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EFFECT OF NUTRIENT MANAGEMENT ON SOIL NUTRIENT AVAILABILITY AT CRITICAL GROWTH STAGES OF RICE IN BLACK SOILS OF KERALA

Danish Tamuly[1] and Betty Bastin[2]

ABSTRACT

A field experiment was carried out during *kharif* 2010 at Chittur, Palakkad district of Kerala located in the Western Ghats. The soil selected for the study had a mean pH value of 6.4 and electrical conductivity of 0.1d Sm^{-1}. The organic carbon content was 0.74%. The status of available N, P and K were 310.5, 5.67 and 154.36 kg ha^{-1} respectively. It was found that, except for available P and B, all other soil nutrients were present either in the medium level or adequate.The field experiment consisted of eleven treatments and three replications each. The treatments consisted of control, farmers practice, soil test based laboratory recommendation, Kerala Agricultural University recommendation, STCR and STCR plus IPNS with or without zinc sulphate. Soil nutrient status at critical growth stages among different treatments revealed highest for available soil N content followed by available K and P. Available Ca was higher than Mg during all the growth stages. Among micronutrients, available Zn reduced while B increased from maximum tillering to harvest. A sharp decline in soil Fe content was observed with the advancement of growth stages. Available Na increased while, Si remained almost uniform throughout the different growth stages.The influence of the excess amounts of basic cations like Ca and Na as well as Fe present in this soil reduced the availability and uptake of major nutrients. The findings revealed through this study will be useful for adopting proper management practices. The productivity of the black soils constrained by the excessive contents of basic cations as well as Fe can be improved by adopting proper drainage as well as integrated nutrient management methods like the application of FYM, crop residues or paddy husk. The improvement in physical condition of the soil as well as the increased supply of Si through incorporation of paddy husk (rich source of Si) needs further investigation.

(Key words: Rice, black soils, major, secondary, micro and beneficial nutrients)

INTRODUCTION

The black soil area is considered as one of the most productive areas for rice cultivation in Kerala. These soils are locally known as Poonthalpadam due to the deep slushy nature of the soil during the major part of the year. Poonthalpadam soil is located in patches in Chittur taluka of Palakkad district. These soils cover an area of approximately 2000 ha (Padmaja *et al.*,1994) in Chittur taluka and is mainly located in the Palakkad gap of Western Ghats. Though the black soil in Kerala is comparatively productive, certain yield limiting factors, especially poor physical condition due to high exchangeable sodium percentage and nutrient imbalance may adversely affect the yield of the crop (Krishnakumar, 1978; George, 1981 and Padmaja *et al.*, 1994). Rice being the staple food of Kerala and Palakkad district being the rice bowl, it becomes imperative to sustain both the production and productivity level of rice to achieve the MDG-1 (Millenium Development Goal 1) of food security. This can be made possible only from a thorough knowledge about the behavior of these black soils during rice cultivation.

MATERIALS AND METHODS

A detailed study was undertaken to evaluate the effect of nutrient management on physico-chemical properties of soil at critical growth stages of medium duration rice variety in black soils of Kerala. For this purpose a farmer's field was selected at Vandithavalam, Chitturtaluk, Palakkad district. Rice crop (*kharif*) was raised during June 2010 to October 2010. This soil showed similarities to the soil order vertisols (Anonymous, 2007). Chittur lies in the eastern side of Palakkad. The field is located at 10^0 38' 03.88" N latitude, 76^0 44' 53.90" E longitude at an elevation of 129 m from the

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1 Asstt Professor (Soil Science), Assam Agricultural University, 785013
(email: danishaau@gmail.com)
2 Professor (Soil Science &Agril Chemistry), Kerala Agricultural University, 680656
(email: bettysusanna@gmail.com)

mean sea level. The soil selected for the study had a mean pH value of 6.4 and electrical conductivity of 0.1d Sm^{-1}. The organic carbon content was 0.74%. The status of available N, P and K were 310.5, 5.67 and 154.36 kg ha^{-1} respectively. It was found that, except for available P and B, all other soil nutrients were present either in the medium level or adequate. The field experiment consisted of eleven treatments and three replications each. The treatments were- Absolute control (T_1- 0:0:0:0 N:P_2O_5:K_2O:Zinc respectively), farmer's practice (T_2 107.50:50.00:112.50:0), recommendation of KAU (Kerala Agricultural University) (KAU, 2010) (T_3-90.00:45.00:45.00:0), Soil Test Laboratory recommendation of Kerala (T_4-87.30:52.65:42.30:0), STCR recommendation (T_5-247.20:135.00:205.00:0), STCR + FYM @ 5 t ha-1 (T_6-234.00:115.26:187.00:0), T_2 + zinc sulphate @ 25 kg ha^{-1} (T_7-107.50:50.00:112.50:9.1), T_3 + zinc sulphate @ 25 kg ha^{-1} (T_8-90.00:45.00:45.00:9.1), T_4 + zinc sulphate @ 25 kg ha^{-1} (T_9-87.30:52.65:42.30:9.1), T_5+ zinc sulphate @ 25 kg ha^{-1} (T_{10}-247.20:135.00:205.00:9.1) and T_6 + zinc sulphate @ 25 kg ha^{-1} (T_{11}-234.00:115.26:187.00:9.1). Farm yard manure was applied in all the plots except control (T_1), STCR (T_5) and STCR along with zinc sulphate (T_{10}). Half of nitrogen, full phosphorus and half of potassium were applied as basal dose. The remaining half of nitrogen and potassium were applied at the active tillering stage of the crop. Zinc sulphate was applied 20 days after transplanting. Sulphur application was done to the plots which did not receive zinc sulphate except control (T_1).The test variety of rice was Uma which is of 125 days duration. Twenty five days old seedlings were transplanted with row spacing of 20 cm and plant spacing of 15 cm at the depth of 2 to 3 cm with2-3 seedlings hill^{-1}. The dates of nursery sowing, transplanting and harvesting of paddy were 1 June, 25 June and 19 October in 2012 respectively.The basic properties of soils were studied before the conduct of the experiment. Soil samples were collected from 0-15 cm depth, processed and analyzed for the physico-chemical properties like single value constants, soil texture (Piper, 1942), pH, EC, CEC (Jackson, 1958), organic carbon (Walkley and Black, 1934), available nutrients, N (Subbiah and Asija, 1956), P (Watanabe and Olsen, 1965), K, Ca, Mg (Jackson, 1958), S (Chesnin and Yien, 1951), Si (Korndorfer *et al.*, 2001), Na (Jackson, 1958) and micronutrients, Zn, Cu, Fe, Mn (Lindsay and Norvell, 1978) and B (Jackson, 1958). Soil samples were collected and analysed at critical growth stages of crop viz., maximum tillering, panicle initiation, flowering and after harvest for the available nutrients, N, P, K, Ca, Mg, S, and micronutrients, Zn, Cu, Fe, Mn, B, Na and Si.Data were subjected to analysis of variance using statistical package 'MSTAT-C' package (Freed, 2006). Whenever the F test was significant (at 5 % level) multiple comparision among the treatments were done with Duncan's Multiple Range test (DMRT). Correlation studies of data were carried out using SPSS package.

RESULTS AND DISCUSSION

Initial soil properties

A perusal of initial physic-chemical properties of black soils of Kerala (Table 1) reveals that the bulk density and particle density (Mg c.c^{-3}) of the soil was 1.31 and 1.98 respectively. The maximum water holding capacity of the soil was 24.330 per cent, the pore space per cent was 34.500. With regards to soil texture, the percentage sand, silt and clay were respectively 10.120, 18.710 and 71.160. The pH of the soil was 6.400. The electrical conductivity (dSm^{-1}) of the soil was 0.100. The cation exchange capacity (CEC) of the soil was found to be 11.38 cmol (p+) kg^{-1}. The organic carbon content of the soil was 0.740 %. Among the major nutrients, the available N (kg ha^{-1}) was found to be 310.500. The available P content (kg ha^{-1}) was 5.670 while, the available K (kg ha^{-1}) was found to be 154.360. Among the secondary nutrients i.e, Ca, Mg and S the values were 1792.010, 484.270 and 32.770 mg kg^{-1}. In the case of micronutrients (mg kg^{-1}), available Fe content was 333.730, followed by Mn 54.390, Cu 5.010, Zn 0.900 and B 0.200. The available Na content of the soil was found to be 108.330 mg kg^{-1} and the Si content was found to be 24.330 mg kg^{-1}.

Available N, P and K in soil

Perusal to data presented in table 2 reveals that the available nitrogen (kg ha^{-1}) at maximum tillering ranged between 372.30 (T_4) and 560.96 (T_1) while at panicle initiation stage the value ranged between 216.41 (T_8) to 290.70 (T_9), at flowering stage 231.48 (T_{10}) to 345.61 (T_5) and at harvest stage the value ranged from 240.62 (T_3) to 335.55 (T_{11}). The available nitrogen was found to be highest at maximum tillering stage and significantly reduced at panicle initiation stage indicating its higher requirement by crop during the vegetative growth stages.Available phosphorus (kg ha^{-1}) at critical growth stages namely maximum tillering stage, panicle initiation stage, flowering stage and harvest stage varied between 20.80 (T_5 and T_7) to 27.60 (T_2), 12.89 (T_6) to 25.78 (T_1), 11.73 (T_2) to 21.54 (T_5) and 23.10 (T_5) to 35.79 (T_8) respectively. Application of FYM and RDF in combination had good impact on nitrogen dynamics related to crop growth among other treatment combinations (Pal *et al.*, 2015). Application of N, half as urea and half as FYM, resulted in higher fertiliser N recovery by rice cv. Pusa Basmati-1 on a sandy loam soil (Sarkar, 2015).The available P content showed an inverted bell curve during the crop growth stages. This means higher availability of P at initial growth stage gradually reducing during panicle initiation and flowering stages and then significantly increasing at harvest stage. This may be attributed to increased mineralization of phosphorus due to higher vegetative growth associated demand which reached an equilibrium at the mid growth stages and consequent higher left over labile phosphorus due to lesser requirement at harvest stage.Singson *et al.* (2013) reported the beneficial role of organic amendment on the availability of phosphorus to rice crop particularly at the later stage of growth. Available potassium ranged from 67.20 (T_7) to 141.86 (T_{11}) kg ha^{-1}at maximum tillering stage, 63.46 (T_8) to 149.33 (T_{11}) kg ha^{-1}at panicle initiation stage, 89.60 (T_1) to 168.00 (T_5) kg ha^{-1} at flowering stage and 78.40 (T_1) to 141.86 (T_{10}) kg ha^{-1}at harvest stage. Effect of zinc sulphate application on K availability was not apparent from the treatments without zinc sulphate. However, treatments with FYM application showed higher available K than without FYM. This established the facts of better microbial activities in FYM treated soil (Stevenson, 1994). The treatments receiving fertilizer doses based on soil test based crop response were found to invariably contain higher available potassium. This might be due to higher application of potassium fertilizer in STCR treated plots.

Available Ca, Mg and S in soil

Among the secondary nutrients (Table 3) at maximum tillering stage, higher values were obtained for Ca followed by Mg and S in soil. The available Ca (mg kg^{-1}) was found to be lowest in T_3, KAU (543.33) and highest in T_8, KAU+$ZnSO_4$ (772.50). The treatments T_1, control (647.50), T_2, FP (638.33), T_4, STL (673.33), T_5, STCR (Soil Test Crop Response) (Ramamoorthy *et al.*, 1967) (639.58), T_6, STCR+FYM (697.50), T_8, KAU+$ZnSO_4$ (772.50) T_{10}, STCR+$ZnSO_4$ (670.83) and T_{11}, STCR+$ZnSO_4$+FYM (635.41) were found at par. At panicle initiation stage, available Ca (mg kg^{-1}) content ranged between 713.73 (T_3, KAU) to 1082.75 (T_6, STCR+FYM). The treatments differed significantly. Among the treatments, T_1, control (992.48), T_2, FP (858.30), T_4, STL (841.28), T_5, STCR (840.13), T_6, STCR+FYM (1082.75), T_8, KAU+$ZnSO_4$ (791.15), T_9, STL+$ZnSO_4$ (766.10), T_{10}, STCR+$ZnSO_4$ (766.75) and T_{11}, STCR+$ZnSO_4$+FYM (748.91) were found on par. The available Mg content (mg kg^{-1}) was highest in T_6, STCR+FYM (665.57) and lowest in T_9, STL+ $ZnSO_4$ (413.64). The available Mg content (mg kg^{-1}) ranged between 400.26 (T_9, STL+$ZnSO_4$) to 442.34 (T_7, FP+$ZnSO_4$). There was significant difference among the treatments. The available S content (mg kg^{-1}) was lowest in T_{10}, STCR+$ZnSO_4$ (46.39) and highest in T_{11}, STCR+$ZnSO_4$+FYM (84.99). There was significant difference between the treatments. The treatments T_3, KAU (79.83), T_4, STL (76.17), T_5, STCR (70.80), T_6, STCR+FYM (61.63), T_7, FP+$ZnSO_4$ (80.89), T_9, STL+ $ZnSO_4$ (71.99) and T_{11}, STCR+$ZnSO_4$+FYM (84.99) were found on par. At harvest stage, available Ca (mg kg^{-1}) ranged between 875.15 (T_{11}, STCR+$ZnSO_4$+FYM) to 1211.16 (T_1, control). All the treatments except T_{11} (STCR+$ZnSO_4$+FYM) were found on par. The content of available Ca was the highest both among secondary nutrients as well as basic cations. The values for the available cations generally decreased in the order Ca>Mg>K>Na. The content of Ca in the soil gradually increased from maximum tillering stage to flowering stage and thereafter it decreased towards the harvest irrespective of the treatments. The increase may be due to the low uptake during the initial growth phases along with the release from the native soil deposits,and the decrease in the availability after flowering upto harvest may be due to the uptake at the reproductive or the maturity phase of the crop. The content of Mg remained almost steady throughout the critical growth stages upto flowering and thereafter there was a decrease for all the treatments. The requirement of Mg by the crop from the flowering to harvest might have resulted in the decrease in the soil content between flowering to harvest stages.

Available micronutrient content in soil

Among micronutrients (Table 4) at maximum tillering stage, highest value was obtained for Fe followed by Mn, Zn, and Cu in the soil. Considering the critical limits of Zn (0.65 mg kg^{-1}), Cu (0.2 mg kg^{-1}), Fe (4.5 mg kg^{-1}) and Mn (1 mg kg^{-1}), all the treatments were under sufficiency range except control. The available Fe content (mg kg^{-1}) ranged between 619.24 (T_6, STCR+FYM) to 866.58 (T_2, FP). All the treatments were on par except treatment T_6 (STCR+FYM). The available Zn content (mg kg^{-1}) ranged between 4.94 (T_1, control) to 10.06 (T_9, STL+$ZnSO_4$). There was significant difference among the treatments. The treatments T_4, STL (6.76), T_7, FP+$ZnSO_4$ (8.96), T_8, KAU+$ZnSO_4$ (7.47), T_{10}, STCR+$ZnSO_4$ (9.81) and T_{11}, STCR+$ZnSO_4$+FYM (7.00) were found at par with each other. The available Cu content (mg kg^{-1}) ranged from 4.38 (T_6, STCR+FYM) to 6.38 (T_{10}, STCR+$ZnSO_4$). All the treatments were on par except treatment T_6(STCR+FYM, 4.38). At panicle initiation stage, the lowest and highest available Fe content (mg kg^{-1}) was found in treatment T_6, (STCR+FYM, 124.98) and T_7, FP+ZnSO4 (599.55) respectively. The available Mn content (mg kg^{-1}) ranged between 29.59 (T_6, STCR+FYM) to 102.53 (T_5, STCR). The treatments T_1, control (68.29), T_2, FP (79.05), T_4, STL (57.94), T_5, STCR (102.53), T_7, FP+$ZnSO_4$ (101.78), T_8, KAU+$ZnSO_4$ (79.76), T_9, STL+$ZnSO_4$ (60.77) and T_{11},STCR+$ZnSO_4$+FYM (79.10) were found at par. The available Cu content (mg kg^{-1}) was lowest in treatment T_6, STCR+FYM (2.97) and highest in treatment T_7, FP+$ZnSO_4$ (5.20). At flowering stage, the available Fe content (mg kg^{-1}) was found to be lowest in treatment T_8(KAU+$ZnSO_4$, 90.65) and highest in treatment T_7(F.P+$ZnSO_4$, 317.72). All the treatments were on par except T_3 (KAU) and T_8 (KAU+$ZnSO_4$). The available Mn content (mg kg^{-1}) was lowest in T_8, KAU+$ZnSO_4$ (26.00) and highest in T_7, FP+ $ZnSO_4$ (88.41). The treatments T_1, control (64.15), T_2, FP (71.71), T_5, STCR (48.11), T_6, STCR+FYM (77.40), T_7, FP+$ZnSO_4$(88.41), T_9, STL+ $ZnSO_4$ (48.78), T_{10}, STCR+$ZnSO_4$ (49.60) and T_{11}, STCR+$ZnSO_4$+FYM (58.89) were found at par.The available Zn content (mg kg^{-1}) varied from 3.42 (T_2, FP) to 5.54 (T_9, STL+$ZnSO_4$). There was significant difference among the treatments. The treatments T_3, KAU (3.81), T_4, STL (3.97), T_6, STCR+ $ZnSO_4$ (4.14), T_7, FP+$ZnSO_4$ (4.66), T_8, KAU+$ZnSO_4$ (4.33), T_9, STL+ $ZnSO_4$ (5.54), and T_{10}, STCR+$ZnSO_4$ (4.76) were found at par. The available Cu content (mg kg^{-1}) ranged from 3.25 (T_1, control) to 4.84 (T_8, KAU+$ZnSO_4$). All the treatments were on par except T_1, control.The available Zn content (mg kg^{-1}) ranged between 1.96 (T_5, STCR) and 5.62 (T_{11}, STCR+$ZnSO_4$+FYM) respectively. The treatments T_1, control (3.36), T_2, FP (3.23), T_3, KAU+FYM (4.02), T_6, STCR+FYM (3.60), T_7, FP+$ZnSO_4$ (4.20), T_9, STL+ $ZnSO_4$ (4.21), T_{10}, STCR+$ZnSO_4$ (3.77) and

Table 1. Initial physic- chemical properties of black soil of Kerala

Sr. no.	Properties	Values
1	Bulk density (Mg c.c^{-3})	1.310
2	Particle density (Mg c.c^{-3})	1.980
3	Maximum water holding capacity (%)	24.33
4	Pore space (%)	34.50
5	Volume expansion (%)	9.240
6	Clay (%)	10.12
7	Silt (%)	18.71
8	Sand (%)	71.16
9	pH	6.400
10	EC (dSm^{-1})	0.100
11	CEC [cmol (p^{+})kg^{-1}	11.38
12	Organic carbon (%)	0.740
	Available nutrients	
13	Nitrogen (kg ha^{-1})	310.5
14	Phosphorous (kg ha^{-1})	5.670
15	Potassium (kg ha^{-1})	154.4
16	Sodium (mg kg^{-1})	108.3
17	Calcium (mg kg^{-1})	1792
18	Magnesium (mg kg^{-1})	484.2
19	Sulphur (mg kg^{-1})	32.77
20	Silicon (mg kg^{-1})	24.33
21	Zinc (mg kg^{-1})	0.900
22	Copper (mg kg^{-1})	5.010
23	Iron (mg kg^{-1})	333.7
24	Manganese (mg kg^{-1})	54.39
25	Boron (mg kg^{-1})	0.200

Table 2: Effect of treatments on available N, P and K content at different growth stages of rice

Treatments	Maximum Tillering (kg ha^{-1})			Panicle intiation (kg ha^{-1})			Flowering (kg ha^{-1})			H (k	
	N	P	K	N	P	K	N	P	K	N	P
T_1 control	560.96^{a}	22.80^{a}	82.13^{abc}	257.33^{ab}	25.78^{a}	102.66^{abc}	279.94^{ab}	16.00^{a}	89.60^{d}	286.40^{ab}	27.18^{ab}
T_2 -Farmer's practice	449.57^{a}	27.60^{a}	89.60^{abc}	237.94^{ab}	20.95^{ab}	100.80^{abc}	241.17^{ab}	11.73^{a}	97.06^{cd}	290.70^{ab}	33.98^{ab}
T_3- KAU	423.48^{a}	21.20^{a}	74.66^{bc}	272.40^{ab}	18.80^{abc}	82.13^{bc}	265.94^{ab}	17.06^{a}	112.00^{bcd}	240.62^{b}	28.09^{ab}
T_4-STL	372.30^{a}	24.40^{a}	89.60^{abc}	258.40^{ab}	19.33^{abc}	65.33^{c}	296.09^{ab}	16.64^{a}	93.33^{d}	297.92^{ab}	30.81^{ab}
T_5- STCR	447.57^{a}	20.80^{a}	74.66^{bc}	230.41^{b}	13.96^{bc}	87.73^{abc}	345.61^{a}	21.54^{a}	168.00^{a}	295.82^{ab}	23.10^{b}
T_6- STCR+FYM	488.71^{a}	22.80^{a}	134.40^{ab}	234.71^{ab}	12.89^{c}	112.00^{abc}	244.40^{ab}	13.86^{a}	138.13^{ab}	295.82^{ab}	30.35^{ab}
T_7- F.P + $ZnSO_4$	451.58^{a}	20.80^{a}	67.20^{c}	222.87^{b}	17.72^{bc}	80.26^{bc}	248.71^{ab}	18.34^{a}	97.06^{cd}	308.37^{ab}	28.09^{ab}
T_8- KAU+ $ZnSO_4$	530.86^{a}	26.40^{a}	82.13^{abc}	216.41^{b}	15.04^{bc}	63.46^{c}	260.56^{ab}	16.21^{a}	100.80^{bcd}	319.87^{a}	35.79^{a}
T_9- STL+ $ZnSO_4$	430.51^{a}	24.00^{a}	82.13^{abc}	290.70^{a}	18.26^{abc}	87.73^{abc}	265.94^{ab}	20.05^{a}	104.53^{bcd}	301.05^{ab}	30.35^{ab}
T_{10}- STCR+ $ZnSO_4$	485.70^{a}	24.60^{a}	89.60^{abc}	265.94^{ab}	17.72^{bc}	138.13^{ab}	231.48^{a}	19.20^{a}	134.40^{abc}	306.28^{ab}	29.45^{ab}
T_{11}-STCR+ $ZnSO_4$+FYM	556.95^{a}	26.00^{a}	141.86^{a}	245.48^{ab}	20.95^{ab}	149.33^{a}	258.40^{ab}	20.26^{a}	134.40^{abc}	335.55^{a}	24.01^{b}
SE(m)±	17.79	0.84	19.45	16.71	2.29	19.12	31.34	1.01	11.56	19.87	3.16
CD (0.05)	-	-	57.97	49.79	6.83	56.98	93.4	-	34.46	59.23	9.41

Table 3: Effect of treatments on available Ca, Mg and S content at different growth stages of rice

Treatments	Maximum Tillering (mg kg^{-1})			Panicle intiation (mg kg^{-1})			Flowering (mgkg^{-1})			Har (mgk	
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S	Ca	Mg
T_1 control	647.50^{ab}	430.02^{a}	69.15^{a}	992.48^{ab}	446.70^{b}	80.28^{a}	2248.33^{a}	420.64^{a}	56.66^{bc}	1211.16^{a}	166.75
T_2 -Farmer's practice	638.33^{ab}	409.03^{a}	73.75^{a}	858.30^{ab}	442.14^{b}	78.02^{a}	2333.33^{a}	438.45^{a}	52.87^{bc}	1110.83^{ab}	157.12
T_3- KAU	543.33^{b}	402.72^{a}	66.06^{a}	713.73^{b}	427.42^{b}	79.52^{a}	1786.66^{a}	414.53^{a}	79.83^{ab}	1045.35^{ab}	157.93
T_4-STL	673.33^{ab}	406.19^{a}	76.81^{a}	841.28^{ab}	418.59^{b}	70.53^{a}	2115.00^{a}	432.02^{a}	76.17^{ab}	1170.35^{ab}	165.90
T_5- STCR	639.58^{ab}	385.61^{a}	76.72^{a}	840.13^{ab}	459.54^{b}	78.65^{a}	2131.66^{a}	441.49^{a}	70.80^{abc}	1149.58^{ab}	160.21
T_6- STCR+FYM	697.50^{ab}	389.58^{a}	83.50^{a}	1082.75^{a}	665.57^{a}	81.28^{a}	1510.00^{a}	430.47^{a}	61.63^{abc}	1135.21^{ab}	165.42
T_7- F.P + $ZnSO_4$	592.08^{b}	454.16^{a}	77.14^{a}	729.00^{b}	429.74^{b}	80.28^{a}	1966.66^{a}	442.34^{a}	80.89^{ab}	1153.08^{ab}	157.19
T_8- KAU+ $ZnSO_4$	772.50^{a}	402.50^{a}	71.91^{a}	791.15^{ab}	469.12^{b}	87.43^{a}	1730.00^{a}	429.83^{a}	55.55^{bc}	1193.70^{a}	169.89
T_9- STL+ $ZnSO_4$	602.08^{b}	409.70^{a}	68.05^{a}	766.10^{ab}	413.64^{b}	81.20^{a}	1546.66^{a}	400.26^{a}	71.99^{abc}	1022.61^{ab}	153.87
T_{10}- STCR+ $ZnSO_4$	670.83^{ab}	421.54^{a}	70.43^{a}	766.75^{ab}	441.40^{b}	100.72^{a}	2055.00^{a}	406.88^{a}	46.39^{c}	1087.53^{ab}	170.39
T_{11}-STCR+ $ZnSO_4$+FYM	635.41^{ab}	417.75^{a}	65.04^{a}	748.91^{ab}	448.14^{b}	88.39^{a}	1913.33^{a}	417.29^{a}	84.99^{a}	875.15^{b}	178.83
SE(m)±	47.28	14.12	4.7	101.34	60.54	6.86	225.56	16.63	6.89	86.85	5.75
CD (0.05)	140.90	-	-	302.00	180.40	-	-	-	24.62	258.80	-

Table 4. Effect of treatments on available Fe, Mn, Zn and Cu content at different growth stages of rice

Treatments	Maximum Tillering (mg kg^{-1})				Panicle intiation (mgkg^{-1})				Flowering (mg kg^{-1})					
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu	Fe	Mn
T_1 control	765.10^{ab}	108.40^{a}	4.94^{c}	5.11^{ab}	457.90^{a}	68.29^{ab}	4.10^{a}	4.18^{a}	237.56^{ab}	64.15^{ab}	3.54^{b}	3.25^{b}	111.82^{a}	21.62^{a}
T_2 -Farmer's practice	866.58^{a}	121.40^{a}	5.76^{bc}	6.05^{ab}	450.66^{a}	79.05^{ab}	3.65^{a}	3.41^{a}	247.10^{ab}	71.71^{ab}	3.42^{b}	3.94^{ab}	124.49^{a}	23.83^{a}
T_3- KAU	830.04^{a}	105.55^{a}	5.46^{c}	5.66^{ab}	143.12^{a}	30.49^{b}	3.65^{a}	3.45^{a}	92.45^{b}	29.70^{b}	3.81^{ab}	4.42^{ab}	74.70^{a}	21.12^{a}
T_4-STL	863.95^{a}	118.06^{a}	6.76^{abc}	6.00^{ab}	346.37^{a}	57.94^{ab}	4.30^{a}	4.37^{a}	99.00^{b}	35.65^{b}	3.97^{ab}	4.73^{ab}	126.95^{a}	20.90^{a}
T_5- STCR	770.50^{ab}	92.95^{a}	5.23^{c}	5.01^{ab}	506.02^{a}	102.53^{a}	4.97^{a}	4.39^{a}	151.46^{ab}	48.11^{ab}	3.56^{b}	4.44^{ab}	151.28^{a}	20.88^{a}
T_6- STCR+FYM	619.24^{b}	97.73^{a}	5.58^{bc}	4.38^{b}	124.98^{a}	29.59^{b}	3.58^{a}	2.97^{a}	231.30^{ab}	77.40^{ab}	4.14^{ab}	3.90^{ab}	79.72^{a}	20.85^{a}
T_7- F.P + $ZnSO_4$	944.70^{a}	110.04^{a}	8.96^{abc}	6.15^{ab}	599.55^{a}	101.78^{a}	6.42^{a}	5.20^{a}	317.72^{a}	88.41^{a}	4.66^{ab}	3.41^{ab}	120.56^{a}	24.35^{a}
T_8- KAU+ $ZnSO_4$	855.70^{a}	110.55^{a}	7.47^{abc}	6.15^{ab}	417.05^{a}	79.76^{ab}	5.33^{a}	4.13^{a}	90.65^{b}	26.00^{b}	4.33^{ab}	4.84^{a}	122.05^{a}	15.56^{a}
T_9- STL+ $ZnSO_4$	824.53^{a}	111.74^{a}	10.06^{a}	6.20^{ab}	395.38^{a}	60.77^{a}	6.18^{a}	4.52^{a}	180.45^{ab}	48.78^{ab}	5.54^{a}	4.20^{ab}	149.75^{a}	19.59^{a}
T_{10}- STCR+ $ZnSO_4$	796.31^{ab}	125.05^{a}	9.81^{ab}	6.38^{a}	134.23^{a}	34.70^{b}	4.30^{a}	4.12^{a}	170.35^{ab}	49.60^{ab}	4.76^{ab}	3.42^{ab}	113.40^{a}	21.50^{a}
T_{11}-STCR+ $ZnSO_4$+FYM	771.83^{ab}	124.02^{a}	7.00^{abc}	5.50^{ab}	292.46^{a}	79.10^{ab}	4.46^{a}	3.44^{a}	214.46^{ab}	58.89^{ab}	3.43^{b}	3.90^{ab}	82.97^{a}	21.70^{a}
SE(m)±	57.61	9.13	0.35	0.56	107.06	16.23	0.6	0.49	57.71	15.07	0.55	0.44	17.12	1.86
CD (0.05)	171.7	-	3.75	1.67	-	48.37	-	-	172.6	44.92	1.65	1.33	-	-

Table 5. Effect of treatments on available B, Na and Si content at different growth stages of rice

Treatments	Maximum Tillering (mg kg^{-1})			Panicle intiation (mg kg^{-1})			Flowering (mg kg^{-1})			Harvest (mg kg^{-1})		
	B	Na	Si	B	Na	Si	B	Na	Si	B	Na	Si
T_1 control	0.44^{a}	46.66^{a}	18.15^{b}	0.19^{ab}	65.83^{abc}	11.75^{b}	0.53^{a}	68.33^{a}	21.87^{ab}	1.66^{a}	76.66^{abc}	13.83^{c}
T_2 -Farmer's practice	0.30^{a}	46.66^{a}	26.78^{b}	0.11^{b}	56.66^{abcd}	23.51^{ab}	0.49^{a}	76.66^{a}	39.58^{ab}	1.45^{a}	80.00^{ab}	17.56^{abc}
T_3- KAU	0.20^{a}	36.66^{a}	20.98^{b}	0.15^{ab}	50.00^{bcd}	41.81^{a}	1.02^{a}	66.66^{a}	26.93^{ab}	1.51^{a}	63.33^{c}	20.38^{abc}
T_4-STL	0.14^{a}	36.66^{a}	18.60^{b}	0.09^{b}	45.83^{d}	20.23^{b}	0.33^{a}	70.00^{a}	28.27^{ab}	1.35^{a}	70.00^{abc}	16.96^{abc}
T_5- STCR	0.32^{a}	40.00^{a}	24.10^{b}	0.18^{ab}	56.66^{abcd}	39.88^{a}	0.45^{a}	73.33^{a}	19.49^{ab}	0.93^{a}	71.66^{abc}	20.23^{abc}
T_6- STCR+FYM	0.17^{a}	46.66^{a}	27.08^{b}	0.10^{b}	66.66^{ab}	23.36^{ab}	0.11^{a}	75.00^{a}	15.62^{b}	1.53^{a}	83.33^{a}	18.60^{abc}
T_7- F.P + $ZnSO_4$	0.38^{a}	50.00^{a}	19.19^{b}	0.08^{b}	55.00^{abcd}	15.17^{b}	0.63^{a}	78.33^{a}	23.95^{ab}	1.24^{a}	78.33^{abc}	29.91^{a}
T_8- KAU+ $ZnSO_4$	0.36^{a}	43.33^{a}	47.91^{a}	0.16^{ab}	71.66^{a}	20.23^{b}	1.14^{a}	81.66^{a}	20.53^{ab}	1.14^{a}	81.66^{ab}	22.91^{abc}
T_9- STL+ $ZnSO_4$	0.21^{a}	36.66^{a}	31.69^{b}	0.28^{a}	53.33^{bcd}	26.04^{ab}	0.68^{a}	66.66^{a}	20.08^{ab}	1.52^{a}	73.33^{abc}	15.77^{bc}
T_{10}- STCR+ $ZnSO_4$	0.63^{a}	43.33^{a}	24.25^{b}	0.11^{b}	48.33^{cd}	18.45^{b}	0.41^{a}	80.00^{a}	45.68^{a}	1.46^{a}	76.66^{abc}	27.67^{ab}
T_{11}-STCR+ $ZnSO_4$+FYM	0.22^{a}	33.33^{a}	47.02^{a}	0.11^{b}	49.16^{bcd}	26.93^{ab}	0.73^{a}	70.00^{a}	30.35^{ab}	0.84^{a}	66.66^{bc}	15.47^{bc}
SE(m)±	0.09	3.44	7.2	0.03	5.17	5.77	0.22	3.47	7.78	0.2	4.48	3.92
CD (0.05)	-	-	14.83	0.12	15.41	17.22	-	-	23.19	-	13.36	11.69

T_{11}, STCR+$ZnSO_4$+FYM (5.62) remained at par. The available Cu content (mg kg^{-1}) was lowest in T_3, KAU (3.27) and highest in T_{11}, STCR+FYM+ $ZnSO_4$ (4.26). All the treatments except T_3 (KAU+FYM) were found on par.The content of Fe was found to be in the toxic range throughout the crop growth. The available soil content decreased in the order Fe>Mn> B. The contents of Zn and Cu remained in between Mn and B and occasionally they varied without any uniformity. The available Fe content was found to continuously decrease with the advancement of growth of the crop until harvest. During maximum tillering stage, the available Fe content was above the toxic level (619.24 to 944.70 mg kg^{-1}). Such a high content of Fe at critical stages may lead to reduction in growth and yield of crop (Mongon, *et al.*, 2014). The same trend was observed at panicle initiation stage except for treatments T_3 (KAU), T_6 (STCR+FYM) and T_{10} (STCR+$ZnSO_4$). It was found that, those treatments in which zinc was applied showed higher content compared to those in which zinc was not applied. Irrespective of the treatments, the zinc level of the soil remained above the critical level (0.6 mg kg^{-1}). At maximum tillering stage (Table 5), available B content (mg kg^{-1}) ranged between 0.14 (T_4, STL) to 0.63 (T_{10}, STCR+$ZnSO_4$).

Available beneficial element in soil

A perusal to table 5 reveals that the available Si content (mg kg^{-1}) was lowest in control and it ranged between 40.66 (T_1, control) to 107.33 (T_8). The difference may be attributed to treatments receiving FYM application. Treatments T_5, STCR (77.66), T_8, KAU+$ZnSO_4$+FYM (107.33), T_9, STL+$ZnSO_4$+FYM (71.00) and T_{11}, STCR+$ZnSO_4$+FYM (105.33) were found on par. At panicle initiation stage, available B content (mg kg^{-1}) ranged from 0.08 (T_7, FP+ZnSO4) to 0.28 (T_9, STL+$ZnSO_4$). Treatments T_1, control (0.19), T_3, KAU (0.15), T_5, STCR (0.18) T_8, KAU+$ZnSO_4$ (0.16) and T_9, STL+ $ZnSO_4$ (0.28) were found on par. Regarding the available Si content (mg kg^{-1}), the range was between 11.75 (T_1, control) and 41.81 (T_3, KAU). Significant difference was observed among the treatments. The treatments T_2, FP (23.51), T_3, KAU (41.81), T_5, STCR (39.88), T_6, STCR+FYM (23.36), T_9, STL+ $ZnSO_4$ (26.04) and T_{11}, STCR+$ZnSO_4$+FYM (26.93) were found on par. The available Na content (mg kg^{-1}) ranged between 45.83 (T_4, STL) and 71.66 (T_8, KAU+$ZnSO_4$). The treatments T_1, control (65.83), T_2, FP (56.66), T_5, STCR (56.66) T_6, STCR+FYM (66.66), T_7, FP+ $ZnSO_4$ (55.00) and T_8, KAU+$ZnSO_4$ (71.66) were found on par. The available Na (mg kg^{-1}) content was found to be lowest in T_3, KAU and T_9, STL+ $ZnSO_4$ (66.66) while it was highest in T_8, KAU+$ZnSO_4$ (81.66). The treatment did not differ significantly. The available Si content (mg kg^{-1}) ranged from 15.62 (T_6, STCR+FYM) and 45.68 (T_{10}, STCR+$ZnSO_4$). All the treatments were on par except T_6 (STCR+FYM). The available Na content (mg kg^{-1}) ranged between 63.33 (T_3, KAU) and 83.33 (T_6, STCR+FYM). All the treatments were on par except T_3, KAU (63.33) and T_{11}, STCR+$ZnSO_4$+FYM (66.66). The available Si content (mg kg^{-1}) ranged between 13.83 (T_1, control) and 29.91 (T_7, FP+$ZnSO_4$). The treatments T_2, FP (17.56), T_3, KAU (20.38), T_4, STL (16.96), T_5, STCR (20.23), T_6, STCR+FYM (18.60), T_7, FP+$ZnSO_4$ (29.91), T_8, KAU+$ZnSO_4$ (22.91) and T_{10}, STCR+$ZnSO_4$ (27.67) remained at par. Ponnamperuma (1964) reported that organic acids resulting from decomposition of organic matter had little role in the solubility of Si.

The influence of the excess amounts of basic cations like Ca and Na as well as Fe present in this soil reduced the availability and uptake of major nutrients. The findings revealed through this study will be useful for adopting proper management practices. The productivity of the black soils constrained by the excessive contents of basic cations as well as Fe can be improved by adopting proper drainage as well as integrated nutrient management methods like the application of FYM, crop residues or paddy husk. The improvement in physical condition of the soil as well as the increased supply of Si through incorporation of paddy husk (rich source of Si) has to be explored.

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