Synergy of reduced gypsum and pressmud – a cost effective approach for sustainable reclamation of degraded sodic lands

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ABSTRACT

The effect of improved practice [IP; gypsum application @ 25% gypsum requirement (GR) +10 t/ha press mud] over existing practice (EP; gypsum application @ 50% GR) on rice productivity and profitability in sodic soils (pH 9.2–10.4) was evaluated at farmers’ fields for 3 years during 2011–14 in Hardoi district of Uttar Pradesh, India. All growth parameters were significantly higher for IP than EP, with 36.5 and 39.3% higher straw and grain yield, respectively. Interaction effect between sodicity levels and reclamation practices were significant for grain and straw yields. Use of IP with S1, S2, S3, and S4 sodicity levels reduced reclamation costs by ₹15480, 18540, 22560 and 24780/ha, respectively. The combination of reduced costs and increased yields in the IP reclamation treatment led to higher returns from rice cultivation in sodic soils, because IP effect on rice yield was better at higher sodicity level, whereas under EP, this was achieved only for sodicity levels of S2 and S3. Soil properties like pH, EC, organic carbon, exchangeable sodium percentage (ESP), contents of cations and anions were improved significantly under IP than EP. Overall, improved practice of sodic soil reclamation had better effects on soil properties and crop yields than the current practices in vogue besides considerable reduction in cost of reclamation.

Key words: Degraded sodic lands, Press mud, Reclamation, Reduced gypsum, Salt tolerant varieties

Land degradation due to presence of salts in the soil is an alarming threat to agricultural productivity and sustainability, particularly in arid and semi-arid regions (Qadir et al. 2006). More than 800 million ha land in 100 countries of the world is affected by salinity of which sodic/solonetz soils constitute 581 million ha (FAO). In India, about 6.73 million ha is salt affected land which represents 2.1% of the geographical area of the country (Mandal et al. 2009). The methods generally used to ameliorate sodic soils are chemical amendments alone or in combination with organic amendments like farmyard manure (FYM), compost, and crop-based interventions (Singh et al. 2009a, b). Of these, chemical amendments like gypsum (CaSO4·2H2O) have been used most extensively for the reclamation of sodic soils (Rana et al. 2014) but it is very costly because of its requirement in large quantity (12-16 t/ha) and high market price (₹3970/tonne) and high market price (₹3970/tonne). It has been estimated that about 60% of the total reclamation cost accounts for gypsum only (Singh et al. 2008). The significance of organic matter in sodic soils has been proven through its effect on improving soil physico-chemical properties for crop growth, besides its role as source of nutrients (Rana et al. 2014, Singh et al. 2017). The application of organic materials in sodic soils increases the available N, P and K and the soil organic carbon (SOC) content, whilst reducing soil bulk density and pH (Dhanushkodi and Subramanian 2012, Rana et al. 2014). However, the availability of FYM in such a large quantity (20 t/ha) is again a major constraint. The press mud, an unused sugar industry by-product contains sizable quantities of macro and micro-nutrients, high calcium sulphate and organic matter supplied Ca directly to the soil which replace excess Na’ from the soil exchange complex, and sulphur convert into sulphuric acid that lower down the soil pH, and improve the physical, chemical and biological properties of sodic soils which can also be an alternative for reclamation of sodic soils (Negim 2016). India produces about 12 million tonnes of press mud per year (Gupta et al. 2011). Thus, present study aimed that the synergy of reduced gypsum and press mud (IP) would prove to be cost effective and sustainable technology for reclamation of degraded sodic lands besides improved crop productivity over sole use of gypsum @ 50% GR (EP).

MATERIALS AND METHODS

A field study at farmers field in village Santaraha of Uttar Pradesh (N 27° 36’ 31” to 27° 36’ 32” latitude, E 80°
11’ 34” to 80º 11’ 52” longitude) during 2011–14 on rice with different sodicity levels and reclamation practices were conducted in factorial design with 3 replications. The experimental soil had initial soil pH 9.2–10.4, EC$_2$ 0.67–2.21 dS/m, exchangeable sodium percentage (ESP) 34–89, and organic carbon 0.08– 0.21% in 0-15 cm soil depth. Field experiment consisted of 4 sodicity levels ($S_1$, $S_2$, $S_3$, and $S_4$) and 2 reclamation practices, i.e. existing practice (EP) including the application of gypsum at 50% GR and the improved practice (IP) application of reduced dose of gypsum at 25% GR + 10 t/ha press mud.

Agriculture grade mineral gypsum containing S (16.1%), Ca (18.3%), Mg (0.04%), and Na (0.18%) was applied in EP treatments @ 50% GR in sodic soils having $S_1$, $S_2$, $S_3$, and $S_4$ sodicity levels. However in IP treatments, reduced dose of gypsum @ 25% GR followed by press mud containing S (0.23%), Ca (11%), Mg (1.65%), total C (26%), total N (1.33%), total P (1.08%), total K (0.53%) and organic matter (30–35%) was applied @10 t/ha. The 30 days old seedlings of salt tolerant variety of rice CSR 36 was transplanted in second week of July each year. Recommended packages and practices for cultivation of rice in sodic soils were followed uniformly in both EP and IP. The crop was harvested at physiological maturity.

**RESULTS AND DISCUSSION**

**Plant growth and yield:** Sodicity levels and reclamation practices had significant effects on rice crop growth. Maximum hills/m$^2$ (31.9) was recorded under $S_1$ treatment and it decreased significantly with increasing sodicity levels. Similarly, successive increment in sodicity levels from $S_1$ – $S_2$, $S_2$–$S_3$, and $S_3$–$S_4$ decreased the dry matter accumulation (DMA) by 33.5%, 46.6%, and 51.7%, respectively. Similar trend was also observed in number of panicles/m$^2$ and LAI. Panicles/m$^2$ ranged from 290.7 (S1)–50.1 (S4). The reduction in plant growth was due to high soil pH and ESP that reduced the nutrient availability to the plants (Noori et al. 2018). The growth reduction under higher sodicity levels may be the result of the toxicity of Na$^+$ ions (Tawakkoli et al. 2017). Poor soil organic matter content is often related to less available nitrogen, and low cation exchange capacity causing a decrease in root growth (Choudhary and Suri 2009). The LAI also decreased significantly with increasing sodicity levels. Maximum LAI (2.35) was recorded with $S_1$ sodicity level and a minimum (1.23) under $S_4$ level (Table 2). This may be due to reduction in the supply of carbohydrates and/or growth hormones, photosynthesis rate and excessive uptake of salts that affects the production of metabolites (Noori et al. 2018). Decomposition of organic matter added through press mud and rice crop residues increased the organic acid exudates and mobilized soil

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**Table 1** Initial characteristics of soils of experimental sites selected for different sodicity levels

| Soil properties | Slightly sodic ($S_1$) | Moderately sodic ($S_2$) | Sodic ($S_3$) | Severely sodic ($S_4$) |
|-----------------|------------------------|-------------------------|---------------|-----------------------|
| pH (1:2)        | 9.2 ± 0.11             | 9.6 ± 0.13              | 10.0 ± 0.14   | 10.4 ± 0.11           |
|                | 0.67 ± 0.11            | 1.42 ± 0.11             | 2.14 ± 0.11   | 2.21 ± 0.11           |
|                | 0.21 ± 0.11            | 0.12 ± 0.08             | 0.08 ± 0.08   | 0.08 ± 0.06           |
|                | 34.0 ± 0.08            | 58.0 ± 0.12             | 78.0 ± 0.14   | 89.0 ± 0.16           |
|                | 8.5 ± 0.11             | 10.2 ± 0.12             | 12.4 ± 0.13   | 13.6 ± 0.16           |
|                | 9.8 ± 0.11             | 11.2 ± 0.12             | 12.6 ± 0.14   | 14.1 ± 0.16           |
|                | 4.7 ± 0.13             | 4.6 ± 0.12              | 3.86 ± 0.11   | 6.80 ± 0.12           |
|                | 9.5 ± 0.46             | 10.5 ± 0.53             | 12.4 ± 0.62   | 14.0 ± 0.54           |
|                | 3.00 ± 0.26            | 4.00 ± 0.32             | 5.30 ± 0.62   | 6.00 ± 0.24           |
|                | 13.80 ± 0.12           | 16.90 ± 0.12            | 19.20 ± 0.12  | 24.80 ± 0.12          |
|                | 0.80 ± 0.04            | 0.80 ± 0.04             | 0.50 ± 0.05   | 0.50 ± 0.02           |
|                | 1.70 ± 0.11            | 1.40 ± 0.12             | 0.60 ± 0.12   | 0.80 ± 0.10           |
|                | 1.60 ± 0.08            | 1.00 ± 0.12             | 0.40 ± 0.12   | 0.60 ± 0.04           |

EC, electrical conductivity; SOC, soil organic carbon; ESP, exchangeable sodium percentage; GR, gypsum requirement; pH and EC(1:2), soil and water suspension ratio of 1:2.
calcium (Kumar et al. 2015). This may be associated with the enhancement of biological activities in the rhizosphere. Across the sodicity levels, IP significantly increased hills/m² (11.9%), panicles/m² (45.6%), dry matter g/m² (25.6%) and LAI (10.9%) over EP (Table 2).

Yield attributes were significantly affected by increasing sodicity levels (Table 2). The reductions in spikelets/panicle from S₁–S₂, S₂–S₃ and S₃–S₄ were 3.5, 1.3 and 18.6%, respectively. The floret fertility with increasing sodicity levels decreased by 12.3, 20.2 and 8.7% and 1000-grain weight by 7.4, 8.5 and 0.9% respectively. A significant reduction in 1000 grain weight was recorded up to S₄ sodicity level over S₁ level, but the difference between S₃ and S₄ was statistically at par. All yield components except 1000-grain weight were observed significantly higher with IP, as compared to EP. The IP recorded 4.1%, and 9.0% higher spikelets/panicle, and floret fertility, respectively, over the EP. This was attributed to the synergistic effect of press mud and gypsum which had additional beneficial effects on the soil physico-chemical properties as well as the rhizosphere environment (Chaum et al. 2011). Press mud as an organic source of amendment may be helpful in leaching the enhancement of biological activities in the rhizosphere. Across the sodicity levels, IP significantly increased hills/m² (11.9%), panicles/m² (45.6%), dry matter g/m² (25.6%) and LAI (10.9%) over EP (Table 2).

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**Improvement in soil properties:** Application of amendments reduced soil pH, EC, and ESP and increased SOC at all sodicity levels under both EP and IP reclamation practices (Table 4). IP reduced the soil pH from 9.2 to 8.5, 9.6 to 8.5, 10.0 to 9.2 and 10.4 to 9.4 and correspondingly increased the organic carbon from 0.21 to 0.32%, 0.12 to 0.26%, 0.08 to 0.16% and 0.08 to 0.14% in S₁, S₂, S₃ and S₄ sodicity levels, respectively. Similarly, ESP also reduced from 34 to 16, 58 to 24, 78 to 29 and 89 to 39 with IP which showed 52.9, 58.6, 62.8, and 56.2% reduction over the initial and 24.6, 20.4, 32.4, and 24.9% over the EP (Table 4). The decrease in soil pH and ESP and increase in

### Table 2 Effect of different sodicity levels and reclamation practices on growth parameters, yield attributes and yields of rice (mean of three years)

| Sodicity levels | Number of hills/m² | Panicles/m² | Dry matter (g/m²) | LAI | Spikelets/panicle | Floret fertility (%) | 1000-grain weight (g) | Straw yield (t/ha) | Grain yield (t/ha) |
|-----------------|--------------------|------------|-------------------|-----|-------------------|---------------------|----------------------|------------------|-----------------|
| S₁              | 31.9               | 290.7      | 1385.5            | 2.3 | 121.6             | 85.2                | 25.4                 | 8.7              | 5.0             |
| S₂              | 26.8               | 199.0      | 919.2             | 2.0 | 115.8             | 74.7                | 23.5                 | 7.6              | 4.4             |
| S₃              | 22.1               | 102.9      | 490.6             | 1.4 | 117.3             | 59.6                | 21.5                 | 4.8              | 2.8             |
| S₄              | 17.7               | 50.1       | 236.7             | 1.2 | 94.30             | 54.4                | 21.7                 | 2.5              | 1.5             |
| SEM±            | 0.83               | 5.05       | 5.63              | 0.03| 2.12              | 0.79                | 0.11                 | 0.04             | 0.02            |
| LSD (P=0.05)    | 2.14               | 8.77       | 18.20             | 0.059| 2.13              | 1.49                | ns                   | 0.14             | 0.08            |

| Reclamation practices | Number of hills/m² | Panicles/m² | Dry matter (g/m²) | LAI | Spikelets/panicle | Floret fertility (%) | 1000-grain weight (g) | Straw yield (t/ha) | Grain yield (t/ha) |
|-----------------------|--------------------|------------|-------------------|-----|-------------------|---------------------|----------------------|------------------|-----------------|
| EP                    | 25.1               | 130.9      | 677.7             | 1.6 | 107.5             | 64.9                | 22.8                 | 5.0              | 2.9             |
| IP                    | 28.1               | 190.5      | 851.4             | 1.8 | 111.9             | 70.7                | 23.2                 | 6.8              | 3.9             |
| SEM±                 | 0.67               | 2.66       | 5.83              | 0.018| 0.64              | 0.45                | 0.22                 | 0.05             | 0.03            |
| LSD (P=0.05)         | 1.86               | 8.77       | 18.20             | 0.059| 2.13              | 1.49                | ns                   | 0.14             | 0.08            |

S₁, Slightly sodic; S₂, moderately sodic; S₃, Sodic; S₄, severely sodic; LSD, least significant difference; LAI, leaf area index; SEM ±, standard error of mean

### Table 3 Interaction effect of sodicity levels and reclamation practices on straw and grain yield of rice

| Sodicity levels | Straw yield (t/ha) | % increase over EP | Grain yield (t/ha) | % increase over EP |
|-----------------|--------------------|--------------------|-------------------|--------------------|
| S₁              | 8.64               | 8.72               | 4.99              | 5.04               |
| S₂              | 7.19               | 7.95               | 4.16              | 4.59               |
| S₃              | 3.40               | 6.28               | 1.96              | 3.63               |
| S₄              | 0.66               | 4.45               | 0.38              | 2.57               |
| LSD (P=0.05)    | 0.28               | 0.16               |                   |                    |

S₁, Slightly sodic; S₂, moderately sodic; S₃, Sodic; S₄, severely sodic; LSD, least significant difference
SOC and improved biological activities in IP may be due to combined use of gypsum and press mud which led to higher biomass production (Singh et al. 2014). Similarly, higher reduction in Na⁺ and increase in Ca²⁺ and Mg²⁺ contents was recorded in IP as compared to EP (Table 4). Moreover, the addition of organic matter produced more organic acids which mobilized the soil calcium as reflected by the soil analysis before and after reclamation (Table 4).

It was observed that sodicity indicators like pH, ESP and SOC were found similar or even better in the IP treatment as compared to the EP treatment. It shows that the reclaiming effect of the press mud @10 t/ha was similar to gypsum @ 25% GR.

**Economic analysis:** The cost of reclamation increased with increasing levels of sodicity for both the practices evaluated. Net savings under IP ranged from 28 to 34% which was comparable with EP, and net savings increased in absolute and relative terms with increasing soil sodicity. Cost of production in the initial year (2011–12) was significantly higher than the subsequent years, due to inclusion of full reclamation costs (Table 5). During 2011–12, highest gross return with EP (₹62760/ha) as well as IP (₹44940/ha), was obtained in S₁ sodicity levels. The IP increased gross returns by 18.8, 12.8, 93.2 and 93.1% with S₁, S₂, S₃ and S₄ sodicity levels respectively over the EP. Same trend was maintained over all 3 years.

The cumulative net returns, showed that during first year of reclamation, only the IP with S₁ and S₂ sodicity levels reached the break-even point (or got close to); EP treatment along with sodicity levels combinations showed substantial negative returns in the first season. In the second season, the break-even point was reached under EP in S₁ and S₂ soils, as well as IP in S₃ soils. During third year, the

| Table 4 Changes in soil properties with different sodicity levels (S₁ – S₄) and reclamation practices (EP and IP) after 3 years of cultivation with rice-wheat cropping system |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Soil parameter                  | EP               | IP               | EP               | IP               | EP               | IP               | EP               | IP               |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| pH                              | S₁              | S₂              | S₃              | S₄              | S₁              | S₂              | S₃              | S₄              |
|                                 | 8.5±0.11        | 8.5±0.12        | 9.2±0.15        | 9.4±0.21        | 8.5±0.11        | 8.5±0.12        | 9.2±0.15        | 9.4±0.21        |
| EC (dS/m)                       | 0.60±0.10       | 0.76±0.12       | 1.32±0.10       | 1.41±0.12       | 0.63±0.15       | 0.76±0.21       | 1.36±0.31       | 1.41±0.32       |
| OC (%)                          | 0.26±0.02       | 0.20±0.02       | 0.14±0.03       | 0.12±0.02       | 0.32±0.04       | 0.26±0.09       | 0.21±0.06       | 0.14±0.04       |
| ESP                             | 21.5±1.23       | 30.4±2.42       | 42.6±2.51       | 51.4±3.28       | 16.2±1.01       | 24.2±1.32       | 28.8±2.28       | 38.6±1.68       |
| CO₃⁻ (meq/l)                    | 0.0±0.00        | 1.4±0.17        | 2.8±0.21        | 16.8±0.24       | 0.0±0.00        | 1.0±0.16        | 2.3±0.14        | 2.6±0.21        |
| HCO₃⁻ (meq/l)                   | 5.5±0.46        | 4.6±0.62        | 4.6±0.58        | 2.2±0.61        | 3.0±0.51        | 2.4±0.38        | 4.4±0.54        | 3.1±0.13        |
| Cl⁻ (meq/l)                     | 2.50±0.32       | 2.00±0.34       | 1.43±0.28       | 3.00±0.31       | 1.60±0.35       | 1.63±0.28       | 1.20±0.34       | 1.40±0.15       |
| Na⁺ (meq/l)                     | 2.30±0.06       | 3.20±0.08       | 3.60±0.12       | 3.80±0.21       | 1.40±0.23       | 2.10±0.18       | 3.20±0.23       | 3.00±0.24       |
| K⁺ (meq/l)                      | 0.80±0.12       | 0.60±0.16       | 0.60±0.13       | 0.60±0.15       | 0.40±0.21       | 0.60±0.18       | 0.60±0.21       | 0.40±0.23       |
| Ca²⁺ (meq/l)                    | 2.50±0.21       | 1.83±0.32       | 1.80±0.24       | 1.41±0.16       | 1.83±0.31       | 1.53±0.12       | 1.84±0.20       | 2.10±0.22       |
| Mg²⁺ (meq/l)                    | 2.30±0.13       | 1.74±0.16       | 2.10±0.12       | 1.10±0.16       | 1.10±0.15       | 1.20±0.20       | 2.13±0.21       | 1.20±0.20       |

EC, Electrical conductivity; SOC, soil organic carbon; ESP, exchangeable sodium percentage; figures in parenthesis shows the values in saturation extract.

Fig 1 Cumulative net returns from rice farming over a three-year period with (A) existing practices.
IP reached the break-even point on the $S_4$ soils, whereas EP still showed high negative returns in $S_2$ and $S_3$. The net returns in all seasons decreased with increasing sodicity for both reclamation practices. All sodicity levels along with IP always achieved higher returns than EP in all seasons, and the returns were often twice or even more. In 2012–13, net returns increased remarkably for both reclamation practices, due to the high expenditure of reclamation occurred during 2011–12. A further increase in net returns occurred in 2013–14 (Fig 1).

The cumulative net returns trend was similar to cumulative B/C ratio (Fig 2). For both the practices, the B/C ratio increased from the first to the third season and it decreased with increasing soil sodicity. The B/C ratio was always higher under IP as compared to EP. Farmers’ acceptable B/C ratios (≥1.5) after 3 years of rice cropping were achieved for IP under $S_1$, $S_2$, and $S_3$, and for EP under $S_1$ and $S_2$. But even under IP, it would take at least 4 years of rice cropping to reach an acceptable B/C ratio on severely sodic soils ($S_4$).

Current findings strongly recommend the replacement of the existing practice (EP) of sodic soil reclamation (gypsum @ 50% GR), with the improved practice (IP), i.e., gypsum at 25% GR + press mud at 10 t/ha for a faster and sustainable reclamation which improved the soil health and crop productivity than EP. Irrespective of sodicity level, IP achieved higher monetary returns than the EP. The IP make the soil reclamation profitable, faster and should, therefore, be easier to adopt by resource limited farmers. Thus, synergy of reduced gypsum and pressmud (IP) may reduce the quantum of gypsum which could contribute for reclaiming larger unproductive degraded sodic lands. Based on this study and similar studies conducted in the region, our recommendation can be applied to a larger area of sodic soils in Indo-Gangetic plains.

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