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SOIL SCIENCE

Effects of liming, soil moisture regimes and application of sulphur and some micronutrients on soil plant availability of nutrients and yield of rice (*Oriza Sativa* L) in acid laterite soil

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Abstract

The productivity of wetland rice is constrained by the reduced availability of S and micronutrients like B, Cu, and Zn in acid laterite soils of West Bengal, India. A greenhouse study was conducted using acid laterite (Ultisol, Salboni loam) to evaluate the effects of liming, soil moisture regime and application of sulfur, boron, copper and zinc on the availability of applied nutrients, growth and yield of rice. The effects of application of lime (2.0 t/ha) over no lime; alternate flooding and drying (AFD) over continuous flooding (CF) and moisture regime maintained at field capacity (FC); and nutrients viz., S, B, Cu and Zn on growth and yield of rice were assessed. Rice cv. IR 36 was grown with NPK applied @ 60 mg N, 30 mg P_2O_5 and 30 mg K_2O/kg soil. S, B, Cu, and Zn were applied @ 10, 0.5, 1.5 and 5 mg/kg of soil, respectively. Application of 22.4 kg S, 1.12 kg B, 3.36 kg Cu, and 11.2 kg Zn/ha significantly enhanced the growth and yield of rice over control in acid laterite soil. Yield response of rice to the application of S, B, Cu and Zn was further improved by liming and alternate flooding and drying during the growing season.

Highlights

- Effect of liming on soil pH in acid laterite soil for favourable growth and yield of rice plant.
- Effect of soil moisture regimes like field capacity, flooding and alternate flooding and drying on availability of sulphur and micro nutrients in rice growing acid laterite soil.
- Effect of application of sulphur and micro nutrients (B, Cu, Zn) and its availability in soil and plant system in acid laterite soil for growth and yield of rice plant.

Keywords: Acid soil, liming, soil moisture, sulphur, micronutrients, rice.

Rice is the most important food for more than 50 percent of the world population and it is cultivated on almost 155 million hectares of the world land area. World rice production in 2008 was approximately 661 million tons and about 90 percent produce in Asia (Knabner *et al.* 2010).

The productivity of rice in India is oscillating around 2 tons per hectare (Mishra 2004) when the average productivity of the world is 3-4 tons per hectare (Genon *et al.* 1994) and the estimated yield potential of the crop is 15 tons per hectare (Smil 2005). There is a large variation among national average yield with a factor of 5 to 6 tons per hectare among industrialized and developing countries (*Bruinsena 2003*). In submerged acid soils, the reduced availability or deficiency of S and micronutrients has often been made up by their soil application at appropriate rates to boost the production of rice (Suresh 1996). In majority of Indian soils, application of Zn at the rate of 11kg Zn per hectare has been found to be adequate for rice (Takkar *et al.* 1989). The deficiency of Cu in some Indian soils has been successfully corrected for rice crop by its soil application at an optimal rate of 12.5kg Cu per hectare. In B deficient soils of eastern and northern India, spectacular responses of cereals including rice have been obtained by the soil application of B at the rate of 0.5-2.5kg/ha (Sakal and Singh 1995).

Management of Sulfur nutrition of rice varies depending whether the soil is submerged throughout the crop cycle as in paddy cultivation, aerated in the root zone as in upland production system or intermittently flooded as in rainfed low land, aerobic and water deficit irrigation production system. Moreover the slower mineralization of organically bound sulfur decreases the availability of sulfur to rice in submerged soils. Hence, sulfur deficiency has increase in prevalence in wet land rice under changing (Bell and Dell 2008). Increase in pH of acid soils due to consumption of protons. Soil solution reaction is neutral at the beginning of rice cropping season, and becomes alkaline at the end, but return to neutral at the beginning of the next cropping season (Kirk 2004). Sulphur deficiency has emerged as an important factor-affecting yield and grain quality of rice. In perennial S deficient soils of India, soil application of S at the rate of 20-40 kg/ha through S containing fertilizers has been found to be highly economical for rice (Tandon 1991).

Al toxicity is considered as one of the primary cause of low rice productivity in acid soils. Al is the most abandoned component in the cultivated soil and can be found in the different forms depending on the pH of the soil solution. At a soil pH lower than 5.0 Al is ionised and become toxic for plants (Xue *et al.* 2006). Periodic lime addition is recommended for naturally acid agricultural soil as soil pH affect nutrient availability and toxicity of element such as Al (Dietzel *et al.* 2009). In two acid sandy soils of Thailand (pH H_2O 4.0 and 4.5) positive response of rice yield to lime in continuously flooded soil was observed by (Khunthasuvon *et al.* 1997). Exchangeable Al in this soil was significantly decreased by flooding or liming (Seng *et al.* 2004). The lack of knowledge regarding availability of Boron, Copper, Zink due to elevated Al level at field capacity and submersed conditions.

Savithri *et al.* 1999 advocated the use of soil amendments like liming, supply of additional micronutrients and drainage for correcting the micronutrient deficiency syndrome. In order to increase the availability of micronutrients to rice, one could try to manipulate some of the factors that affect the availability of micronutrients in soil, such as pH by liming, redox potential by irrigation and drainage. When submerged soils are drained off, the redox potential increases rapidly, the soil solution may become supersaturated with respect to Fe and Mn oxides, and co-precipitation of other metals with Fe or Mn may become important (Harmsen and Vlek 1985). Rice yield can be enhanced three fold by draining the soil for 9 days 1 month after planting. The water-soluble Fe content is considerably reduced by flooding and draining, and this reduction in soluble Fe substantially increased the grain yield of rice. Increasing the redox potential by alternate flooding and drying as induced naturally by rainfall distribution and artificially by irrigation scheduling may inhibit the deleterious effects of wetland rice soil. Up on the increasing availability of oxygen when the field are drained the rapid oxidation of Fe^{2+} leads to a change in soil solution chemistry (Kirk 2004).

Although, liming has become a common practice to enhance the nutrient availability to rice and non-rice crops in acid soil, the transformation and availability of micronutrients and sulfur in lime amended acid soils have rarely been defined. Most of the earlier research on the transformation and availability of micronutrients due to changes in pH and Eh have been performed in either normal or alkali soils. It is not fully understood how liming changes the concentration of iron, manganese and aluminum in acid soils and controls the changes in pH and Eh, which in turn effect the availability of micronutrient and sulfur to rice under varying soil moisture regime. Considering the above facts, a greenhouse study was carried out to evaluate the effects of liming, soil moisture regime and application of S and few select micronutrients (B, Cu and Zn) on soil and plant availability of S, B, Cu and Zn as well as on growth and yield of rice.

Materials and Methods

Characterization of soil

The growth and yield responses of rice were assessed in two seasons wet (June to Sepetember) and winter (November to February) season (2013) in a controlled greenhouse experiment with the acid laterite (Ultisol, Salboni sandy loam). Bulk soil samples of Durgapur Clay loam soils were collected from the surface layer (0-20 cm) of the rice fields at Durgapur, West Bengal, India. The soils were air dried and processed. A uniform quantity of 5 kg processed soil was taken and filled in a series of plastic pots. Some soil physico-chemical properties were selected (Table 1). Soil particle size was examined by hydrometer method (Bouyoucos 1936). Soil pH was measured in a 1:2.5 soil to distilled water ratio using pH meter and soil cation exchange capacity was measured by using ammonium accetate leachate method (Jackson 1973). Organic carbon and organic mat er was determined by rapid titration method (Walkley and Black 1934). Calcium carbonate was estimated by rapid titration method (Piper 1950). Total content of S, B, Cu, Zn, Fe, Mn and Al in this soil were determined using anhydrous Na_2CO_3 fusion method (Jackson 1973). Available S in exchangeable form was determined by 0.15% CaCl2 extractable method (Williams and Stainberg 1962). Soil available B as hot water soluble form was determined by hot water extractable method (Berger and Truog 1944). Soil available Cu, Zn, Fe and Mn were estimated in exchangeable and organic bonded form by 0.005 DTPA (pH 7.3) extractable method (Lindsay and Norvel 1978). Soil available Al in exchangeable form was determined by 1 N KCL extractable method (McLean 1965). Lime requirement in laterite and alluvial soil were evaluated by pH buffer method. The equilibrium pH method for lime requirement was adopted considering the buffer capacity of soil (Jackson 1973).

Table 1. Physico-chemical properties of soil

Properties	Values
Sand %	63.7
Silt %	19.4
Clay %	16.9
pH	4.8
CEC (CmolC/kg)	4.65
Organic carbon (gkg^{-1})	5.0
Organic matter (gkg^{-1})	8.6
Calcium Carbonate (gkg^{-1})	4.5
Total S ($mgkg^{-1}$)	437
Total B ($mgkg^{-1}$)	10.81
Total Cu ($mgkg^{-1}$)	17.50
Total Zn ($mgkg^{-1}$)	41.90
Total Fe ($mgkg^{-1}$)	18700
Total Mn ($mgkg^{-1}$)	533
Total Al ($mgkg^{-1}$)	54890

For each treatment combination, the levels of N, P and K were maintained at 60 mg N, 30 mg P_2O_5 and 30 mg K_2O per kg of soil. N, P, K, S, Zn, Cu and B were applied respectively in the form of Analar grade urea ($CO(NH_2)_2$), Potassium di-hydrogen orthophosphate (KH_2PO_4), Potassium chloride (KCl), Calcium sulfate ($Ca SO_4$, 2 H_2O), Zinc sulfate ($Zn SO_4$, 7 H_2O) Copper sulfate ($Cu SO_4$, $5H_2O$) and Borax ($Na_2B_4O_7$, 10 H_2O) respectively. All the treatments were replicated thrice in the experiment. Ten numbers of 10 days old rice seedlings of rice cv. IR-36, were transplanted in each plastic pot. FC and AFD soil moisture regimes were maintained with the help of Tensiometers. The Details of the treatments arranged in the Split-Split Plot design of the experiment and replicated thrice as stated below:

Treatments

Main plot

L_0 = Soil without liming

L_1 = Soil with liming @ 2 tons ha^{-1}

Sub-Plot

FC = Field Capacity (0-30 Kpa soil matric potential)

CF = 5±1 Flooding

AFD = Alternate Flooding (5±1) and Drying (30 Kpa soil matric potential)

Sub-sub Plot

C = Control (without S, B, Cu and Zn)

S = @ 10 mg kg^{-1} soil

S+B @ 10 mg S kg^{-1} soil + 0.5 mg B kg^{-1} soil

S+Cu @ 10 mg S kg^{-1} soil + 1.5 mg Cu kg^{-1} soil

S+Zn @ 10 mg S kg^{-1} soil+ 5 mg Zn kg^{-1} soil

S+B+Cu+Zn @ 10 mg S + 0.5 mg B+ 1.5 mg Cu + 5 mg Zn per kg soil

Soil and plant analysis

Soils and plants were analysed 60 and 120 days after rice planting for soil availability and plant concentration of S, B, Cu, and Zn. After 60 days of planting, 2 rice plants from each treatment combination were harvested for the analysis of available micronutrients and sulfur. About 50 grams soil sample was also collected from each treatment combination for the analysis of available micronutrients and sulfur. Finally after the attainment of maturity, the remaining two rice plants were harvested, threshed and sampled separately for grain and straw. Soil samples weighing 50 g were collected at the harvest time from each treatment combination. The samples of soil, plant (after 60 days) grain and straw were analyzed for available sulfur and micronutrients.

The plant samples including the straw and grains of rice plants, were washed with double distilled water, dried in air and then in oven at 70°C, and ground by Pestle and mortar. 1 g processed plant sample was taken in a 100 ml conical flask and digested with a diacid mixture (HNO_3: $HClO_4$:: 10: 4) on hot plate for the analyses of Sulphur, copper, zinc, iron and manganese. For boron, 0.5 g processed plant sample was taken in a quartz dish and dry ashed in muffle furnace at 550°C overnight and cooled. 10 ml of 0.1 M HCl was added in the quartz dish to dissolve the dry ash. The solution was covered by glass and allowed to stand for 4 hours. Subsequently, it was filtered into a test tube. The diacid extract of plant sample was analyzed for copper, zinc, iron and manganese with the help of Atomic Absorption Spectrophotometer (Pye-Unicam-SP9-800 made in U.K). For boron, 0.1 M hydrochloric acid extract was analyzed colorimetrically with the help of Autoanalyser (CFA system 4, Chemlab, made in U.K) by using Azomethine – H indicator (Basson 1969). The plant extract was analyzed for sulfur by the Turbidimetric method using a colorimeter.

Statistical Analyses

Statistical analyses were performed with the help of the MSTAT computer package to estimate the regression equations relating dependent variables with independent variables. In order to test the significance of different treatments individually as well as in combinations, ANOVA was performed on the experimental data for the split-split plot design by the method described by Gomez and Gomez (1984) (Gomez and Gomez 1984). The comparisons between the treatment means were tested and least significant difference (LSD) were calculated at 5% level of significance.

Results and Discussion

Growth and yield of rice

The growth responses of rice to liming, soil moisture regime and application of S, B, Cu and Zn were characterized at 60 days and 120 days growth stage by number of tillers per plant and shoot weight per plant, at panicle initiation stage by plant height, whereas the yield response of rice at maturity was characterized by the yield attributes viz., number of panicle per plant, length of panicle, number of grains per panicle, 1000 grain yield, straw yield per plant and grain yield per plant. Results showed that application of lime @ 2 tons ha^{-1} significantly increased plant height, number of tillers per plant and shoot weight per plant in laterite soil. In response to these increases in growth parameters, most of the yield attributes of rice were also significantly enhanced on liming in laterite soil. The grain yield of rice per plant increased significantly from 6.5 g to 8.6 g per plant in laterite soil. The favourable responses of growth and yield parameters of rice to the application of lime in laterite soil is attributable to the increases in soil and plant availability of B, Cu and Zn (Table 4, 5,6,7, 8 and 9) due to liming.

The growth and yield parameters of rice were significantly affected by soil moisture regime. The maximum growth and yield of rice were observed under AFD moisture regime closely followed by those under continuous flooding (F) in laterite soil. The growth and yield of rice under FC moisture regime were significantly lower than those under flooding and AFD moisture regimes. Although soil and plant availability of S, B, Cu and Zn, Fe and Mn were higher under FC than F moisture regime, the growth and yield of rice increased under F regime due to increased availability of moisture and macronutrients. Higher growth and yield of rice under AFD than F regime, are attributed to the greater availability of S, B, Cu and Zn under AFD compared to F moisture regime (Table 2, 3, 4, 5,6, 7, 8 and 9).

The data presented in Table 10 and 11 reveal that the growth and yield of rice in acid laterite soils of West Bengal, India, responded significantly to the application of S, B, Cu and Zn either singly or in combination. Grain yield per plant of rice under the treatments of S, S+B, S+Cu, S+Zn, S+B+Cu+Zn were significantly higher than control in both laterite soil. In laterite soil the treatments of S+B, S+Zn and S+B+Cu+Zn resulted in significantly higher grain yield than other treatments. The maximum grain yield in laterite soil occurred under S+B in wet season and under S+Zn in winter season. The results on the yield responses of rice to the application S and micronutrients thus indicate that application of S, B and Zn in laterite soil is essential for the maximum yield of rice.

Nutrient availability

Sulphur

The data on available S concentration of soil as well as of rice plant (after 60 days of growth period), straw and grain as analyzed in wet and winter season experiments with acid laterite soils is presented in Table 2 and 3. It is seen from the tables that liming @ 2 tons ha^{-1} significantly decreased S concentration in laterite soil. S concentration in rice plant after 60 days of growth period as well as in straw and grain at harvest were also significantly reduced due to liming.

S concentration in soil, plant, straw and grain was also significantly affected by soil moisture regime in acid laterite soil. S concentration in soil under flooding was significantly lower than those under FC and AFD moisture regimes. The concentration of S under FC was, in general, significantly higher than those under AFD (Bell and Dell 2008).

Boron

The data on concentration of Hot water soluble B in soil as well as in plant, straw and grains as analysed in wet and winter season experiments are presented in Table 4 and 5. It is apparent from the tables that the concentration of available B in soil, plant, straw and grains were significantly increased by the application of the lime @ 2 tons ha^{-1} in laterite soils.

The concentration of B in rice plant, straw and grains was also significantly affected by soil moisture regime. B concentration under flooding was significantly lower than those under FC and AFD soil moisture regimes in laterite soils. AFD moisture regime induced significantly higher concentration of available B in soil, rice plant, straw and grains compared to flooding and FC regimes in laterite soils (Sakal and Singh 1995). This increase in B concentration in soil and rice plant under AFD may be ascribed to decrease in available Fe under this moisture regime. Application of B @ 0.5 mg kg^{-1} of soil along with S significantly enhanced the concentration of B in soil, plant, straw and grains over control.

Copper

Application of lime @ 2 tons ha^{-1} significantly decreased the concentration of available Cu in aterite soils (Table 6 and 7). At harvest the concentration of Cu in straw and grains of rice was significantly higher in limed than unlimed laterite soil. Cu concentration in straw and grain was significantly lower in limed than unlimed alluvial soil. The results suggest that the organic complexed and amorphous fractions of Cu which are adsorbed by Fe and Mn hydroxides in limed soil are gradually becoming available to rice plant in laterite soil, due to this the Cu concentration in straw and grains increased on liming in laterite soil.

The availability of Cu in soil and rice plant was significantly influenced by soil moisture regime. In laterite soils, the concentration of Cu in soil, plant, straw and grain was significantly lower under flooding than FC and AFD moisture regimes. The concentration of available Cu under AFD moisture regime was significantly higher than that under flooding. The maximum concentration of Cu in soil, plant, straw and grain was however observed under field capacity regime. Application of Cu along with S significantly enhanced the concentration of available Cu in soil, plant, straw and grain over control. Application of Cu in combination with S, B and Zn also significantly increased Cu concentration in soil, plant, straw and grains laterite soil (Savithri *et al.* 1999).

Zinc

Application of lime @ 2 tons ha^{-1} significantly decreased the available concentration of Zn in soil and rice plant af er 60 days of growth period in laterite soils (Table 8 and 9). Soil availability of Zn af er 120 days of growth period was also significantly lower in limed than unlimed soil. The trends of Zn availability in rice straw and grains as affected by liming in acid laterite were similar to those observed with Cu. As discussed for Cu, the organic complexed and amorphous fractions of Zn, which were adsorbed on Fe and Mn hydroxides in limed laterite soil became gradually available to rice plant.

Soil and plant availability of Zn was also significantly affected by soil moisture regime. The available concentration of Zn in soil, plant, straw and grains was significantly lower under flooding than FC and AFD regimes in laterite soils. Zn concentration under AFD was significantly higher than flooding. However, FC regime induced the maximum availability of Zn in soil and rice plant (Kirk 2004)

Application of Zn @ 5 mg kg^{-1} of soil along with S significantly enhanced the concentration of Zn in soil, rice plant, straw and grains over control in both laterite and alluvial soils. Application Zn along with S, B and Cu also significantly enhanced Zn availability in soil, plant, straw and grain.

Relationships of soil availability and plant concentration

The soil available concentration of S, B, Cu and Zn under different treatments of nutrient applications: S, S+B, S+Cu, S+Zn, S+B+Cu+Zn in limed and unlimed soils were regressed with their concentration in rice plant af er 60 days of growth. The results indicate that in unlimed soil where the S availability is relatively high, S possibly forms complexes with micronutrients. Hot water extractable B was highly significantly related with the plant concentration of B in unlimed and limed laterite soil, particularly under the treatments where B was applied either with S or with the combination of S, Cu and Zn. Similar was the trend observed with Zn. The available soil concentration of S, B, Cu and Zn under different nutrient applications: S, S+B, S+Cu, S+Zn, S+B+Cu+Zn in limed and unlimed soils were also regressed with their concentration in rice straw and grains. As observed with the plant concentration of S, the S concentration in rice straw and grains was also highly significantly related with 0.15% $CaCl_2$

Table 2. Effects of liming, soil moisture regime and application of S and micronutrients on S content of soil and rice plant in laterite soil (Wet season, 2013)

Treatments	Concentration of Sulphur (mg kg-1)				
	Soil (after 60 days)	Plant (after 60 days)	Soil (after 120 days)	Straw (after 120 days)	Grain (after 120 days)
Unlimed	31.63	2735	30.20	1960	1139
Limed	24.70	2548	23.69	1534	952
LSD (0.05)	0.28	3.52	0.17	35.89	13.01
Field Capacity	28.83	2807	27.98	1885	1102
Flooding	26.72	2365	25.42	1660	1003
Alternate flooding and drying	28.94	2754	27.45	1697	1033
LSD (0.05)	0.21	15.92	0.19	20.51	4.47
Control	22.07	2335	20.76	1401	929
S	28.93	2864	27.60	1671	1074
S + B	31.98	2628	29.83	1721	997
S + Cu	28.56	2691	26.70	1866	1081
S + Zn	25.73	2699	26.84	1916	1074
S + B + Cu + Zn	31.71	2634	29.96	1909	1120
LSD (0.05)	0.42	30.74	0.39	17.50	10.14

Table 3. Effects of liming, soil moisture regime and application of S and micronutrients on S content of soil and rice plant in laterite soil (winter season, 2013)

Treatments	Concentration of Sulphur (mg kg^{-1})				
	Soil (after 60 days)	Plant (after 60 days)	Soil (after 120 days)	Straw (after 120 days)	Grain (after 120 days)
Unlimed	30.77	2686	29.71	1922	1068
Limed	23.87	2480	22.65	1552	920
LSD (0.05)	0.28	8.53	0.24	13.30	6.00
Field Capacity	27.85	2739	26.77	1888	1031
Flooding	26.07	2337	24.85	1635	941
Alternate flooding and drying	28.04	2673	26.91	1689	1009
LSD (0.05)	0.14	8.82	0.17	8.59	4.40
Control	21.04	2380	20.09	1362	861
S	28.25	2754	27.28	1643	1012
S + B	30.44	2559	29.49	1747	979
S + Cu	27.74	2622	26.74	1870	1032
S + Zn	26.53	2597	24.57	1904	1016
S + B + Cu + Zn	29.92	2584	28.89	1898	1061
LSD (0.05)	0.16	10.16	0.15	10.11	9.76

Table 4 Effects of liming, soil moisture regime and application of S and micronutrients on B content of soil and rice plant in laterite soil (wet season, 2013)

Treatments	Concentration of Boron (mg kg^{-1})				
	Soil (after 60 days)	Plant (after 60 days)	Soil (after 120 days)	Straw (after 120 days)	Grain (after 120 days)
Unlimed	0.19	38.86	0.17	17.69	15.60
Limed	0.20	43.66	0.18	18.71	16.45
LSD (0.05)	0.0047	0.24	0.002	0.24	0.31
Field Capacity	0.20	40.25	0.18	17.43	15.25
Flooding	0.18	41.32	0.17	18.45	16.26
Alternate flooding and drying	0.20	42.20	0.18	18.72	16.57
LSD (0.05)	0.0076	0.079	0.007	0.10	0.16
Control	0.15	35.24	0.13	16.88	15.01
S	0.14	36.36	0.12	16.93	14.24
S + B	0.28	48.41	0.26	20.73	18.74
S + Cu	0.15	38.97	0.13	16.05	13.68
S + Zn	0.16	40.83	0.15	16.87	14.80
S + B + Cu + Zn	0.29	47.74	0.28	21.72	19.68
LSD (0.05)	0.0066	0.42	0.007	0.317	0.26

Table 5 Effects of liming, soil moisture regime and application of S and micronutrients on B content of soil and rice plant in laterite soil (winter season, 2013)

Treatments	Concentration of Boron (mg kg^{-1})				
	Soil (after 60 days)	Plant (after 60 days)	Soil (after 120 days)	Straw (after 120 days)	Grain (after 120 days)
Unlimed	0.18	31.16	0.15	14.96	12.79
Limed	0.19	36.35	0.16	16.09	13.94
LSD (0.05)	0.0073	0.14	0.0025	0.19	0.14
Field Capacity	0.199	32.21	0.16	14.45	12.24
Flooding	0.168	33.87	0.14	15.75	13.56
Alternate flooding and drying	0.197	35.17	0.17	16.36	14.28
LSD (0.05)	0.0059	0.12	0.002	0.071	0.059
Control	0.13	31.51	0.11	16.32	14.40
S	0.14	30.80	0.09	14.24	11.71
S + B	0.28	38.84	0.25	18.21	16.19
S + Cu	0.14	31.64	0.10	13.10	10.95
S + Zn	0.14	32.15	0.12	12.86	10.75
S + B + Cu + Zn	0.29	38.06	0.16	18.39	16.15
LSD (0.05)	0.004	0.19	0.0036	0.083	0.077

Table 6. Effects of liming, soil moisture regime and application of S and micronutrients on Cu content of soil and rice plant in laterite soil (wet season, 2013)

Treatments	Concentration of Copper (mg kg^{-1})				
	Soil (after 60 days)	Plant (after 60 days)	Soil (after 120 days)	Straw (after 120 days)	Grain (after 120 days)
Unlimed	1.51	15.63	1.26	8.94	4.93
Limed	0.97	13.98	0.94	11.30	6.85
LSD (0.05)	0.074	0.492	0.097	0.149	0.059
Field Capacity	1.92	18.63	1.87	10.68	5.98
Flooding	0.83	12.09	0.65	9.21	5.37
Alternate flooding and drying	0.98	13.69	0.77	10.47	6.32
LSD (0.05)	0.020	0.115	0.023	0.085	0.027
Control	0.80	14.10	0.77	9.28	5.47
S	0.81	14.55	0.79	10.30	5.48
S + B	0.82	13.76	0.78	8.83	5.22
S + Cu	2.05	16.61	1.62	11.51	6.70
S + Zn	0.88	12.92	0.80	8.61	5.24
S + B + Cu + Zn	2.09	16.88	1.81	12.19	7.24
LSD (0.05)	0.041	0.186	0.047	0.092	0.069

Table 7. Effects of liming, soil moisture regime and application of S and micronutrients on Cu content of soil and rice plant in laterite soil (winter season, 2013)

Treatments	Concentration of Copper (mg kg^{-1})				
	Soil (after 60 days)	Plant (after 60 days)	Soil (after 120 days)	Straw (after 120 days)	Grain (after 120 days)
Unlimed	1.44	15.93	1.42	9.03	5.02
Limed	0.92	15.56	0.89	10.87	6.09
LSD (0.05)	0.059	3.13	0.07	0.063	0.073
Field Capacity	1.85	17.66	1.84	10.26	5.68
Flooding	0.77	14.28	0.75	9.41	5.19
Alternate flooding and drying	0.92	15.31	0.89	10.18	5.79
LSD (0.05)	0.026	1.05	0.018	0.089	0.026
Control	0.75	15.13	0.72	9.95	5.44
S	0.77	15.02	0.75	9.48	4.83
S + B	0.79	13.77	0.76	8.73	5.06
S + Cu	1.94	18.11	1.92	11.26	6.64
S + Zn	0.81	13.35	0.79	8.27	4.39
S + B + Cu + Zn	2.01	19.13	1.99	12.02	6.98
LSD (0.05)	0.047	0.10	0.041	0.106	0.052

Table 8 Effects of liming, soil moisture regime and application of S and micronutrients on Zn content of soil and rice plant in laterite soil (wet season, 2013)

Treatments	Concentration of Zinc (mg kg^{-1})				
	Soil (after 60 days)	Plant (after 60 days)	Soil (after 120 days)	Straw (after 120 days)	Grain (after 120 days)
Unlimed	2.39	50.93	2.10	53.15	24.32
Limed	1.95	49.20	1.74	59.83	27.03
LSD (0.05)	0.028	0.186	0.059	0.319	0.182
Field Capacity	2.54	66.36	2.30	60.27	26.41
Flooding	1.81	40.38	1.60	53.23	24.30
Alternate flooding and drying	2.16	43.45	1.84	55.95	26.32
LSD (0.05)	0.014	0.215	0.018	0.141	0.122
Control	1.42	44.61	1.33	54.68	24.88
S	1.42	43.93	1.50	52.66	25.35
S + B	1.30	46.71	1.24	52.29	24.56
S + Cu	1.41	46.71	1.40	53.30	23.84
S + Zn	3.76	58.74	3.10	63.52	28.26
S + B + Cu + Zn	3.69	59.67	2.92	62.47	27.17
LSD (0.05)	0.224	0.478	0.033	0.172	0.191

Table 9. Effects of liming, soil moisture regime and application of S and micronutrients on Zn content of soil and rice plant in laterite soil (winter season, 2013)

Treatments	Concentration of Zinc (mg kg^{-1})				
	Soil (after 60 days)	Plant (after 60 days)	Soil (after 120 days)	Straw (after 120 days)	Grain (after 120 days)
Unlimed	2.29	49.77	2.25	50.51	23.42
Limed	1.82	47.99	1.84	53.03	23.87
LSD (0.05)	0.038	0.287	0.018	0.040	0.769
Field Capacity	2.47	56.41	2.50	52.96	25.04
Flooding	1.68	42.02	1.65	50.30	22.31
Alternate flooding and drying	2.01	48.21	1.98	52.06	23.58
LSD (0.05)	0.047	0.137	0.014	0.107	0.363
Control	1.30	44.45	1.28	49.39	22.56
S	1.47	44.21	1.45	48.06	21.29
S + B	1.31	45.35	1.28	48.29	22.34
S + Cu	1.38	46.34	1.35	48.87	22.19
S + Zn	3.31	56.34	3.38	57.98	26.79
S + B + Cu + Zn	3.55	56.60	3.53	58.03	26.70
LSD (0.05)	0.051	0.449	0.018	0.165	0.356

Table 10. Effects of lime, soil moisture regimes, S, B, Cu and Zn on growth and yield of rice in laterite soil (wet season, 2013)

Treatment	Plant height[1] (cm)	Tillers/ plant[2] (no.)	Shoot weight/ plant[2] (g)	Number of panicles/ plant (no.)	Grains/ panicle (No.)	1000 grains weight (g)	Straw yield/plant (g)	Grain yield/ plant (g)
A. Lime								
No lime	91.3	6.0	3.5	12.0	140	22.2	8.4	6.5
Lime @ 2.0 t/ha	95.8	7.0	3.6	13.0	161	23.2	9.2	8.6
LSD(0.05)	1.4	0.1	0.1	0.3	6	1.5	0.2	0.5
B. Soil Moisture Regimes								
Field capacity	92.4	6.0	2.5	10.0	117	22.5	7.9	6.3
Flooding	92.0	7.0	4.0	14.0	159	22.9	8.8	7.7
Alternate Flooding and Drying	96.4	8.0	4.1	15.0	176	22.7	9.6	8.6
LSD(0.05)	0.8	0.2	0.1	0.4	5	0.7	0.1	0.3
C. Nutrient application								
Control	91.6	6.0	3.2	12.0	132	21.0	8.1	6.5
S	94.3	7.0	3.5	13.0	150	22.4	8.7	7.4
S+B	92.8	7.0	3.7	13.0	163	23.0	9.1	8.1
S+Cu	92.7	7.0	3.5	14.0	154	22.6	8.9	7.5
S+Zn	95.5	7.0	3.6	13.0	150	23.2	8.8	7.9
S+B+Cu+Zn	94.6	8.0	3.7	14.0	155	23.8	8.9	8.0
LSD(0.05)	0.9	0.3	0.1	0.5	5	0.4	0.2	0.3
[1] At Panicle Initiation Stage; [2] At 60 days after planting								

Table 11. Effects of lime, soil moisture regimes, S, B, Cu and Zn on growth and yield of rice in laterite soil (winter season, 2013)

Treatment	Plant height[1] (cm)	Tillers/ plant[2] (no.)	Shoot weight/plant[2] (g)	Number of panicles/plant (no.)	Grains/ panicle (No.)	1000 grains weight (g)	Straw yield/ plant (g)	Grain yield/ plant (g)
A. Lime								
No lime	82.8	9.0	2.5	17.0	132	22.7	16.2	13.6
Lime @ 2.0 t/ha	84.7	9.0	2.2	16.0	150	23.8	15.4	14.0
LSD(0.05)	0.9	0.5	0.0	0.6	1	0.3	0.1	0.2
B. Soil Moisture Regimes								
Field capacity	84.8	9.0	1.9	15.0	109	22.9	15.2	11.2
Flooding	82.4	10.0	2.5	17.0	150	23.5	15.9	15.1
Alternate Flooding and Drying	83.9	10.0	2.7	16.0	164	23.4	16.4	15.1
LSD(0.05)	0.8	0.3	0.1	0.5	3	0.4	0.1	0.3
C. Nutrient application								
Control	80.7	9.0	2.3	15.0	119	21.4	13.5	11.4
S	83.8	9.0	2.4	16.0	142	23.2	16.0	13.8

S+B	85.4	10.0	2.4	15.0	151	23.4	16.6	14.4
S+Cu	83.4	9.0	2.4	16.0	143	23.4	16.2	13.4
S+Zn	84.1	10.0	2.3	17.0	142	23.8	16.1	15.1
S+B+Cu+Zn	85.0	10.0	2.4	18.0	151	24.5	16.4	14.7
LSD(0.05)	0.5	0.5	0.1	0.7	2	0.3	0.2	0.2
[1] At Panicle Initiation Stage; [2] At 60 days after planting								

extractable S in unlimed laterite soil. However, in limed soil the relationships became weaker when S was applied with Zn or particularly in grains. Hot water extractable B was found to be highly significantly related with concentration of B in straw and grains under the treatments where B was applied either singly or combination with other nutrients in limed and unlimed laterite soil. In general, similar were the trends observed for the relationships of plant concentration of Cu and Zn with DTPA extractable Cu and Zn.

The findings of these regression analyses indicate that the available soil concentration of S, B, Cu and Zn extracted respectively by 0.15% $CaCl_2$, hot water and DTPA, were significantly related with their concentration in plant, straw and grains of rice. This confirms the suitability of these extractants in acid laterite soil. Significant relationships between soil and plant concentration under different treatments of S, B, Cu and Zn applications also point to the favourable response of rice plants to the application of S, B, Cu and Zn.

Conclusion

Soil available concencentration of S, B, Cu and Zn under different treatments of nutrient application; S, S+B, S+Cu, S+Zn, S+B+Cu+Zn in limed and unlimed soils was, in general, significantly related with their plant concentration. In case of Cu and Zn, the relationship of DTPA extracteable soil conctration. With their plant conctration became stronger on liming. Under different treatments of S, B, Cu and Zn applications indicated favourable response of rice plants to the application of S, B, Cu and Zn and also confirmed the suitability of 0.15% $CaCl_2$ and hot water as extractants of respectively S and B and 0.005 M DTPA (pH 7.3) as extractant of Cu and Zn in acid laterite soil. Application of lime @2.0 t/ha significantly increased plant height, number of tillers per plant and shoot height per plant in laterite soil. The grain yield in limed soil was not significantly higher than unlimed soil in wet Season. However, in winter season, the grain yield per plant was higher in limed than unlimed soil. The growth and yield parameters of rice were significantly affected by soil moisture regime. The maximum growth and yield of rice was observed under AFD moisture regime closely followed by F in laterite soil. Application of S along with B and Zn in laterite soil helped attaining the maximum grain yield of rice under AFD moisture regime. Application of S, B, Cu and Zn respectively at the rate of 22.4, 1.12, 3.36 and 11.2 kg per ha significantly enhances the growth and yield of rice over control in laterite soil. The yield response of rice to the application of S, B, Cu, Zn is improved by liming the soil and maintaining the moisture regime of alternate flooding and drying.

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