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Effect of Gypsum and Wheat Straw Incorporation on Physico-chemical Properties of Coastal 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

Abstract: A field experiment was conducted during *Kharif-Rabi* season of 2020-21 to 2023-24 at Coastal Soil Salinity Research Station, NAU, Danti-Umbharat, Gujarat to evaluate the effect of gypsum and wheat straw incorporation on physico-chemical properties of coastal soil under a rice-wheat cropping system. Total fifteen treatment combinations comprising of five levels of gypsum *i.e.*, G_1: No gypsum, G_2: Phosphogypsum @ 25 % GR, G_3: Phosphogypsum @ 50 % GR, G_4: Granular gypsum @ 25 % GR, G_5: Granular gypsum @ 50 % GR taken under main plot given to *kharif* rice crop and three wheat crop residue incorporation levels

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after *rabi* wheat crop *i.e.*, R_1: No straw incorporate, R_2: 50 % wheat straw incorporate, R_3: 100 % wheat straw incorporate were evaluated in split plot design with three replications. Results showed that application of phosphogypsum and granular gypsum at 50% gypsum requirement effectively reduced soil exchangeable sodium percentage (ESP) and bulk density, while improving water stable aggregates. Wheat straw incorporation at 100% enhanced soil organic carbon, water-stable aggregates and reduced bulk density. Therefore, use of gypsum and wheat crop residue incorporation can be considered a sustainable strategy for improving soil health and managing sodicity in coastal soils.

Keywords: Coastal soils; gypsum; sodicity; soil properties; wheat residue incorporation.

1. Introduction

The rice-wheat cropping system (RWCS) is a dominant cereal-based cropping system in South Asia and plays a critical role in regional food security. However, large areas under RWCS-especially in irrigated and coastal belts-are affected by salinity and sodicity, which reduce soil fertility, impair soil physical structure and limit crop productivity. Soil sodicity is characterized by high pH, elevated exchangeable sodium percentage (ESP) and poor aggregate stability, and requires integrated approaches for sustainable reclamation and long-term maintenance of soil health (Qadir et al., 2014; Qadir & Oster, 2004).

Gypsum ($CaSO_4 \cdot 2H_2O$) is a widely used chemical amendment for reclamation of sodic soils because soluble calcium displaces exchangeable sodium and promotes Na^+ leaching, thereby improving soil structure and hydraulic conductivity (Qadir et al., 2014). Phosphogypsum (PG) a phosphatic fertilizer industry by-product and commercial granular gypsum differ in chemical composition, solubility and potential ancillary effects (nutrient inputs, trace elements) (Hasana et al., 2022).

Complementary to chemical amendments, incorporation of crop residues (e.g., wheat straw) enhances soil organic carbon, stimulates biological activity, and improves aggregate stability and porosity. Field studies consistently showed that residue return increases soil organic carbon and improves soil physical properties in arable systems, including rice–wheat rotations (Wang et al., 2020). Combining organic residue management with chemical amendments such as gypsum can have synergistic effects: residues improve soil aggregation and water retention while gypsum supplies exchangeable Ca^{2+} that facilitates structural re-formation and sodium displacement. Recent experimental work demonstrates beneficial effects of gypsum (alone or combined with organic amendments) on soil physical and chemical properties and crop responses in degraded soils. (Elbagory et al., 2024).

Despite this body of work, comparative field evaluations of different gypsum levels together with graded levels of wheat residue incorporation under coastal, sodic rice–wheat systems remain limited. To address this gap, we evaluated five gypsum treatments (no gypsum; phosphogypsum and granular gypsum at 25% and 50% gypsum requirement) combined with three wheat residue incorporation levels (0, 50 and 100%) in a split-plot field experiment conducted at the Coastal Soil Salinity Research Station, Navsari Agricultural University, Danti–Umbharat, Gujarat.

2. Materials and Methods

This field trial was carried out (*Kharif* 2020-21 to *Rabi*-2023-24) at the Coastal Soil Salinity Research Station, Navsari Agricultural University, Danti-Umbharat in the South Gujarat near the Arabian Sea, India. Geographically, Danti-Umbharat is situated at 20° 83′ N latitude and 72° 50′ E longitude at an elevation of 2.5 m above mean sea level on the western coastal belt of India. The climate of this region is characterized by fairly hot summer, moderately cold winter, humid and warm monsoon. The area receives an annual average rainfall of 1100 mm, most of which occurs from the second week of June to last week of September. The soil of the experimental had EC = 1.15 and 1.18 dS m^{-1}; pH = 8.52 and 8.61; ESP = 15.68 and 17.83 %, Avail. nitrogen =239 and 233 kg/ha, Avail. P_2O_5 = 152 and 143 kg/ha, Avail. K_2O = 1588 and 1736 kg/ha, organic carbon = 0.55 and 0.46 % at 0-15 cm and 15-30 cm soil depth, respectively. Total fifteen treatment combinations comprising of five levels of gypsum i.e., G_1: No gypsum, G_2: Phosphogypsum @ 25 % GR, G_3: Phosphogypsum @ 50 % GR, G_4: Granular gypsum @ 25 % GR, G_5: Granular gypsum @ 50 % GR taken under main plot given to *kharif* rice crop and three wheat crop residue incorporation levels given after *rabi* wheat crop i.e., R_1: No straw incorporate, R_2: 50 % wheat straw incorporate, R_3 : 100 % wheat straw incorporate were evaluated in split plot design with three replications. The 100 % gypsum requirement during 2021-22, 2022-23 and 2023-24 were 7.46, 4.30 and 3.05 t/ha, respectively. The phosphogypsum and granular gypsum was applied 30 days before transplanting of *kharif* rice at a time of land preparation. The analysis of phosphogypsum and granular gypsum used in the experiment are given in Table 1. Wheat straw incorporate in terms of straw production in respective plots was added after harvest of *rabi* wheat crop. After harvest of *rabi* wheat crop, wheat straw was incorporated in respective treatments by rotavator.

The treatments were replicated on plots with size 8.10 × 4.00 m^2 in *kharif* rice which was split in 2.70 × 4.00 m^2 size in *rabi* wheat. Twenty-five days old rice seedlings of GNR-7 were transplanted in July. Dose of NPK for rice and wheat crop were 120:30:00 and 180-90-00 NPK kg/ha., respectively. A full dose of phosphorus was applied as basal dose for all the crops. Nitrogen was applied as per recommendation in different crops. All the crops were grown with the recommended package of practices. Crop was harvested at maturity. After harvesting of *kharif* rice crop, wheat crop was sown in *rabi* season within same layout.

Soil samples were collected from each plot at 0–15 cm and 15–30 cm depths before and after harvest of both rice and wheat crops during each year of the study. The samples were air-dried, processed and analysed following standard procedures. Soil pH and electrical conductivity were determined in a 1:2.5 soil–water suspension using a digital pH meter and conductivity meter, respectively, following standard soil analytical procedures Jackson (1973). Exchangeable Na^+ ions were divided by the soil's cation exchange capacity to get ESP, which was then multiplied by 100 (Richards, 1954). Available nitrogen was estimated using the alkaline $KMnO_4$ oxidation method (Subbiah and Asija, 1956), available phosphorus by the Olsen extraction method suitable for alkaline soils (Olsen, 1954), and available potassium by neutral ammonium acetate extraction (Jackson, 1973). Soil organic carbon was determined by the Walkley and Black's rapid titration method (Jackson, 1973). Soil bulk density was measured using the core sampler method (Singh, 1980), and water-stable aggregates were determined by the wet-sieving technique (Yoder, 1936). Data over the last three years were considered for analysis. The data were subjected to analysis of variance appropriate for a split-plot design. Treatment means were compared using the critical difference test at the 5% level of significance.

3. Results and Discussion

3.1 Soil Chemical Properties

3.1.1 Soil $pH_{2.5}$

After harvest of *kharif* rice and *rabi* wheat: The results of soil $pH_{2.5}$ as affected by different gypsum and wheat straw incorporation levels after harvest of *kharif* rice and *rabi* wheat are given in Table 2. Application of phosphogypsum and granular gypsum at both 25% and 50% GR generally lowered soil $pH_{2.5}$ compared to the control. Among gypsum treatments, G_5 (granular gypsum @ 50% GR) and G_3 (phosphogypsum @ 50% GR) showed the greatest reduction in soil $pH_{2.5}$ at 0-15 cm soil depth. This aligns with earlier findings that gypsum application improves soil properties gradually particularly in sodic soils by enhancing Ca^{2+} availability and promoting Na^+ leaching (Qadir et al., 2004). The effect was less pronounced at 15-30 cm soil depth where non-significant differences recorded. Incorporation of wheat straw also contributed to a marginal decline in soil $pH_{2.5}$ over time. Application of 100% straw incorporation (R_3) showed slightly lower $pH_{2.5}$ values compared to no straw incorporation (R_1) particularly in the 0-15 cm soil depth. This can be attributed to decomposition of wheat straw residues, which produce organic acids and enhance microbial activity thus buffering soil alkalinity (Shan et al., 2008). Interaction effect of gypsum and wheat straw incorporation failed to exert any significant difference on soil $pH_{2.5.}$

3.1.2 Soil $EC_{2.5}$

After harvest of *kharif* rice and *rabi* wheat: Soil $EC_{2.5}$ after harvest of *kharif* rice and *rabi* wheat during 2021-22 to 2023-24 remained within the non-saline range across soil depths (Table 3). The effects of gypsum and wheat straw incorporation levels on soil $EC_{2.5}$ were statistically non-significant. Slightly higher $EC_{2.5}$ values after *rabi* wheat than after *kharif* rice may be due to reduced leaching under non-flooded conditions. Overall, the results indicate that use of gypsum and wheat straw incorporation does not induce salt accumulation and is safe for soil salinity management under the rice–wheat cropping system.

3.1.3 Soil ESP

After harvest of *kharif* rice. The results depicted in Table 4 regarding ESP in soil after harvest of *kharif* rice. Gypsum significantly affected the soil ESP at 0-15 cm soil depth during all the years. During first year, significantly higher reduction in soil ESP was recorded with G_3 (phospho gypsum @ 50% GR) (10.78 %) as compared to other gypsum levels, but was found at par with G_5 (granular gypsum @ 50% GR) at 0-15 cm soil depth. During second and third year, significantly higher reduction in soil ESP (8.69 and 7.76 %) was recorded with G_5 (granular gypsum @ 50% GR) as compared to other gypsum levels, but was found comparable to level G_3 (phospho gypsum @ 50% GR) at 0-15 cm soil depth. The reduction in soil ESP might be due to gypsum application effectively replaces exchangeable sodium with calcium in the exchange complex, improving soil structure and leaching of sodium, particularly in the 0-15 cm soil depth (Noonari et al., 2025). At 15-30 cm soil depth, non-significant different recorded in soil ESP during all the years.

Wheat straw incorporation slightly lowered ESP, although differences were statistically non-significant at both the soil depths during all the years. Incorporation of 100% wheat straw (R_3) reduced ESP at 0-15 cm compared to no incorporation. This effect can be attributed to organic matter decomposition which releases organic acids and enhances calcium availability, thereby facilitating sodium displacement and improving aggregate stability (Ran et al., 2022). Interaction effect of gypsum and wheat straw incorporation levels failed to exert any significant difference on soil ESP at both the soil depths during all the years.

After harvest of *rabi* wheat. The results showed in Table 4 regarding ESP in soil after harvest of *rabi* wheat. Gypsum significantly affected the soil ESP at 0-15 cm soil depth during all the years. During first year, significantly higher reduction in soil ESP was recorded with G_3 (phospho gypsum @ 50% GR) (9.65 %) as compared to other gypsum levels, but was found at par with G_5 (granular gypsum @ 50% GR) at 0-15 cm soil depth. During second and third year, significantly higher reduction in soil ESP (8.84 and 7.20 %) was recorded with G_5 (granular gypsum @ 50% GR) as compared to other gypsum levels, but was found comparable to level G_3 (phospho gypsum @ 50% GR) at 0-15 cm soil depth. These results clearly demonstrate the residual effect of gypsum in reducing soil sodicity beyond the *kharif* crop, showing carry-over effects into the *rabi* season. Gypsum provides soluble Ca^{2+}, which replaces exchangeable Na^{+} on the soil exchange complex, thereby reducing ESP and improving soil physical conditions (Luiz et al. 2022). The greater effectiveness of 50% GR over 25% GR confirms earlier findings that higher gypsum doses are more efficient in sodic soil reclamation (Zaka et al., 2018). At 15-30 cm soil depth, non-significant different recorded in soil ESP during all the years.

The incorporation of wheat straw reduced ESP somewhat, however the results were not statistically significant at both the depths during all the years. The lowest ESP at 0-15 cm soil depth was observed under 100% straw incorporation (R_3) followed by 50% straw incorporation (R_2) as compared to no straw incorporation (R_1). Interaction effect of gypsum and wheat straw incorporation failed to exert any significant difference on soil ESP at both the soil depths during all the years.

3.2 Soil Available Nitrogen (SAN)

After harvest of *kharif* rice and *rabi* wheat: The effects of gypsum application, wheat straw incorporation and their interaction were statistically non-significant on SAN across years, depths, and seasons except after harvest of *rabi* wheat at 0-15 cm soil depth during third year (Table 5). Nevertheless, plots receiving gypsum showed a consistent numerical increase in SAN, particularly at higher application rates (50% GR), which may be attributed to improved soil structure, reduced sodicity and enhanced microbial activity favoring nitrogen mineralization (Richards, 1954).

Wheat straw incorporation also resulted in higher SAN compared to no residue incorporation, with 100% straw incorporation generally recording the highest values. The differences in SAN among wheat straw incorporation levels were significant at 0-15 cm soil depth during third year. During third year, significantly higher SAN was recorded with level R_3 (100 % wheat straw incorporate) (286 kg/ha) which was at par with level R_2 (50 % wheat straw incorporate) at 0-15 cm soil depth. This increase is likely due to decomposition of crop residues, improved soil organic matter status and enhanced nutrient cycling (Wang et al., 2024 and Singh et al., 2019). Overall, the results suggest that gypsum application and residue incorporation helps in maintaining SAN availability without adverse effects under the rice–wheat cropping system.

3.3 Soil Available Phosphorus (SAP)

After harvest of *kharif* rice and *rabi* wheat: The effects of gypsum application, wheat straw incorporation and their interaction were statistically non-significant on SAP during all the years, both depths and cropping seasons (Table 6). However, gypsum-treated plots showed a consistent numerical increase in SAP, particularly at 50% GR and in the surface soil (0–15 cm). Wheat straw incorporation also resulted in slightly higher SAP to no residue incorporation, with 100% straw incorporation generally recording higher values. Overall, the results indicated that gypsum application and wheat straw incorporation help sustain soil phosphorus availability without adverse effects under the rice–wheat cropping system.

3.4 Soil Available Potassium (SAK)

After harvest of *kharif* rice and *rabi* wheat: SAK showed numerical variation among gypsum treatments across soil depths (0-15 and 15-30 cm) during 2020-21 to 2023-24; however, these differences were statistically non-significant (Table 7). Among the treatments, granular gypsum at 50% GR (G_5) consistently recorded higher SAK values compared to the no-gypsum control. A gradual decline in SAK across years was evident under most treatments, likely due to continuous crop removal under intensive rice–wheat cropping. Wheat straw incorporation resulted in numerically higher SAK with increasing residue levels, with 100% wheat straw incorporation (R_3) showing consistently greater K values across depths and seasons, though differences remained non-significant. The interaction between gypsum levels and wheat straw incorporation had no significant effect on SAK during all years of study (Table 7).

3.5 Soil Organic Carbon (SOC)

After harvest of *kharif* rice: The results of SOC as affected by different gypsum and wheat straw incorporation levels after harvest of *kharif* rice is given in Table 8. Gypsum did not significantly affect the SOC at both depths during all the years.

The differences in SOC among wheat straw incorporation levels were significant at 0-15 cm soil depth during third year. During third year, significantly higher SOC was recorded with level R_3 (100 % wheat straw incorporate) (0.75 %) which was at par with level R_2 (50 % wheat straw incorporate) at 0-15 cm soil depth. Continuous residue addition supplies organic carbon and enhances microbial activity, leading to gradual SOC accumulation under rice-based systems (Habig & Swanepoel, 2015). Higher SOC in surface soil compared to subsurface soil reflects surface residue placement and limited vertical movement of organic carbon. At 15-30 cm soil depth, non-significant different recorded in SOC during all the years. Interaction effect of gypsum and wheat straw incorporation was non-significant difference on SOC.

After harvest of *rabi* wheat: The results of SOC as affected by different gypsum and wheat straw incorporation levels after harvest of *rabi* wheat is given in Table 8. Gypsum did not significantly affect the SOC at both depths during all the years.

The differences in SOC among wheat straw incorporation levels were significant at 0-15 cm soil depth during second and third years. During second and third years, significantly higher SOC was recorded with level R_3 (100 % wheat straw incorporate) (0.72 and 0.76 %) which was at par with level R_2 (50 % wheat straw incorporate) at 0-15 cm soil depth during third year only. Residue retention enhances carbon inputs and slows SOC mineralization, resulting in improved soil carbon sequestration under intensive cropping (Xue et al., 2024 and Singh et al., 2019). Across treatments, SOC remained consistently higher in surface soil than subsurface soil due to greater organic inputs and microbial activity near the soil surface (Duan et al., 2022). At 15-30 cm soil depth, non-significant different recorded in SOC during all the years. Interaction effect of gypsum and wheat straw incorporation failed to exert any significant difference on soil organic carbon.

3.6 Soil Physical Properties

3.6.1 Soil Bulk Density (g/cm^3) (BD)

After harvest of *rabi* wheat: The results of BD as affected by different gypsum and wheat straw incorporation levels after harvest of *rabi* wheat are given in Table 9.

Gypsum significantly affected the BD at 0-15 cm soil depth during second and third years. During second and third year, significantly lower BD was recorded with G_5 (granular gypsum @ 50% GR) (1.31 and 1.29 g/cm^3) as compared to other gypsum levels, but was found at par with G_3 (phospho gypsum @ 50% GR) at 0-15 cm soil depth. The reduction was more pronounced in the higher gypsum doses, suggesting enhanced flocculation of dispersed clay and improved soil aggregation due to calcium addition. Similarly results have been reported by Lebron et al., (2002).

The differences in BD among R levels was significant at 0-15 cm soil depth during second and third years. During second and third years, significantly lower BD was recorded with level R_3 (100 % wheat straw incorporate) (1.34 and 1.32 g/cm^3) which was at par with level R_2 (50 % wheat straw incorporate) during third year at 0-15 cm soil depth. This lower BD is likely due to increased organic matter content, enhanced microbial activity, and formation of stable aggregates. Residue incorporation significantly decreased bulk density compared to residue removal or burning has been documented by (Singh et al., 2019). Interaction effect of gypsum and wheat straw incorporation failed to exert any significant difference on BD.

3.6.2 Water Stable Aggregates (%) (WSA)

After harvest of *rabi* wheat: The per cent WSA distribution in soil were estimated for sizes >2 mm, 1.00 - 2.00 mm, 0.50 - 1.00 mm, 0.25 - 0.50 mm, 0.10 - 0.50 mm and < 0.10 mm after harvest of *rabi* wheat and the results are given in Tables 10 a to c, respectively. Initial values of WSA under sizes > 2 mm, 1.00 - 2.00 mm, 0.50 - 1.00 mm, 0.25 - 0.50 mm, 0.10 - 0.50 mm and < 0.10 mm were 1.66 %, 2.54 %, 5.18 %, 22.78 % and 33.14 % and 34.70 %, respectively.

First year (2021-22): The effect of gypsum significantly affected the WSA for > 2.00 mm and 1.00 - 2.00 mm size after first year of the experiment (Table 10 a). level G_5 (granular gypsum @ 50 % GR) recorded significantly higher WSA (2.30 % and 4.20 %, respectively) for >2.00 mm and 1.00 - 2.00 mm WSA size as compared to rest of the gypsum levels but which was at par with level G_3 (phospo gypsum @ 50 % GR). This improvement can be attributed to the addition of calcium from gypsum, which promotes flocculation of dispersed clay particles and enhances aggregate stability. Similar improvements in aggregate size distribution following gypsum application have been reported by Yadav et al., (2021). Gypsum levels failed to show any significant difference for 0.50 - 1.00 mm, 0.25 - 0.50 mm, 0.10 - 0.50 mm and < 0.10 mm WSA sizes during first year.

Wheat straw incorporation levels failed to show any significant difference for all WSA sizes during first year (Table 10 a). Interaction effect of gypsum and wheat straw incorporation failed to exert any significant difference on WSA.

Second year (2022-23): The effect of gypsum significantly affected the WSA for > 2.00 mm, 1.00 - 2.00 mm and 0.50 - 1.00 mm size after second year of the experiment (Table 10 b). Level G_3 (phospho gypsum @ 50 % GR) recorded significantly higher WSA (3.40 %) in > 2.00 mm size but which was at par with level G_5 (granular gypsum @ 50 % GR). For 1.00 - 2.00 mm and 0.50 - 1.00 mm size WSA size, level G_5 (granular gypsum @ 50 % GR) recorded significantly higher WSA (4.32 and 7.39 %, respectively) as compared to rest of the gypsum levels but which was at par with level G_3 (phospo gypsum @ 50 % GR). This enhancement is ascribed to the calcium that gypsum provides, which increases aggregate stability and encourages flocculation of scattered clay particles. Similarly, have been reported by Chaudhari et al. (2020) and Shedge et al., (2018). Gypsum levels failed to show any significant difference for 0.25 - 0.50 mm, 0.10 - 0.50 mm and < 0.10 mm WSA sizes during second year.

The results pertaining to wheat straw incorporation levels indicated that significant higher WSA % was recorded in 100 % wheat straw incorporate (R_3) in > 2.00 mm (3.12 %), 1.00 - 2.00 mm (3.78 %) and 0.50 - 1.00 mm size (6.60 %) but which were at par with level R_2 during second year (Table 10 b). Wheat straw incorporation levels failed to show any significant difference in 0.25 - 0.50 mm, 0.10 - 0.50 mm and < 0.10 mm WSA sizes during second year (Table 10 b). This might be due to improved soil structure due to added organic matter and biological binding agents. This agrees with findings of Sharma and Singh (2023), who reported straw incorporation improves soil structure and WSA. Interaction effect of gypsum and wheat straw incorporation failed to exert any significant difference on WSA.

Table 1. Composition of phosphogypsum and granular gypsum

Particulars	Phosphogypsum	Granular gypsum
Moisture content (%)	1.00	2.15
N (%)	-	-
P (%)	0.903	0.361
K (%)	0.031	0.071
Ca (%)	15.019	19.74
Mg (%)	1.338	-
Na (%)	0.104	0.343
Fe (ppm)	2243.7	15563.3
Mn (ppm)	285.7	272.3
Zn (ppm)	23.7	1136.0
Cu (ppm)	11.13	29.07

Table 2. Effect of different treatments on soil $pH_{2.5}$

Treatments	Soil $pH_{2.5}$											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Main plot: Gypsum												
G_1: No gypsum	8.55	8.59	8.47	8.58	8.62	8.53	8.53	8.42	8.44	8.67	8.72	8.73
G_2: Phosphogypsum @ 25% GR	8.47	8.45	8.25	8.34	8.56	8.43	8.45	8.37	8.16	8.54	8.70	8.56
G_3: Phosphogypsum @ 50% GR	8.42	8.47	8.19	8.50	8.50	8.41	8.43	8.35	8.03	8.60	8.61	8.45
G_4: Granular gypsum @ 25% GR	8.40	8.57	8.26	8.47	8.60	8.39	8.42	8.36	8.17	8.53	8.66	8.54
G_5: Granular gypsum @ 50% GR	8.35	8.53	8.23	8.42	8.56	8.41	8.29	8.35	8.15	8.53	8.59	8.49
SEm±	0.08	0.10	0.07	0.08	0.05	0.05	0.10	0.08	0.09	0.11	0.06	0.12
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	2.97	3.36	2.40	2.78	1.87	1.91	3.39	3.00	3.30	3.95	2.09	4.08
Subplot: Wheat straw incorp.												
R_1: No straw incorporate	8.46	8.56	8.31	8.46	8.58	8.48	8.48	8.40	8.23	8.58	8.67	8.55
R_2: 50 % wheat straw incorporate	8.44	8.53	8.28	8.45	8.54	8.42	8.42	8.39	8.18	8.56	8.66	8.53
R_3: 100 % wheat straw incorporate	8.41	8.47	8.26	8.47	8.59	8.41	8.37	8.33	8.17	8.58	8.64	8.58
SEm±	0.03	0.05	0.04	0.03	0.02	0.02	0.05	0.05	0.04	0.04	0.02	0.04
C.D. at 5%	NS	NS	NS	NS	NS	0.05	NS	NS	NS	NS	NS	NS
CV (%)	1.58	2.25	1.91	1.56	1.01	0.78	2.09	2.21	1.91	1.62	1.00	1.60
Interaction (GxR)												
SEm±	0.08	0.11	0.09	0.08	0.05	0.04	0.10	0.11	0.09	0.08	0.05	0.08
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	8.44	8.52	8.28	8.46	8.57	8.44	8.42	8.37	8.19	8.57	8.66	8.55

Table 3. Effect of different treatments on soil $EC_{2.5}$ (dS/m)

Treatments	Soil $EC_{2.5}$ (dS/m)											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Main plot: Gypsum												
G_1: No gypsum	1.13	1.06	1.08	1.08	1.06	1.05	1.28	1.34	1.27	1.20	1.19	1.14
G_2: Phosphogypsum @ 25% GR	1.19	1.02	1.06	1.08	1.02	0.98	1.31	1.27	1.21	1.01	1.15	1.09
G_3: Phosphogypsum @ 50% GR	1.20	1.04	0.99	1.13	0.99	1.00	1.36	1.19	1.11	1.13	1.17	1.06
G_4: Granular gypsum @ 25% GR	1.25	1.03	1.03	1.18	1.03	1.04	1.50	1.22	1.12	1.20	1.16	1.09
G_5: Granular gypsum @ 50% GR	1.28	1.04	0.92	1.30	1.04	0.89	1.43	1.18	1.18	1.17	1.11	1.09
SEm±	0.04	0.04	0.04	0.06	0.05	0.04	0.05	0.08	0.06	0.05	0.04	0.06
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	9.71	12.48	13.01	14.60	13.93	11.62	11.94	18.82	16.01	13.85	11.48	15.36
Subplot: Wheat straw incorp.												
R_1: No straw incorporate	1.24	1.07	1.05	1.12	1.00	0.99	1.45	1.21	1.23	1.14	1.16	1.10
R_2: 50 % wheat straw incorporate	1.23	1.03	1.02	1.18	1.06	0.99	1.35	1.31	1.19	1.13	1.19	1.13
R_3: 100 % wheat straw incorporate	1.15	1.01	0.98	1.16	1.02	0.99	1.33	1.20	1.12	1.16	1.12	1.06
SEm±	0.04	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	12.74	10.50	7.85	10.29	12.92	11.87	9.61	11.39	10.91	12.70	8.81	9.94
Interaction (GxR)												
SEm±	0.09	0.06	0.05	0.07	0.08	0.07	0.08	0.08	0.07	0.08	0.06	0.06
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	1.21	1.04	1.02	1.16	1.03	0.99	1.38	1.24	1.18	1.14	1.16	1.09

Table 4. Effect of different treatments on soil ESP

Treatments	Soil ESP											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Main plot: Gypsum												
G_1: No gypsum	15.56	14.54	14.80	17.46	17.79	17.31	14.19	13.61	14.09	15.82	16.96	16.09
G_2: Phosphogypsum @ 25% GR	12.44	11.23	10.07	15.90	15.68	14.92	11.64	10.22	10.02	16.20	15.59	14.53
G_3: Phosphogypsum @ 50% GR	10.78	9.41	8.24	14.55	15.14	13.81	9.65	8.95	8.20	14.97	13.93	13.37
G_4: Granular gypsum @ 25% GR	12.52	10.84	10.16	15.96	15.78	14.70	11.88	10.32	9.27	17.06	15.54	14.43
G_5: Granular gypsum @ 50% GR	10.91	8.69	7.76	14.56	15.08	14.16	9.97	8.84	7.20	16.17	14.62	13.19
SEm±	0.50	0.49	0.53	0.72	0.76	0.81	0.59	0.41	0.45	0.57	0.68	0.72
C.D. at 5%	1.62	1.59	1.71	NS	NS	NS	1.93	1.34	1.45	NS	NS	NS

Treatments	Soil ESP											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
CV (%)	12.00	13.33	15.45	13.69	14.30	16.25	15.47	11.86	13.68	10.72	13.33	15.00
Subplot: Wheat straw incorp.												
R_1: No straw incorporate	12.67	11.07	10.67	15.77	15.82	15.13	11.84	10.55	10.11	16.31	15.50	14.61
R_2: 50 % wheat straw incorporate	12.77	10.91	10.15	15.71	15.87	14.72	11.47	10.59	9.96	15.87	15.55	14.45
R_3: 100 % wheat straw incorporate	11.88	10.84	9.80	15.58	16.00	15.09	11.09	10.02	9.19	15.95	14.93	13.91
SEm±	0.31	0.14	0.24	0.32	0.23	0.28	0.31	0.24	0.31	0.24	0.25	0.25
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	9.64	5.05	9.24	7.94	5.56	7.20	10.45	8.99	12.15	5.85	6.27	6.66
Interaction (GxR)												
SEm±	0.69	0.32	0.54	0.72	0.51	0.62	0.69	0.54	0.68	0.54	0.55	0.55
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	12.44	10.94	10.20	15.69	15.89	14.98	11.47	10.39	9.76	16.04	15.33	14.32

Table 5. Effect of different treatments on soil available N (kg/ha)

Treatments	Soil available N (kg/ha)											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Main plot: Gypsum												
G_1: No gypsum	243	249	262	224	233	212	230	259	267	215	238	233
G_2: Phosphogypsum @ 25% GR	251	264	294	239	236	230	235	276	274	235	246	242
G_3: Phosphogypsum @ 50% GR	246	270	292	246	249	227	255	294	289	224	258	253
G_4: Granular gypsum @ 25% GR	253	259	284	234	244	227	250	258	266	252	248	232
G_5: Granular gypsum @ 50% GR	273	263	287	246	260	234	262	267	271	251	237	243
SEm±	9.81	10.61	10.24	7.98	12.24	8.45	9.26	14.51	10.87	11.81	8.61	8.64
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	11.62	12.19	10.82	10.07	15.01	11.23	11.27	16.08	11.92	15.03	10.52	10.77
Subplot: Wheat straw incorp.												
R_1: No straw incorporate	246	251	273	235	237	225	242	265	258	233	242	237
R_2: 50 % wheat straw incorporate	252	262	286	233	242	227	250	272	276	242	245	243
R_3: 100 % wheat straw incorporate	262	270	292	245	255	226	248	276	286	233	250	242
SEm±	4.48	5.81	5.17	5.10	8.18	6.49	2.42	5.32	7.16	3.90	4.03	5.10
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	21.12	NS	NS	NS

Treatments	Soil available N (kg/ha)											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Interaction (GxR)												
SEm±	10.01	13.00	11.56	11.41	18.29	14.52	5.41	11.89	16.01	8.71	9.02	11.41
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	6.85	8.62	7.05	8.32	12.96	11.13	3.80	7.61	10.13	6.40	6.36	8.21
Mean	253	261	284	238	244	226	247	271	274	236	246	241

Table 6. Effect of different treatments on soil available phosphorus (kg/ha)

Treatments	Soil available phosphorus (kg/ha)											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Main plot: Gypsum												
G_1: No gypsum	149	149	170	129	118	113	152	155	184	129	121	118
G_2: Phosphogypsum @ 25% GR	162	153	176	144	145	138	157	177	194	139	134	141
G_3: Phosphogypsum @ 50% GR	160	159	180	147	144	127	159	172	200	138	146	143
G_4: Granular gypsum @ 25% GR	159	153	174	148	138	125	169	160	190	141	129	136
G_5: Granular gypsum @ 50% GR	166	164	169	162	145	127	174	168	203	152	134	140
SEm±	8.04	7.28	8.85	7.08	6.87	6.33	8.69	6.65	7.75	5.17	5.42	7.31
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	15.2	14.1	15.3	14.5	15.0	15.1	16.07	11.99	11.98	11.10	12.23	16.19
Subplot: Wheat straw incorp.												
R_1: No straw incorporate	152	148	162	147	132	121	156	162	188	140	130	129
R_2: 50 % wheat straw incorporate	157	158	175	144	143	128	161	170	196	139	138	138
R_3: 100 % wheat straw incorporate	168	160	184	147	138	129	169	167	199	141	130	140
SEm±	4.35	3.55	6.49	4.57	4.39	4.22	3.63	3.85	4.18	3.16	2.63	5.59
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	10.6	8.8	14.5	12.1	12.4	13.0	8.67	8.96	8.33	8.76	7.66	15.99
Interaction (GxR)												
SEm±	9.74	7.93	14.51	10.23	9.82	9.44	8.13	8.60	9.34	7.07	5.88	12.50
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	159	155	174	146	138	126	162	166	194	140	133	135

Table 7. Effect of different treatments on soil available potassium (kg/ha)

Treatments	Soil available potassium (kg/ha)											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Main plot: Gypsum												
G_1: No gypsum	1314	1294	1226	1423	1262	1239	1268	1232	1188	1353	1272	1215
G_2: Phosphogypsum @ 25% GR	1414	1406	1254	1566	1361	1314	1390	1291	1233	1359	1356	1312
G_3: Phosphogypsum @ 50% GR	1441	1324	1311	1445	1434	1389	1386	1320	1263	1457	1376	1359
G_4: Granular gypsum @ 25% GR	1543	1368	1366	1468	1457	1345	1557	1376	1289	1587	1452	1405
G_5: Granular gypsum @ 50% GR	1556	1504	1441	1685	1586	1427	1464	1417	1379	1575	1424	1260
SEm±	65	73	54	66	73	64	69	54	62	76	67	64
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	13.34	15.93	12.18	13.00	15.50	14.26	14.56	12.12	14.63	15.59	14.53	14.71
Subplot: Wheat straw incorp.												
R_1: No straw incorporate	1447	1351	1302	1481	1440	1325	1385	1311	1209	1449	1371	1262
R_2: 50 % wheat straw incorporate	1417	1381	1318	1567	1447	1336	1418	1304	1242	1497	1364	1320
R_3: 100 % wheat straw incorporate	1498	1406	1338	1505	1372	1367	1436	1367	1360	1453	1393	1348
SEm±	35	19	22	38	34	28	29	33	44	43	41	44
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	9.26	5.25	6.34	9.81	9.40	8.19	7.85	9.68	13.40	11.48	11.63	13.12
Interaction (GxR)												
SEm±	78	42	48	86	77	63	64	74	98	97	92	99
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	1454	1379	1319	1517	1420	1343	1413	1327	1270	1466	1376	1310

Table 8. Effect of different treatments on soil organic carbon (%)

Treatments	Soil organic carbon (%)											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
Main plot: Gypsum												
G_1: No gypsum	0.57	0.61	0.68	0.45	0.46	0.49	0.60	0.64	0.70	0.46	0.51	0.52
G_2: Phosphogypsum @ 25% GR	0.62	0.63	0.71	0.48	0.49	0.54	0.60	0.65	0.72	0.53	0.52	0.54
G_3: Phosphogypsum @ 50% GR	0.59	0.66	0.70	0.48	0.52	0.53	0.65	0.72	0.75	0.48	0.55	0.56
G_4: Granular gypsum @ 25% GR	0.63	0.68	0.72	0.46	0.53	0.52	0.65	0.69	0.73	0.51	0.53	0.54
G_5: Granular gypsum @ 50% GR	0.67	0.66	0.73	0.51	0.55	0.56	0.57	0.72	0.77	0.55	0.55	0.58
SEm±	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatments	Soil organic carbon (%)											
	After harvest of *kharif* rice						After harvest of *rabi* wheat					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
CV (%)	14.58	11.75	10.50	13.82	12.85	14.14	12.21	10.64	10.47	14.01	12.36	12.35
Subplot: Wheat straw incorp.												
R_1: No straw incorporate	0.59	0.62	0.66	0.47	0.50	0.51	0.59	0.66	0.71	0.51	0.51	0.52
R_2: 50 % wheat straw incorporate	0.61	0.65	0.71	0.46	0.51	0.52	0.61	0.67	0.74	0.49	0.55	0.55
R_3: 100 % wheat straw incorporate	0.64	0.68	0.75	0.49	0.51	0.54	0.65	0.72	0.76	0.52	0.54	0.57
SEm±	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
C.D. at 5%	NS	NS	0.05	NS	NS	NS	NS	0.04	0.04	NS	NS	NS
CV (%)	7.95	10.63	9.59	10.12	9.75	5.55	11.29	7.16	6.41	9.77	10.09	9.26
Interaction (GxR)												
SEm±	0.03	0.04	0.04	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	0.61	0.65	0.71	0.47	0.51	0.53	0.61	0.68	0.74	0.50	0.53	0.55

Table 9. Effect of different treatments on soil bulk density (g/cm^3) after wheat

Treatments	0-15 cm		
	2021-22	2022-23	2023-24
Main plot: Gypsum			
G_1: No gypsum	1.45	1.45	1.44
G_2: Phosphogypsum @ 25% GR	1.43	1.40	1.39
G_3: Phosphogypsum @ 50% GR	1.37	1.34	1.31
G_4: Granular gypsum @ 25% GR	1.42	1.43	1.41
G_5: Granular gypsum @ 50% GR	1.34	1.31	1.29
SEm±	0.03	0.02	0.03
C.D. at 5%	NS	0.06	0.08
CV (%)	6.27	4.97	6.33
Subplot: Wheat straw incorp.			
R_1: No straw incorporate	1.42	1.42	1.42
R_2: 50 % wheat straw incorporate	1.40	1.39	1.36
R_3: 100 % wheat straw incorporate	1.38	1.34	1.32
SEm±	0.02	0.01	0.02
C.D. at 5%	NS	0.04	0.05
CV (%)	5.19	3.51	4.74
Interaction (GxR)			
SEm±	0.04	0.03	0.04
C.D. at 5%	NS	NS	NS
Mean	1.40	1.39	1.37

Table 10 a. Effect of different treatments on water stable aggregates after wheat

Treatment	Water stable aggregates (%) (2021-22)					
	> 2 mm	1 mm	0.5 mm	0.25 mm	0.1 mm	< 0.1 mm
Main plot: Gypsum						
G_1: No gypsum	1.57	2.43	5.27	21.70	35.45	33.57
G_2: Phosphogypsum @ 25% GR	1.77	2.82	5.32	25.02	33.17	31.90
G_3: Phosphogypsum @ 50% GR	2.09	3.60	6.18	28.86	34.80	24.46
G_4: Granular gypsum @ 25% GR	1.57	3.37	5.78	24.75	32.67	31.86
G_5: Granular gypsum @ 50% GR	2.30	4.20	6.82	26.57	30.04	30.07
SEm±	0.11	0.21	0.38	1.61	1.84	1.28
C.D. at 5%	0.37	0.67	NS	NS	NS	NS
CV (%)	18.4	18.7	19.4	19.0	16.6	12.6
Subplot: Wheat straw incorp.						
R_1: No straw incorporate	1.84	3.01	5.89	24.89	34.72	29.66
R_2: 50 % wheat straw incorp.	1.81	3.29	5.53	25.07	33.81	30.49
R_3: 100 % wheat straw incorp.	1.93	3.54	6.21	26.19	31.15	30.97
SEm±	0.09	0.15	0.20	0.89	1.37	0.95
C.D. at 5%	NS	NS	NS	NS	NS	NS
CV (%)	18.3	17.1	13.0	13.5	15.9	12.0
Interaction (GxR)						
SEm±	0.20	0.32	0.44	1.99	3.06	2.11
C.D. at 5%	NS	NS	NS	NS	NS	NS

Table 10 b. Effect of different treatments on water stable aggregates after wheat

Treatment	Water stable aggregates (%) (2022-23)					
	> 2 mm	1 mm	0.5 mm	0.25 mm	0.1 mm	< 0.1 mm
Main plot: Gypsum						
G_1: No gypsum	2.53	2.56	5.30	17.53	38.64	33.45
G_2: Phosphogypsum @ 25% GR	2.74	2.88	5.53	19.41	38.43	31.01
G_3: Phosphogypsum @ 50% GR	3.40	4.21	6.57	26.16	34.31	25.34
G_4: Granular gypsum @ 25% GR	2.63	3.53	5.98	19.34	33.40	35.12
G_5: Granular gypsum @ 50% GR	2.83	4.32	7.39	27.65	30.93	26.87
SEm±	0.18	0.23	0.36	1.43	2.39	1.34
C.D. at 5%	0.59	0.76	1.19	NS	NS	NS
CV (%)	19.1	19.9	17.7	19.5	18.4	13.2
Subplot: Wheat straw incorporate						
R_1: No straw incorporate	2.49	3.16	5.62	22.27	36.04	30.42
R_2: 50 % wheat straw incorp.	2.87	3.56	6.24	22.03	35.65	29.64

Treatment	Water stable aggregates (%) (2022-23)					
	> 2 mm	1 mm	0.5 mm	0.25 mm	0.1 mm	< 0.1 mm
R_3: 100 % wheat straw incorp.	3.12	3.78	6.60	21.76	33.74	31.01
SEm±	0.14	0.15	0.26	1.08	1.55	1.06
C.D. at 5%	0.40	0.45	0.75	NS	NS	NS
CV (%)	18.5	16.7	16.0	18.9	17.0	13.5
Interaction (GxR)						
SEm±	0.30	0.34	0.57	2.41	3.46	2.37
C.D. at 5%	NS	NS	NS	NS	NS	NS

Table 10 c. Effect of different treatments on water stable aggregates after wheat

Treatment	Water stable aggregates (%) (2023-24)					
	> 2 mm	1 mm	0.5 mm	0.25 mm	0.1 mm	< 0.1 mm
Main plot: Gypsum						
G_1: No gypsum	5.95	3.14	5.74	20.07	36.65	28.45
G_2: Phosphogypsum @ 25% GR	6.27	3.28	6.39	19.88	36.37	27.82
G_3: Phosphogypsum @ 50% GR	7.51	5.56	6.84	20.52	33.06	26.50
G_4: Granular gypsum @ 25% GR	6.32	3.23	6.08	20.35	36.49	27.52
G_5: Granular gypsum @ 50% GR	7.69	4.86	7.63	20.81	33.26	25.75
SEm±	0.40	0.22	0.41	1.14	1.84	1.27
C.D. at 5%	1.30	0.72	1.32	NS	NS	NS
CV (%)	17.7	16.5	18.6	16.8	15.7	14.0
Subplot: Wheat straw incorporate						
R_1: No straw incorporate	6.24	3.72	6.42	20.05	36.66	26.90
R_2: 50 % wheat straw incorp.	6.76	3.97	6.22	19.83	35.75	27.46
R_3: 100 % wheat straw incorp.	7.24	4.34	6.97	21.09	33.09	27.26
SEm±	0.25	0.16	0.19	0.42	1.37	0.94
C.D. at 5%	0.73	0.47	0.57	NS	NS	NS
CV (%)	14.1	15.5	11.2	8.0	15.1	13.4
Interaction (GxR)						
SEm±	0.55	0.36	0.42	0.94	3.06	2.11
C.D. at 5%	NS	NS	NS	NS	NS	NS

Third year (2023-24): The effect of gypsum significantly affected the WSA for > 2.00 mm, 1.00 - 2.00 mm and 0.50 - 1.00 mm size after third year of the experiment (Table 10 c). Level G_5 (granular gypsum @ 50 % GR) recorded significantly higher WSA (7.69 % and 7.63 %, respectively) as compared to rest of the gypsum levels but which were comparable with level G_3 (phospo gypsum @ 50 % GR) in > 2.00 mm and 0.50 - 1.00 mm size. In 1.00 - 2.00 mm size, level G_3 (phospho gypsum @ 50 % GR) recorded significantly higher WSA (5.56 %) but which was at par with level G_5 (granular gypsum @ 50 % GR). The improvement is attributed to calcium-induced flocculation of dispersed clay particles, leading to more stable aggregates. Chaudhari et al. (2020) reported that gypsum application significantly improved water-stable aggregates (WSA) in partially reclaimed salt-affected soils of South Gujarat. Gypsum levels failed to show any significant difference for 0.25 - 0.50 mm, 0.10 - 0.50 mm and < 0.10 mm WSA sizes during third year (Table 10 c).

The results pertaining to wheat straw incorporation levels indicated that significant higher WSA % was recorded in 100 % wheat straw incorporate (R_3) for> 2.00 mm (7.24 %), 1.00 - 2.00 mm (4.34 %) and 0.50 - 1.00 mm size (6.97 %) but which were at par with level R_2 during third year for > 2.00 mm and 1.00 - 2.00 mm WSA size. Wheat straw incorporation levels failed to show any significant difference in 0.25 - 0.50 mm, 0.10 - 0.50 mm and < 0.10 mm WSA sizes during third year (Table 10 c). This might be due to reflecting the role of added organic matter and microbial binding agents in aggregate formation. Similarly, have been reported by Mondal et al. (2019). Interaction effect of gypsum and wheat straw incorporation failed to exert any significant difference on WSA.

4. Conclusions

The three years study concluded that the application of gypsum at 50% GR and 100% wheat straw incorporation proved most effective in improving soil chemical and physical properties of coastal soils without adversely affecting soil electrical conductivity and available nutrient status. Application of phosphogypsum and granular gypsum at 50% gypsum requirement effectively reduced soil exchangeable sodium percentage (ESP) and bulk density, while improving water stable aggregates. Wheat straw incorporation at 100% enhanced soil organic carbon, water-stable aggregates and reduced bulk density. Therefore, use of gypsum and wheat crop residue incorporation can be considered a sustainable strategy for improving soil health and managing sodicity in coastal soils.

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 the writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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