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Sulphur and Zinc Fertilization Effects on Growth and Yield Response of Rice

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Authors' contributions

This work was carried out in collaboration between all authors. Author AMK designed the study, wrote the protocol, wrote the first draft of the manuscript and managed the literature searches and all laboratory analyses. Authors NAA and JMRS involved in site selection, edited the data, reviewed and edited the protocol and manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Information on critical concentration and optimum rates of fertilizers is very important in the correction of sulphur (S) and zinc (Zn) deficiencies. A study was carried in the screen house experiments to establish optimum rates and critical concentrations of sulphur and zinc in both soil and rice shoots using soils of Kilombero district, Tanzania. Two experiments were conducted, one with varied levels of S and the other with varied levels of Zn. The treatments were absolute control for both experiments, three levels of S namely 0, 20 and 40 mg kg^{-1} soil and three levels of Zn namely 0, 5 and 10 mg kg^{-1} soil. Rice (variety SARO-5) was grown in pots arranged in a randomized complete block design with three replications. The results indicated that soil critical concentration of S was 10.0 mg kg^{-1} and the S critical range in rice shoots was 0.18 to 0.25%. Established critical level of soil Zn was 1.4 mg kg^{-1} while the Zn shoots critical concentration was 22 mg kg^{-1}. Grain yield was significantly increased for plants grown in eight and three out of ten soils tested due to an application of S and Zn, respectively. Rates of 20 mg S and 5 mg Zn kg^{-1} soil were optimum rates for soils with low S and Zn, respectively. The results indicated that 17 and 6 out of

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19 studied soils of Kilombero had S and Zn concentration below the critical level, respectively. It was concluded that sulphur deficiency was widely spread and its application and management is crucial, while Zn deficiency was an emerging problem in the paddy soils of Kilombero valley.

Keywords: Cate-Nelson; critical range; critical concentration; optimum rate.

1. INTRODUCTION

Rice (*Oryza sativa* L.) ranks second after maize in Tanzania as an important staple and cash crop. However, rice productivity is low and it is continuously declining. A productivity trend between year 2009 and 2012 showed a yield decrease of about 1.5 to 1.0 t ha^{-1} under lowlands- rainfed [1,2]. By contrast, the reported yields are far below the potential of 4.3 to 6.5 t ha^{-1} for common improved rice varieties like SARO-5 [3]. Several factors are reported to cause that decrease [1,4,5] such as pests and diseases, inadequate water for irrigation and inadequate water management, low soil fertility and long-term continuous cultivation without applying balanced nutrients. Low soil fertility and imbalanced nutrients application are important and their improvements may boost rice production for majority of Tanzanian farmers particularly those of Kilombero district.

Few rice farmers use inorganic fertilizers in Kilombero district and for those using fertilizers, nitrogen is the common nutrient applied. About four percent of rice producers in Kilombero [1] apply fertilizers containing nutrients like phosphorus (P), potassium (K), sulphur (S), zinc (Zn) as a result these nutrients are gradually declining in soils. On the other hand, S is also lost from soils through leaching, burning and crop uptake. Apart from 1 kg S and 40 g Zn lost per hectare through producing one tone grain of the high-yielding rice variety [6], other nutrients like 22 kg N, 3.1 kg P, 28 kg K are also exported from the soil. A recent study [7] supports the hypothesis that S and Zn are low and emerging as limiting factors for rice production in soils of Kilombero. Similarly, another study [5] found 40% and 10% of soil samples taken from five rice-producing areas in Kilombero district had low levels of S and Zn, respectively. A recent researcher [8] found all (100%) of the twenty soil samples sampled in Kilombero rice production areas were S deficient while 29% were deficient in Zn. This suggests that application of S and Zn fertilizers may be necessary to optimize rice yields. However, there are neither critical levels nor recommendations of S and Zn established for rice in Tanzania.

Sulphur is known to enhance nitrogen utilization and chlorophyll formation. It is a component of enzymes, proteins and vitamins essential for protein synthesis and about 90% of plant S is present as a constituent of the amino acids: cysteine, methionine and cystine [9]. It has been reported that application of 40 kg S ha^{-1} resulted in higher assimilates in after onset of reproductive stage of rice than without S treatment, indicating S is highly involved in signaling process of photosynthetic materials to seed production [10,11]. Ali et al. [12] observed a combination of S and P at 40 and 35 kg ha^{-1} respectively, to increase dry matter yield (DMY) by 30%, grain yield by 61.1% and rice straw yield by 65.1%.

Zinc is also reported as an important micronutrient for rice production because it is required in a large number of enzymes and plays an essential role in DNA transcription. It is either as a metal constituent in an enzymes or as a functional co-factor of number of enzymes reactions [13]. It is reported that high amount of zinc is contained in pollen and mostly zinc is diverted to seed only during seed formation and an application of zinc improves grain formation [6,10,11,14].

Estimating nutrient availability for the plant is done through soil and plant analysis by comparing the results with the recommended critical values to determine if the tested nutrient is sufficient to produce maximum plant growth and yield [15]. Generally, critical value or range is a 5 to 20% [16,17] yield reduction above which the plant is adequately supplied with nutrients or below which it is deficient. Among other techniques [18] the graphical method is commonly used by several researchers to establish critical values of nutrients including Zn and S [19,20] by delineating soils that are expected to respond to fertilizer from those not expected to respond. The soil critical concentrations for cereals are reported to be between 6 and 12 mg kg^{-1} for S and 0.2 to 2.0 mg kg^{-1} for Zn [16,20,21,22,23,24,25,26]. The reported critical values for rice plant tissues are between 0.11% and 0.22% for S, 25, and 50 mg kg^{-1} for Zn [12,22].

The information on response and critical levels of S and Zn for Tanzania in respect to rice is lacking. Therefore, the objectives of this study were to (i) establish critical levels of S and Zn for both soil and rice plant tissues. (ii) determine the extent of S and Zn deficiencies in soils of Kilombero district.

2. METHODOLOGY

Screen house experiments were conducted at Sokoine University of Agriculture (SUA), Morogoro, Tanzania from December 2013 to May 2014. Within Kilombero district, Tanzania 19 villages famous in rice production were surveyed and soil samples were collected at a depth of 0 - 30 cm for laboratory analysis. The district is located along the Kilombero valley with annual rainfall ranging between 1200 and 1400 mm falling between December to June and annual temperature ranges between 26 and 32ºC [27]. The study area is located at elevations between 266 and 318 meters above sea level and with coordinates ranging between longitudes 35.54294 and 36.54863, and latitudes 7.50141 to 8.19438.

After soil analysis, soils with varied levels of S and Zn from 10 villages were selected for the screen house experiments. Two set of experiments were conducted, one for evaluating response of rice to S and the other for evaluating response of rice to Zn. The treatments for experiment one contained S applied at rates of 0, 20 and 40 mg kg^{-1} soil while experiment two comprised of Zn applied at 0, 5, and 10 mg kg^{-1} soil. Both experiments had absolute controls that had no nutrients applied. The experimental units were arranged in a randomized complete block design (RCBD) with three replicates. The blocking variable was light gradient in the screen house, which occurred during the mornings and evenings. The pots were randomly arranged in blocks (replicates) to counteract light gradient. The used screen house can protect plants from external pests but less effective in ensuring uniform sunlight.

Other necessary nutrients were applied at levels that will not limit the response of rice to S and Zn as per soil test results obtained. Potassium was applied as KCl, phosphorus as triple super phosphate (TSP), zinc as ZnSO4, calcium as $CaSO_4$, and these two fertilizers supplied varied S and Zn. Zinc nitrate $[Zn(NO_3)_2]$ and $CaCl_2$ were used to supply Zn and Ca, in treatments that did not need application of sulphur and zinc, respectively. Magnesium was applied as MgO. All nutrients were applied at planting except N, for which 60% was applied at 21 days after sowing (DAS) and 40% was applied at 49 DAS at a total rate of 600 mg N kg^{-1}, applied as urea. The applied nutrients were designated as $N_{600}P_{80}K_{400}Mg_{24}Ca_{50}$ for the nutrients other than S and Z, where the subscript numbers on each element indicate nutrient rates applied in mg kg^{-1} soil.

Eight pre-geminated rice seeds (variety SARO 5) were sown in five litres plastic pots, which were potted with 3.8 kg of 8 mm sieved soil. Potted soil was moistened to field capacity and equilibrated for one day before sowing. Water content was maintained close to field capacity for the first 21 days after which thinning was done to remain with two seedlings and urea was applied. Then the pots were continuously flooded to maturity of plants. Out of two plants, one was harvested by cutting 1 cm above the soil surface during booting stage (63 DAS). Shoots were dried at 70ºC to constant weight for dry matter yields and plant tissue analysis. The shoots were weighed, ground with a cyclone mill and sieved through a 1-mm sieve for plant analysis. The remaining plant was grown to maturity for grain yield (GY) determination. Grain yield was recorded at 14% moisture content.

2.1 Soil and Plant Tissue Analysis

A representative composite soil sample was collected from each site for laboratory analysis. Soil pH was analyzed (1: 2.5 soil: water suspension) by using a pH meter [28]. Extractable P by Bray-1 because all soils had pH below 7 [29], basic cations (Ca, Mg, K and Na) from ammonium acetate (NH_4Oac) leachate [30], Zn by Diethylene triamine pentaacetic acid (DTPA) method [31] and their concentration in the filtrate were determined by atomic absorption using appropriate standards, extractable sulphur by $BaCl_2$ turbidity method [32]. The plant samples were digested in a digestion block at 125ºC using the HNO_3- H_2O_2 wet digestion procedure [33] The extracted S in the digest was analyzed by $BaCl_2$ turbidity method while in the same digest Zn was determined by atomic absorption spectrophotometry.

Table 1. The initial nutrient status of soils used in the screen house experiment

Site/ village	pH	P	Ca	K	Mg	Na
		(mg kg^{-1})	(cmol (+)kg^{-1})			
Kisawasawa	5.1	12.6	4.7	0.3	2.8	0.5
Signali-2	6.1	20.7	10.0	0.5	3.0	0.3
Mbasa-1	4.5	1.9	0.9	0.1	0.1	0.4
Mbasa-2	4.7	1.9	2.0	0.1	0.1	0.4
Magombera-2	4.9	1.9	1.6	0.1	0.7	0.3
Mkula-1	5.3	2.3	4.3	0.2	1.5	0.1
Mkula-2	5.9	2.2	8.0	0.2	4.5	0.1
Mang'ula -1	5.6	2.0	6.7	0.2	2.9	0.1
Mang'ula -2	5.6	11.3	6.0	0.2	2.4	0.1
Mngeta-1	5.8	7.1	6.7	0.5	2.6	0.5
Range	4.5-6.1	1.9-20.7	0.9 -10	0.1-0.5	0.1 -4.5	0.1 -0.5

2.1.1 General physical – chemical characteristics of soils used in the study

The initial nutrient status of soils used in the pot experiments is given in Table 1. The adjustment of N, P, K, Ca and Mg was done by applying fertilizers described above in order to avoid limitations of untested nutrients.

The status of initial S and Zn for the 19 soils collected during survey including the ten soils used in the screene house experiment is provided in Table 2.

Table 2. Status of zinc and sulphur in soils sampled during survey in Kilombero district

Site/ village	Zn (mg kg^{-1})	S (mg kg^{-1})
Kisawasawa-1	2.4	1.2
*Kisawasawa-2	2.6	1.9
Kisawasawa-3	3.1	6.7
Signali-1	4.6	5.7
*Signali-2	3.4	7.6
Kanolo	2.1	5.2
Njage-1	0.5	2.8
Njage-2	1.9	4.7
*Mbasa-1	0.4	1.3
*Mbasa-2	0.5	3.2
Mbingu	1.3	1.2
Magombera-1	0.9	7.2
*Magombera-2	1.3	2.4
*Mkula-1	2.1	6.2
*Mkula-2	1.6	4.5
* Mang'ula -1	0.2	12.1
* Mang'ula -2	1.5	11.6
*Mngeta-1	3.0	4.1
Mngeta-2	2.6	7.5
Mean	1.95	5.1
Range	0.2- 5.6	1.2 -12.1

** Indicates the soils used in the green-house experiment*

2.2 Sulphur and Zn Critical Levels Determination

The Critical levels of sulphur and zinc in soils and plants were established by the graphical method of Cate and Nelson [18]. This method consists of constructing graphs of the relative yield on the Y axis and nutrient concentration on the X axis. The positive and negative quadrants of fertilizer response and non-response, respectively were demarcated. The formula by [34] was used to calculate percent relative yield as:

> [(Grain or DM yield of S or Zn control treatment(s) x 100) / Maximum yield of treatment with all nutrients] (i)

2.3 Data Analysis

All the data collected, i.e. grain yield (GY) response, nutrient concentration in plant shoots, dry matter yield (DMY) response to S and Zn were subjected to analysis of variance using GenStat Discovery Edition 15. Means were compared by Duncan Multiple Range Test (DMRT) at P=0.05. The coefficient of variation (CV) in percentage was recorded.

3. RESULTS AND DISCUSSION

3.1 Dry Matter Yield Response to Sulphur and Zinc

3.1.1 Dry matter yield response to sulphur application

The effects of added sulphur to different soils on rice DMY are presented in Table 3. Sulphur application increased DMY significantly over the control treatment for seven soils namely Mkula-1, Mkula-2, Mbasa-1, Mbasa-2, Magombera, Kisawasawa and Mngeta-1. There was no a significant increase in DMY yield to S application in soils from Signali, Mang'ula -1 and Mang'ula -2. The latter two soils had relatively high S concentrations of 12.1 and 11.6 mg kg^{-1} respectively.

Table 3. Dry matter yield response to applied S in ten soils from Kilombero district

Site	S rates applied (mg kg^{-1}soil)				CV (%)
	AbC	S_0	S_{20}	S_{40}	
	Dry matter yield (g pot^{-1})				
Mngeta-1	5.1c	13.4b	36.1a	47.3a	25.6
Signali	5.2b	23.9a	45.7a	45.4a	26.8
Kisawasawa	1.8d	13.3c	38.8b	47.3a	10.3
Mkula-2	5.6c	17.1b	40.6a	43.1a	21.5
Mkula-1	3.5c	19.83b	31.9a	36.5a	23.1
Mbasa-1	3.8 b	15.1b	34.3a	36.8a	16.8
Mbasa-2	4.0c	16.1c	33.3b	46.5a	26.2
Magombera	2.5c	16.1b	32.9a	33.2 ab	24.1
Mang'ula -2	4.2b	39.8a	41.0a	43.1 a	13.3
Mang'ula -1	11.9b	46.8a	54.7a	57.7a	15.0

Means in the same row bearing the same letter(s) are not significantly different at (P=0.05); CV = Coefficient of variations. Treatment abbreviations with subscript numbers indicate the S rates applied in mg kg-1 soil. AbC = Absolute control

An application of 40 mg S kg^{-1} was superior to 20 mg S kg^{-1} in the soils with S less than 3.2 mg kg^{-1} (i.e. Kisawasawa and Mbasa-2), but not in other soils. Further increase in DMY due to increase in S application at 40 mg S kg^{-1} suggest that at least 40 mg S kg $^{-1}$ is needed for a significant DMY increase in soils with S less 3.2 mg kg^{-1}.

Several researchers reported a significant increase effect of S on rice DMY. Singh et al., [11] reported a significant increase in DMY resulted from application of 40 mg S kg^{-1} over without S treatment. An application of S from sulphur-coated urea increased DMY [35] and it was suggested that S improved N utilization hence high DMY. Furthermore, an application of 45 kg S ha^{-1} gave higher amount of straw than 30 kg S ha^{-1} [36], which justifies a significant increase of DMY due to S application in the treatments that received S in the current study.

3.1.2 Dry matter yield response to Zinc application

The effects of added zinc to different soils on rice DMY are given in Table 4. In all soils application of N, P, K, Ca and Mg increased DMY significantly over the absolute control. Zinc application increased rice DMY significantly in only three soils (Kisawasawa, Mbasa-2, and Mang'ula-1) out of ten soils tested. The significant increase in DMY at Kisawasawa and Mbasa-2 occurred when Zn was applied at 10 mg kg^{-1} but not at 5 mg kg^{-1}. The Mbasa soil had Zn levels < 0.5 mg kg^{-1} soil indicating that below this Zn concentration 10 mg kg^{-1}can be optimal for increasing DMY. The significant increase in DMY for the Kisawasawa soil at 10 mg kg^{-1} rate was not expected since the soil had 2.6 mg kg^{-1}, which is a relatively high level of Zn. It can be generalized that 5 mg kg^{-1} rate had a significant effect on DMY of rice grown in all the soils with low Zn levels.

Similarly, other researchers have reported significant effects in rice DMY when Zn was applied in soils with varied DTPA-Zn levels. Significant DMY increase was observed [37] when an application of 5 and 7.5 mg Zn kg^{-1} was done in a soil with DTPA-Zn 0.86 mg kg^{-1} in India. Fageria et al. [14] reported DMY increase to occur in an Inceptisol after applying 5 mg Zn kg^{-1}. Kandali et al. [38] reported a significant increase in straw yield when 4.2 mg Zn ha^{-1} was applied in a soil with DTPA- Zn 0.55 mg Zn kg$^{-1.}$ The lack of response of plants grown in the six soils is justified by [22] who concluded that soils with zinc above 0.8 mg Zn kg^{-1} were not expected to give any response. Other researchers, [14] reported a no significant effect between 5 and 120 mg Zn kg^{-1} rates when Zn was applied in an acidic soil with 1.4 mg Zn kg^{-1} which supports the no DMY increase in the treatments that received 5 and 10 mg Zn kg^{-1} application rates.

Table 4. Dry matter yield response to applied Zn in ten soils from Kilombero district

Site/village	Zn rates applied (mg kg^{-1}soil)				
	AbC	Zn_0	Zn_5	Zn_{10}	CV (%)
	Dry matter yield (g pot^{-1})				
Mngeta-1	5.1b	29.7a	38.5a	36.1a	31.8
Signali	5.2b	28.1a	45.7a	36.9a	30.9
Kisawasawa	1.8c	17.9b	27.0b	47.3a	22.2
Mkula-2	5.6b	26.3a	40.6a	26.2a	29.4
Mkula-1	3.5b	24.8a	31.9a	21.9a	28.9
Mbasa-1	3.8b	22.1a	26.9a	28.9a	41.8
Mbasa-2	4.03c	26.0b	33.28b	46. 5a	23.8
Magombera	2.49b	29.4a	32.9a	34.2a	23.1
Mang'ula -2	4.2b	41.2a	43.1a	39.9a	20.9
Mang'ula -1	11.9c	32.9b	54.7a	56.3a	17.7

Means in the same row bearing the same letter(s) are not significantly different at (P=0.05); CV = Coefficient of variations. Treatment abbreviations with subscript numbers indicate the Zn rates applied in mg kg-1soil. AbC = Absolute control

Lack of dry matter yield increase of corn between the Zn treated and untreated treatments in all the soils with the Zn concentration above the critical concentration has also been reported by [20]. Msolla et al. [23] reported that nine out of 10 soils with Zn levels below 1.1 mg kg^{-1} DTPA- Zn gave significant DMY responses when 5 and 10 mg Zn kg^{-1} were applied into the soils.

3.2 Grain Yield Response to Sulphur and Zinc Application in Soils of Kilombero District

3.2.1 Grain yield response to sulphur application

The effects of added sulphur to different soils on rice grain yields are presented in Table 5. The minimum grain yields were obtained in the absolute control treatments. Sulphur application at 20 mg kg^{-1} increased grain yield significantly over the S-control treatment for eight soils namely Mkula-1, Magombera, Mbasa-1, Mbasa-2, Mkula-2, Kisawasawa, Signali and Mngeta-1. The response was obtained in soils with S approaching 7.6 mg kg^{-1}. No significant increases in grain yield due to S application in soils from Mang'ula -1 and Mang'ula -2. For six soils out of eight soils that responded to S, an application of 40 mg S kg^{-1} did not show any significant increase in grain yield over 20 mg S kg^{-1}.

Similar results showing low grain yield when no fertilizers are used were reported by other reserchers [39]. The most likely cause of low grain production in this study might be low nutrient levels due to prolonged cultivation without nutrient replenishment [27] and low inherent soil nutrients (Tables 1 and 2). Sulfur application at 20 mg S kg^{-1} doubled and trippled rice grain yield indicating that an application of S to about 80% of soils in Kilombero district is likely to increase grain yield significantly.

Table 5. Grain yield response to S appliation in different soils

	S rates applied (mg kg^{-1}soil)				
Site	**AbC.**	**S_0**	**S_{20}**	**S_{40}**	**CV (%)**
	Grain yield (g pot^{-1})				
Mngeta-1	8.3c	27.9b	67.4a	50.1a	23.1
Signali	9.9c	30.2b	60.8a	66.2a	22.6
Kisawasawa	4.5b	11.7b	45.5a	50.9a	45.4
Mkula-2	12.1c	26.1b	54.2a	46.4a	12.2
Mkula-1	8.6d	30.5c	39.8b	51.1a	12.1
Mbasa-1	4.5b	7.7b	46.3a	47.1a	16.8
Mbasa-2	2.9d	15.3c	30.8b	40.8a	14.7
Magombera	4.6c	15.1b	46.7a	47.4a	9.7
Mang'ula -2	7.5b	47.2a	51.5a	57.8a	12.4
Mang'ula -1	10.8b	63.2a	68.2a	59.7a	11.1

Means in the same row bearing the same letter(s) are not significantly different at (P=0.05); CV = Coefficient of variations. Treatment abbreviations with subscript numbers indicate the S rates applied in mg kg-1soil. AbC = Absolute control

Lack of S response in Mangula-1 and Mangula-2 can be explained by the relatively higher SO_4-S concentrations in these areas, i.e. 12.1 and 11.6 mg S kg^{-1} respectively. In two soils, namely Kisawasawa and Mbasa -1, S was the most limiting factor because there was no response to other nutrients without S application (Table 5). In addition, S is also a major limiting factor in Mbasa -2, Magombera, Mkula -1 and Mkula- 2 soils because S application resulted in big responses close to 100%. The lack of response due to application of 40 mg S kg^{-1} over 20 mg S kg^{-1} in six soils indicates that application of 20 mg S kg^{-1} was optimal under screen house experiment.

It can be concluded that an application of 20 mg S kg^{-1} was optimal and S application significatly incresed both DMY and GY in most of the soils with S below 7.6 mg kg^{-1}. There was a significant DMY increase when 40 mg S kg^{-1} was applied but in the same soils this treatment did not increase grain yield significantly.

3.2.2 Grain yield response to zinc application

Effect of added zinc to different soils on rice grain yields is presented in Table 6. Zinc application increased rice grain yield significantly in four soils (Mbasa-1, Mbasa-2 Mang'ula -1 and Magombera) with Zn levels ≤ 1.3 mg kg^{-1} soil out of ten soils tested. Zinc application at 10 mg kg^{-1} soil decreased yields significantly in soils of Signali and Mngeta with soil Zn 3.4 and 3.0 mg Zn kg^{-1} respectively indicating may be toxicity was approaching. There was a decreasing but insignificant in yield for soils of Kisawasawa, Mkula-2 and Mangula with Zn levels 2.6, 1.6, and 1.5 respectively due to application of 5 over 10 mg Zn kg^{-1}.

Rasavel and Ravichandran [39] observed a similar trend in an alkali soil with DTPA-Zn of 0.21 mg kg^{-1} at Tamil Nadu, India. The results also indicated that Zn is a major limiting factor in Mbasa-1 and Mbasa-2 soils because Zn application resulted in close to 100% increase in grain yield. The grain yield increase can be explained by the fact that Zn controls enzymes related to reproduction [14,40]. The decrease in yield due to application of Zn at 10 mg Zn kg^{-1} suggests that Zn may approach the toxic levels when high rate of Zn is applied in soils with Zn above 3.0 mg kg^{-1} in soil. Sakal et al. [41] reported yield decrease when 5 and 10 mg Zn kg^{-1} were applied in calcareous soil with high levels of Zn. It is concluded that application of Zn in soils with low Zn concentrations from Kilombero resulted in increasing both the DMY and grain yield.

Table 6. Grain yield response to different rates of Zn in different soils

Site/Village	Zn Rates applied (mg kg^{-1}soil)				CV (%)
	AbC	Zn_0	Zn_5	Zn_{10}	
	Grain yield (g pot^{-1})				
Mngeta-1	8.3c	61.1b	67.4b	56.2a	11.2
Signali	9.9c	59.5a	60.8a	45.6b	4.2
Kisawasawa	4.5b	39.0a	45.5a	39.2a	26.6
Mkula-2	12.1b	48.4a	54.2a	43.8a	23.9
Mkula-1	8.6b	41.7a	39.9a	47.8a	19.8
Mbasa-1	4.53c	16.8b	30.2a	47.1a	33.1
Mbasa-2	2.9c	10.1b	31.6a	40.5a	13.5
Magombera	4.6c	28.7b	38.3a	46.7a	18.2
Mang’ula -2	7.5b	43.7a	51.5a	40.8a	19.2
Mang’ula -1	10.8d	23.9c	56.4b	68.2a	14.2

Means in the same row bearing the same letter(s) are not significantly different at (P=0.05); CV = Coefficient of variations. Treatment abbreviations with subscript numbers indicate the Zn rates applied in mg kg-1soil. AbC = Absolute control

3.3 Sulphur and Zinc Critical Levels in Soils

3.3.1 Sulphur critical level in soils

Estimates of critical concentration of S in soils using Cate and Nelson graphical method [18] are given in Fig. 1. The established critical S concentration in soils for rice under pot conditions was 10.0 mg kg^{-1}. Generally, the relative yield steadily increases with increase in soil S concentration. The lowest relative yield was obtained from the soil with sulphur 1.9 mg kg^{-1} and the highest relative grain yield was obtained from the soil with 12.1 mg kg^{-1}.

This S critical level in soil falls within the range of 6-12 mg kg^{-1}reported for most crops by [21]. Dobermann and Fairhust [22] reported the critical level of <5 mg kg^{-1}using 0.05 M HCl extractant. Huda et al. [24] reprted critical levels of 9.7 and 17.8 mg kg^{-1} for $CaCl_2$ and $NaHCO_3$ extractants, respectively.

3.3.2 Zinc critical level in soils

An estimate of zinc critical concentration by the Cate and Nelson graphical method [18] is given in Fig.2. The established critical concentration from this study was 1.4 mg kg^{-1}. The relative yield increases with increase in soil Zn up to the critical level of 1.4 mg kg^{-1} and leveled off. These results are close to the zinc critical level of 1.1 mg kg^{-1} established by [23] although it is relatively higher than that of 0.8 mg kg^{-1} using the DTPA extractant reported by [22,16].

3.4 Sulphur and Zinc Fertility Categories/ Status

The extractable S status of rice-growing areas of the Kilombero district is presented in Tables 2 and 7. Taking into consideration of the established critical level in this study, 17 (89.5%) out of 19 soils were deficient in S. Comparable results were reported by [8] that all the 20 soils sampled in Kilombero valley in her study contained S <5 mg S kg^{-1}, which fall in the deficiency range. These results taken together imply that S deficiency is a major factor limiting rice production in Kilombero district and that S application is very important when targeting higher grain yields.

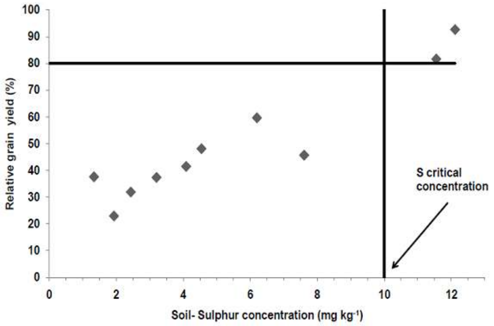

Fig. 1. Soil critical level of S for rice

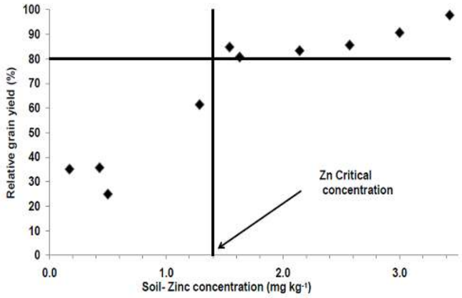

Fig. 2. Soil Zn critical level for rice

Table 7. Soil fertility categories and available S status of rice growing soils in Kilombero

Fertility category	Extractable S (mg kg^{-1})		
	Critical level	Range	Percentage of sampled soils
Deficient	< 10	1.2 – 7.6	89.5
Adequate	> 10	11.2 – 12.1	10.5

Table 8. Soil fertility categories and available Zn status of rice growing soils in Kilombero district

Fertility category	Extractable Zn (mg kg^{-1})		Percentage of sampled soils
	Critical level	Range	
Deficient	< 1.4	0.20 – 1.30	31.6
Adequate	> 1.4	1.50 – 4.60	68.4

The extractable DTPA-Zn status of rice-growing areas of the Kilombero district is presented in Tables 2 and 7. Considering the established critical concentration in this study, 31.6% of the studied soils from Kilombero district are deficient in Zn. Similarly, [42] reported three of the six soil samples from Kilombero district to contain Zn levels less than the established critical concentration. These results, taken together, imply that Zn is emerging plant nutrition problem in paddy soils of Kilombero.

3.5 Effects of S and Zn Fertilizer Application on Nutrient Concentration in Rice Shoots

3.5.1 Sulphur concentration on rice plants

The effect of added S to different soils in S-shoots concentrations is given in Table 9. The lowest values of S in rice shoots were recorded in the S control treatments for all the soils under study. Application of S increased S concentration in shoots in eight soils namely: Mngeta-1, Signali, Kisawasawa, Mkula-2, Mkula-1, Mbasa-1, Mbasa-2, and Magombera but did not increase shoot S concentration in two soils of Mang'ula -2 and Mang'ula -1.

Lower S concentration in S control treatment indicates that the application of other nutrients without S increased dry matter yield to without a corresponding increase in S uptake hence leading to a dilution effect. This suggests that application of S is important to achieve high DMY and grain yields. The lower grain yield and DMY obtained in the absolute control accompanied with high values of S in rice tissues in the same treatment than the treatment without S justify the need for nutrient balance. Ali et al. [12] reported rice shoots of a treatment without S application to contain between 0.11% and 0.22% similarly to the concentration observed in shoots grown in Mang'ula -1, Magombera, Mbasa-1 and Mbasa-2 in the without S treatment.

3.5.2 Zinc concentration on rice plants

The effects of added Zn to different soils on Zn-tissue concentration are given in Table 10. The rice plants grown in four soils (Mang'ula -1, Magombera, Mbasa-1 and Mbasa-2) had significantly greater Zn concentration with application of Zn at 5 mg kg^{-1} soil than the Zn-control. Application of Zn at 10 mg kg^{-1} to soils with >2.6 mg Zn kg^{-1}soil did not increase zinc tissue concentration and these soils were Mngeta, Signali and Kisawasawa. Anomalies of Mbasa-1 and Magombera having higher Zn levels in the plants from absolute control treatment are unexplained. An application of Zn at rate 10 mg kg^{-1} soil had a significant increase in Zn tissues to the 5 mg kg^{-1} treatment for the soil from Mbasa-1, which had 0.5 mg kg^{-1} soil concentration.

Table 9. Sulphur concentration in rice plants grown in ten soils applied with S

Village	S Rates applied (mg kg^{-1}soil)				CV. (%)
	AbC	S_0	S_{20}	S_{40}	
	Shoots- S concentration (%)				
Mngeta-1	0.23a	0.14b	0.23a	0.22a	20.8
Signali	0.15ba	0.12b	0.24a	0.26a	33.3
Kisawasawa	0.26b	0.14c	0.25b	0.33a	11.7
Mkula-2	0.28b	0.16c	0.24b	0.32a	10.0
Mkula-1	0.13d	0.16c	0.22b	0.25a	5.6
Mbasa-1	0.25a	0.12b	0.22a	0.22a	10.4
Mbasa-2	0.22a	0.13b	0.25a	0.25a	3.2
Magombera	0.21a	0.12b	0.22a	0.25a	12.0
Mang'ula -2	0.19b	0.27a	0.22ba	0.19b	12.9
Mang'ula -1	0.32a	0.29a	0.32a	0.31a	4.6

Means in the same row bearing the same letter(s) are not significantly different at (P=0.05); CV = Coefficient of variations. Treatment abbreviations with subscript numbers indicate the S rates applied in mg kg-1soil. AbC = Absolute control

Table 10. Zinc concentration in rice plants grown in ten soils applied with Zn

Village	Zn rates applied (mg kg^{-1}soil)				CV (%)
	AbC	Zn_0	Zn_5	Zn_{10}	
	Zn- shoots concentration (mg kg^{-1})				
Mngeta-1	36.0a	32.6 a	44.7a	52.8a	17.1
Signali	22.6a	32.4a	28.9a	33.9a	20.2
Kisawasawa	32.1a	30.7a	39.2a	45.5a	14.3
Mkula-2	23.9b	28.2b	32.9b	47.6a	13.8
Mkula-1	28.9b	32.7b	33.6b	47.8a	11.9
Mbasa-2	19.6b	14.5b	53.5a	56.6a	12.2
Mbasa-1	28.9c	11.4d	42.1b	54.9a	9.4
Magombera	37.4a	18.4b	36.9a	33.7a	11.7
Mang'ula -2	23.1b	24.3b	26.9ba	31.0a	8.2
Mang'ula -1	15.12b	13.3b	31.2a	35.6a	22.9

Means in the same row bearing the same letter(s) are not significantly different at (P=0.05); CV = Coefficient of variations. Treatment abbreviations with subscript numbers indicate the Zn rates applied in mg kg-1soil. AbC = Absolute control

Doberman and Fairhust suggested zinc concentration in rice tissues between 10 to 20 mg kg^{-1} to be deficient, which was observed in the three soils of Mang'ula-1, Magombera, Mbasa-1, Mbasa-2. This phenomenon was expected since these soils had low levels of Zn concentration and resulted in plants with relatively low DMY and grain yields which was accompanied with low Zn concentration in the Zn without treatment.

The trend why absolute control concentrations was high, it was similarly observed by [20] where anomalies of greater Zn concentration in the absolute control than in NPK fertilized treatments was observed and hindered the establishment of the critical shoot Zn concentrations. In the experiment [43] observed an addition of a small amount of zinc in a low zinc content soil resulted in a remarkable increase in dry weight which was associated with increased zinc content. An application of 5.25 Zn kg ha^{-1} was reported [38] to increase zinc concentration which is a similar effect of applying 5 Zn mg kg^{-1} treatment in shoots grown in Mang'ula-1, Magombera, Mbasa-1 and Mbasa-2 soils.

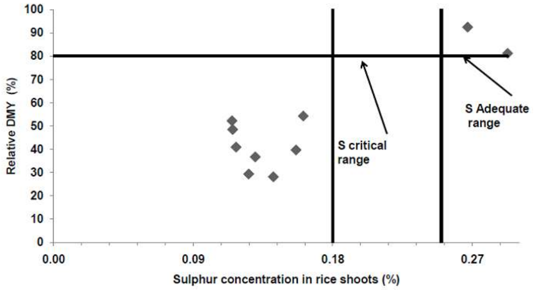

Fig. 3. Critical concentration range of S in rice shoots

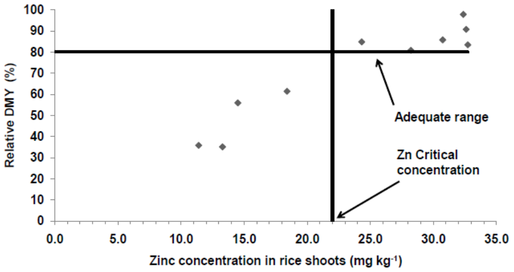

Fig. 4. Critical concentration of Zn in rice shoots

3.6 Critical Levels of S and Zn in Rice Shoots

This study also involved establishing the critical levels of S and Zn in rice shoots (Figs. 3 and 4).

3.6.1 Critical level of S in rice shoots

The Cate and Nelson plot depicted on Fig. 3 suggests the critical range of S in rice shoots to be 0.18 - 0.25%. The plants grown in soils below this critical range had a significant DMY and grain yield increase due to S application. It was suggested [22] that 0.15% S as the highest concentration in plant tissues where response to S fertilizer is not expected study.

3.6.2 Critical level of Zn in rice shoots

The critical concentration of Zn in rice shoots was approximated to be 22.0 mg kg^{-1} (Fig. 4)., This critical concentration is close to the lower level of the optimum range of 25-50 mg kg^{-1} reported by [22] as well as the lower level of the sufficiency range of 20-160 mg kg^{-1} reported by Campbell [44].

4. CONCLUSION

It was concluded that:

- Established soil critical concentration of S for rice is 10.0 mg kg^{-1}. This study revelead that 17 out of 19 soils of Kilombero studied are deficient in S for rice production. The established rice shoots-S critical range is 0.18 - 0.25%. An application of 20 mg kg^{-1} soil was optimum rate for soils deficient in S.
- Established soil critical concentration of Zn for rice is 1.4 mg kg^{-1}. Only six out of 19 soils were deficient in Zn for rice production. The established rice shoots-Zn concentration is 22 mg kg^{-1}. An application of 5 mg kg^{-1} soil was optimum rate for soils deficient in Zn. These results indicate that S is a big problem and its application and management is very crucial while Zn is an emerging problem in the pady soils of Kilombero valley.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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