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Amelioration of acidity and iron toxicity in lateritic lowland rice soil using non-conventional sources of calcium

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Abstract
A field experiment was conducted to evaluate the effectiveness of non conventional sources of calcium like phosphogypsum, limestone powder and their blends in managing soil acidity and iron toxicity and enhancing the yield of rice in comparison to conventional shell lime. The results revealed that all the liming treatments significantly reduced the soil acidity and iron toxicity problem in rice field. The soil pH was increased from 4.61 in control to 5.33 in the treatment receiving shell lime@ 600 kg ha^{-1}. The exchangeable calcium content in soil increased from 749 mg kg^{-1} in control to 909 mg kg^{-1} in phosphogypsum applied treatment. The 0.1 N HCl extractable iron content in soil was reduced from 511 mg kg^{-1} in control to 353 mg kg^{-1} in lime stone powder 300 kg ha^{-1} + phosphogypsum 300 kg ha^{-1} applied treatment. The availability of N(295.8 kg ha^{-1},K (1 06.8 kg ha^{-1}), Mg (58.2 mg $kg^{-1)}$, S (31.65 mg $kg^{-1)}$, Zn(4.19 mg $kg^{-1)}$, Cu (3.79 mg $kg^{-1)}$ and B (0.26 mg $kg^{-1)}$ were the highest in treatment receiving lime stone powder 300 kg ha^{-1} + phosphogypsum 300 kg ha^{-1} whereas P (97.35 kg ha^{-1}) was the highest in treatment receiving shell lime@ 600 kg / ha. The available Mn and exchangeable Al were found to decrease with the application of liming materials.The uptake of nutrients, growth and yield parameters of rice were significantly increased due to the influence of liming treatments. The highest grain yield of rice (5.73 t ha^{-1}) was obtained in the combined application of lime stone powder 300 kg ha^{-1} + phosphogypsum 300 kg ha^{-1}.

Keywords: Iron toxicity, soil acidity, phosphogypsum, lime stone powder, rice yield

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Introduction

Lowland rice is a staple food for more than 50% world population. The midland rice fields of Kerala mainly constitute the drainage basins of hills and hillocks which usually accumulates all the leachates washed down from the hills. The soils being lateritic in nature the extent of reduced forms of iron accumulating in these soils are high and toxicity of iron and acidity are the major constraints which create soil stress and high yielding rice varieties perform to a level of only 50% of their potential yield. Iron toxicity is well recognized as the most widely distributed nutritional disorder in lowland rice production (Dobermann and Fairhurst, 2000) [3]. In acid soils, iron toxicity is one of the important constraints to rice production, and together with Zn deficiency, it is the most commonly observed micronutrient disorder in wetland rice (Neue *et al.*, 1998) [9]. The H^+ ion associated with soil acidity has indirect effects on mineral elements in low pH soils so that deficiencies of P, Ca, Mg, K, and Zn and toxicities of Fe, Al and Mn commonly appear (Clark *et al.*, 1999) [2]. Iron toxicity symptoms in rice is seen as bronzing, when Fe^{2+} concentration in soil solution is 250-500 mg kg^{-1} due to reduced conditions under prolonged submergence (Sarkar, 2013) [11]. Soil pH is an important chemical property, which determines iron solubility and its uptake by plants. In addition as pH increases, Fe is converted to less soluble forms, principally to the oxide Fe_2O_3.The precipitation of Fe $(OH)_3$ occurs as the concentration of OH^- ions increases (Fageria *et al.*, 1990) [4].

Liming the soil before planting is the recommendation given in such situations. It is found that even high rates of lime @ 600 Kg/ha is not sufficient to contain iron toxicity and to get sustained high yields in the region. Plants suffer from acute nutritional deficiencies induced by the hostile soil pH and high Fe^{2+} ions.

The cost of conventionally used shell lime is high and inhibitive and so farmers limit the use of lime to bare minimum quantities, much lower to the recommended doses. The use of non conventional liming materials is beneficial because of low cost and effectiveness in reclaiming soil acidity and iron toxicity. Hence the present investigation was carried out to evaluate the effectiveness and suitability of nonconventional calcium sources like limestone powder and phosphogypsum along with conventionally used shell lime in these soils to alleviate iron toxicity and acidity problems and to enhance the availability and uptake of nutrients and yield of rice.

Materials and methods

A field experiment was carried out in farmers filed at Karivellur which is geographically located at12.2°N latitude, 75.1°E longitude and at an altitude of 106 m above mean sea level, having a humid tropical climate. The experimental soil was sandy loam belonging to the taxonomical order Inceptisol, having pH 4.7, EC 0.12 dSm-1, CEC 7.25 c mol (p+) kg-1, organic carbon 0.33%, available nitrogen 220.8 kg ha-1, available P2O5 61.6 kg ha-1, available K2O 58.56 kg ha-1, available Ca 561.75 mg kg-1, available Mg 45.7 mg kg-1, available S 13.25 mg kg-1,available Fe 544.2 mg kg-1, available Mn 32.85 mg kg-1,, available Cu 1.26 mg kg-1, available Zn 2.65 mg kg-1, available B 0.16 mg kg-1 and exchangeable Al 135.5 mg kg-1. The experiment was laid out in randomized block design with four replications using rice variety Athira as test crop. There were 5 treatments *viz.* T1-Control (No Amendments), T2- Shell Lime (Calcium oxide) 600 Kg / ha, T3 - Limestone powder (Calcium carbonate) 600 kg / ha, T4 - Phosphogypsum (Calcium sulphate) 600 kg / ha and T 5 - Limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha. The phosphogypsum used in the study was obtained from FACT Udyogamandal while limestone powder and shell lime were procured locally. N, P and K fertilizers were applied as per package of practices recommendations (POP) of KAU (2011) [6]. Soil samples, initial and collected at harvest stage from each treatment were analyzed for pH in 1:2.5 (soil : water) suspension using pH meter, available nutrients like nitrogen by alkaline permanganate method, phosphorus by bray extraction followed by colorimetric method, potassium by flame photometer, and Ca, Mg, Fe, Mn, Cu, Zn and Al by atomic absorptions spectrophotometer method. B and S were analysed by photo colorimetric method. Plant samples were analyzed for N by Kjeldahl method, phosphorus by vanado molybdate yellow colour method using colorimeter, K by flame photometer, Ca, Mg, Fe Mn, Cu and Zn by atomic absorption spectrophotometer, B by azomethane-H colorimetric method and S by spectrophotometric method. The uptake of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B were calculated. The biometric observations *viz.*, plant height, number of productive tillers plant-1, thousand grain weight, grain and straw yield were recorded. The results obtained were statistically analyzed using statistical analysis software (SAS).

Result and discussion

Soil pH

All the liming treatments significantly increased the pH of the soil compared to control (T1). The highest pH of 5.33 was recorded in T2 (Shell Lime@ 600 Kg / ha) which was found to be on par with treatments T3, T4 and T5 which might be attributed to the neutralising effect of these liming materials. The effect of phosphogypsum was less pronounced in comparison to other sources which may be due to the fact that phosphogypsum contains slight amounts of phosphoric acid as reported by Jena (2013) [5].

Table 2: Effect of treatments on soil pH

Treatment	Soil pH (at harvest)
T1. Control – No Amendments	4.61
T2. Shell Lime 600 Kg / ha	5.33
T3.Limestone powder 600 Kg / ha	5.26
T4. Phosphogypsum 600 Kg / ha	5.10
T5. Limestone powder 300 Kg / ha + Phosphogypsum 300 Kg / ha	5.22
CD (0.05)	0.25

Availability of nutrients in soil

Application of different liming treatments significantly increased the availability of nitrogen, phosphorus and potassium in soil. The highest available N of 295.8 kg ha -1 and available K of 106.8 kg ha -1 were recorded in limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha(T5) applied treatment, whereas the highest available P of 97.35 kg ha -1 was observed in shell lime 600 kg / ha(T2) applied treatment however these were found to be on par with other liming treatments. In spite of the enhanced removal of N for increased dry matter production, there was an increase in alkaline $KMnO_4$- N content of the soil in the case of application of different liming material which may be due to their positive effect on N availability since in the present study, appreciable increase in pH of soil was also evidenced in these treatments. The available P in the soil was maximum in the treatment T2 (97.35 kg ha-1) followed by T5 (91.57 kg ha-1) and T4 (87.32 kg ha-1). The increased available P content in soil might be due to the fact that the anions can replace the phosphate anion $[HPO_4]^{2-}$ from aluminum and iron phosphates there by increasing the solubility of phosphorus. The increased availability of K in soil is attributed to the production of hydrogen ions during reduction of Fe and Al which would have helped in the release of K from the exchange sites or from the fixed pool to the soil solution. Similar results were reported by Patrick and Mikkelsen (1971) [10].

The exchangeable calcium in the soil was significantly increased in all the treatments in comparison to control and it ranged from 749 (T1) to 909 ppm (

T4). Among the amendments, the effect of phosphogypsum was more pronounced which may be due to its better solubility in comparison to other liming materials as reported by Jena (2013) [5]. The available Mg (58.2 ppm) and S (31.65 ppm) in soil were found to be the highest in treatment T5 (Limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha). The increased availability of magnesium may be attributed to the increased pH of soil due to the addition of liming materials. The higher available sulphur in soil might be attributed to phosphogypsum which contains sulphate.

All the liming sources tried were able to significantly reduce the available iron concentration in soil from 511 ppm (T1) to 353 ppm (T5). The combined application of Limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha was more effective in reducing iron toxicity which may be due to their effects in decreasing surface and sub soil acidity and increasing exchangeable calcium in soil respectively. However its performance was on par with the other sources. The available Mn content in soil was significantly decreased from 32.85 ppm in T1(control) to 25.6 ppm in T2 (Shell Lime 600 Kg / ha). Similarly exchangeable aluminum was decreased from 204 ppm in T1 to 148 ppm in T2 which might be due to the reduction in soil acidity in these treatments. Availability of Zn, B and Cu were not significantly influenced by the treatments, however combined application of lime stone powder + phosphogypsum gave the highest values for available Zn, B and Cu showing a positive influence of liming materials on their availability.

Table 3: Effect of treatments on availability of major and secondary nutrients in soil

	Treatment	Av. N (kg ha -1)	Av.P (kg ha -1)	Av.K (kg ha -1)	Av.Ca (ppm)	Av.Mg (ppm)	Av.S (ppm)
T1	. Control – No Amendments	241.5	72.60	64.5	749	47.30	21.12
T2.	Shell Lime 600 Kg / ha	290.2	97.35	97.4	894	54.41	30.41
T3.	Limestone powder 600 Kg / ha	287.3	81.00	91.7	871	52.58	30.08
T4.	Phosphogypsum 600 Kg / ha	291.6	87.32	87.2	909	53.52	31.60
T5.	Limestone powder 300 Kg / ha + Phosphogypsum 300 Kg / ha	295.8	91.57	106.8	902	58.20	31.65
	CD (0.05)	10.62	7.55	11.38	40.1	2.33	1.45

Table 4: Effect of treatments on availability of micro nutrients in soil

	Treatment	Av. Fe (ppm)	Av. Mn (ppm)	Av. Zn (ppm)	Av. Cu (ppm)	Av. B (ppm)	Ex.Al (ppm)
T1.	Control – No Amendments	511	32.85	4.00	3.68	0.23	204.0
T2.	Shell Lime 600 Kg / ha	387	25.60	4.09	3.79	0.24	148.0
T3.	Limestone powder 600 Kg / ha	369	27.90	4.04	3.76	0.24	160.0
T4.	Phosphogypsum 600 Kg / ha	375	25.70	4.18	3.75	0.23	155.3
T5.	Limestone powder 300 Kg / ha + Phosphogypsum 300 Kg / ha	353	25.76	4.19	3.79	0.26	154.6
	CD (0.05)	29.8	1.26	NS	NS	NS	35.1

Uptake of nutrients by rice

The total uptake of N was the highest in T2 (186.2 kg ha-1) which was on par with T5(181.9 kg ha-1) indicating that addition of liming materials altered the soil pH which might have naturally enhanced absorption of N by plant ultimately leading to higher N uptake (Table 5). The uptake of P was maximum in the treatment T2

(34.59 kg ha-1) followed by T5 (33.19 kg ha-1) and T4 (31.11 kg ha-1) owing to the reason that the phosphate anions released from Fe and Al phosphate by exchange of anions produced by the liming materials would have increased the availability of phosphorus in soil. This would have resulted in better absorption of P by plant which has reflected in higher uptake of P by plant in these treatments (Table 5). Application of phosphogypsum @ 600 kg ha-1 (T4) resulted in greater uptake of K (258.7 kg ha-1), Ca (17.72 kg ha-1), Mg (6.58 kg ha-1) and S (17.71 kg ha-1) by plant followed by limestone powder 300 kg ha-1 + phosphogypsum 300 kg ha-1 (T5) which is attributed to the higher availability of these nutrients in the soil. The sulphur added through phosphogypsum contributed to greater availability of sulphur in soil which in turn enhanced the sulphur uptake by rice plant.

With regard to the uptake of micronutrients, the total uptake of iron in rice was significantly reduced in the treatments receiving different liming materials compared to control. The HCl extractable iron in the soil was also low for the above treatments due to the favourable effect of liming materials in reducing soil acidity and improving the oxidation power of rice roots thereby reducing iron toxicity in the soil. This might have naturally resulted in reduced absorption of iron and this coupled with the dilution effect attributed by high dry matter production would have contributed to the reduced content of iron in straw and grain and thereby total iron uptake. Similar results were reported by Padmaja and Verghese (1972) [9].

There was a significant reduction in the Mn uptake in the case of treatments receiving different liming treatments. The application of phosphogypsum @ 600 kg/ha(T4) followed by Limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha (T5) resulted in significantly lower content and uptake of Mn in grain and straw. This may be due to dilution effect. The increased dry matter production in straw and grain might have resulted in decreased content and uptake of Mn. Similar results were reported by Marschner (1995) [8].

The results obtained from the present investigation revealed a significant increase in total uptake of Zn, Cu and B in plant. Application of phosphogypsum @ 600 kg/ha was found to be superior to other treatments. However the HCl extractable Zn and Cu content and also hot water extratable B in soil were not influenced by the treatments, but this coupled with the better biomass (root and shoot) associated with the above treatments would have contributed to the higher uptake of Zn, Cu and B in plant. These results corroborates with the findings of Bridgit (1999) [1].

Table 5: Effect of treatments on uptake of major and secondary nutrients in rice

	Treatment	. N (kg ha -1)	P (kg ha -1)	K (kg ha -1)	Ca (kg ha -1)	Mg (kg ha -1)	S (kg ha -1)
T1.	Control – No Amendments	122.8	19.53	180.5	15.06	4.87	12.64
T2.	Shell Lime 600 Kg / ha	186.2	34.59	238.1	16.28	5.98	17.46
T3.	Limestone powder 600 Kg / ha	155.3	28.78	226.0	15.31	5.21	15.77
T4.	Phosphogypsum 600 Kg / ha	175.8	31.11	258.7	17.72	6.58	17.71
T5.	Limestone powder 300 Kg / ha + Phosphogypsum 300 Kg / ha	181.9	33.19	248.0	16.96	6.25	16.88
	CD (0.05)	6.7	5.63	13.5	1.14	0.32	1.18

Table 6: Effect of treatments on uptake of micro nutrients in rice

Treatment		Fe(kg ha -1)	Mn (kg ha -1)	Zn (kg ha -1)	Cu (kg ha -1)	B (kg ha -1)
T1.	Control - No Amendments	2.98	2.89	0.26	0.37	0.045
T2.	Shell Lime 600 Kg / ha	2.72	2.84	0.37	0.45	0.048
T3.	Limestone powder 600 Kg / ha	2.76	2.73	0.32	0.40	0.040
T4.	Phosphogypsum 600 Kg / ha	2.68	2.87	0.46	0.48	0.048
T5.	Limestone powder 300 Kg / ha + Phosphogypsum 300 Kg / ha	2.70	2.72	0.43	0.43	0.046
CD (0.05)		0.18	0.14	0.04	0.03	0.005

Table 7: Effect of treatments on growth parameters, yield attributes and yield of rice

Treatment		Plant height (cm)	Number of tillers/ plant	Productive tillers /plant	Panicle weight plant^{-1} (g)	Thousand grain weight (g)	Grain Yield (t / ha)	straw yield (t ha^{-1})
T1.	Control – No Amendments	84.33	16.00	15.66	37.13	29.43	4.46	5.85
T2.	Shell Lime 600 Kg / ha	88.00	18.00	17.00	40.60	30.20	5.55	6.67
T3.	Limestone powder 600 Kg / ha	83.33	16.66	15.33	36.26	29.53	5.61	6.43
T4.	Phosphogypsum 600 Kg / ha	91.00	19.66	18.33	44.06	30.60	5.40	6.64
T5.	Limestone powder 300 Kg / ha + Phosphogypsum 300 Kg / ha	87.33	18.93	17.00	38.00	29.76	5.73	6.92
CD (0.05)		3.61	1.30	2.44	6.18	1.47	0.39	0.40

Growth and yield of rice

Application of different liming sources accomplished significant variation in plant growth parameters like plant height, number of tillers plant^{-1} and productive tillers plant^{-1}. The treatment receiving Phosphogypsum 600 kg / ha was superior but was found to be on par with the treatments Limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha and Shell Lime 600 kg / ha. This can be attributed to the significant increase in soil pH in these treatments and also positive influence on the availability and uptake of macro and micro nutrients except Fe and Mn. Similar reports were made by Padmaja and Verghese (1972) [9].

The yield attributes (panicle weight plant^{-1} and thousand grain weight), grain and straw yield of rice were significantly influenced by the application of various liming soures. Application of Phosphogypsum 600 kg / ha was significantly superior with respect to yield attributes which was on par with Shell Lime 600 kg / ha and Limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha In the case of grain and straw yield, all the treatments resulted in significant increase over control. The treatment receiving Limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha was superior but was on par with the sources Phosphogypsum 600 kg / ha and Shell Lime 600 kg / ha. The tune of increase in grain and straw yield in the superior treatment (Limestone powder 300 kg / ha + Phosphogypsum 300 kg / ha) was 5.73 and 6.92 t ha^{-1} respectively (Table 7). The positive trend of results for yield obtained is quite reasonable because a significant increase was noticed in these treatments for available nutrients in soil, plant growth parameter likes plant height, number of tillers plant^{-1} and productive tillers plant^{-1}, yield attributes like panicle weight plant^{-1} and thousand grain weight and also the prevalence of substantial synergistic effect of treatments on availability, absorption and translocation of nutrients. Similar results have also been reported by Bridgit (1999) [1] and Sarkar (2013) [11].

Conclusion

The results of the field experiment indicate that iron toxicity and soil acidity in laterite derived paddy soils can be managed by the combined soil application of 300 kg/ha of limestone powder and 300 kg/ha of phosphogypsum. The availability of nutrients in soil, uptake of nutrients by plant and the growth and yield of rice crop was increased due to the combined application of 300 kg/ha of limestone powder and 300 kg/ha of phosphogypsum.

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