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Amelioration strategy for iron and aluminium toxicity on rice in acid sulphate soils of Kuttanad

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Abstract
Kuttanad the rice bowl of Kerala, constitute acid sulphate soils, face different risks like iron and aluminium toxicity, which causes a decline in rice production in the state. A pot culture experiment was carried out to examine suitable amelioration strategies for the management of iron and aluminium toxicity in rice grown in the acid sulphate soils of Kuttanad. Bulk soil samples were collected from the 'Kari' lands of Kuttanad, brought to College of Agriculture, Padannakkad, and analysed for various physical and chemical properties. The analytical results revealed the condition of highly acidic pH and toxic levels of Fe and Al in the soil. Experimental treatments were designed based on this analysis according to the recommendations of KAU POP in two different popular rice varieties Uma and Prathyasa. The treatment combinations included lime (T_1); magnesium carbonate + ½ lime (T_2); phosphogypsum + ½ lime (T_3); lime + potassium silicate 0.25% + 0.25% boron (T_4); magnesium carbonate + ½ lime + potassium silicate 0.25% + 0.25% Boron (T_5); phosphogypsum + ½ lime + potassium silicate 0.25% + 0.25% boron (T_6); and control (T_7). Different parameters like pH, EC, organic carbon available nutrients like N, P, K, Ca, Mg, S, micronutrients B, Zn, Cu, Mn, Fe and Al were analysed at 30, 60 days after transplanting and at the time of crop harvest. The findings of the experiment revealed that application of phosphogypsum + ½ lime with a foliar spray of 0.25% boron and 0.25% potassium silicate significantly improved crop performance. The positive effects of this treatment included increased soil pH and enhanced available soil nutrient content. This further enabled better nutrient uptake by the plant leading to improved yield and other yield attributes of rice. The treatment also reduced Fe, Al, and Mn toxicity in the soil.

Keywords: Iron and aluminium toxicity, rice, acid sulphate soils Kuttanad

1. Introduction
Rice (*Oryza sativa* L.) is a widely grown crop, the world over. It is staple food for the majority of population and is the principal dietary item of the people of India. Rice is the most important cereal and staple food consumed in Kerala though the state's production meets just 16.55% of the demand. Kuttanad of Alleppey district, the rice bowl of Kerala is a unique agricultural tract lying 0.6 to 2.2 m below the mean sea level on the west coast of India. It has a geographic area of 0.85 lakh ha. This comprised of 50,000 ha of rice fields, out of which 14,227 ha belongs to acid sulphate soils (Typic sulfaquent) known as the 'Kari' lands which is the most problematic area of rice cultivation. The rice cultivation in Kuttanad face risks associated with waterlogging, extreme acidity and toxicities of iron and aluminium (Thampatti and Jose, 2000) [24]. Rice yield losses associated with iron toxicity ranges from 12 to 100% depending on the rice cultivars and the prevailing iron toxicity levels (Abifarin, 1988) [1].
Aluminum toxicity is also one of the major concerns of low rice productivity in wetland acid sulphate soils (Fageria and Carvalho, 1982) [13]. Aluminum toxicity affects about 40-70% of the world's arable land, which otherwise has the immense potential for food crop and biomass production. The occurrence of metal toxicity predominantly of iron and aluminium in many cases can be overcome by the addition of lime (Calcium carbonate), or slaked lime (Calcium hydroxide), magnesium carbonate or other alkaline/liming materials to increase the soil pH and precipitate the toxic metals and thus increase plant growth.
Since the acid sulphate soils of Kuttanad is an important problematic area with extreme acidity, toxicity of iron, aluminium coupled with deficiency of phosphorous, application of different amendments and other nutrients should be used for successful cultivation in these areas.

2. Materials and methods
The pot culture experiment was conducted in College of Agriculture, Padanakkad to study the iron and aluminium toxicity problem in rice grown on acid sulphate soils of Kari lands in Kuttanad and to examine the effect of different amelioration strategies.

The experiment was conducted in completely randomized design with seven treatments and three replications. The soil sample collected from the Kari lands of Kuttanad (Latitude: 9°: 18ˈ: 56ˈˈ.99, longitude: 76°: 24ˈ: 30ˈˈ.68) and brought to College of Agriculture, Padanakkad. The soil was thoroughly mixed and equal quantity (22.5 kg) of the soil was transferred to different pots of uniform size (40 cm length and 20 cm breadth). Rice seeds of Uma and Prathyasa varieties were germinated in moistened filter paper. Uma (MO-16) is the most popular and commonly cultivated variety in Kuttanad which is a medium duration variety, Prathyasa (MO-21) is a newly developed short duration variety that shows iron and aluminium toxicity symptoms in the initial growing period and then recovers without affecting the yield. The germinated seeds were carefully transferred to nursery containing potting mixture. Different amelioration strategies as amendments were imposed into the pot. The treatment combinations were: lime (T_1); magnesium carbonate + ½ lime (T_2); phosphogypsum + ½ lime (T_3); lime + potassium silicate 0.25% + 0.25% boron (T_4); magnesium carbonate + ½ lime + potassium silicate 0.25% + 0.25% Boron (T_5); phosphogypsum + ½ lime + potassium silicate 0.25% + 0.25% boron (T_6) and control (T_7).

The seedlings were maintained for two weeks in the nursery and after that it was transplanted into the already filled pots which contained the soil collected from Kuttanad such that each pot contains two seedlings. Nitrogen, phosphorus and potassium application were followed as per package of practices recommendations, KAU (2011) uniformly for all the treatments. Water level in the pot was maintained as 5 cm from the surface of top soil.

Number of tillers in each plant of different treatments was taken at 30, 60 days after transplanting and at harvest. Total grain yield of each plant in all treatments were taken at the time of harvest. Soil samples for laboratory analysis were collected from all the treatments at the time of harvest. The soil samples were analyzed for pH, EC, organic carbon (OC), Ca, Mg, S, Mn Fe and Al using standard procedure. Plant samples were collected at harvest and analyzed for Ca, Mg, Fe and Al content using standard procedures. The yield and yield parameters variation with treatment application were also noted.

3. Results

The results showed significant effect on rice grain yield, number of tillers, soil pH, Ca, Mg, Fe, Al and plant nutrient concentration of P, Ca, Mg, Fe and Al as influenced by treatments and varieties at the time of harvest.

The effect of different treatments on the number of tillers at 30 days, 60 days and at harvest of the rice plant grown in the pot culture experiment are given in the Table 1. The treatment application showed significant effect on number of tillers of the rice plant grown in pot culture. The treatments were significant at 30 DAT, application of lime + foliar spray of 0.25% boron and 0.25% potassium silicate and phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate showed a greater number of tillers (21.6). At 60 DAT (23.8) and at harvest (26.7) application of phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate showed greater number of tillers. Control showed minimum number of tillers throughout the experiment. The grain yield of the plant was found to be significant. The grain yield of the crop in the pot culture study is represented in Table 2. The Application of lime + foliar spray of 0.25% boron and 0.25% potassium silicate (T_4) recorded highest grain yield per plant (76.6 g/pot) and control showed lowest yield T_1 (74.17 g/pot). This may be due to the ameliorating effect of lime on reduced Fe, Al toxicity, increased Ca content and also enhancing the soil conditions for better plant growth.

The effect of treatment application on the pH of the soil at harvest stage of the crop in the pot culture study is furnished in Table 2. The varieties did not show any significant difference among the pH of the soil. The variety V_1 (5.79) comparatively showed more soil pH than V_2 (5.73). There was significant influence by the application of treatments on increasing the soil pH. The treatment T_4 showed higher pH (6.03) in the soil over other treatments which is on par with T_1 (6.01), T_6 (5.96), T_3 (5.92). The lowest pH in the soil was shown by T_7 control (4.88). The treatment and variety interaction were not showed any significance. The treatment T_1 (6.01) in V_1 and T_4 (6.05) in V_2 showed higher pH. Treatment T_7 in both varieties showed lowest pH.

The results of available Ca content on different amendments were done at harvest stage of crop. The data obtained by statistical analysis of the results are given in the Table 3. The varieties did not show any significant difference. Similar results were recorded by the two varieties. The treatments showed significant difference with different amendments with respect to calcium content. The treatment T_6 (779.08 mg kg^{-1}) showed higher amount of available Ca in soil which was on par with T_3, T_1 and T_4.

Table 1: Effect of application of amendments and their combinations on no. of tillers of plant

Treatments	30 DAT			60 DAT			At harvest		
	Uma	Prathyasa	Mean	Uma	Prathyasa	Mean	Uma	Prathyasa	Mean
T_1	21.83	20.00	20.92	22.67	22.33	22.50	25.83	25.67	25.75
T_2	21.50	21.67	21.58	21.67	22.50	22.08	24.00	24.50	24.25
T_3	19.83	21.00	20.42	21.33	22.00	21.67	25.17	25.00	25.08
T_4	18.83	20.33	19.58	22.17	23.00	22.58	25.67	26.00	25.83
T_5	20.83	21.83	21.33	21.83	22.83	22.33	24.33	25.50	24.92
T_6	21.17	22.00	21.58	23.83	23.83	23.83	26.50	26.83	26.67
T_7	18.50	18.50	18.50	19.83	19.17	19.50	22.00	21.67	21.83
Mean	20.35	20.76		21.91	22.24		24.78	25.03	
Comparison	SEm(±)	CD (5%)		SEm(±)	CD (5%)		SEm(±)	CD (5%)	
V	0.38	NS		0.26	NS		0.23	NS	
T	0.71	2.08		0.50	1.46		0.43	1.25	
V x T	1.01	NS		0.71	NS		0.61	NS	

Note: T_1: lime; T_2: magnesium carbonate + ½ lime T_3: phosphogypsum @ 500 kg ha^{-1} + ½ lime; T_4: lime + potassium silicate 0.25% + 0.25% boron; T_5: magnesium carbonate + ½ lime + potassium silicate 0.25% + 0.25% boron; T_6: phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate 0.25% + 0.25% boron; T_7: control; DAT: days after transplanting; DAT: days after transplanting

Table 2: Effect of application of amendments and their combinations on yield and pH

Treatments	Grain yield (g/pot)			Soil pH after amendment addition		
	Uma	Prathyasa	Mean	Uma	Prathyasa	Mean
T_1	73.77	74.57	74.17	6.01	6.00	6.01
T_2	60.47	63.00	61.73	5.74	5.65	5.70
T_3	72.63	71.03	71.83	5.96	5.86	5.91
T_4	75.89	77.17	76.52	6.00	6.05	6.02
T_5	62.50	64.20	63.35	5.940	5.71	5.82
T_6	73.86	72.69	73.28	6.01	5.91	5.96
T_7	55.10	54.20	54.65	4.87	4.88	4.87
Mean	67.75	68.13		5.79	5.72	
Comparison	SEm(±)	CD (5%)		SEm(±)	CD (5%)	
V	0.58	NS		0.03	NS	
T	1.08	3.16		0.05	0.14	
V x T	1.53	NS		0.07	NS	

Note: T_1: lime; T_2: magnesium carbonate + ½ lime T_3: phosphogypsum @ 500 kg ha^{-1} + ½ lime; T_4: lime + potassium silicate 0.25% + 0.25% boron; T_5: magnesium carbonate + ½ lime + potassium silicate 0.25% + 0.25% boron; T_6: phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate 0.25% + 0.25% boron; T_7: control

The data obtained for analyzing the available magnesium from the soil at harvest stage of the crop are statistically analyzed and presented in Table 3. The varieties Uma (V_1) and Prathyasa (V_2) provide analogous results. There was no significant difference between the varieties. The treatments showed variation in available Mg values and are significantly different. The treatment T_5 registered higher magnesium content (74.27 mg kg^{-1}) in the soil even after plant uptake which may be because of the magnesium that applied through the treatment. Treatment T_2 (72.51 mg kg^{-1}) and T_3 (67.05 mg kg^{-1}) gave values on par to T_5. The interaction effect of treatments and varieties did not show any significant difference.

The results of analysis of available sulphur content in soil at harvesting stage of the pot culture experiment is given in Table 3. The effect of varieties Uma and Prathyasa did not showed any significant difference. The treatments have significant effect on available sulphur content. The highest sulphur content was showed by T_7, the control (192.12 mg kg^{-1}). The lowest value of available sulphur was reported by the treatment T_4 (155.79 mg kg^{-1}), which was on par with T_1, T_3, T_6, T_2 and T_5. The interaction effect of variety and treatment had no significant effect on available S content.

The effects of different amendments on iron content in the harvest stage of pot culture experiment were statistically analyzed and are given in Table 4. The effect of treatments showed significant difference for available iron content. Treatment T_7 recorded highest iron content (371.33 mg kg^{-1}) which was on par with treatment T_5 and T_2. The treatment T_6 showed the lowest value of iron content (164.67 mg kg^{-1}) which was on par with treatment T_4 (171 mg kg^{-1}) and T_3 (182.67 mg kg^{-1}). There was no significant difference among the interaction of amendments and varieties. The analyzed value for Al in soil at the harvest stage of the pot culture experiment is presented in Table 4. The variety Uma and Prathyasa have similar results and their interaction was not significant. The treatments had a significant effect on aluminium content in the soil. The treatment T_7 (212.54 mg kg^{-1}) showed significantly higher amount of exchangeable aluminium which was on par with T_5. The lowest value for aluminium content was recorded by treatment T_6 (100.82 mg kg^{-1}) which is on par with T_3, T_1 and T_4. The interaction of varieties and different amendments did not show any significant difference. The effects of different amendments on the availability of manganese content in soil at the harvest stage of the pot culture experiment are given in Table 4. The varieties did not have any significant effect on manganese content. The highest available manganese content was observed in treatment T_7, the control (33.50 mg kg^{-1}) and lowest available Mn was shown by T_6 (23.48 mg kg^{-1}) which was on par with T_4, T_1 and T_3. There was no significant difference between the effect of varieties and amendments interaction.

The effect of treatment application on the P concentration in the plant at harvest stage of the crop in the pot culture study is represented in Table 5. The treatments, varieties and interaction between variety and treatment were found to be significant in case of P content in plants. The highest P content in plant (0.22%) was recorded by T_6 and control showed the lowest value. The effect of treatment application on the Ca concentration in the plant at harvest stage of the crop in the pot culture study is given in Table 5. Application of amendments showed significant effect in uptake of Ca by the rice plants. The treatment T_3 recorded highest Ca content in plants (1.82%). The treatment with no amendment application, control showed lowest concentration of Ca in plants. The effect of treatment application on the Mg concentration in the plant at harvest stage of the crop in the pot culture study is represented in Table 5. Application of amendments showed significant effect in uptake of Mg by the rice plants. The treatment T_2 recorded highest Mg content in plants (0.34%). Control showed lowest concentration of Mg in plants.

The effect of treatment application on the Fe concentration in the plant at harvest stage of the crop in the pot culture study is displayed in Table 6 (fig 1). The effect of treatments on concentration of iron in plants was found to be significant. The varieties did not show any significance with uptake of iron. There was significant effect by the variety and treatment interaction. The treatment application of lime (T_1) showed lowest concentration of iron in plants (159.917 mg kg^{-1}). The effect of treatment application on the Al concentration in the plant at harvest stage of the crop in the pot culture study is represented in Table 6 (fig 2). The treatments, variety and interaction of treatment and variety showed significance on the concentration of aluminium in plants. Treatment T_6 showed lowest uptake of Al by plants (291.37 mg kg^{-1}) and control showed the highest uptake. The data were also subjected to correlation. The results of correlation analysis are given in the Table 7. There was significant correlation between yield, pH, available P, Ca, Fe, Al, plant Ca and Fe.

Table 3: Effect of different amendments and their combinations on availability of secondary nutrients in soil of pot culture

Treatments	Ca (mg kg^{-1})			Mg (mg kg^{-1})			S (mg kg^{-1})		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	717.92	705.17	711.54	57.72	51.12	54.42	158.82	156.33	157.57
T_2	681.17	635.42	658.29	74.42	70.62	72.51	167.28	173.87	170.57
T_3	776.25	752.37	764.31	65.88	68.22	67.05	160.04	158.40	159.22
T_4	719.08	689.58	704.33	53.07	54.53	53.80	158.88	152.71	155.79
T_5	672.08	677.5	674.79	74.27	74.30	74.28	170.49	171.81	171.15
T_6	784.83	773.33	779.08	64.55	64.30	64.42	163.95	158.37	161.16
T_7	300.02	307.25	303.64	46.18	45.70	45.94	193.65	190.57	192.12
Mean	664.48	648.66		62.29	61.25		167.58	166.01	
Comparison	SEm(±)	CD (5%)		SEm(±)	CD (5%)		SEm(±)	CD (5%)	
V	15.56	NS		1.63	NS		3.15	NS	
T	29.11	84.76		3.05	8.89		5.88	17.14	
V x T	41.16	NS		4.32	NS		8.32	NS	

Note: T_1: lime; T_2: magnesium carbonate + ½ lime T_3: phosphogypsum @ 500 kg ha^{-1} + ½ lime; T_4: lime + potassium silicate 0.25% + 0.25% boron; T_5: magnesium carbonate + ½ lime + potassium silicate 0.25% + 0.25% boron; T_6: phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate 0.25% + 0.25% boron; T_7: control; SEm: Standard error mean; CD: critical difference.

Table 4: Effect of different amendments and their combinations on iron, aluminium and manganese in soil of pot culture

Treatments	Available Fe (mg kg^{-1})			Exchangeable Al (mg kg^{-1})			Available Mn (mg kg^{-1})		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	208.33	241.33	224.83	108.17	107.17	107.67	24.90	25.79	25.34
T_2	333.67	354.00	343.83	188.87	123.00	155.93	27.07	27.10	27.08
T_3	177.33	188.00	182.67	103.93	102.30	103.12	25.23	25.85	25.54
T_4	203.67	138.33	171.00	106.33	139.00	122.67	25.02	25.74	25.38
T_5	319.67	382.00	350.83	193.00	142.73	167.87	26.84	26.00	26.77
T_6	143.33	186.00	164.67	98.27	103.37	100.82	23.33	23.60	23.48
T_7	373.00	369.67	371.33	220.58	204.50	212.54	33.88	33.12	33.50
Mean	251.28	265.62		145.59	131.72		26.61	26.85	
Comparison	SEm(±)	CD (5%)		SEm(±)	CD (5%)		SEm(±)	CD (5%)	
V	10.71	NS		8.65	NS		0.37	NS	
T	20.03	58.34		16.17	47.09		0.701	2.04	
V x T	28.33	NS		22.87	NS		0.992	NS	

Note: T_1: lime; T_2: magnesium carbonate + ½ lime T_3: phosphogypsum @ 500 kg ha^{-1} + ½ lime; T_4: lime + potassium silicate 0.25% + 0.25% boron; T_5: magnesium carbonate + ½ lime + potassium silicate 0.25% + 0.25% boron; T_6: phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate 0.25% + 0.25% boron; T_7: control. SEm: Standard error mean; CD: critical difference.

Table 5: Effect of application of amendments and their combinations on concentration of P, Ca and Mg in plant

Treatments	Plant P (%)			Plant Ca (%)			Plant Mg (%)		
	Uma	**Prathyasa**	**Mean**	**Uma**	**Prathyasa**	**Mean**	**Uma**	**Prathyasa**	**Mean**
T_1	0.17	0.14	0.15	1.72	1.69	1.70	0.16	0.15	0.15
T_2	0.13	0.10	0.12	1.48	1.59	1.54	0.35	0.33	0.34
T_3	0.13	0.17	0.15	1.82	1.81	1.82	0.21	0.17	0.19
T_4	0.21	0.12	0.16	1.70	1.72	1.71	0.16	0.16	0.16
T_5	0.12	0.15	0.14	1.48	1.38	1.43	0.31	0.33	0.32
T_6	0.26	0.17	0.22	1.78	1.82	1.80	0.18	0.18	0.18
T_7	0.12	0.11	0.11	1.30	1.31	1.30	0.11	0.11	0.11
Mean	0.16	0.14		1.61	1.62		0.21	0.20	
Comparison	SEm(±)	CD (5%)		SEm(±)	CD (5%)		SEm(±)	CD (5%)	
V	0.002	0.005		0.06	NS		0.006	NS	
T	0.003	0.009		0.12	0.35		0.010	0.05	
V x T	0.005	0.013		0.17	NS		0.015	NS	

Note: T_1: lime; T_2: magnesium carbonate + ½ lime T_3: phosphogypsum @ 500 kg ha^{-1} + ½ lime; T_4: lime + potassium silicate 0.25% + 0.25% boron; T_5: magnesium carbonate + ½ lime + potassium silicate 0.25% + 0.25% boron; T_6: phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate 0.25% + 0.25% boron; T_7: control

Table 6: Effect of application of amendments and their combinations on concentration of Fe and Al in plant

Treatments	Plant Fe (mg kg^{-1})		Mean	Plant Al (mg kg^{-1})		Mean
	V_1	V_2		V_1	V_2	
T_1	159.32	160.52	159.92	284.23	302.33	293.28
T_2	219.25	225.84	222.55	302.05	319.67	310.86
T_3	190.05	192.52	191.28	286.87	319.67	303.27
T_4	165.45	165.72	165.58	295.37	298.00	296.68
T_5	219.65	193.05	206.35	296.37	363.33	329.85
T_6	192.38	219.27	205.83	282.40	300.33	291.37
T_7	363.85	420.18	392.02	366.30	382.33	374.32
Mean	215.71	225.29		301.94	326.52	
Comparison	SE(m)	CD (5%)		SE(m)	CD (5%)	
V	3.47	NS		1.32	3.85	
T	6.49	18.89		2.47	7.21	
V x T	9.18	26.72		3.50	10.20	

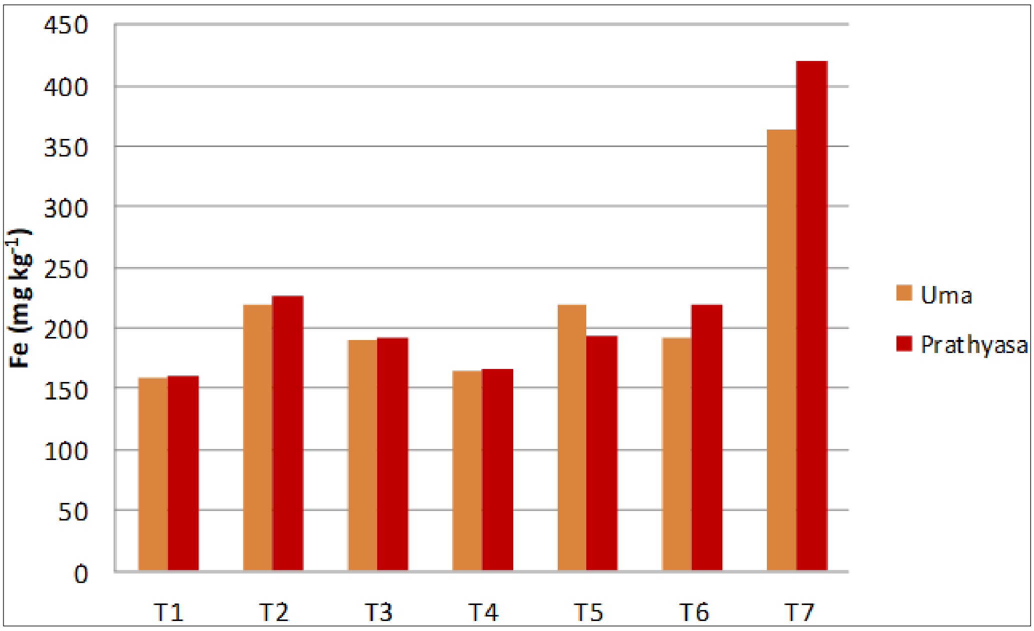

Fig 1: Plant Fe content as influenced by treatments in pot culture experiment

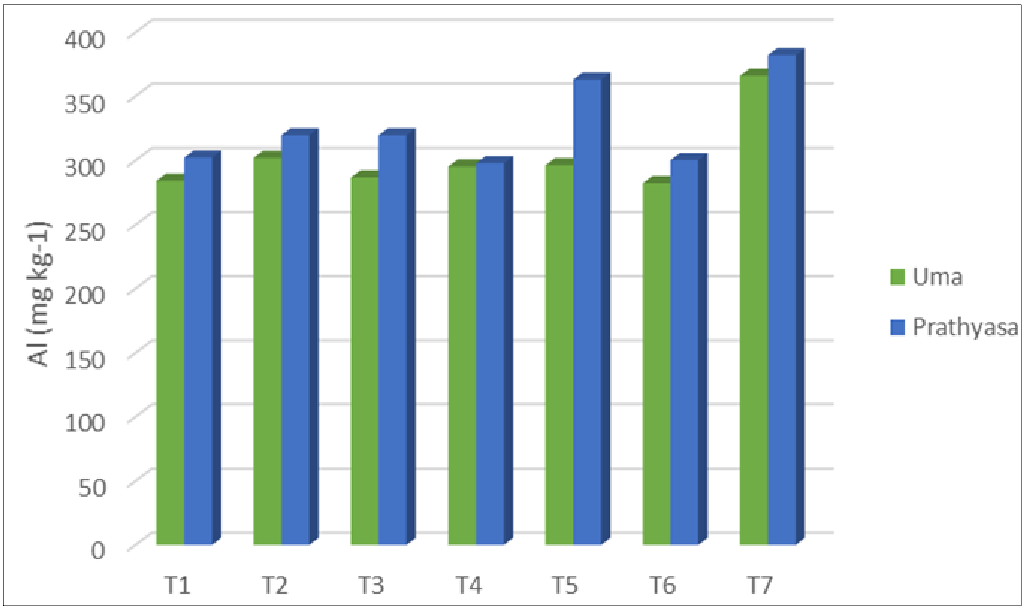

Fig 2: Plant Al content as influenced by treatments in pot culture experiment

Table 7: Correlation of yield, pH, available P, Ca, Fe, Al, plant Ca, Fe and Al in pot culture experiment

	Yield	pH	P	Ca	Fe	Al	Plant Ca	Plant Fe	Plant Al
Yield	1.00								
pH	0.86**	1.00							
P	0.89**	0.83**	1.00						
Ca	0.81**	0.96**	0.89**	1.00					
Fe	-0.90**	-0.71**	-0.90**	-0.68**	1.00				
Al	-0.87**	-0.75**	-0.89**	-0.81**	0.75**	1.00			
Plant Ca	0.89**	0.79**	0.97**	0.82**	-0.92**	-0.89**	1.00		
Plant Fe	-0.84**	-0.96**	-0.77**	-0.92**	0.62*	0.76**	-0.72**	1.00	
Plant Al	-0.28	-0.42	-0.38	-0.39	0.36	0.14	-0.33	0.37	1

** Significant at 1% level of significance; * Significant at 5% level of significance

4. Discussion

The different amendments showed significant effect on number of tillers of the rice plant grown in pot culture. The treatments were significant at 30 DAT, treatment T_4 and T_6 showed more number of tillers. At 60 DAT and at harvest application of phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate (T_6) showed a greater number of tillers. Control showed minimum number of tillers throughout the experiment. This may be due to the action of lime and phosphogypsum in alleviating the Fe, Al toxicity of soil and improving the plant growth and also availability of more Ca and Mg from the treatment application. Similar results were also reported by Chang and Thomas (1963) [9]; Isabelo and Jack., (1993) [16]; Crusciol *et al*., (2016) [10]; Elisa *et al*., (2016) [12].

The grain yield of the plant was found to be significant. Application of lime + foliar spray of 0.25% boron and 0.25% potassium silicate recorded highest grain yield per plant and control showed lowest yield. This may be due to the ameliorating effect of lime on reduced Fe, Al toxicity, increased Ca content and also enhancing the soil conditions for better plant growth. Similar results were also reported by Ponnamperuma and Nhung (1965) [19]; Chang and Thomas (1963) [9]; Isabelo *et al*., (1993) [16]; Elisa *et al*., (2016) [12]; Crusciol *et al*., (2016) [10] The varieties and interaction of treatment and variety was found to be non-significant.

The application of amendments had profound effect on pH of the soil. Application of lime + foliar spray of 0.25% boron and 0.25% potassium silicate showed highest value of pH at the time of harvest. Control showed the lowest value of pH. Lime has the capacity to increase soil pH. Moreover, the calcium present in lime also helps in reducing the soil acidity. Application of lime to the soil surface is the most efficient practice to reduce soil acidity and thereby increase soil pH (Crusciol *et al*., 2016) [10]. Application of lime alone and lime + phosphogypsum also recorded high pH values following lime + foliar spray of 0.25% boron and 0.25% potassium silicate. The effect of lime + phosphogypsum to increase the soil pH is also reported by (Crusciol *et al*., 2016) [10]. There was no significant effect with respect to two different varieties Uma and Prathyasa on soil pH. The interaction effect of treatment and variety also found to be non-significant. This may be because of the action of amendments in soil was uniform which was not affected by the varieties.

The available Ca content in soil was found to be significant with respect to treatment application. Application of phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate in soil significantly increases the available Ca content higher than other treatments. This indicates the capacity of phosphogypsum and lime to increase the Ca content in soil. Sancho *et al.*, (2009) [23]; Crusciol *et al.*, (2016) [10] reported that phosphogypsum and lime increases the Ca concentration of soil and also improves the soil fertility. The varieties and interaction of varieties and treatments were found to be non-significant with respect to available Ca content in soil.

The treatments show significant effect for available Mg content in soil. Application of magnesium carbonate + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate showed highest amount of magnesium in soil. This may be due to the availability of magnesium through the magnesium carbonate which is a good source of magnesium. Delmez *et al.*, (1996) [11] reported that the application of magnesium carbonate will increases the available magnesium content in the soil. There was no significant effect shown by varieties and interaction of varieties and treatments on available Mg content in soil.

The available sulphur content in soil significantly increased with the application of different amendments but it did not show any significance on the effect of varieties and interaction of varieties and treatments. Application of lime + foliar spray of 0.25% boron and 0.25% potassium silicate showed the lowest value of available sulphur. The highest value of available sulphur was showed by control. Since the study was conducted using acid sulphate soil, treatment (T_7) control reported highest sulphur with the absence of ameliorative measures. Haynes and Naidu, (1991) [14] and Astrom *et al.*, 2007 [5] reported that liming decreases the sulphur content of the acid sulphate soils.

There was a significant reduction in iron content in soil caused by the application of different amendments. Minimum iron content was recorded by phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate application. Maximum Fe concentration was recorded by control. Application of amendments as phosphogypsum + ½ lime, lime alone, lime and foliar spray also recorded lower iron content in soil. Application of phosphogypsum reduces Fe content in soil Quintero *et al.* (2014) [20]. Chang and Thomas (1963) [9] also showed that the amount of Fe and Al released into the soil solution decreased with application of gypsum. Ponnamperuma and Nhung (1965) [19] reported that lime ($CaCO_3$) decreases the iron content of the soil. Benckiser *et al*., (1984) [8] suggested that calcium and magnesium plays a crucial role in alleviating iron toxicity in rice. The ameliorating effect of mined gypsum or phosphogypsum is due to the supply of calcium and also due to the enhanced mobility of gypsum (Hoveland, 2000) [5].

Aluminium content in soil was significantly reduced by application of amendments. The lowest Al content was noted with the application of phosphogypsum + ½ lime + foliar

spray of 0.25% boron and 0.25% potassium silicate application. Highest Al concentration in soil was recorded in control treatment. Calcium in phosphogypsum is more soluble and it plays a prominent role in alleviating Al toxicity (Alva and Sumner, 1989) [3]. Similar results were recorded by Ponnamperuma and Nhung (1965) [19]; Chang and Thomas (1963) [9]; Isabelo *et al*., (1993) [16]; Crusciol *et al*., (2016) [10].
The available manganese status in soil varied significantly with the application of treatments. The highest manganese content in soil was recorded in control. The application of phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate recorded lowest concentration of Mn in soil. Similar results were reported by Alcordo and Rechcigl, (1993) [2]; Saha *et al.*, (2008) [22]; Rasouli *et al.*, (2013) [21]; Quintero *et al.*, (2014) [20].
The treatments, varieties and interaction between variety and treatment were found to be significant in case of P content in plants. The highest p content in plant was recorded by phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate and control showed the lowest value of plant phosphorus content. This may be due to the availability of phosphorus from the applied phosphogypsum. Ayadi *et al*., (2015) [7] reported that application of phosphogypsum increased the inorganic phosphorus content and P uptake by plants. The variety Uma showed significantly higher P in plant compared to Prathyasa variety.
Application of amendments showed significant effect in uptake of Ca by the rice plants. The treatment application of phosphogypsum + ½ lime recorded highest Ca content in plants. The treatment with no amendment application, control showed lowest concentration of Ca in plants. This may be due to the high concentration of Ca available from lime and phosphogypsum. Mc-Cray *et al.,* (1991); Mrabet *et al*., (2003) [18]; Astolfi and Zuchi, (2013) [4] also reported similar results.
Amendments application also showed significant effect in content of Mg by the rice plants. The treatment application of magnesium carbonate + ½ lime recorded highest Mg content in plants. The treatment with no amendment application, control showed lowest concentration of Mg in plants. This may be due to the high concentration of Mg available from magnesium carbonate. Mann, (1930) [17] also reported similar results. Varieties and interaction between variety and treatment were non-significant in case of Mg uptake.
The effect of treatments on concentration of iron in plants was found to be significant. The varieties did not show any significance with uptake of iron. There was significant effect by the variety and treatment interaction. The treatment application of lime showed lowest concentration of iron in plants. This may be due to the action of Ca in lime and the increase in pH. Similar results were reported by Mann, (1930) [17]; Ponnamperuma and Nhung (1965) [19]; Tran and Vo (2004) [25]; Saha, *et al.*, (2008) [22] and Azman *et al.*, (2014). Control showed the highest uptake of Fe by plants. The treatments, variety and interaction of treatment and variety showed significance on the concentration of aluminium in plants. Application of phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate showed lowest uptake of Al by plants. Control showed the highest uptake of Al compared to the treatment application. This may be due to the effect of phosphogypsum in alleviating Al toxicity since it decreases acidity in soil and contain soluble Ca which reduces the uptake of Al by plants. Similar results were recorded by (Alva and Sumner,1989) [3]; Isabelo *et al*., (1993) [16]; Mrabet *et al*., (2003) [18]; Crusciol *et al*., (2016) [10]. The variety Prathyasa contained more Al concentration in plant than Uma variety. This may be due to the morphological character of Prathyasa which showed more toxicity symptoms than Uma but will not reflect it on yield parameters.
There was significant correlation between yield, pH, available P, Ca, Fe, Al, plant Ca and Fe. Application of lime (Ca sources) increases the pH and also decreases the Fe and Al concentrations (Crusciol *et al*., 2016) [10]. Ponnamperuma and Nhung (1965) [19] reported that lime ($CaCO_3$) decreases the iron content of the soil. Benckiser *et al*., (1984) [8] suggested that calcium and magnesium plays a crucial role in alleviating iron toxicity in rice.

5. Conclusions
The positive effects of the amendment application and foliar spray of boron and silicon in the reduction of Fe and Al content in soil and plant, increased pH and uptake of nutrients indicate the need of their application to rice grown on acid sulphate soil. The pot study shown that application of phosphogypsum + ½ lime + foliar spray of 0.25% boron and 0.25% potassium silicate significantly improved the available nutrient content of the soil, content and uptake of nutrient by the plant and yield and of rice. It was also effective in reducing the toxicity of Fe, Al and Mn in the soil. This effect can be further evaluated by conducting field study and also can be evaluated on other crops grown in acid sulphate soil. After evaluations, this treatment combination could be used as a formulation to apply for the reclamation of acid sulphate soils all over the world and thereby can increase the rice production.

6. References

1. Abifarin AD. Grain yield loss due to iron toxicity. WARDA (W. Afr. Rice Dev. Assoc.) Tech. Newsl. 1988;8(1):1-2.
2. Alcordo IS, Rechcigl JE. Phosphogypsum in agriculture: A review. Adv. in Agron. 1993;49:55-118.
3. Alva AK, Sumner ME. Alleviation of aluminum toxicity to soybeans by phosphogypsum or calcium sulfate in dilute nutrient solutions. Soil Sci. 1989;147(4):278-285.
4. Astolfi S, Zuchi S, Adequate S. Supply protects barley plants from adverse effects of salinity stress by increasing thiol contents. Acta physiologiae plantarum. 2013;35(1):175-181.
5. Astrom M, Osterholm P, Barlund I, Tattari S. Hydrochemical effects of surface liming, controlled drainage and lime-filter drainage on boreal acid sulfate soils. Water, Air Soil Pollution. 2007;179(1):107-116.
6. Ayadi A, Chorriba A, Fourati A, Gargouri-Bouzid R. Investigation of the effect of phosphogypsum amendment on two Arabidopsis thaliana ecotype growth and development. Environ. Ttechnol. 2015;36(12):1547-1555.
7. Ayadi A, Chorriba A, Fourati A, Gargouri-Bouzid R. Investigation of the effect of phosphogypsum amendment on two Arabidopsis thaliana ecotype growth and development. Environ. Ttechnol. 2015;36(12):1547-1555.
8. Benckiser G, Santiago S, Neue HU, Watanabe I, Ottow JCG. Effect of fertilization on exudation, dehydrogenase activity, iron-reducing populations and Fe^{2+} formation in the rhizosphere of rice (*Oryza sativa* L.) in relation to

iron toxicity. Plant and soil. 1984;79(3):305-316.
9. Chang ML, Thomas GW. A Suggested Mechanism for Sulfate Adsorption by Soils1, 2. Soil Science Society of America Journal. 1963;27(3):281-283.
10. Crusciol CA, Artigiani AC, Arf O, Carmeis Filho AC, Soratto RP, Nascente AS. Soil fertility, plant nutrition, and grain yield of upland rice affected by surface application of lime, silicate, and phosphogypsum in a tropical no-till system. Catena. 2016;137:87-99.
11. Delmez JA, Kelber J, Norword KY, Giles KS, Slatopolsky E. Magnesium carbonate as a phosphorus binder: a prospective, controlled, crossover study. Kidney Int. 1996;49(1):163-167.
12. Elisa AA, Ninomiya S, Shamshuddin J, Roslan I. Alleviating aluminum toxicity in an acid sulfate soil from Peninsular Malaysia by calcium silicate application. Solid Earth. 2016;7(2):367.
13. Fageria NK, Carvalho JRP. Influence of aluminum in nutrient solutions on chemical composition in upland rice cultivars. Plant Soil. 1982;69(1):31-44.
14. Haynes RJ, Naidu R. Effects of Lime additions on the availability of phosphorus and sulphur in some temperate and tropical acid soils. In Plant-Soil Interactions at Low pH. Springer Netherlands. 1991, p. 267-274.
15. Hoveland CS. Achievements in management and utilization of southern grasslands. J Range Manag. 2000, p.17-22.
16. Isabelo SA, Jack ER. Phosphogypsum in agriculture. Adv. Agron. 1993;49:55-118.
17. Mann HB. Availability of manganese and of iron as affected by applications of calcium and magnesium carbonates to the soil. Soil Sci. 1930;30(2):117-142.
18. Mrabet R, Abril JM, Perianez R, Manjon G, Garcia-Tenorio R, Delgado A. Phosphogypsum amendment effect on radionuclide content in drainage water and marsh soils from southwestern Spain. J. Environ. Quality. 2003;32(4):1262-1268.
19. Ponnamperuma FN, Nhung MTM. Effects of calcium carbonate, manganese dioxide, ferric hydroxide, and prolonged flooding on chemical and electrochemical changes and growth of rice in a flooded acid sulfate soil. Soil Science. 1965;102(1):29-41.
20. Quintero JM, Enamorado S, Mas JL, Abril JM, Polvillo O, Delgado A. Phosphogypsum amendments and irrigation with acidulated water affect tomato nutrition in reclaimed marsh soils from SW Spain. Spanish J Agric. Res. 2014;12(3):809-819.
21. Rasouli F, Pouya AK, Karimian N. Wheat yield and physico-chemical properties of a sodic soil from semi-arid area of Iran as affected by applied gypsum. Geoderma, 2013;193:246-255.
22. Saha JK, Adhikari T, Mandal B. Effect of lime and organic matter on distribution of zinc, copper, iron, and manganese in acid soils. Commun. Soil Sci. Plant Analy. 2008;30(13-14):1819-1829.
23. Sancho MI, Espejo R, Peregrina F. Potentially toxic effects of phosphogypsum on palexerults in Western Spain. Soil Sci. Soc. Am. J. 2009;73(1):146-153.
24. Thampatti KCM, Jose AL. Characterisation of acid saline rice-based wetland ecosystem of Kuttanad, Kerala and their salinity protection by Thanneermukkom regulator. Agropedol. 2000;10:108-115.
25. Tran KT, Vo TG. Effects of mixed organic and inorganic fertilizers on rice yield and soil chemistry of the 8th crop on heavy acid sulphate soil (Hydraquentic Sulfaquepts) in the Mekong Delta of Vietnam. 6th Internat. Symp. Plant Soil Low pH. Sendai, Japan. 2004. August 1-5.