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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 S_1, S_2, S_3, and S_4 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 S_2 and S_3. 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 ($CaSO_4$. $2H_2O$) 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). 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 27^0 36' 31" to 27^0 36' 32" latitude, E 80^0

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11' 34" to 80^0 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, exchangable 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- slightly sodic (pH 9.2), S_2- moderately sodic (pH 9.6), S_3- sodic (pH 10.0), and S_4- severely sodic (pH 10.4)] 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. Straw and grain yields of each treatment were measured after threshing manually following standard procedures (Rana *et al.* 2014). After 3 years of rice-wheat system, soil samples were collected from 5 places in each treatment plot, and analyzed for pH, EC, SOC, ESP and soluble cations and anions using standard laboratory methods.

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
EC (1:2)(dS/m)	0.67 ± 0.11	1.42 ± 0.15	2.14 ± 0.11	2.21 ± 0.14
SOC (%)	0.21 ± 0.08	0.12 ± 0.04	0.08 ± 0.06	0.08 ± 0.06
ESP	34.0 ± 1.23	58.0 ± 1.64	78.0 ± 2.21	89.0 ± 1.82
GR (t/ ha)	8.5 ± 1.10	10.2 ± 0.87	12.4 ± 1.12	13.6 ± 0.88
$CaCO_3$ (g/ kg)	9.8 ± 0.62	11.2 ± 1.12	12.6 ± 2.13	14.1 ± 1.16
CO_3^{--} (meq/ l)	4.7 ± 0.43	4.6 ± 0.36	3.86 ± 0.52	6.80 ± 1.12
HCO_3^- (meq/ l)	9.5 ± 0.46	10.5 ± 0.53	12.4 ± 0.62	14.0 ± 0.54
Cl^- (meq/l)	3.00 ± 0.26	4.00 ± 0.32	5.30 ± 0.28	6.00 ± 0.24
Na^+ (meq/ l)	13.80 ± 0.12	16.90 ± 0.10	19.20 ± 0.08	24.80 ± 0.08
K^+ (meq/ l)	0.80 ± 0.04	0.80 ± 0.04	0.50 ± 0.03	0.50 ± 0.02
Ca^{++} (meq/ l)	1.70 ± 0.11	1.40 ± 0.08	0.60 ± 0.12	0.80 ± 0.10
Mg^{++} (meq/l)	1.60 ± 0.08	1.00 ± 0.06	0.40 ± 0.04	0.60 ± 0.08

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

All the data were subjected to analysis of variance (ANOVA) using MSTAT-C software version 2.1. The least significant difference (LSD) at 5% probability was used to compare treatment means. Data were presented as means across experiments for all parameters and their effects were reported. Economic analysis of different treatments was based on total production cost (fixed and variable), gross return, net return and benefit/cost ratio. The reclamation cost was calculated on the basis of expenditure involved on bunding @ ₹ 2840/ ha, leveling @ ₹ 14620/ha, leaching @ ₹ 5460/ha, gypsum @ ₹ 3970/ton, press mud @ ₹ 545/ tonne, and installation of tube wells @ ₹ 2880/ha. Costs of production were assumed to be identical for both EP and IP because cost of inputs including fertilizers and seed were the same for both EP and IP. Gross returns were calculated on the basis of minimum support price of rice and the prevailing market rate for rice straw and net returns by deducting costs of production from the gross returns. Benefit/cost ratios were computed by dividing benefits by the costs.

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 (S_4). 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

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

Treatment	Number of hills/m^2	Panicles/ m^2	Dry matter (g/m^2)	LAI	Spikelets / panicle	Floret fertility (%)	1000-grain weight (g)	Straw yield (t/ha)	Grain yield (t/ha)
Sodicity levels									
S_1	31.9	290.7	1385.5	2.3	121.6	85.2	25.4	8.7	5.0
S_2	26.8	199.0	919.2	2.0	115.8	74.7	23.5	7.6	4.4
S_3	22.1	102.9	490.6	1.4	117.3	59.6	21.5	4.8	2.8
S_4	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	17.48	16.9	0.12	7.1	2.76	0.37	0.11	0.06
Reclamation practices									
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

S_1, Slightly sodic; S_2, moderately sodic; S_3, Sodic; S_4,severely sodic; LSD, least significant difference; LAI, leaf area index; SEM ±, standard error of mean

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/m^2 (11.9%), panicles/m^2 (45.6%), dry matter g/m^2 (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 S_1–S_2, S_2–S_3 and S_3–S_4 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 S_4 sodicity level over S_1 level, but the difference between S_3 and S_4 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 of excessive ions to deeper soil layers, lowering the salt concentration in the top soil which favored plant growth, and grain and straw yields (Singh *et al.* 2015, 2016). The interaction effect between sodicity levels and reclamation practices for grain and straw yields were significant (Table 3). Maximum straw (8.68 t/ha) and grain (5.01 t/ha) yields were recorded at pH 9.2 (S_1) and minimum at pH 10.4 (S_4). The grain yield reduction with progressive increase in sodicity from S_1–S_2, S_2–S_3, and S_3–S_4, was 12.0, 36.4 and 46.4%, respectively. Maximum yield reduction was recorded when sodicity increased from S_3 to S_4. This must be attributed to a combination of reduced assimilate source and a partial destruction of the assimilate sink with

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
	EP	IP		EP	IP	
S_1	8.64	8.72	1	4.99	5.04	1
S_2	7.19	7.95	11	4.16	4.59	10
S_3	3.40	6.28	85	1.96	3.63	85
S_4	0.66	4.45	574	0.38	2.57	576
LSD (P=0.05)	0.28			0.16		

S_1, Slightly sodic; S_2, moderately sodic; S_3, sodic; S_4, severely sodic; LSD, least significant difference

increasing sodicity. Across all sodicity levels, IP produced 36.8 and 37.1% higher straw and grain yield over the EP. The IP significantly increased the straw and grain yields under all sodicity levels except S_1. Therefore, the IP led to yield enhancements with increasing sodicity levels. So, it may be a sustainable reclamation and yield maximizing technology for sodic soils.

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 S_1, S_2, S_3 and S_4 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 4 Changes in soil properties with different sodicity levels (S_1 – S_4) and reclamation practices (EP and IP) after 3 years of cultivation with rice-wheat cropping system

Soil parameter	EP				IP			
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
pH_2	8.5±0.14	9.0±0.11	9.4±0.16	9.6±0.21	8.5±0.11	8.5±0.12	9.2±0.15	9.4±0.21
EC_2 (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
CO_3^{--} (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
HCO_3^- (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
Ca^{++} (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
Mg^{++} (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

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 Ca^{++} and Mg^{++} 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 S_1 sodicity levels. The IP increased gross returns by 18.8, 12.8, 93.2 and 93.1% with S_1, S_2, S_3 and S_4 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 S_1 and S_2 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 S_1 and S_2 soils, as well as IP in S_3 soils. During third year, the

Table 5 Average reclamation costs of different study sites (S_1 – S_4) and the reclamation practices (EP and IP)

Sodicity levels	EP (₹/ ha)	IP (₹/ ha)	Net saving (₹/ ha over EP)	Relative saving % over EP
S_1	62760	44940	17820	28
S_2	69000	48540	21360	31
S_3	79140	53100	26040	33
S_4	84180	55620	28560	34

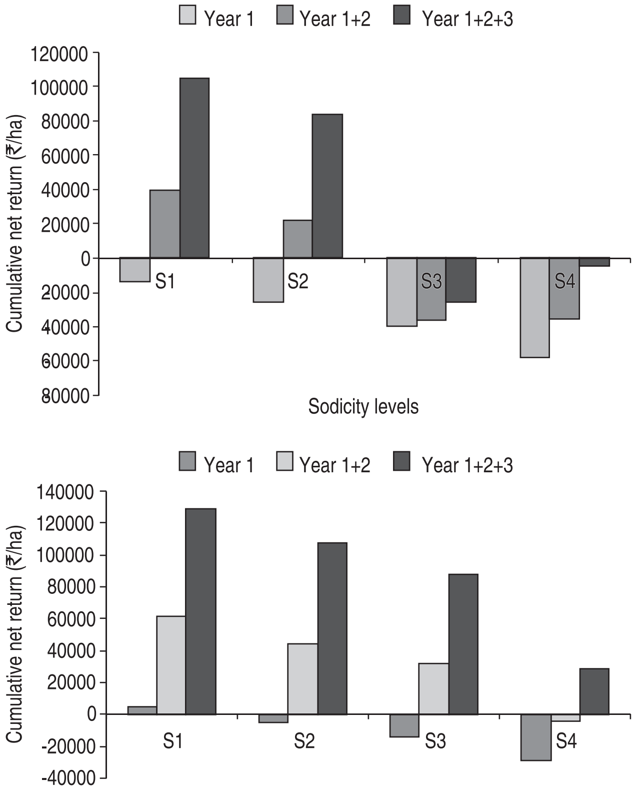

Fig 1 Cumulative net returns from rice farming over a three-year period with (A) existing practices.

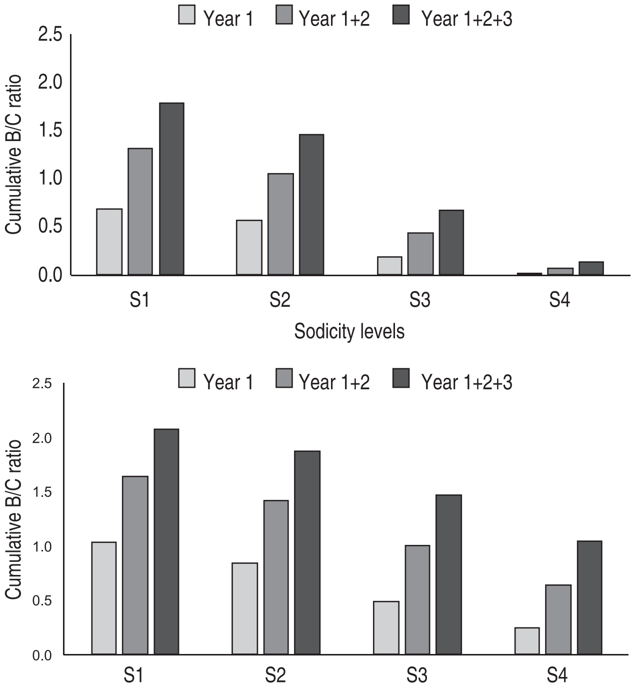

Fig 2 Benefit/cost ratios for rice farming over a three-year period with (A) existing (EP) and (B) improved (IP) practices of reclamation.

IP reached the break-even point on the S_4 soils, whereas EP still showed high negative returns in S_3 and S_4. 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. B/C ratio was always higher under IP as compared to EP. Farmers' acceptable B/C ratios ($\geq$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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