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Effect of Liming on Soil Properties, Nutrient Content and Yield of Wetland Rice in Acid Tropical Soils of Kerala

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Abstract

The acid tropical soils of Kerala are characterized with low levels of basic cations and high levels of acidic cations like iron and manganese. Rice grown under flooded conditions are associated with high concentration of iron in the rhizosphere due to reduced soil environment. Higher iron content in the rhizosphere has antagonistic effect on uptake of essential nutrients leading to reduction of yield. An experiment was conducted in the first crop season of 2015 to study the influence of lime application on soil properties, plant nutrient content and yield of rice. The treatments included three sources of lime viz. calcium oxide, calcium carbonate and dolomite applied in three doses viz. as per POP recommendation, as per ΔpH and as per lime requirement based on SMP buffer method and a control with no lime application. Application of calcium carbonate as per lime requirement based on SMP buffer method increased the soil pH from 4.90 to 7.10 at harvest of the crop when compared to 4.85 in the control plot. Lime applied as per lime requirement based on SMP buffer method increased the availability of potassium, calcium, sulphur and reduced the levels of available iron, manganese, copper and zinc. Content of potassium, calcium and sulphur in plant increased with dose of lime applied while the plant content of magnesium, iron, manganese, zinc and copper decreased. Application of dolomite increased the available magnesium in soil and the magnesium content in plant. Dolomite applied as per ΔpH was found to be the optimum dose in increasing the yield of rice.

Keywords: Soil acidity, liming, nutrient content, wetland rice

1. Introduction

The state of Kerala exists as a narrow strip of land along the west coast of India sloping down from the high altitudes of Western Ghats through foot hills and mid land laterites to the coastal plains and further to deltaic deposits lying at or below mean sea level. The tropical humid climate prevalent in the state with bi-modal pattern of south-west and north-east monsoons resulted in leaching of bases and subsequent accumulation of iron, aluminium and manganese (Nair et al., 2011; Sureshkumar et al., 2018). Deficiency of basic cations and high saturation of soil CEC with H^+ and Al^{3+} ions is a problem inherent in these highly weathered soils that limit agricultural yields (Ryan et al., 2011; Nair et al., 2013). Rice grown under flooded conditions are associated with high concentration of iron in the rhizosphere due to reduced soil environment. Reduction of iron occurs within a few days due to absence of oxygen, resulting in enormous increase in concentration of ferrous (Fe^{2+}) ion. The iron content in rice leaves increased when the divalent cationic charge fraction in the soil solution accounted for by Fe^{2+} is high. The increase in the iron content in leaves occur at the expense of other cations like calcium and magnesium as the uptake of divalent cations by rice is non-specific(Moore and Patrick, 1989). When the availability of calcium is low, the plasma membrane initiates non-specific absorption. The function of the membrane is restored only with increase in availability of calcium thus increasing the absorption of other cations (Fageria, 2009). Higher concentration of Fe^{2+} in the rhizosphere has antagonistic effects on the uptake of essential nutrients which leads to reduction in rice yield (Fageria et al., 2008). The nutrient stress associated with iron toxicity in wetland rice can be suppressed with the use of balanced fertilizers (Patra and Mohanty, 1994).

Effective measures to ameliorate iron toxicity include periodic surface drainage and liming acid soils. Flooding tends to change the pH of soil to neutrality. This is mainly due to reduction of Fe and Mn oxides which consumes H^+ ions (Fageria et al., 2011). Hence liming is a requisite for plant nutrition rather than pH correction in lowland rice. Lime acts as a source of calcium and/or magnesium and decreases acetate extractable Fe in soils (Seng et al., 2006). Calcium sufficiency in soil stimulates the absorption of P and K and accelerates translocation of photosynthetic products in rice (Kawasaki, 1995). Fertilization with nitrogen, phosphorus, potassium, calcium and magnesium is found to improve the iron excluding mechanism of rice.

With these considerations, current study was undertaken with an objective to study the influence of different liming material on the soil properties, plant nutrient content and yield of wetland rice.

2. Materials and Methods

2.1. Experimental layout

Field experiment was conducted at Regional Agricultural Research Station, Pattambi, Palakkad district, in the first cropping season of 2016. The climate is tropical sub humid to humid (mean annual temperature 27.6 °C; rainfall 1966 mm) with a dry period of around five months. The soil is sandy clay loam in texture with pH 4.9. The experiment was laid out in randomised block design with three replications. Ten treatments were imposed that included three sources of liming material applied at three doses with one control treatment. The three sources included calcium oxide (S_1), calcium carbonate (S_2) and dolomite (S_3). The three doses included (i) application as per package of practices recommendations (600 kg ha^{-1} of $CaCO_3$) of Kerala Agricultural University (L_1) (KAU, 2011) (ii) as per ΔpH (6.5-measured pH x 0.3375 t ha^{-1} of $CaCO_3$) (L_2) (DOA, 2013) (iii) as per lime requirement based on SMP buffer method (L_3) (Shoemaker et al., 1961). The different liming materials were applied based on their calcium carbonate equivalents, which were 137% for calcium oxide, 97% for calcium carbonate and 99% for dolomite (Table 1).

2.2. Crop culture

Jyothi, a short duration variety of 110–120 days was used for the study. Plots of 5x4 m^2 were prepared by constructing bunds of 30 cm width and height. Fertilizers were given as per the package of practices recommendations of Kerala Agricultural University, modified based on soil test results. Liming materials were applied in two splits. The first split was applied as basal dose, and the second as top dressing one week before panicle initiation.

The crop was harvested from each plot and the weight of straw and grain was recorded separately and expressed as t ha^{-1}.

2.3. Collection and analysis of soil and plant samples

Rhizosphere soil samples (0–15 cm) were drawn from each plot at harvest, dried under shade, sieved through 2 mm sieve and analysed for available nutrients using standard procedures. Plant samples were collected from each plot at harvest stage, washed and dried to constant weight, powdered in stainless steel grinder, digested with di-acid mixture (HNO_3 and $HClO_4$ 4:1) and analysed for nutrient content using standard procedures.

2.4. Statistical analysis

The experimental data were analysed as factorial Randomised Block Design with the sources and doses of liming materials as the main factors. In addition to include the control treatment the data were analysed as complete RBD with ten treatments and the effects of treatments were assessed by analyzing the data as a 3^2+1 experiment.

Table 1: Treatment combinations and quantity of liming material added

Treatment combination	Source used	Dose	Quantity applied (t ha^{-1})
S_1L_1	Calcium oxide	As per POP recommendationsof Kerala Agricultural University	0.438
S_1L_2	Calcium oxide	As per ΔpH	0.394
S_1L_3	Calcium oxide	As per lime requirement based on SMP buffer method	3.905
S_2L_1	Calcium carbonate	As per POP recommendations	0.619
S_2L_2	Calcium carbonate	As per ΔpH	0.557
S_2L_3	Calcium carbonate	As per lime requirement based on SMP buffer method	5.516
S_3L_1	Dolomite	As per POP recommendations	0.606
S_3L_2	Dolomite	As per ΔpH	0.545
S_3L_3	Dolomite	As per lime requirement based on SMP buffer method	5.404
Control	Nil	Nil	0

3. Results and Discussion

The quantity of liming materials added was based on their calcium carbonate equivalents. The sources used (calcium oxide, calcium carbonate and dolomite) basically differed in their solubility and reactivity for neutralizing soil acidity. While burnt lime and limestone acted as sources of calcium, dolomite added both calcium and magnesium to soil. The effect of liming on electrochemical properties and available nutrient content in the soil are presented in Table 2.

3.1. Soil pH

The different sources and doses of liming materials added had significant effect on pH of soil. The treatment combinations with dose as per SMP buffer method (L_3) recorded significantly higher soil pH. SMP buffer method of lime requirement estimates the quantity of lime required to neutralize the total

Table 2: Effect of treatment combinations on soil properties at harvest of rice

Treatment combinations	soil pH	Available nutrients					
		Phosphorus	Potassium	Calcium	Magnesium	Iron	Manganese
		kg ha^{-1}		mg kg^{-1}			
S_1L_1	4.94	12.46	65.17	246.97	30.52	218.87	16.15
S_1L_2	4.94	12.44	62.27	223.97	30.61	219.23	16.10
S_1L_3	6.42	13.50	68.96	1000.25	24.71	178.60	14.39
S_2L_1	5.04	12.72	65.83	350.92	30.86	185.87	16.33
S_2L_2	5.05	13.06	64.76	340.82	32.26	218.87	16.49
S_2L_3	7.10	12.42	70.23	2403.70	29.78	168.93	14.47
S_3L_1	4.97	12.32	62.67	235.83	60.46	235.65	17.05
S_3L_2	5.02	11.94	65.74	228.73	57.40	250.07	17.65
S_3L_3	6.02	12.97	69.32	797.27	141.67	207.43	15.79
$p<0.05$	0.10	0.25	0.56	342.37	6.26	7.70	0.95
Control	4.85	12.02	55.88	145.87	31.83	269.40	17.12
F statistic (Treatments vs control)	79.3**	35.71**	151.15**	19.54**	85.97**	363.6**	11.41**

$^{**}p< 0.01$

acidity, whereas the lime applied as per ΔpH neutralizes only the active acidity. The quantity of liming material added as per dose L_3 is much higher than the other two doses, and hence a considerable increase in soil pH was recorded. The application of calcium carbonate as per the lime requirement (S_2L_3) increased the soil pH from 4.90 to 7.10 and was significantly superior over other treatment combinations, while in the control plot the pH decreased to 4.85.

3.2. Available phosphorus

The initial status of available P in soil was 12.05 kg ha^{-1}. The treatments imposed were found to increase the available phosphorus content in soil when compared to the control plot. This might be because of the formation of mono or di calcium phosphates which are more soluble. Fageria et al. (1995) reported an increase of soil phosphorus as pH increased from 5.0 to 6.5, due to release of P ions from Al and Fe oxides.

3.3. Available potassium

Available potassium in the control plot decreased significantly from the initial status of 74.88 kg ha^{-1} to 55.88 kg ha^{-1}. The potassium content in the control plot was significantly lower than the lime treated plots. Calcium from the liming materials added would have replaced potassium from the exchange sites thus increasing the labile pool. Available potassium was significantly higher in the treatment where calcium carbonate was applied as per lime requirement (S_2L_3). In soils with pH dependent charges, increase in pH with liming enhances the CEC of soil thus improving the ability to retain potassium (Ernani et al., 2012).

3.4. Available calcium

The initial status of available calcium was 181.85 mg kg^{-1}. The application of liming materials significantly increased the available status of calcium in soil while the availability of calcium decreased to 145.87 mg kg^{-1} in the control plot. The application of calcium carbonate as per lime requirement (S_2L_3) was significantly superior with respect to availability of calcium over all other treatment combinations. This was concurrent to the significantly higher pH recorded in this treatment.

3.5. Available magnesium

The initial status of available magnesium was 36.28 mg kg^{-1}. Application of different doses of dolomite (S_3) could significantly influence the available magnesium status in soil and was superior over the other two sources of liming materials added. The applied dolomite with 10.4 per cent magnesium could improve the magnesium status in soil due to slow release on account of low solubility, whereas application of soluble magnesium sulphate in other treatments would have led to loss of magnesium. As magnesium is unable to replace other cations like calcium from the exchange complex, it is compelled to remain in solution thus leading to loss. Highest magnesium content was recorded in treatment with dolomite applied as per lime requirement (S_3L_3) due to the higher quantity of dolomite applied.

3.6. Available iron and manganese

The available iron in the control plot increased from the initial status of 235.70 mg kg^{-1} to 269.40 mg kg^{-1} which can be attributed to the reduction of ferric to ferrous form due to flooding. The available manganese content also increased from the initial status of 13.43 to 17.12 mg kg^{-1} in the control plot. The decrease in the status of available Fe and Mn found in the treatments where liming materials were added can be attributed to the exchange of reduced ferrous iron and manganous ion from the exchange sites by Ca added through lime and its subsequent precipitation. Precipitation of Fe^{2+} as $Fe_3O_4.nH_2O$ and Mn as $MnCO_3$ under flooded condition was reported by Ponnamperuma (1972). Application of calcium carbonate as per lime requirement (S_2L_3) was found effective in significantly reducing the content of available Fe in soil. This is also concurrent to the increase in pH of soil recorded in this treatment.

3.7. *Plant nutrient content*

The nutrient content in the straw and grain are presented in Tables 3 and 4. Nitrogen content in straw was significantly higher in the treatments where calcium carbonate and dolomite were applied as per lime requirement. The nitrogen content in grain however was not significantly influenced by the different sources and doses of lime. The lack of any significant difference in the nitrogen content in grain might be due to the mobility of nitrogen and resultant translocation. The phosphorus content in the straw and grain was significantly lowest in the treatment where calcium carbonate was applied as per lime requirement (S_2L_3). The potassium content in the straw was significantly higher in the treatment where dolomite was applied as per lime requirement,

Table 3: Effect of treatment combinations on primary nutrient content (%) in plant

Treatment combinations	Nitrogen		Phosphorus		Potassium	
	Straw	Grain	Straw	Grain	Straw	Grain
S_1L_1	0.69	1.24	0.110	0.32	1.30	0.28
S_1L_2	0.70	1.21	0.108	0.33	1.28	0.30
S_1L_3	0.77	1.27	0.102	0.32	1.34	0.29
S_2L_1	0.73	1.25	0.098	0.29	1.31	0.29
S_2L_2	0.67	1.25	0.104	0.30	1.28	0.31
S_2L_3	0.82	1.26	0.091	0.28	1.34	0.30
S_3L_1	0.66	1.23	0.116	0.32	1.35	0.29
S_3L_2	0.69	1.22	0.112	0.32	1.40	0.29
S_3L_3	0.81	1.23	0.108	0.34	1.45	0.27
$p<0.05$	0.04	0.04	0.016	0.02	0.10	NS
Control	0.55	1.22	0.123	0.30	1.32	0.29
F statistic (Treatments vs control)	176^{**}	3.70	16.67^{**}	0.01	5.67^{*}	3.23

$^{**}p< 0.01$; $^{*}p<0.05$

Table 4: Effect of treatment combinations on secondary and micronutrient content (mg kg^{-1}) in plant

Treatment combinations	Calcium		Magnesium		Iron		Manganese	
	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
S_1L_1	6280	238.73	1077	1404	444.07	311.18	375.55	41.33
S_1L_2	6219	235.87	1075	1397	447.84	319.87	372.93	37.23
S_1L_3	6674	416.80	1070	1413	409.53	292.70	368.73	35.63
S_2L_1	6097	236.57	1020	1418	425.50	312.50	362.62	37.90
S_2L_2	5561	237.77	1018	1411	432.80	316.77	370.22	37.15
S_2L_3	6120	402.47	995	1415	398.30	290.23	296.20	34.63
S_3L_1	5227	224.90	1032	1424	483.37	315.24	410.90	38.12
S_3L_2	5215	206.50	1030	1424	486.73	316.90	416.67	40.07
S_3L_3	5427	369.20	1147	1444	429.90	304.82	374.10	36.87
$p<0.05$	189.93	9.84	44.38	25.80	10.97	11.52	18.42	2.42
Control	5210.33	229.87	1040	1309	520.10	312.37	405.27	36.07
F statistic (Treatments vs control)	181.38^{**}	316.40^{**}	386.42^{**}	61.94^{**}	56.71^{**}	24.08^{**}	26.29^{**}	0.89

$^{**}p< 0.01$; $^{*}p<0.05$

whereas potassium content in the grain was not found to be significantly influenced by the different sources and doses of liming materials added. Calcium content in the straw and grain was significantly higher in the treatment where calcium oxide was applied as per lime requirement (S_1L_3) which might be because of the higher solubility of calcium oxide making calcium more available in the initial stages of plant growth leading to higher plant absorption. Magnesium content in the straw and grain was significantly higher in the treatment where dolomite was applied as per lime requirement (S_3L_3) which is concurrent to the higher available magnesium status recorded in this treatment. Iron content in straw was significantly lower in the treatment where calcium carbonate was applied as per lime requirement while calcium oxide and calcium carbonate applied as per lime requirement recorded significantly lower iron content in grain.

3.8. Grain and straw yield

The data on biometric observations viz., number of productive tillers, the number of grains per panicle, thousand grain weight, straw and grain yield are presented in Table 5. The yield in the control plot was significantly lower than the plots where different treatments were imposed, indicating the beneficial influence of liming on the yield of rice. The data on number of productive tillers, grains per panicle, thousand grain weight and grain yield confers that application of dolomite as per ΔpH was the optimum dose of liming material to significantly increase crop yield.

Table 5: Effect of treatment combinations on biometric observations and yield of rice

Treatment combinations	No. of productive tillers	No. of grains panicle^{-1}	Thousand grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
S_1L_1	7.50	105.97	27.29	5.43	6.62
S_1L_2	7.50	105.27	27.40	5.43	6.68
S_1L_3	7.61	106.23	27.08	5.48	6.79
S_2L_1	7.47	105.18	27.36	5.42	6.75
S_2L_2	7.50	105.11	27.39	5.40	6.73
S_2L_3	7.48	105.26	26.95	5.46	6.55
S_3L_1	7.63	107.27	27.51	5.46	6.72
S_3L_2	7.60	107.47	27.50	5.46	6.78
S_3L_3	7.67	107.98	27.02	5.51	6.70
$p<0.05$	0.09	0.55	0.12	0.05	0.06
Control	7.45	103.90	27.25	5.38	6.47
F statistic (Treatments vs control)	118.88**	27.61**	12**	48.00**	215**

$^{**}p< 0.01$; $^{*}p<0.05$

4. Conclusion

Application of liming material reduced the content of acidic cations in soil as well as in plant, concomitant to the quantity applied. Whereas, the yield contributing characters revealed that application of dolomite as per ΔpH was optimum. A moderate amount of liming material is sufficient to ameliorate the toxicity of acidic cations. Application of dolomite could maintain a balance between the calcium and magnesium content in soil as well as improve the uptake of magnesium by the crop.

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