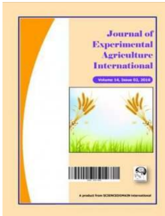

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Optimum Levels of Sulphur and Zinc for Rice in Lowland Areas of Kilombero District, Tanzania

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Authors' contributions

This work was carried out in collaboration between all authors. Author AMK designed the study, managed the field experiment, 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

Two on-farm experiments were carried out from January to May of 2014 and 2015 at Mkula, Mbasa and Kisawasawa sites to establish optimum rates of sulphur (S) and zinc (Zn) for rice production in Kilombero district, Tanzania. The treatments tested were: an absolute control and a control for N in both of the experiments. The other treatments for S experiment were a control for S, and sulphur rates of either 10 or 20 kg S ha^{-1}. The second experiment testing Zn had treatments: a control for Zn, Zn rates of either 2.5 or 5.0 kg ha^{-1}. All treatments other than the absolute control received all other limiting nutrients at adequate rates. The test crop was rice variety SARO-5. The results indicated that S application increased grain yield (GY) by 1.8, 2.8 and 1.8 t ha^{-1} at Mbasa, Mkula and Kisawasawa, respectively. The shoot S concentration increased from 0.13 to 0.29; 0.13 to 0.24 and 0.16 to 0.22% at Mbasa, Mkula and Kisawasawa, respectively. Zinc application increased yield significantly only at Mbasa site by 2.8 t ha^{-1} and shoot-Zn concentration from 11.5 to 27.0 mg kg^{-1}.

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The optimum rate of sulphur at Mbasa and Kisawasawa was 10 kg S ha^{-1} and 20 kg ha^{-1} at Mkula site. For zinc, the optimum rate at Mbasa site was 2.5 kg Zn ha^{-1}. It was concluded that sulphur application was needed in all the test sites to optimize yield while Zn was needed only at one site (Mbasa).

Keywords: Optimum rates; field experiment; nutrient responses.

1. INTRODUCTION

In Tanzania, rice (*Oryza sativa* L.) is the second widely cultivated cereal as staple and cash crop after maize. It is a major source of income, food and employment across the country, and particularly rural areas of Kilombero Valley in Tanzania. However, rice productivity is low and it is continuously declining in Tanzania. Many research works mentioned rice productivity to be as low as 1.0 t ha^{-1} under lowlands - rainfed [1,2]. Such yields are far below the potential of SARO-5 improved rice variety, which has recorded yields of more than 6.5 t ha^{-1} in experimental plots of fertilizer trials [3,4].

Soil is the main source of plant nutrients and supplies at least 14 mineral nutrients to plants, some of which are sulphur and zinc [5]. Nutrient balance is very important in rice production and blanket use of fertilizer adversely affects its production. Nutrients in soil whether naturally endowed or artificially maintained are major determinants of success or failure of a crop production system [6]. Declining soil and crop productivity is a major problem facing smallholder farmers in Kilombero valley, Tanzania [4,7] and this is caused by continuous cropping without addition of adequate external soil fertility inputs [1,8]. Recent studies have indicated that sulphur deficiency is a major problem covering more than 80% of soils in Kilombero valley [4,9]. A recent screen house study [9] demonstrated that rice grown in soils containing extractable S concentrations <10 mg kg^{-1} responded to S application, which requires confirmation under field conditions by establishing optimum levels of S in rice fields of Kilombero valley. Previously, other researchers reported critical values or ranges for S. Citing few, [10] reported an S soil critical range of 6-12 mg kg^{-1} in soils for most crops. Author [11] reported S critical value of < 5 mg kg^{-1} using 0.05 M HCl extractant while [12] using different extractants reported critical levels of 9.7 and 17.8 mg kg^{-1} for $CaCl_2$ and $NaHCO_3$, respectively.

Several studies have documented effects of S application on rice tissue concentration and grain yields. Very recently, [9] reported that application of all other limiting nutrients except S in soils with less than 10 mg kg^{-1} led to low levels of S in rice shoots ranging from 0.12 to 0.16% and low grain yields. This might be attributed to the fact that S 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 [13]. Consequently, S enhances nitrogen utilization and chlorophyll formation as a result affects plant vigor, nutrient concentration and grain yields. [14] reported that application of 30 kg S ha^{-1} increased rice yield significantly over the control in S deficient soil in India. [6] reported that application of S and other limiting nutrients increased rice yield by 35.16% above the control, indicating that inclusion of S was beneficial in rice production.

Zinc is an important micronutrient for rice production because it is required in a large number of enzymes and plays an essential role in DNA transcription. In addition, Zn is either a metal constituent in many enzymes or is a functional co-factor of a number of enzyme reactions [5,11]. It has previously been observed [15] that $ZnSO_4$ application at a rate of 6 mg Zn kg^{-1} soil increased grain yield by 41% over the control when applied in a soil with available Zn of 0.9 mg kg^{-1}. In the same study Zn application increased significantly rice shoot Zn concentration from 7.09 mg kg^{-1} (rated as low) to 18.84 mg kg^{-1} (rated as sufficient). In the same way, [16] reported a significant increase in grain yield after application of 5 mg kg^{-1} in a pot experiment using a soil with 0.86 mg kg^{-1}. Likewise, [6] reported an increase in Zn concentration in rice shoots from 27.0 in the control to 40.0 mg kg^{-1} after supplementing Zn on top of other necessary nutrients.

Earlier studies by [4,9] reported zinc deficient soils in Kilombero to constitute about 30% of the tested soils indicating that Zn deficiency is emerging as a problem for high rice yields. Only four percent of farmers in Kilombero district use inorganic fertilizers [1] supplying only N and P yet about 75% of farmers produce the high yielding improved variety TXD 306 (SARO -5) with a high demand of nutrients [7]. Therefore, inclusion of S and Zn fertilizers is likely to improve rice productivity. However, optimum rates of S and Zn in rice fields of Kilombero have not been established. Therefore, the objectives of the study were (i) To determine the response of rice to S and Zn in the cultivated rice fields in Kilombero valley (ii) To establish optimum rates of S and Zn for rice in Kilombero valley.

2. METHODOLOGY

2.1 General Description of the Study Area

The study area comprised three sites namely: Mkula, Kisawasawa and Mbasa located in Kilombero district, Tanzania. The study was carried out in the three sites during two different seasons: January to May of 2014 and 2015. The sites elevation ranged between 266 and 318 meters above sea level. The specific coordinates of the sites are given in Table 1.

During the growing seasons, the temperature ranged between 29.0 and 33.8℃. Total annual rainfall recorded 1138.1 mm in season one and 995.3 mm in season two with monthly rainfall peaks in March and April according to Kilombero Sugar Weather Station. Comparable rainfall and temperature data (rainfall between 1200 and 1400 mm falling between December to June and annual temperature ranges between 26 and 32℃ in Kilombero valley) have been reported by [8].

2.2 Soil Sampling and Sample Preparation

Soil samples were collected at a depth of 0 – 20 cm from representative sites in important rice producing areas of Kilombero district. In each site a minimum of 10 sub-samples using an auger were collected randomly in a relatively uniform area of about 0.5 ha. The soil sub-samples from each site were mixed thoroughly to constitute a representative composite sample, which was sent to SUA for laboratory analysis.

2.3 Soil Analysis

Soil pH was analyzed (1: 2.5 soil: water suspension) by using a pH meter [17], extractable P was determined according to the Bray 1 method [18] and colour development by phospho-molybdate blue method [19]. Exchangeable cations (Ca, Mg, K and Na) were determined from ammonium acetate (NH_4Oac) leachate [20]. Zinc was determined by Diethylene-triamine-pentaacetic-acid (DTPA) method [21] and its concentration in the filtrate was determined by atomic absorption spectrophotometry using appropriate standards. Extractable sulphur was extracted by calcium orthophosphate and determined by $BaCl_2$ turbidity method [22].

2.4 Management of Field Experiment and Data Collection

2.4.1 Experimental design

Two field experiments were carried out at three sites namely, Mkula, Mbasa and Kisawasawa for 120 days. At Mkula site, one acre was demarcated after soil analysis, where half of it was used in the first season (January to June 2014). The remaining (adjacent) part was used in the second season (January to June 2015). These fields are hereafter referred to as Mkula A and B. Mbasa site was used only during season one (December to June 2014) while Kisawasawa was used during the second season (January to June 2015).

The first experiment was carried out to assess rice response to sulphur and the second was to assess rice response to zinc. The treatments tested in the first experiment were: i) an absolute control, where no fertilizer was applied (T1), ii) a control for N but containing S and Zn (T2), iii) a control for S but containing adequate N and Zn (T3), iv) adequate levels of N and Zn plus a sulphur rate of 10 kg S ha^{-1} (T4) and v) adequate levels of N and Zn plus an S rate of 20 kg S ha^{-1} (T5). These treatments were designated as: T1= $N_0S_0Zn_0$, T2= $N_0S_{20}Zn_5$, T3= $N_{100}S_0Zn_5$, T4= $N_{100}S_{10}Zn_5$, and T5= $N_{100}S_{20}Zn_5$. In the second experiment comparable treatments were used but the nutrient under test was Zn and three rates of 0, 2.5 and 5.0 kg Zn ha^{-1} were applied while N and P were applied at adequate rates of 100 and 20 kg ha^{-1}, respectively. The five treatments were designated as T1= $N_0S_0Zn_0$, T2= $N_0S_{20}Zn_5$, T3= $N_{100}S_{20}Zn_0$, T4= $N_{100}S_{20}Zn_{2.5}$ and T5= $N_{100}S_{20}Zn_5$. The subscript number on each element indicates nutrient rates applied in kg ha^{-1}. Other necessary nutrients (i.e. P, K, Mg and Ca) were applied to all treatments except the absolute control, to avoid untargeted nutrients from limiting the response of rice to S and Zn as per soil test results obtained. The experimental units were arranged in a randomized complete block design (RCBD) with three replicates. Potassium was applied as KCl, phosphorus as triple super phosphate (TSP), zinc as $ZnSO_4$, calcium as $CaSO_4$ in the Zn experiment or $CaCl_2$ in the S experiment, and magnesium as $MgSO_4$ in the Zn experiment or $MgCl_2$ in the S experiment. All nutrients were applied at planting except N, for which 60% was applied at 21 days after transplanting/ or sowing and 40% was applied 28 days after the first N application making a total rate of 100 kg N ha^{-1} applied as urea. Fertilizers were broadcasted and thoroughly mixed into the soil using hand hoes. Urea was broadcasted uniformly on moist soil in the appropriate plots.

Land ploughing, harrowing and levelling was done using hand hoe twenty days before planting. Bunds were used to demarcate the blocks and plots and to minimize water movement from one plot to another. Each specific treatment was allocated within a plot making five plots within a block. The space between blocks was 1 m while the distance between the plots was 0.5 m and the plot area was 12 m^2.

Different sowing systems were used: direct sowing at Mbasa and Kisawasawa while raising seedlings in a nursery followed by transplanting was done at Mkula. The spacing was maintained as 0.2 m x 0.2 m for both direct sowing and transplanting. Direct sowing was done by sowing four to five seeds per hill and seedlings were thinned to two plants per hill 14 days after sowing (DAS). The nursery at Mkula was maintained for 18 days before transplanting seedlings to experimental plots. Two water management scenarios were used namely: sole dependence on rainfall used at Mbasa and Kisawasawa while at Mkula rainfall was supplemented with irrigation to maintain flooding. Flooding was done at 18 DAS or immediately after transplanting and was continually maintained up to 10 days before rice harvesting. A pesticide, Blast 60 EC (active ingredients Acetamiprid + Lambdacyhalothrin) was used once at 35 days after sowing (DAS) to control white flies and other pests.

2.4.2 Rice plant sampling, sample preparations and analysis

Rice plant samples were collected at booting stage (75 DAS). Three hills from the mid two rows in each plot were selected randomly and cut at 1 cm above the ground. The shoots were cleaned with distilled water, and then dried at 70℃ to attain constant weight. The dried shoots were weighed, ground with a cyclone mill and sieved through a 1-mm sieve for plant analysis. The remaining plants in the field were grown to maturity.

The plant samples were digested in a digestion block at 125ºC using the HNO_3-H_2O_2 wet digestion procedure [23]. Sulfate-S in the digest was determined by the $BaCl_2$ turbidity method using a spectrophotometer [23]. While in the same digest, Zn was determined by atomic absorption spectroscopy [23].

2.4.3 Harvesting of rice and grain yield determination

The grain yield (GY) was obtained at maturity (120 days after sowing) by harvesting panicles. One border row in each side (20 cm) was not harvested and only panicles of inner rows were harvested making a harvest area of 9.36 m^2. The harvested rice was then threshed, sun dried to achieve moisture content of about 14% and winnowed to remove unfilled grains before weighing. The GY was expressed in t ha^{-1}.

2.5 Statistical Data Analysis

All the data collected, including grain yield (GY) and nutrients concentration in rice shoots in response to S and Zn were subjected to analysis of variance using Gen-Stat Discovery Edition 15. Means were compared by Duncan's Multiple Range Test (DMRT) at P = 0.05. The coefficient of variation (CV) in percent and least significant difference (LSD) were reported.

3. RESULTS AND DISCUSSION

3.1 Soil Properties of the Study Sites

Soil characteristics of the three sites used in this study are given in Table 1. The pH ranged between 4.5 and 5.9 for the three sites was found to be medium at Kisawasawa and low at Mbasa and Mkula sites. Soil pH was rated according to [10] : < 5.5 as low and 5.5 to 7.0 as medium. Potassium concentration in soil ranged between 0.18 and 0.26 (cmol (+) kg^{-1} which fall in the low to medium ranges according to [10]: i.e. < 0.2 (cmol (+) kg^{-1} as low K and from 0.2 to 0.4 (cmol (+) kg^{-1} as medium. All the three study sites had low total N (i.e. 0.11 – 0.16%). According to [11], total nitrogen (TN) is rated as ≤ 0.1% very low, 0.1 to 0.2% as low, while 0.2 to 0.5% is rated as medium. [4] reported that nine out of 20 sites surveyed in Kilombero district had ≤ 0.2% total N, which indicates that N is a problem in most of the fields in the current study area. Extractable S ranged from 1.3 to 4.5 mg kg^{-1}. [11] reported sulphur critical range to be 6 to 12 mg kg^{-1} below which response to S fertilizers is expected and vice versa. Recently, [9] established 10 mg kg^{-1} as the critical concentration for S in soils of Kilombero district. Soil Zn concentration ranged between 0.5 to 2.6 mg kg^{-1} which falls in the low to high ranges according to [9,10,24].

3.2 Response of Rice to S under Field Conditions in Kilombero Valley

Grain yield and shoot S concentrations recorded at Mkula A and B sites are presented in Table 2. Grain yield at Mkula A site ranged between 2.83 and 7.27 t ha^{-1}; the lowest yield from absolute control treatment and the highest was from T5. The grain yields at Mkula A site in treatments T2 and T3 were comparable. Application of N, P, K and Zn while excluding S (T3) increased yield by 2.64 t ha^{-1} over the absolute control. A similar trend was observed at Mkula B site whereby treatment T3 gave significantly higher GY than T1 and the difference was 3.16 t ha^{-1}. Grain yield at 20 kg S ha^{-1}, (T5) was significantly higher than that at 10 kg S ha^{-1} ha at Mkula A site, but at Mkula B site yield at 20 kg S ha^{-1} was comparable to that at 10 kg S ha^{-1}. Grain yield difference between the S control treatment (T3) and the 20 kg S ha^{-1} treatment (T5), was 1.8 and 1.14 t ha^{-1} for Mkula A site and Mkula B site, respectively indicating that application of S was advantageous for rice production. Application of S at 20 kg ha^{-1} (T5) in addition to N, P, K and Zn increased GY by more than 4 t ha^{-1} over the absolute control (T1) at both sites indicating that farmers who do not apply all the deficient nutrients in their fields sacrifice a substantial GY.

Concentration of S in rice shoots was affected by application of S at Mkula A and B sites (Table 2). The treatments which did not receive S (T1 and T3) had low shoot S concentration compared to those that received S (T2, T4 and T5). Concentration of S in shoots increased with increasing S application and ranged from 0.22 to 0.29% for the treatments (T2, T4 and T5) which received S. The treatments without S (i.e. T1 and T3) had low shoot S concentration ranging between 0.14 and 0.15% indicating that application of S was important in increasing S concentration in plants.

The GY and shoot S concentration data recorded at Mbasa and Kisawasawa sites are presented in Table 3. Application of S at Mbasa site increased rice GY significantly from 4.57 t ha^{-1} to 7.39 t ha^{-1} for the S control treatment (T3) and T5, respectively. The two S rates tested, i.e. 10 and 20 kg S ha^{-1}, produced comparable grain yields. Application of other nutrients without N (T2) produced significantly higher yield than the absolute control (T1) treatment. However, the highest yield was obtained when N and S plus other nutrients were applied together (T5). Application of S either at 10 or at 20 kg ha^{-1} (T4 and T5) in addition to N, P, K and Zn produced 2.5 t ha^{-1} more GY than the S control (T3) treatment, indicating that S application had a big impact in increasing rice productivity at Mbasa site.

Grain yield at Kisawasawa was influenced by S application and the rates of 10 and 20 kg S ha^{-1} had comparable grain yields. Exclusion of N while applying S (T2) did not increase yield significantly and the treatments recorded very low GY compared to other treatments. This indicated that N was the most limiting nutrient in this site and that it has to be corrected first before response to other limiting nutrients can occur. The trend of rice yield response to S application at Kisawasawa was comparable to that at the other sites (Mkula and Mbasa). Application of S either at 10 or at 20 kg S ha^{-1} (T4 and T5) increased rice grain yield by more than 1.5 t ha^{-1} demonstrating the importance of S in increasing GY.

Concentration of S in rice shoots at Mbasa site ranged between 0.13 and 0.24% and was low in treatments that did not receive S (T3) and the absolute control (T1). The S concentration increased with increasing S application and the highest S concentration (0.24%) in T5 was significantly higher than 0.13% in the S control treatment (T3).

The response of rice to S (T4 and T5) was expected since the soil at all sites had S concentration lower than the critical level of

10 mg kg^{-1} established by [9] for Kilombero soils. Similarly, [11] reported that for soils with S levels below 5 mg kg^{-1} using 0.05 M HCl extractant, S application would increase GY and yields attributes. Equally, [14] reported the highest grain yield when S was applied at the rate of 30 kg ha^{-1} in a soil with 7.9 kg S ha^{-1} (equal to 2.8 mg kg^{-1}) supporting the highest increases in GY in treatments T4 and T5 in all the three sites. At all sites, high values of S in rice shoots occurred in treatments T4 and T5 (i.e. 10 and 20 kg S ha^{-1}) which also produced high GY compared to other treatments, indicating that application of S had positive effects on increasing both rice GY and S concentration in plants.

However, T1 and T2 treatments recorded concentrations lower than the established critical concentration/ range, indicating that low shoot S concentration is associated with low supply of S in soil. Recently, [4] found shoot-S concentration below 0.1% in all the treatments without S in experiments conducted at Mbasa, Kilombero district with soil sulphur level of 0.22 mg kg^{-1}. The results for all the sites are in conformity with other researchers [6,14,25,26,27,28] who reported that S application increased yield components of rice and GY. From the overall results of Mbasa and Kisawasawa sites, it is apparent that sulphur plays an important role in determining the yield and S concentration in rice shoots and that T4 and T5 treatments with 10 and 20 kg S ha^{-1} performed equally well. Therefore, an application of 10 kg S ha^{-1} is recommended for optimum yields of rice at the two sites. However, application of S at 20 kg S ha^{-1} was found to be optimum at Mkula site. From the above discussion, it was concluded that the four sites had low levels of S in soils. Application of S increased rice grain yield and shoot S concentration significantly.

3.3 Response of Rice to Zn under Field Conditions in Kilombero Valley

Zinc concentration in rice shoots and GY for Mkula A and B sites is presented in Table 4. At both sites, application of Zn at either 2.5 or 5.0 ha^{-1} (T4 and T5) did not increase grain yield significantly. Similarly, Zn application did not increase shoot Zn concentration significantly. Similar results were found at Kisawasawa site (Table 5). These results indicated that the soils at Mkula and Kisawasawa sites had enough Zn for rice growth and yield.

The results of GY and shoot Zn concentration recorded at Mbasa site are presented in Table 5. Zinc application at either 2.5 or 5 kg Zn ha^{-1} with all other necessary nutrients (T4 and T5) increased yield significantly above the Zn control but yields of T4 and T5 were comparable. There was a grain yield difference of about 2.8 t ha^{-1} when 5 kg Zn ha^{-1} was applied over the Zn control treatment (T3) indicating that the use of Zn was very crucial in increasing rice yields.

The concentration of Zn in rice shoots at Mbasa increased significantly with increase in Zn rates. The lowest shoot-Zn concentration was recorded in the treatments without Zn (T1 and T3) and the values were below the reported critical concentration.

On the other hand, the entire range of shoot Zn concentration values obtained at Mkula and Kisawasawa sites fell in a narrow range of 23.6 - 35.5 mg kg^{-1} which falls in the sufficiency range of 18-50 mg kg^{-1} reported by [9,11,29]. The results are consistent with those of [9,11,14] who reported that soils with sufficient levels of Zn do not to respond to Zn application. It evident from this study that Kisawasawa and Mkula soils with Zn levels above 1.4 mg kg^{-1} do not need Zn application at present.

The increase in rice GY at Mbasa site was expected as the level of Zn in soil was low (Table 1). Similar results were reported by [6] in which application of Zn on top of N, P, K, and S increased GY significantly by about 5.5% compared to zinc control treatment. Other workers have also reported comparable results. For example, [30] found significant increase in rice grain yield at three sites in Tabora district, Tanzania in soils with zinc levels < 0.64 mg kg^{-1} after applying 20 and 10 kg of $ZnSO_4$ and ZnO, respectively. Likewise, [16] reported 86% increase in grain yield after application of 5 mg Zn kg^{-1} soil in a pot experiment using a soil with 0.86 mg kg^{-1}. [12] reported that ZnSO4 application at a rate of 6 mg Zn kg^{-1} soil applied to a soil with DTPA available Zn of 0.9 mg kg^{-1} increased grain yield by 41%. Overall, it is evident from the above discussion that the three sites (Mkula A and B and Kisawasawa) had sufficient Zn supply at present and only Mbasa site had deficient Zn in soil. Application of 2.5 kg Zn ha^{-1} was found to be the optimum rate for Mbasa site.

Table 1. Selected soil chemical properties of the study sites

Site	Site location (Coordinates)	pH	TN (%)	P mg kg^{-1}	K (cmol (+) kg^{-1})	Mg (cmol (+) kg^{-1})	Ca (cmol (+) kg^{-1})	Na (cmol (+) kg^{-1})	S mg kg^{-1}	Zn mg kg^{-1}
Mkula	036°55'08.1" E 07°47'41.4'' S	5.9	0.13	2.2	0.18	6.0	4.5	0.1	4.5	1.6
Mbasa	036°42'42.8" E 08°05'46.0'' S	4.5	0.11	1.9	0.14	0.9	0.1	0.4	1.3	0.5
Kisawasawa	036°53'4" E 08°05'46.0'' S	5.1	0.16	12.6	0.26	4.7	2.8	0.5	1.9	2.6

Table 2. Effect of sulphur application on rice grain yield and shoot-S concentration at Mkula A and B sites

Treatment no.	Mkula A site				Mkula B site		
	Nutrient rates (kg ha^{-1})	Shoot -S concentration (%)	Grain yield (t ha^{-1})	GY change due to S application (t ha^{-1})	Shoot -S concentration (%)	Grain yield (t ha^{-1})	GY change due to S application (t ha^{-1})
T1	$N_0S_0Zn_0$	0.15b	2.83e		0.15b	2.69c	
T2	$N_0S_{20}Zn_5$	0.27a	3.77d		0.24a	2.91c	
T3	$N_{100}S_0Zn_5$	0.14b	5.47c		0.14b	5.85b	
T4	$N_{100}S_{10}Zn_5$	0.29a	6.18b	0.71	0.26a	6.59ab	0.74
T5	$N_{100}S_{20}Zn_5$	0.27a	7.27a	1.8	0.27a	6.99a	1.14
	LSD	0.04	0.618		0.028	0.776	
	CV. (%)	9.7	6.4		7.1	8.20	

Means in the same column bearing the same letter(s) are not significantly different at P=0.05; CV = Coefficient of variations. LSD = Least significant difference; Treatment rates abbreviations with subscript numbers indicate the nutrient rates applied in kg ha^{-1}.
"T" followed by a number indicates the treatment number

Table 3. Effect of sulphur application on rice grain yield and shoot S concentration at Mbasa and Kisawasawa sites

Treatment no.	Mbasa				Kisawasawa		
	Nutrient rates (kg ha^{-1})	Shoot -S concentration (%)	Grain yield (t ha^{-1})	GY change due to S application (t ha^{-1})	Shoot -S concentration (%)	Grain yield (t ha^{-1})	GY change due to S application (t ha^{-1})
T_1	$N_0S_0Zn_0$	0.14c	1.61d		0.16c	2.47c	
T_2	$N_0S_{20}Zn_5$	0.19b	2.13c		0.20b	2.56c	
T_3	$N_{100}S_0Zn_5$	0.13c	4.57b		0.16c	4.95b	
T_4	$N_{100}S_{10}Zn_5$	0.23a	7.08a	2.51	0.21a	6.45a	1.50
T_5	$N_{100}S_{20}Zn_5$	0.24a	7.39a	2.82	0.22a	6.76a	1.81
	LSD	0.045	0.509		0.039	0.493	
	CV (%)	13.2	5.9		11	5.7	

Means in the same column bearing the same letter(s) are not significantly different at P=0.05; CV = Coefficient of variations. LSD = Least significant difference; Treatment rates abbreviations with subscript numbers indicate the nutrient rates applied in kg/ ha.
"T" followed by a number indicates the treatment number

Table 4. Effect of zinc application on rice grain yield and shoot Zn concentration, at Mkula A and B sites

Treatment no.	Mkula A site				Mkula B site		
	Nutrient rates (kg ha^{-1})	Shoot -Zn concentration (mg kg^{-1})	Grain yield (t ha^{-1})	GY change due to Zn application (t ha^{-1})	Shoot -Zn concentration (mg kg^{-1})	Grain yield (t ha^{-1})	GY change due to Zn application (t ha^{-1})
T_1	N_0S_0 Zn_0	25.8a	2.83a		24.6b	2.69b	
T_2	N_0S_{20} Zn_5	27.5a	3.77b		28.9b	2.91b	
T_3	$N_{100}S_{20}$ Zn_0	26.7a	7.19c		29.6b	6.73a	
T_4	$N_{100}S_{20}$ $Zn_{2.5}$	26.3a	7.05c	-0.14	29.3b	6.88a	0.15
T_5	$N_{100}S_{20}$ Zn_5	26.6a	7.27c	0.08	35.3a	6.99a	0.26
	LSD	4.104	0.555		5.29	0.751	
	CV. (%)	8.1	5.2		9.5	7.6	

Means in the same column bearing the same letter(s) are not significantly different at P=0.05; CV = Coefficient of variations. LSD = Least significant difference; Treatment rates abbreviations with subscript numbers indicate the nutrient rates applied in kg/ ha.
"T" followed by a number indicates the treatment number

Table 5. Effect of zinc application on rice grain yield and shoot Zn concentration at Mbasa and Kisawasawa sites

Treatment no.	Mbasa site				Kisawasawa site		
	Nutrient rates (kg ha^{-1})	**Shoot -Zn concentration (mg kg^{-1})**	**Grain yield (t ha^{-1})**	**GY change due to Zn application (t ha^{-1})**	**Shoot -Zn concentration (mg kg^{-1})**	**Grain yield (t ha^{-1})**	**GY change due to Zn application (t ha^{-1})**
T_1	N_0S_0 Zn_0	13.02c	1.62d		23.6a	2.47a	
T_2	N_0S_{20} Zn_5	19.3b	2.13c		27.4a	2.56a	
T_3	$N_{100}S_{20}$ Zn_0	11.51c	4.56b		26.7a	6.41b	
T_4	$N_{100}S_{20}$ $Zn_{2.5}$	19.03b	7.09a	2.53	27.9a	6.33b	-0.08
T_5	$N_{100}S_{20}$ Zn_5	27.01a	7.39a	2.83	29.6a	6.76b	0.35
	LSD	2.65	0.509		7.270	0.436	
	CV (%)	7.8	8.9		14.3	4.6	

Means in the same column bearing the same letter(s) are not significantly different at P=0.05; CV = Coefficient of variations. LSD = Least significant difference; Treatment rates abbreviations with subscript numbers indicate the nutrient rates applied in kg/ ha.
"T" followed by a number indicates the treatment number

4. CONCLUSIONS

We conclude that all soils in rice fields under this study have low sulphur status while zinc deficiency was found only at one site indicating their deficient intensity in Kilombero district. The need for S application is inevitable although its good response is determined not only by soil test S but also sufficiency of other essential nutrients in the soil. There was also significant response of rice to Zn application in the soil that was deficient in Zn, indicating the need for soil testing for Zn to guide its application. Application of 10 kg S ha^{-1} was recommended as optimum rate for Mbasa and Kisawasawa while 20 kg S ha^{-1} was recommended for Mkula site. The optimum rate of Zn application is 2.5 kg Zn ha^{-1}, for Zn deficient soils like Mbasa site in Kilombero district.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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