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Impact of pressmud application in reclamation of high RSC irrigation water induced soil sodification and sustaining rice (*Oryza sativa*) - wheat (*Triticum aestivum*) production in Indo-Gangetic Plains

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ABSTRACT

Farmers mostly prefer mineral gypsum as reclamation ameliorant for sodic soils. Timely availability of quality product many a times hampers the pace of reclamation process impairing crops productivity to a greater extent. To measure the reclamative efficiency of pressmud in sodic ecosystems dominating rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.)system, a total of 37 farmer's participatory trials were carried out in Kaithal district of Haryana state. Soil incorporation of pressmud at 10 t/ha improved the plants adaptation through significant improvement in agro-physiological and biochemical parameters of crop response. Concomitant reduction in spikelets sterility (~21%) and chaffy grains per panicle (~17%) in rice under pressmud ameliorated plots imparted yield advantage to the tune of ~21% under sodic conditions. In wheat, pressmud application increased productive tillers per mrl (13%), spikelets per spike (8%), grains per earhead (10%) and 1000-grain weight (2%) elucidating ~14% yield gain compared to farmer's managed plots. System productivity in terms of wheat equivalent yield improved by ~15% per cent due to pressmud application under a variable range of soil pH (7.18-8.65) and RSC_{iw} (1.6-7.6 me/L). Pressmud incorporation resulted in reduction of Na saturation in soil-plant continum and neutralized soil alkalinity with consequent reduction in soil pH to the extent of 0.07-0.44 units with a mean value of 8.47 after crop harvest against initial value of 8.68. Amelioration of sodic soils through pressmud application showed economic benefits of ₹ 24779 / ha with incremental benefit-cost ratio of 5.04 for each rupee invested against the added cost of ₹ 4920 / ha. Field application of pressmud not only ensured the safe disposal of this waste byproduct but also helped in achieving the sustainable yields. Evidences from farmer's participatory trials revealed that pressmud can serve as affordable alternative amendment to gypsum in sodic land reclamation programme. In nutshell, scientific diagnosis of field problems, strong farmers-scientist interface and participatory research could work as suitable and location specific adaptive strategies in arresting the salt induced land degradation and strengthening farmers' livelihood.

Key words: Economics, Physiological parameters, Pressmud, Rice-wheat system, Yield

Salt induced land degradation is a major obstacle in optimal utilization of land resources and threatening agricultural sustainability (Meena *et al.* 2019). In India, about 6.73 million hectare (Mha) of arable land have become less productive due to salt accumulation (salinity/sodicity) and losing 16.84 million tonnes of farm production annually valued at INR 230.19 billion (Sharma *et al.* 2015). Such economic losses are likely to attain epic proportions as salt affected area is projected to increase up to16.2 Mha by 2050 (Vision 2050, www.cssri.res.in). Over-exploitation of groundwater for irrigating rice-wheat system is responsible for declining water table and deterioration in irrigation water quality (Jalota *et al.* 2018). Subsequently, scarcity of good quality water for agricultural use is now becoming a major issue enforcing farmers to use poor quality (alkali) waters. Continuous use of bicarbonate dominated high residual alkalinity irrigation water (RSC_{iw}) results in sodium (Na^+) saturation of clay complexes. Clay minerals dominated by Na^+ cations; as in case of high RSC water induced soil sodification, causes dispersion of clay particles (Minhas *et al.* 2019), reduces the permeability of soil profile (Choudhary *et al.* 2011), poses physical and nutritional constraints to plant growth (Bhardwaj *et al.* 2019) making these soils

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unsuitable for agriculture.

Mined gypsum ($CaSO_4.2H_2O$) is the most preferred amendment among farmers for reclamation of sodic lands (Sharma *et al.* 2015). But the limited availability of gypsum (6-7 million tonnes annually) with increased production costs, reduced government subsidy for agricultural use, competing demands from industries and even timely availability of quality product also hampers the pace of reclamation process. Pressmud, an organic waste by-product of sugar industry enhances organic matter content of soil, improves soil physical conditions, acts as a soil conditioner and valuable nutrient source for macro and important micronutrients (Zn, Cu, Fe and Mn) generally found deficient in calcareous alkaline soils (Kumar *et al.* 2017, Muhammad and Khattak 2009). Pressmud application increases soil atmospheric CO_2 concentration by producing organic acids, which, in turn, increases solubility of $CaCO_3$ and other calcic minerals; improves structural stability, water and nutrient availability; better growth and consequently higher crop yield (Dotaniya *et al.* 2016).

Looking to the modernized exploitive agriculture, degrading natural resources and changing climatic scenario, there is need to explore the alternative sources utilizing locally available agricultural inputs (pressmud) towards reclamation and management of sodic soils, neutralization of high RSC irrigation water in augmenting the agricultural productivity. This will also help in reducing the farmer's dependence on gypsum use to reclaim huge chunk of ever increasing sodic soils (caused by anthropogenic and natural process). Further, disposal problem and environment concerns managing huge volume of unused pressmud will also be addressed in long-run. This background propelled the present study to examine the impact of pressmud application on the yield and productivity of rice-wheat system, understanding the mechanisms of plant salt-tolerance and improvement of soil properties in high RSC water irrigated sodic soils of Indo-Gangetic plains (IGPs). This study has more significance being carried out in farmer's participatory mode which yields more realistic results.

MATERIALS AND METHODS

Farmers' knowledge, aptitude and practices (KAP) towards field applicability of pressmud for sustainable management of high RSC water induced soil sodification was tested using structure questionnaire through stratified random sampling. None of the interviewed farmer had ever applied pressmud in their fields. The introduction of pressmud for reclamation of sodic soils and neutralization of residual alkalinity in irrigation water was a new idea among the farming community in this agro-ecological region. Farmer's participatory field trials were conducted in Kaithal district of Haryana state in the adopted villages under Farmer FIRST Project of Indian Council of Agricultural Research (ICAR), New Delhi during 2017-18. Nearly 11.3% of total geographical area of Kaithal district is salt affected, out of which 6.8% is sodic and 4.4% is saline in nature. Within Kaithal block, slight to moderate sodic soils predominates where groundwater used for irrigation purpose is of alkali

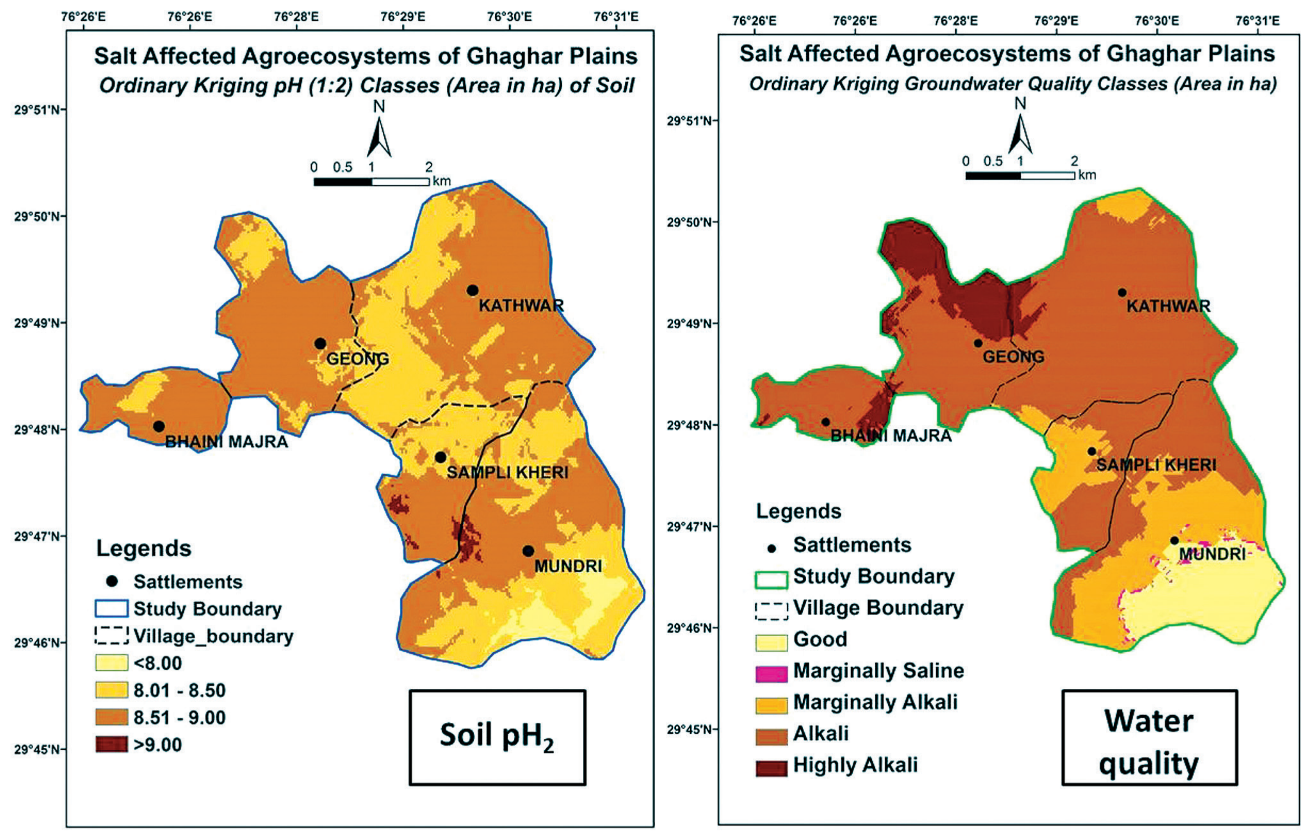

Fig 1 Extent and distribution of sodic soils and status of irrigation water quality in the study area.

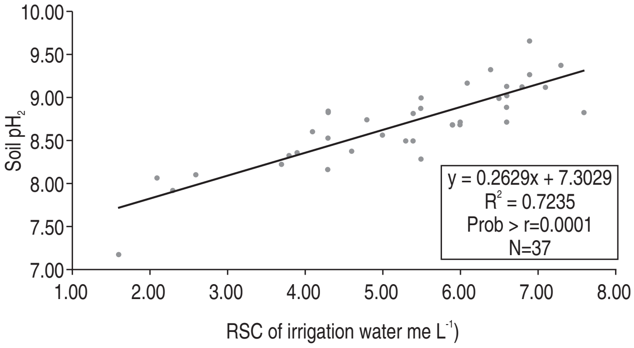

Fig 2 Relationship between irrigation water residuality and soil sodicity in the study area.

(high RSC) nature. The district Kaithal owns a Co-operative Sugar Mill having crushing capacity of 2500 tonnes of cane per day (TCD) producing huge quantity of pressmud. The field applicability of this industrial by-product was almost negligible in the surrounding areas. However, the sun-dried pressmud is mostly used for preparing compact blocks/shells used for firewood purpose in the brick-kilns.

Five village namely Mundri, Geong, Sampli Kheri, Kathwar and Bhaini Majra were purposefully selected with in the vicinity (5-10 km radius) of Kaithal sugarmill where 40.1% of the cultivated land is sodicity affected (soil pH_2>8.5) and 90% area (marginally alkali; 17.4%; alkali: 62.7% and highly alkali: 9.2%) is represented by high residual alkalinity in irrigation water (RSC_{iw}>2.5 me/L, threshold value for safe use of underground water for irrigation purpose) (Fig 1). Cumulative probability analysis of collected soil and water samples (Fig 2) indicated strong positive relationship between soil sodification with continued irrigation with high RSC_{iw} (R^2=0.72). Rice-wheat is the dominating cropping system in the region and is the main source of farmers' livelihood.

Spatial variability was observed at farmer's fields (Fig 3) with respect to soil sodicity [soil pH_2 mean: 8.68±0.51, range: 7.18-9.65, CV: 6%]; soil ESP [mean: 19.4±9.5%, range: 6.0-33.4%, CV: 49%], irrigation water quality [RSC_{iw} mean: 5.25±1.5 me/L, range: 1.6-7.6 me/L, CV: 29%] and soil nutrient [available nitrogen mean: 134±44.8 kg N/ha, range: 69-257 kg N/ha, CV: 33%; available phosphorus mean: 20.1±17.8 kg P/ha, range: 2.7-62.0 kg P/ha, CV: 88%; available potassium mean: 343±77.2 kg K/ha, range: 219-512 kg K/ha, CV: 23%] status. The selected sites were characterized with high RSC irrigation water (RSC_{iw}>2.5 me/L, 92%) induced soil sodification (soil pH_2>8.5, 73%; ESP>15%, 65%) and tested low in available N (97%), medium to high in available phosphorus (65%) and high in available K (97%).

To evaluate the effect of pressmud application, farmers' participatory research trials were carried out at selected 37 locations in the rice-wheat cropping system covering 1000-2000 m^2 area at each location depending on the farm size availability. The field trials were conducted with two treatments; (a) Without amendment (farmer's practice; FP) and (b) With amendment using pressmud (PM) at 10 t/ha on dry weight basis. The nutritional composition of sugarcane pressmud is given in Table 1. Pressmud was applied in the month of June and incorporated into top 10 cm soil layer, 2-3 weeks prior to rice transplanting. Succeeding wheat crop was raised on residual effect of pressmud applied in rice crop only. However, recommended fertilizer application (N:P:K) was done at 60:26:50 kg/ha in rice and 150:26:50 kg/ha in wheat in all the plots following standard procedures of fertilizer scheduling. Rice (cv. Basmati CSR 30) was grown during mid-June to October and wheat (cv. KRL 210) during November to April. All other agronomic practices including irrigation, weed management, plant protection measures etc. were adopted following standard protocols for crop raising under salt affected environments.

Table 1 Composition of pressmud

Parameter	Value
*p*H	5.2 ± 0.08
EC_2 (dS m^{-1})	1.1 ± 0.06
Moisture	48.8 ± 1.5%
Carbon (%)	30.7 ± 1.1%
Nitrogen (%)	2.31 ± 0.5%
Sulphur (%)	1.44 ± 0.07%
Calcium (%)	2.17 ± 0.05%
Magnesium (%)	1.08 ± 0.03%

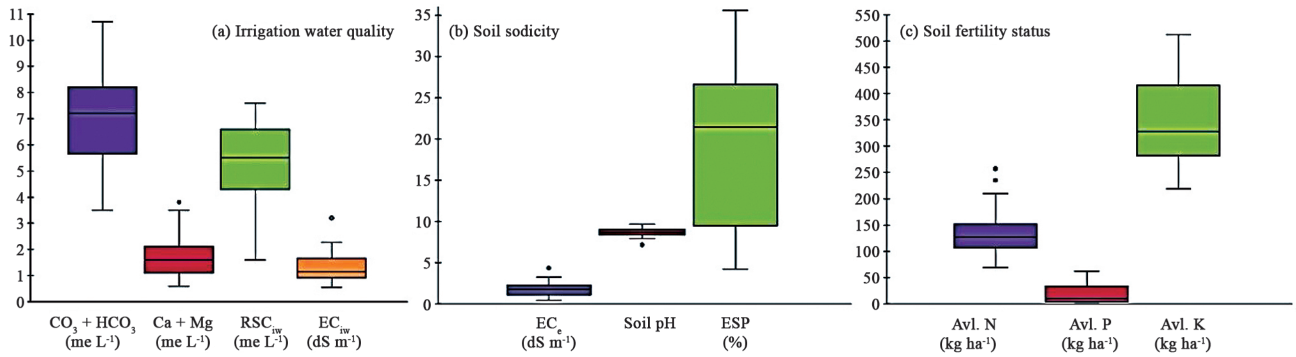

Fig 3 Catalogue of (a) irrigation water quality (b) soil sodicity and (c) soil fertility status of selected farmers' sites (N=37). Bars represent quartiles with median and spread. Capped lines indicate standard error of the mean.

Physiological observations on plant water relations (relative water content, RWC); stress injury (membrane injury index, MII); gas exchange parameters (photosynthetic rate, Pn; transpiration, E; stomatal conductance, gS; chlorophyll fluorescence, Fv/Fm; photon quantum yield, YII); biochemical parameters (proline content, P; chlorophyll content, CC) and ionic concentration (Na/K ratio) in root and shoot portions were recorded at flowering stage as per established standard protocols. Ten representative plants were randomly selected from each plot to record the crop specific biometric observations and the recorded data for each parameter were averaged over considering each farmer as a replicate. The plot-wise yield data was taken with the help of quadrate (2 m × 2 m) placed randomly at two places at crop harvest in each field. The yield samples were sun dried to a constant weight and threshed manually to record final yield which was then expressed in t/ha.

The data recorded for each parameter were compared statistically using ANOVA and z-test for independent sample set. Mean comparison was performed based on Duncan's Multiple Range Test (DMRT) at $P<0.05$. The observed values for each variable were tested for their normality distribution through Spahiro-Wilk test (W). In rice, the traits grain per panicle (W=0.006), chaffy grains per panicle (W=0.017), photosynthetic rate (W=0.005), proline content (W=0.033), chlorophyll content (W=0.003) under farmer's practice and Na/K ratio (root) (W=0.035) under pressmud application were not following normal distribution. Therefore, the transformed data for these traits was statistically analysed. Similarly in wheat, the data set for productive tillers/mrl (W=0.024), relative water content (W=0.0254), chlorophyll content (W=0.007), chlorophyll fluorescence (W=0.010) under farmer's practice and proline content (W=0.029) and chlorophyll fluorescence (W=0.011) under pressmud application following non-normal distribution were transformed. These transformed values were subjected to analysis of variance and mean comparisons was done through DMRT.

RESULTS AND DISCUSSION

Physiological and biochemical indices

Significant ($P<0.05$) changes in plant water status (RWC), stress injury (MII), gas exchange parameters (Pn, gS, E, Fv/Fm and YII), biochemical parameters (P and CC) and Na/K concentration (shoot and root) were noticed in both rice and wheat crops under pressmud ameliorated plots, reflecting its effectiveness in reducing the compounded adverse impact of residual alkalinity in irrigation water and soil sodicity compared to without pressmud plots (farmer's practice). Pressmud application increased leaf RWC from 82 to 85% in rice and 73 to 81% in wheat whereas MII reduced by 11.7% in rice and 13.1% in wheat compared to unamended plots (Fig 4a). Significantly higher values for photosynthetic indices, viz. Pn (23.27 and 20.53 µmol CO_2 m^{-2} s^{-1}), gS (2.27 and 1.33 mol H_2O m^{-2} s^{-1}), E (9.49 and 2.59 m mol H_2O m^{-2} s^{-1}), Fv/Fm (0.61 and 0.58) and YII (0.55 and 0.56) were observed for rice and wheat crops, respectively due to pressmud application (Fig 4b). Reduction in proline content to the extent of ~20% in rice and ~18% in wheat was noticed, whereras chlorophyll content improved by ~22% in rice and ~24% in wheat when pressmud was applied (Fig 4c). Pressmud applied plots exhibited good control on accumulation of toxic ions (Na^+) and maintained higher concentration of essential ions (K^+) (Fig. 4d). Lower ionic (Na^+/K^+) concentration was observed in both shoot and root portions through pressmud application.

Biometric observations and yield assessment

More pronounced complementary effects were observed on yield attributing parameters in both rice and wheat crops when pressmud was used as reclamative ameliorant (Table 2). Remarkable reduction in productive tillers (15%), grains per panicle (13%) and 1000-grain weight (5%) was observed in rice crop where no amendment was used to mitigate the adverse impact of sodicity. The spikelets sterility increased from 5.2 to 6.6% and chaffy grains per panicle increased from 8.0 to 9.6 in rice crop under high RSC irrigation water induced sodification (farmer's practice). In wheat, pressmud amelioration increased number of productive tillers per mrl (13%), spikelets per spike (8%), grains per earhead (10%) and 1000-grain weight (2%) compared to farmer's managed plots (Table 2).

Mean grain yields of both rice and wheat harvested over 37 locations strongly ($P<0.05$) reflected the influence

Table 2 Effect of pressmud application on the yield attributing characters of rice and wheat crops

Trait	Without pressmud (Farmers' practice)	With pressmud	Z score	Pr (>|Z|)
Rice				
Productive tillers per hill	14.9 ± 0.30	17.4 ± 0.33	-5.74	0.0000
Spikelets sterility (%)	6.6 ± 0.49	5.2 ± 0.36	2.2	0.0312
Grains per panicle	57.7 ± 0.81	66.5 ± 0.79	-7.81	0.0000
Chaffy grains per panicle	9.6 ± 0.50	8.0 ± 0.35	2.63	0.0105
Ear filling ratio (%)	0.60 ± 0.001	0.68 ± 0.002	-12.43	0.0000
1000-grain weight (g)	25.1 ± 0.11	26.4 ± 0.11	-8.28	0.0001
Wheat				
Productive tillers per mrl	58.5 ± 0.85	65.3 ± 0.51	-6.870	0.0001
Spikelets per spike	16.5 ± 0.13	17.7 ± 0.10	-7.640	0.0001
Grains per earhead	54.1 ± 0.80	59.2 ± 0.52	-5.290	0.0001
1000-grain weight (g)	40.0 ± 0.21	40.9 ± 0.19	-3.170	0.0020

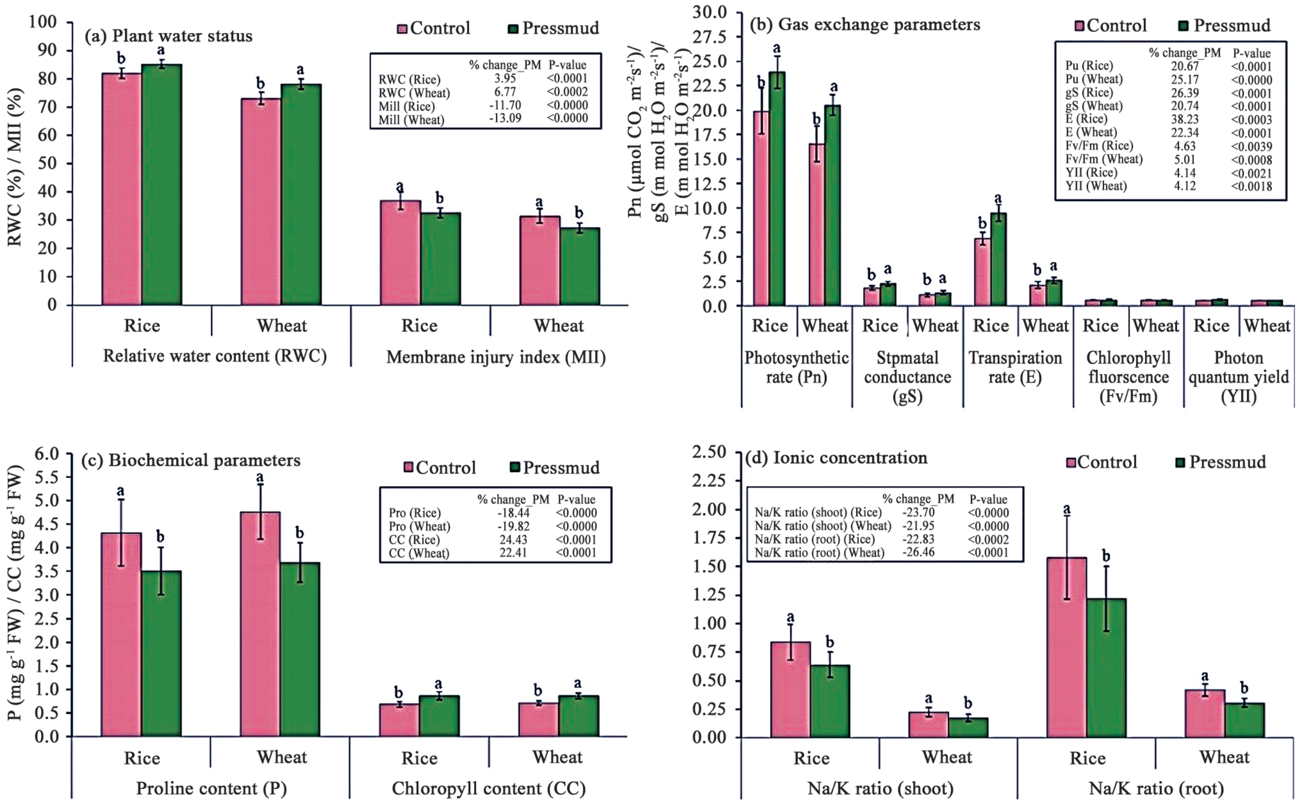

Fig 4 Effect of pressmud application on (a) plant water relation status [relative water content (RWC) and stress injury [Membrane injury index (MII)]; (b) gas exchange parameters [photosynthetic rate (Pn), stomatal conductance (gS), transpiration (E), chlorophyll fluorescence (Fv/Fm) and photon quantum yield (YII)]; (c) biochemical parameters [proline content (P) and chlorophyll content (CC)] and (d) ionic concentration [Na/K ratio (shoot) and (root)] for physiological adaptation to stress environments. Capped lines indicate standard error of the mean. Vertical bars labeled with different lowercase letters differ significantly according to DMRT (*P<0.05*).

of pressmud application (Fig. 5) and elucidated yield improvement to the tune of 15.3% (0.41 t/ha) in rice, 14.4% (0.55 t/ha) in wheat and 14.9% (1.42 t/ha) in system productivity (wheat equivalent yield) compared to farmer's practice. Pressmud application apart from its ameliorative action, also improved the nutrient availability in soil-plant continuum, soil physical conditions, water infiltration rate, aggregation and organic carbon (Choudhary *et al.* 2011). Consequently, incorporation of pressmud increased the soil atmospheric CO_2 concentration by producing organic acids, which in turn resulted in increased solubility of native $CaCO_3$ and other calcic minerals (Dotaniya *et al.* 2016).

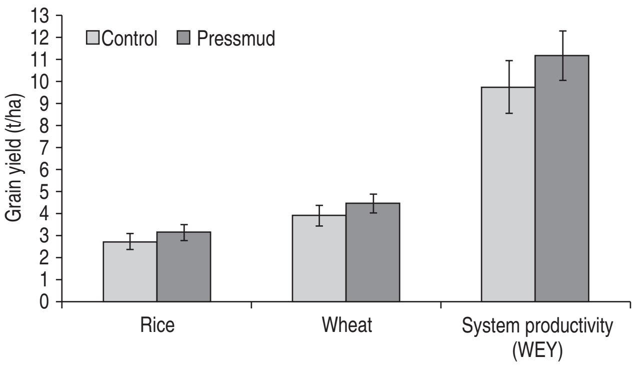

Fig 5 Effect of pressmud application on grain yield of rice, wheat and system productivity (wheat equivalent yield). Capped lines indicate standard error of the mean.

Change in soil sodicity

Irrigation with high RSC_{iw} waters (1.6-7.6 me/L) without

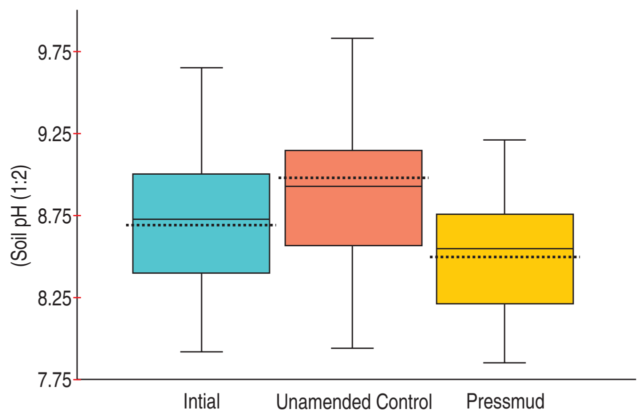

Fig 6 Change in soil pH due to continued irrigation with high RSC_{iw} and pressmud application at selected sites (N=37). Bars represent quartiles with median and spread, and dotted lines represent mean. Capped lines indicate standard error of the mean.

Table 3 Partial budgeting for system productivity (WEY) in response to pressmud application

Parameter	Value
Incremental yield (t/ha)	1.42
Added returns (×10^3 ₹/ha)	24.79
Added cost (×10^3 ₹/ha)	4.92
Incremental income (×10^3 ₹/ha)	19.88
Incremental input-output ratio	5.04

neutralization amendment (as in case of FP) increased stress intensity through buildup in soil sodicity and increased soil pH from the initial mean value of 8.68 to 8.85 recorded after crop harvest (averaged over 37 locations). Magnitude of reduction in soil pH under pressmud ameliorated plots invariably increased with the increase in soil sodification. The decomposition of pressmud neutralized alkalinity and favoured dissolution of native carbonate minerals declining soil pH to the extent of 0.07-0.44 units with a mean reduction of 0.21 units compared to initial value.

Economic analysis

Economic analysis (Table 3) revealed an incremental input-output ratio of 5.04 for each rupee invested towards the cost of pressmud application (including material cost, labour and transportation charges), highlighting its affordability as cost effective reclamation ameliorant under sodic ecosystems.

Conclusions

The present study was the first attempt in evaluating the field applicability of pressmud for managing high RSC irrigation water induced soil sodification under farmer's management practices in north-western IGPs. The results indicated promising impact of pressmud application in improving the physiological adaptation of crops plants and yield attributing traits culminating in enhanced productivity of rice-wheat system under sodic ecosystem. Pressmud amelioration also reduced the Na saturation in soil-plant continuum with consequent reduction in soil pH, an indicator of improved soil health under stress environments. Better utilization of this low cost agricultural waste material from sugar industry will not only help in achieving sustainable yields but also reduce the dependency on chemical amendment (gypsum) as reclamative/ neutralization amendment for sodic soils. The concerned farmers were really convinced with the introduction of this radical technology and possible alternative to mined gypsum in mitigating the land and environment degradation in salt affected agro-ecosystems. The information generated herein will generate useful insights for convincing the developmental agencies so that such agro-techniques receive policy and government support for managing the widespread problems in different parts of country with similar agro-ecological situations.

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