79	47.31	60.27	54.12
CD (P=0.05)	Cs = 0.048, Gl = 0.042, Cs×Gl = 0.084				Cs = 1.304, Gl = 1.130, Cs×Gl = 2.26			

Table 4 Effect of gypsum and cropping sequence on soil bulk density and hydraulic conductivity

Treatment	Bulk density (g/cm^3)				Hydraulic conductivity(cm/h)				Available water content (%)			
	Control	25%GR	50%GR	Mean	Control	25%GR	50%GR	Mean	Control	25%GR	50%GR	Mean
	Soil depth 0-15 cm											
T_1 (R –W)	1.56	1.54	1.53	1.54	1×10^{-3}	2×10^{-3}	3×10^{-3}	2×0^{-3}	15.3	16.5	17.1	16.3
T_2 (S-R-W)	1.54	1.53	1.51	1.53	2×10^{-3}	4×10^{-3}	5×10^{-3}	3.7×10^{-3}	16.1	16.9	17.5	16.8
T_3 (R-W-S)	1.54	1.52	1.50	1.52	2×10^{-3}	4×10^{-3}	5×10^{-3}	3.7×10^{-3}	16.5	17.1	17.8	17.1
T4 (S-R-W-Regular)	1.53	1.50	1.49	1.51	2×10^{-3}	4×10^{-3}	5×10^{-3}	3.7×10^{-3}	16.7	17.5	18.1	17.5
Mean	1.54	1.52	1.51						16.15	17.0	17.63	
CD (P=0.05)	Cs=0.0056, Gl =0.0049, Cs×Gl=0.010				Cs=NS, Gl=NS, Cs×Gl=NS				Cs=0.040, Gl=0.035, Cs×Gl=0.069			
	Soil depth 15-30 cm											
T_1 (R –W)	1.66	1.66	1.65	1.65	0.7×10^{-3}	0.6×10^{-3}	1×10^{-3}	0.3×10^{-3}	10.25	10.38	11.12	10.58
T_2 (S-R-W)	1.65	1.64	1.65	1.65	1×10^{-3}	1×10^{-3}	2×10^{-3}	1.33×10^{-3}	10.55	10.58	11.42	10.85
T_3 (R-W-S)	1.65	1.64	1.64	1.64	1×10^{-3}	1×10^{-3}	2×10^{-3}	1.33×10^{-3}	10.62	10.73	11.62	10.99
T4 (S-R-W-Regular)	1.64	1.63	1.63	1.63	1×10^{-3}	2×10^{-3}	2×10^{-3}	1.7×10^{-3}	10.72	10.88	11.81	11.14
Mean	1.65	1.64	1.64						10.54	10.64	11.49	
CD (P=0.05)	Cs=NS, Gl=NS, Cs×Gl=NS				Cs=NS, Gl=NS, Cs×Gl=NS				Cs=0.028, Gl=0.024, Cs×Gl=0.048			

Present results indicate that green manuring as sesbania along with gypsum application, decreased pH of the soil significantly as compared with gypsum alone under rice - wheat crop rotation. Singh *et al.* (1981) also observed the similar observations.

Electrical conductivity (EC)

The values of EC were decreased when gypsum and sesbania were applied (Table 4). EC of surface soil decreased with increasing dose of gypsum in 0-15 cm soil layer. Effect of gypsum and green manure was more pronounced on surface layer whereas its effect was non-significant in sub-surface soil layer (15-30 cm) under all cropping sequences. Maximum surface soil EC (0.54 dS/m) was recorded in R-W cropping sequence without sesbania inclusion. Further, in subsequent years reduction in EC of surface soil was observed under all cropping sequences. Among the gypsum treated plots, maximum reduction in EC was observed in 50%GR alone and in combination of sesbania in 0-15 cm soil layer during both the years. This may be attributed to the improvement in porosity and hydraulic conductivity, which resulted in enhancing the leaching of salts. After decomposition of sesbania green manure, organic acids are formed. Results indicate that

Table 5 Effect of gypsum and cropping sequence on soil porosity, void ratio and water permeability

Treatment	Soil physical properties											
	Porosity (%)				Void ratio				Water permeability (cm^2)			
	Control	25%GR	50%GR	Mean	Control	25%GR	50%GR	Mean	Control	25%GR	50%GR	Mean
Soil depth 0-15 cm												
T_1 (R –W)	0.40	0.41	0.41	0.41	0.66	0.68	0.68	0.67	1.02×10^{-8}	2.04×10^{-8}	3.06×10^{-8}	2.04×10^{-8}
T_2 (S-R-W)	0.41	0.41	0.42	0.41	0.68	0.69	0.69	0.69	2.04×10^{-8}	4.08×10^{-8}	4.08×10^{-8}	3.78×10^{-8}
T_3 (R-W-S)	0.41	0.42	0.42	0.42	0.68	0.69	0.70	0.69	2.04×10^{-8}	4.08×10^{-8}	4.08×10^{-8}	3.78×10^{-8}
T4 (S-R-W-Regular)	0.41	0.43	0.43	0.42	0.70	0.70	0.71	0.71	2.04×10^{-8}	4.08×10^{-8}	4.08×10^{-8}	3.78×10^{-8}
Mean	0.41	0.42	0.42	0.42	0.68	0.69	0.70	0.69	1.79×10^{-8}	3.57×10^{-8}	3.82×10^{-8}	
CD (P=0.05)	Cs=0.0003, Gl=0.0003, Cs×Gl=0.001				Cs=0.0098, Gl=NS, Cs×Gl=0.017				Cs=1.087, Gl=NS, Cs×Gl=1.883			
Soil depth 15-30 cm												
T_1 (R –W)	0.360	0.36	0.37	0.37	0.58	0.59	0.59	0.59	0.6×10^{-8}	0.7×10^{-8}	1.02×10^{-8}	3.06×10^{-8}
T_2 (S-R-W)	0.37	0.37	0.37	0.37	0.59	0.61	0.60	0.61	1.02×10^{-8}	1.02×10^{-8}	1.02×10^{-8}	1.36×10^{-8}
T_3 (R-W-S)	0.37	0.37	0.37	0.37	0.59	0.61	0.62	0.61	1.02×10^{-8}	1.02×10^{-8}	1.02×10^{-8}	1.36×10^{-8}
T4 (S-R-W-Regular)	0.37	0.38	0.38	0.37	0.60	0.62	0.62	0.61	1.02×10^{-8}	2.04×10^{-8}	2.04×10^{-8}	1.73×10^{-8}
Mean	0.37	0.37	0.37	0.37	0.59	0.61	0.61		0.77×10^{-8}	1.02×10^{-8}	1.27×10^{-8}	
CD (P=0.05)	Cs=0.0003, Gl=0.0003, Cs×Gl=0.001				Cs=0.0004, Gl=0.0003, Cs×Gl=0.001				Cs=0.476, Gl=NS, Cs×Gl=NS			

Table 6 Effect of gypsum application and cropping sequence on average yield of rice and wheat crops

Treatment	Yield of rice and wheat crop (Mg/ha)							
	Rice				Wheat			
	Control	25%GR	50%GR	Mean	Control	25%GR	50%GR	Mean
T_1 (R –W)	3.06	3.43	3.78	3.42	2.00	3.14	3.37	2.84
T_2 (S-R-W)	3.41	4.23	4.52	4.05	2.85	3.45	3.60	3.30
T_3 (R-W-S)	3.45	4.31	4.49	4.08	2.90	3.49	3.56	3.32
T4 (S-R –W-Regular)	3.66	4.62	4.94	4.41	2.95	3.58	3.69	3.41
Mean	3.40	4.15	4.43		2.68	3.42	3.56	
CD (P=0.05)	Cs = 0.051, Gl = 0.044, Cs×Gl = 0.088				Cs = 0.058, Gl = 0.050, Cs×Gl = 0.101			

gypsum and organic acids exhibit their synergistic effect in sodic soil reclamation. They react with sodium ions and form the salts which leach down into the lower horizons and accumulate in subsoil layers resulted in higher reduction in surface soil EC. Sharma *et al*. (1982) also reported the higher EC in 15-30 cm soil layer in all the gypsum treated plots in comparison to 0-15 cm soil layers. It shows that maximum salts release from the surface layer and accumulated in 15-30 cm soil layer. This was because of lower hydraulic conductivity of 15-30 cm soil layer

Organic carbon

The data on the effect of gypsum levels alone and in combination with sesbania shows that soil organic carbon content increased with increasing dose of gypsum in surface (0-15 cm) and subsurface (15-30 cm) soil (Table 4). Maximum OC was recorded when 50% GR was applied alone and in combination with sesbania followed by 25% GR + sesbania treatment. Among the possible reasons for increase in OC may be due to the fact that green manure facilitated the buildup of organic carbon content and gave higher rice and wheat grain yields (Swarup 1991). The lower magnitude of OC in subsurface soil was observed as compared to surface soil and similar trend was observed in all the cropping sequences. The changes in organic carbon content were observed in 'B' category sodic soils under different cropping sequence with or without gypsum and green manuring could be attributed to higher biological activities of the rice roots and crop growth under submergence condition and inclusion of larger amount of carbon through green manuring biomass. Similar results were also reported by Singh *et al.* (1997) and Singh *et al.* (2009).

Sodium adsorption ratio (SAR) and exchangeable sodium percent (ESP)

The data on the effect of various treatments on SAR and ESP of the soil after reclamation has been presented in Table 5. In 'B' class sodic soil both the parameters decreased significantly when it was treated with gypsum alone and in combination with sesbania green manure under rice-wheat cropping system. Results of SAR and ESP showed significant reduction in all the treatments compared with control. The most effective treatment combination was gypsum with 50% GR with sesbania. The minimum decrease in these parameters were recorded when sesbania and gypsum with 25%GR were tried alone. The decrease in SAR and ESP were essentially observed due to the removal of exchangeable sodium from the soil complex. This reduction could be due to replacement of Na as monovalent on the exchange complex by Ca^{2+} from the soil solution (Amstrong and Tonton 1992, Gharaibeh *et al.* 2009).

Bulk density

Data in Table 6 indicate that bulk density of surface soil decreased significantly (1.54 to 1.50 g/cm) with increase dose of gypsum. Sesbania as green manure alone and in combination with gypsum also play a vital role in reducing bulk density of surface soil. Minimum bulk density in 0-15 cm soil layer was recorded when gypsum was applied at 50% GR in combination with sesbania green manure followed by 25% GR + sesbania treatment. Further, surface soil bulk density was observed lower under S-R-W cropping sequence in comparison to R-W cropping sequence. Due to addition of organic carbon bulk density of surface layer was also improved (lower down) under S-R-W and S-R-W cropping sequence in comparison to R-W, cropping system. It may be due to addition of organic carbon through sesbania green manuring which improved soil structure through the aggregation of soil particles. Due to decrease in sodium and increase in carbon content there might have resulted into decrease in dispersion ratio and increase in flocculation and further improved the bulk density. These findings are in accordance with the observations of Gorbunov (1980).

Hydraulic conductivity

The data on the effect of gypsum and sesbania alone or in their combination on the hydraulic conductivity are shown in Table 6. The hydraulic conductivity of surface soil (0-15 cm) increased with increasing dose of gypsum. Green manuring with sesbania further enhanced the soil hydraulic conductivity. Maximum hydraulic conductivity in 0-15 cm soil layer was recorded in 50% GR alone and in combination with sesbania green manure, followed by 25% GR + sesbania treated plots under all cropping systems**.** Among the cropping systems the values of hydraulic conductivity were at par in all the cropping sequences except R-W cropping system being the lowest. It may be due to the addition of organic matter in 0-15 cm, improvement in soil structure with gypsum as well as and sesbania being deep rooted crop after decomposition process, roots in the soil make small channels which facilitate water movement in the soil. Chabra and Abrol (1977) also observed that rice roots provides channels for the movements of water, which increased permeability and helps in leaching of salts. Whereas in subsoil layer (15 –30 cm) hydraulic conductivity was lower under all cropping sequences, because of the high clay content with calcium carbonates concressions and its cementing effects reduced the downward movement of water and increased the accumulation of salts from upper surface horizons. Thus, very little effect of gypsum and green manuring was observed on subsoil hydraulic conductivity. The improvement in bulk density in different combinations may be the main cause of increase in hydraulic conductivity.

Available water content (AWC)

Available water content (AWC) increased with increase dose of gypsum under all cropping sequences in 0-15 cm soil layer. Gypsum in combination with sesbania green manure further enhanced the soil water availability (Table 6). Maximum available moisture content was recorded in 0-15 cm soil layer with 50% GR alone and in combination with sesbania green manure followed by 25% GR + Sesbania treatment (Table 4). Under S-R-W cropping sequence AWC was higher in comparison to R-W cropping system. Due to improvement in water holding capacity and availability to the crop plants for longer period because of an improvement in organic carbon content, bulk density, porosity, void ratio etc. resulted into higher crop yields. In subsoil layer, available water content was lower in comparison to surface soil layer under all cropping sequences. Due to increase in organic carbon content reduction in bulk density and increase in porosity was also reported by Hussain *et al.* (2001).

Porosity and void ratio

The effects of the gypsum and green manuring alone and in combination on porosity and void ratio was positive but statistically at par (Table 7).The most efficient treatment here was the combination of gypsum (50%GR) with sesbania green manure. The most inferior treatment was the R-W treatment. However, all the treatments were significantly better than control. Among the cropping sequences, inclusion of sesbania either before or after the rice–wheat crop proved superior to rice-wheat alone, when tried in various combinations of gypsum. There is inverse relationship between bulk density and porosity/void ratio. Therefore, decrease in the value of former resulted in an increase in the latter. Whereas, in subsoil (15-30 cm) porosity and void ratio value were lower under both the R-W and S-R-W or

R-W-S cropping sequence. Amelioration activities do not effect the porosity and void ratio of subsoil, hence, the subsoil was dispersed and compacted in nature having less porosity which results in low infiltration rate with low saturated hydraulic conductivity and pounding of irrigation water.

Water permeability

The data (Table 7) shows that gypsum and sesbania increased the water permeability of surface soil (0-15 cm) significantly in their all treatment combinations than control. In subsoil, water permeability was significantly lower than surface soil layer. This may be due to the fact that in subsoil layer the ameliorative effect of gypsum and sesbania was very less, therefore soil was dispersed in nature and became so compacted that water could not move easily across the soil mass. However, the best treatment effect was under gypsum (50% GR) with sesbania in rice-wheat cropping sequence. It was statistically at par with the application of gypsum (25%GR) with sesbania. An improvement in bulk density, porosity and void ratio could have contributed into enhanced water permeability.

Crop yields

Rice and wheat yield was significantly increased when gypsum levels were applied alone and in combination with sesbania green manure (Table 8) under the rice–wheat cropping sequences. The most superior combination was the integration of gypsum (50% GR) + sesbania (61.44% more yield). However, under gypsum (25% GR) + sesbania treatment this increase was recorded as 50.98 percent, which is at par with earlier. The improvement in physic-chemical properties of salt affected soil, as observed in the earlier sections can be attributed to be the major reason for increase in crop yields.

From the study at farmer's fields, three options may be concluded and recommended for increasing crop productivity and sustainability of 'B' class sodic soil, viz. 1.Inclusion of sesbania in rice -wheat cropping system from the beginning was economical and should be grown for green manuring regularly. 2. Using 25% GR + green manuring would be more economical and can save 50% cost of gypsum and its results were at par with 50% GR alone for the maintaining of soil productivity in rice - wheat cropping system. 3. Cultivation of sesbania alone in 'B' category sodic soil was equally good as 25% GR alone for the amelioration of sodic soils and improvement of their productivity under rice-wheat cropping system.

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