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Assessment of Iron Toxicity in Lateritic Wetland Soils of Kerala and Management using Non Conventional Sources of Lime

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ABSTRACT

Iron toxicity and acidity are the major constraints in the laterite derived paddy soils of Kerala. More than 90 % of the midland lateritic rice soils in the northern part of Kerala are strongly acidic in reaction with pH values in the range of 4.5 to 5.5. The content of 0.1 N HCl extractable Fe in soil varied from 52.21 – 414.9 mg kg^{-1} and more than 50 % of the rice soils showed iron toxicity problem (> 250 mg kg^{-1} of available iron). A field experiment conducted to evaluate the effectiveness of non conventional liming materials like phosphogypsum, limestone powder and their blends in managing iron toxicity and soil acidity for enhancing the yield of rice in comparison to conventional shell lime revealed that all the liming treatments significantly reduced the soil acidity and iron toxicity problem. The highest pH of 5.33 was recorded in the treatment receiving shell lime@ 600 kg / ha. 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 nutrients were the highest in treatment receiving lime stone powder 300 kg ha^{-1} + phosphogypsum 300 kg ha^{-1}. The available Mn and exchangeable Al were found to decrease with the application of liming materials. 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

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Introduction

Rice is one of the important food grain crops cultivated in midlands of Kerala and in recent years rice production is declining due to many reasons. Among them soil acidity and toxicity of iron are the major constraints in the laterite derived mid land paddy soils. Iron toxicity is well recognized as the most widely distributed nutritional disorder in lowland rice production (Dobermann and Fairhurst, 2000). In acid soils, iron toxicity is one of the important constraints to rice production (Neue *et al.*, 1998). 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). A common treatment to reduce the solubility of Al, Fe and other metals in soil is to increase the soil pH. Acidity and Fe toxicity in surface soil can be ameliorated through liming (Barber and Adams, 1984). The bulk of agricultural lime comes from ground limestone, and can be calcite ($CaCO_3$), dolomite ($CaCO_3$, $MgCO_3$), or a mixture of the two. Other materials used to neutralize soil acidity, including marl, slag from iron and steel making, flue dust from cement plants, and refuse from sugar beet factories, paper mills, calcium carbide plants, rock wool plants, and water softening plants (Thomas and Hargrove, 1984).

The midland rice fields of Kerala mainly constitute the drainage basins of hills and hillocks which usually accumulates all the leachate 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 is a major constraint which create soil stress in laterite derived wet land paddy soils and high yielding rice varieties perform to a level of only 50% of their potential yield. 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). 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 study the extent of iron toxicity and acidity in rice soils of northern Kerala, to delineate the locations with toxic concentrations of HCl extractable iron and to evaluate the effectiveness and suitability of nonconventional calcium sources like limestone powder and phosphogypsum along with conventionally used shell lime in these soils with respect to availability of nutrients and yield of rice..

Materials and Methods

The midland rice fields selected for the study is situated in the northern part of Kerala which lies between 12^0 06’ 41” and 12^0 41’ 32” N latitude and 74^0 59’ 31” and 75^0 15’ 59” E longitude and the average elevation is 50 to 300 m above mean sea level. Surface (0-20 cm) soil samples (3500 numbers) were collected from selected rice fields to assess the extent of soil acidity and iron toxicity in soil.

Soil pH was determined in 1:2.5 (soil : water) suspension using pH meter and the extent of acidity was classified based on the range values given in KAU (2011). The available Fe in soils were extracted with 0.1 N HCl extract and the quantity was determined using AAS as given by Sims and Johnson (1991). Iron toxicity problem in the study area was interpreted based on the critical level given in KAU (2011).

A field experiment was carried out in farmers filed at Karivellur which is geographically located at 12.2°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). Soil samples collected at harvest stage from each treatment were analyzed for 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. 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).

Results and Discussion

Soil acidity

The pH values of rice soils are given in Table 1, which varied from 4.21 to 7.44 indicating that the soils are very strongly acidic to neutral in reaction except Padana soils where pH was 6.17 to 9.56 (neutral to alkaline reaction). More than 90% of soils are strongly acidic and the reasons for the low pH is that the rice soils are lateritic and derived from acidic parent material. The dominance of Fe, Mn and Al in these soils also contribute to soil acidity due to the hydrolysis of these ions in exchange sites of soil complexes. Similar results were also reported by Jena (2013). The higher pH in Padana soils is attributed to the high amount of alkaline earth minerals and intrusion of sea water into rice fields as also reported by Balpande *et al.*, (2007).

Iron toxicity

The content of 0.1 N HCl extractable Fe in soil varied from 52.21 – 414.9 mg kg^{-1} (Table 2). More than 50 % of the locations recorded iron toxicity problem**.** Nileswaram recorded maximum iron toxicity where 82% of samples were found to have toxic concentration of iron. The concentration of Fe^{2+} increases due to the reason that the midland rice fields of the study area constitute the drainage basins of hills and hillocks, which accumulates all the leachates washed down from hills and the soils being lateritic with high in iron content, the extent of reduced forms of iron accumulating is also high as reported by Jena (2013) in acid soils.

Effect of liming on 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) (Fig. 1).

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).

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). 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 and 4).

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).

Table.1 Soil pH and extent of soil acidity in rice soils

Rice Soils Locations	Soil pH		Extent of soil acidity (%)				
	Range	Mean	Extreme acid 3.5-4.4	Very strong acid 4.5-5.0	Strong acid 5.1-5.5	Moderate acid 5.6-6.0	Slight acid 6.1-6.5
Pilicode	4.21-6.14	5.32	8	22	31	28	11
Cheruvathur	4.37-5.92	5.43	9	26	47	18	Nil
Padana	6.17-9.56	7.91	Nil	Nil	Nil	Nil	4
Trikaripur	4.53-6.28	5.54	Nil	18	25	41	16
Kodombelur	4.93-6.58	5.82	Nil	8	44	37	7
Kinanur	4.75-5.33	5.17	Nil	62	38	Nil	Nil
Kanhangad	4.57-7.44	6.13	Nil	9	29	31	10
Kayyur Chemeni	4.59-5.75	5.21	Nil	55	28	17	Nil
Chemnad	5.16-5.31	5.26	Nil	Nil	100	Nil	Nil
Uduma	5.43-5.81	5.69	Nil	Nil	53	47	Nil
Pallikara	4.63-5.64	5.25	Nil	12	80	8	Nil
Pullur Periya	4.28-5.75	5.28	Nil	76	19	5	Nil
Puthige	4.91-5.45	5.24	Nil	28	72	Nil	Nil
Kuttikol	4.88-5.55	5.30	Nil	17	83	Nil	Nil
Meencha	5.76-6.17	6.01	Nil	Nil	Nil	89	11
Kumbla	5.36-6.12	5.88	Nil	Nil	32	58	10
Enmakaje	4.55-5.67	5.23	Nil	21	79	Nil	Nil
Nileswar	3.76-5.36	4.67	22	55	23	Nil	Nil
Kasargode	4.97-5.02	5.00	Nil	95	5	Nil	Nil
Chengala	4.45-5.48	5.04	Nil	88	12	Nil	Nil
Manjeswar	5.94-7.08	6.63	Nil	Nil	Nil	15	61
Vorkadi	5.57-6.84	6.37	Nil	Nil	Nil	18	58
Mangalpady	4.71-6.31	5.56	Nil	12	25	29	34
Panathady	6.07-6.41	6.19	Nil	Nil	Nil	Nil	100
Kallar	5.93-6.30	6.03	Nil	Nil	Nil	36	64
Karadukka	4.93-5.76	5.41	Nil	28	56	16	Nil
Muliyar	5.01-5.75	5.31	Nil	Nil	86	14	Nil
Paivaligai	5.5-6.85	6.33	Nil	Nil	Nil	18	58
Belur	5.18-6.55	5.72	Nil	Nil	8	71	21
Kumbadaje	5.43-6.95	5.66	Nil	Nil	22	18	31

Table.2 Content of available iron and extent of iron toxicity in rice soils

Sl No	Rice Soils Locations	0.1 N HCl extractable Fe content (mg kg $^{-1}$)		Extent of iron toxicity (%)
		Range	Mean	
1	Pilicode	52.21 – 269.5	221.7	27
2	Cheruvathur	173.6 – 349.4	275.4	38
3	Padana	112.6 – 240.7	216.9	22
4	Trikaripur	59.63 – 114.8	87.1	Nil
5	Kodombelur	83.62 – 234.5	209.6	23
6	Kinanur Karimthalam	73.09 – 188.3	152.4	Nil
7	Kanhangad	57.7 – 288.5	217.2	14
8	Kayyur Chemeni	112.4 – 303.2	273.4	38
9	Chemnad	188.5 – 382.4	327.5	72
10	Uduma	152.8 – 188.5	169.8	Nil
11	Pallikara	153.5 – 299.3	237.4	59
12	Pullur Periya	142.85 – 225.8	200.6	12
13	Puthige	127.1 – 302.6	267.1	65
14	Kuttikol	162.5 – 307.6	230.8	61
15	Meencha	66.33 – 132.8	74.3	Nil
16	Kumbla	147.4 – 270.2	176.2	28
17	Enmakaje	97.71 – 180.3	131.8	Nil
18	Nileswar	186.9 – 414.9	383.6	82
19	Kasargode	58.52 – 74.12	69.3	Nil
20	Chengala	80.76 – 146.1	102.4	Nil
21	Manjeswar	88.26 – 198.4	132.7	Nil
22	Vorkadi	123.1 – 209.5	142.8	8
23	Mangalpady	66.25 – 135.28	118.7	Nil
24	Panathady	118.2 – 190.6	149.6	Nil
25	Kallar	149.45 – 308.1	223.8	56
26	Karadukka	138.5 – 183.6	151.2	46
27	Muliyar	82.01 – 175.2	102.7	Nil
28	Paivaligai	76.6 – 119.38	113.0	Nil
29	Belur	86.65 – 135.6	102.8	Nil
30	Kumbadaje	57.36 – 80.66	49.3	Nil

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

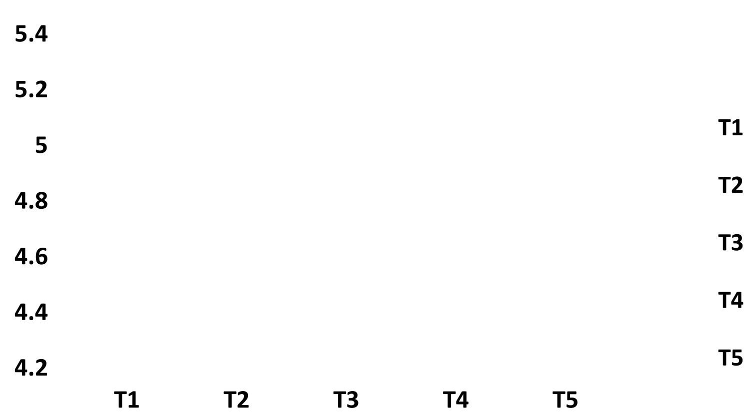
Table.4 Effect of treatments on availability of micro nutrients in soil

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

Table.5 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

Fig.1 pH of soil as influenced by various treatments



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 sources. 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 5). 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) and Sarkar (2013).

From the study it can be concluded that laterite derived paddy soils of northern Kerala have acidity and iron toxicity problems. The results from 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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