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Response of Rice to Phosphorus and Potassium Fertilization Based on Nutrient Critical Levels in Plants and Soils of Kilombero Valley

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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, 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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Short Research Article

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ABSTRACT

Phosphorus (P) and potassium (K) optimization is crucial for achieving high yields of rice. This study objective was to establish optimum rates and critical concentrations of P and K in soil and rice shoots using soils from Kilombero district, Tanzania. Two-screen house experiment was carried out from December 2013 to May 2014 at Sokoine University of Agriculture (SUA), each using 10 soils collected from different sites in Kilombero valley. The first experiment had varied levels of P, namely 0, 40 and 80 mg kg^{-1} soil and the second with varied levels of K, namely 0, 200 and 400 mg kg^{-1} soil. Absolute control treatment was included in both experiments. Rice (variety TXD 306) was grown in pots arranged in a randomized complete block design with three replications. The results showed that soil critical concentration of P was 8.0 mg kg^{-1} and the shoots-P critical concentration was 0.16%. Established critical concentration of K in soil was 0.2 cmol (+) kg^{-1} and the shoots- K concentration was 1.4%. Grain yield increased significantly for rice grown in

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seven and six out of ten soils tested due to an application of P and K, respectively. The study recommends 40 mg P and 400 mg K kg^{-1} soil as optimum rates for P and K fertilization, respectively in deficient soils, under screen house conditions. A study revealed that eight and nine out of 19 studied soils from Kilombero are deficient in P and K, respectively for rice production. It was concluded that P and K are yield-limiting nutrients and their applications and management are crucial in the paddy soils of Kilombero valley.

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

1. INTRODUCTION

Rice (*Oryza sativa* L.) is an important staple and cash crop in Tanzania. However, productivity of rice is continually declining in Kilombero, Tanzania. Recent research [1,2] reported rice yield to range between 500 and 2000 kg ha^{-1} under rainfed lowlands of Kilombero district. The reported yield is lower than the potential of the widely grown rice variety, TXD 306 commonly known as SARO 5, of 4.3 to 6.5 t ha^{-1} [3]. Several factors are reported to cause the decrease in rice productivity, which include pests and diseases [4] inadequate water for irrigation [5], and inadequate water management [6] low soil fertility and long-term continuous cultivation without applying balanced nutrients [2,7,8]. Low soil fertility and imbalanced plant nutrition are important and their improvements may boost rice production for majority of Tanzanian farmers particularly those of Kilombero district. Currently only four percent of rice producers in Kilombero district [2] apply fertilizers containing nutrients like phosphorus (P), potassium (K), sulphur (S), zinc (Zn) and as a result, these nutrients are gradually declining in soils.

Phosphorus is vital to plant growth [9] and is found in every living plant cell. It is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starch, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next. Several researchers reported low soil phosphorus levels in the Kilombero valley and ranked P as a limitation to rice production [10]. More studies by [8] and [11] found 60% and 67% respectively, of soils under paddy production areas in Kilombero district, have insufficient P for adequate rice production.

Potassium is one of the three essential macronutrients required in the largest amount for plant growth and yield [9]. In most cases, K is lost from soils through leaching and burning or removal of plant residues. Rice straw removal and burning to clear the land for the succeeding rice crop are common practices in most rice fields of Kilombero. A recent study [11] showed three soils out of six samples collected in paddy soils of Kilombero district had low levels of K. Other researchers also reported the low K status in many villages of Kilombero valley [8,10,12]. The trend of low K in many soils in Kilombero may necessitate the application of K containing fertilizers. It is estimated that high amount of K at 14.5 kg is needed for producing one tone of rice [13,14].

It can be generalized that despite the importance of P and K in rice production, there are neither critical levels nor recommendations of P and K fertilization for Kilombero district. In addition, the information on response and critical levels of P and K for Tanzania in respect to rice is lacking. Therefore, the objectives of this study were (i) to determine the response of rice to P and K and (ii) to establish critical levels of P and K in soil and plant tissues for fertilization decision making.

2. METHODOLOGY

This study was conducted in a screen house located (6.8405° S, 37.6533° E) at SUA, Morogoro using soil samples collected from Kilombero district, Tanzania. The Kilombero 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 32℃ [15].

Within Kilombero district, 19 villages famous in rice production were surveyed and soil samples were collected for laboratory analysis. After analysis, soils with varied levels of P and K from 10 villages were selected and used for the screen house experiments. Two set of experiments were conducted, one for evaluating response of rice to P and the other experiment for evaluating response of rice to K. The treatments for experiment one contained P applied at rates of 0, 40 and 80 mg kg^{-1} soil while experiment two comprised of K applied at 0, 200, and 400 mg kg^{-1} soil. Both experiments had an absolute control that had no any nutrients applied. The experimental units were arranged in a randomized complete block design (RCBD) with three replicates. The blocking variable was sunlight 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 is less effective in ensuring uniform sunlight. Other essential nutrients (i.e. N, S, Mg, Ca and Zn) were applied to avoid untargeted nutrients to limit the response of rice to P and K. Potassium was applied as KCl, phosphorus as triple super phosphate (TSP), zinc as ZnSO4, calcium as $CaSO_4$, and magnesium was applied as MgO. All nutrients were applied at planting except N, 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 rate of applied nutrients other than P and K were designated as $N_{600}S_{20}Mg_{24}Ca_{50}Zn_5$, where the subscript numbers on each element indicate nutrient rates applied in mg kg^{-1} soil.

Eight pre-geminated rice seeds (TXD 306 variety also known as SARO 5) were sown in five-litre plastic pots containing 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 at 1 cm above the soil surface during booting stage at 63 DAS. Shoots were dried in the oven at 65℃ to constant weight, and weighed to obtain dry matter yields (DMY), also used for 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 Tissues Laboratory Analysis

The representative half kilogram of a composite soil sample collected from each site was analysed in the SUA Soil Science laboratory. Soil pH was analyzed in 1: 2.5 soil: water suspension by using a pH meter [16], Extractable P was determined according to the Bray I method [17] following colour development using molybdenum blue method [18]. Basic cations (Ca, Mg, K and Na) from ammonium acetate (NH_4Oac) leachate [19], Zn by Diethylene triamine penta acetic acid (DTPA) method [20] and their respective concentration in the filtrate were determined by atomic absorption spectroscopy using appropriate standards. Extractable sulphur extracted by Calcium orthophosphate and used $BaCl_2$ turbidity method [21].

The plant samples were digested in a digestion block at 125℃ using the HNO_3- H_2O_2 wet digestion procedure [22]. The extracted P in the digest was analysed following colour development using molybdenum blue method 18], while in the same digest K was determined by atomic absorption spectroscopy [22].

2.2 Potassium and Phosphorus Critical Levels Determination

The Critical levels of P and K in soils and plants were established by the graphical method of Cate and Nelson [23]. This method consists of constructing graphs of the relative yield (RY) 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 percentage relative yield (s) was calculated as:

[GY or DMY of P or K control treatment(s) x 100 / A treatment giving maximum yield] (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 P and K were subjected to analysis of variance using GenStat Discovery Edition 4.

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 General Characteristics of Soils Used in the Study

The initial nutrient status of soils used in the pot experiments is presented in Table 1 while the status of initial P and K for the 19 soils collected during survey is provided in Table 2.

Table 1. The initial chemical nutrients of soils used in the screen house experiment

Site/ village	pH	Ca	Mg	Na	Zn	S
			($cmol_{(+)}$ kg^{-1})			mg kg^{-1}
Kisawasawa-2	5.1	4.7	2.8	0.5	2.6	1.9
Signali-2	6.1	10.0	3.0	0.3	3.4	7.6
Mbasa-1	4.5	0.9	0.1	0.4	0.4	1.3
Mbasa-2	4.7	2.0	0.1	0.4	0.5	3.2
Magombera-2	4.9	1.6	0.7	0.3	1.3	2.4
Mkula-1	5.3	4.3	1.5	0.1	2.1	6.2
mkula-2	5.9	8.0	4.5	0.1	1.6	4.5
Mangula -1	5.6	6.7	2.9	0.1	0.2	12.1
Mangula -2	5.6	6.0	2.4	0.1	1.5	11.6
Mngeta-1	5.8	6.7	2.6	0.5	3.0	4.1

The values were used to categorize the status of the two nutrients (Tables 7 and 8) under study in the district.

Table 2. The status of P and K in the soils sampled during survey in Kilombero district

Site/ village	P (mg kg^{-1})	K ($cmol_{(+)}$ kg^{-1})
Kisawasawa-1	14.6	0.16
*Kisawasawa-2	12.6	0.27
Kisawasawa-3	25.5	0.25
Signali-1	23.1	0.44
*Signali-2	20.7	0.45
Kanolo	21.5	0.23
Njage-1	15.5	0.10
Njage-2	9.0	0.16
*Mbasa-1	1.9	0.12
*Mbasa-2	2.3	0.18
Mbingu	25.4	0.32
Magombera-1	6.8	0.27
*Magombera-2	1.9	0.10
*Mkula-1	2.3	0.15
*Mkula-2	2.2	0.18
* Mang'ula -1	2.0	0.20
* Mang'ula -2	11.3	0.21
*Mngeta-1	7.1	0.48
Mngeta-2	18.4	0.40

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

3.2 Dry Matter Yield Response to Phosphorus and Potassium

3.2.1 Dry matter yield response to phosphorus application

The rice dry matter yield (DMY) response to applied P is presented in Table 3. An absolute control treatment produced low DMY compared to the treatments applied with the varied nutrients. An application of P increased DMY significantly in the eight studied soils from Mkula-1, Mang'ula-1, Magombera, Mbasa -1, Mbasa -2, Mkula-2 Mngeta-1 and Signali villages.

Application of 80 mg P kg^{-1} soil was superior to 40 mg P kg^{-1} soil in significantly increasing DMY in soils from Mkula-1, Mang'ula -1, Magombera, Mbasa-2, Mkula-2, Signali and Mngeta-1. The better performance of 80 kg P kg^{-1} indicates that this rate was optimal under screen house condition for most of soils with available soil P below 7.1 mg kg^{-1}. There was a steady increase in DMY as the rates of P were increased in all the soils having low P. No DMY increase with increase in rate of P was observed in the two soils from Mang'ula -2 and Kisawasawa villages, the soils had high amount of P in soils.

The finding is consistent with findings of past studies by different authors, [24] reported increase of DMY after 30 mg P kg^{-1} application in soils with P below 7.1 mg kg^{-1}. The same author [24] indicated soils with very low P needed higher amount of about 60 to 120 mg P kg^{-1} soil to increase DMY significantly. The results are further supported by [25] who reported an application of 22 kg P ha^{-1} increased dry matter yield of rice by 99.3 and 127.4% in the neutral and alkali soils with Olsen's – P 0.11 and 0.12 mg kg^{-1}, respectively. Similarly, [26] reported 80% increase in shoot dry weight after the application of 131 kg P ha^{-1}, compared with the control treatment. The no increase in DMY in the two soils is supported by [14] mentioned that plants grown in soils with P below 7.0 mg kg^{-1} might not respond to P applications because the soils under this study had higher levels of P.

3.2.2 Dry matter yield response to K applied to different soils

The DMY response to applied K is presented in Table 4. Application of either 200 or 400 mg of K kg^{-1} soil increased DMY significantly for plants grown in low K soils from Mkula-1, Mang'ula -1, Magombera, Mbasa-1, Mbasa-2, Mkula-2 villages. The DMY of rice grown in soils from Mngeta-1, Mang'ula -2, Signali and Kisawasawa were not significantly affected by K application. An application of 400 mg K kg^{-1} was superior to 200 mg K kg^{-1} in soils from Mkula-2, Mbasa-1, Magombera and Mbasa-2. An application of 200 mg kg^{-1}soil performed equally with 400 mg K kg^{-1} in increasing DMY in soil Mang'ula -1. The response of K obtained in soils with K concentration approaching 0.20 cmol (+) kg$^{-1.}$

There are similarities between the results under this study and other research works. For example [27,28] reported an increase of DMY from 22 to 27% after an application of 74 and 114 kg K ha^{-1}, respectively in a soil containing 0.08 cmol (+) kg^{-1} soil. Further, [29] found application of 65 mg K kg^{-1} soil giving high yields of straw in the pot experiment. In addition, an application of 415 and 1245 mg K kg^{-1} soil increased dry matter significantly in soils of Iran [30]. The reported findings shows that increase in K rates further increase the DMY in soils with low K. Likewise, [31] found no increase in DMY in the pot experiment when a maximum of 50 mg kg^{-1} was applied in a soil containing 0.4 cmol (+) kg^{-1}. This indicates that sometimes K applied in soils with high K like Kisawasawa, Mngeta-1, and Signali cannot give a significant response in DMY accumulation.

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

Village/ site	P rates applied (mg kg^{-1} soil)				CV (%)
	ABC control	P_0	P_{40}	P_{80}	
	Dry matter yield (g pot^{-1})				
Mngeta-1	5.13c	27.92b	30.08b	37.32a	12.8
Signali	5.23c	39.11ab	31.08b	45.74a	17.4
Kisawasawa	1.76b	31.21a	27.57a	47.33a	13.2
Mkula-1	3.51d	13.48c	21.02b	31.91a	19.2
Mkula-2	5.59d	15.15c	24.92 b	40.6a	13.2
Mbasa-1	3.79b	11.89b	28.09a	34.31a	25.0
Mbasa-2	1.6c	8.0c	17.35b	27.65a	10.1
Magombera	2.49c	2.7c	16.96b	32.98a	24.1
Mang'ula -2	4.16b	35.39a	33.49a	43.06a	16.2
Mang'ula -1	11.98c	19.99c	37.03b	54.69a	25.1

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 P rates applied in mg kg^{-1} soil. ABC = Absolute control

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

Village/ site	K rates applied (mg kg^{-1} soil)				CV (%)
	ABC	K_0	K_{200}	K_{400}	
	Dry matter yield (g pot^{-1})				
Mngeta-1	5.13b	32.72a	33.14a	36.06a	27.9
Signali	5.23b	33.13a	35.86a	45.74a	27.2
Kisawasawa	1.76c	30.14a	32.2a	32.87a	17.3
Mkula-1	3.51c	14.69b	29.93a	31.91a	16.4
Mkula-2	5.59c	26.16b	26.77b	40.6a	19.1
Mbasa-1	3.79c	11.89c	28.09b	44.31a	11.36
Mbasa-2	1.37c	12.38b	11.98b	36.62a	29.3
Magombera	2.49c	15.27c	28.52b	43.65a	12.4
Mang'ula -1	11.98c	32.94b	54.69a	56.23a	6.9
Mang'ula -2	4.16c	36.76a	40.26a	43.06a	9.1

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 K rates applied in mg kg^{-1} soil. ABC = Absolute control

3.3 Grain Yield Response to Phosphorus and Potassium Application in Soils of Kilombero District

3.3.1 Grain yield response to phosphorus application

The grain yield response to applied P is presented in Table 5. The rice plants grown in seven soils with low P namely Mkula-1, Mang'ula -1, Magombera, Mbasa-1, Mbasa-2, Mkula-2, and Mngeta-1 gave higher grain yield with P fertilizer application than without P fertilizer application.

The two rates of P, an application of 40 and 80 mg kg^{-1} soil did not differ significantly in grain yield. An application of 80 mg/kg had significantly greater grain yield over the 40 mg/kg only in Mbasa-1 and Mbasa-2 soils which had very low soil test P (i.e. 1.9 and 2.3 mg kg^{-1}, respectively) and responded to P application.

Taking into consideration both DM and grain yields, an application of 40 mg kg^{-1} can be recommended as an optimal rate for the screen house trial for soils containing P less than 7.1 mg kg^{-1}. The results agree with [32] who reported an application of 31 kg P ha^{-1} during the field experiment increased grain yield by 42% in shallow Red Brown Terrace soils of Bangladesh. It was further observed a significant increase in grain yield after applying different levels of P over control in a soil with extractable P of 2.9 mg kg^{-1} [25]. High doses of P might have improved P availability and uptake to plants resulting in increased grain yield attributes and GY [9] justifying grain yield increase due to 80 mg kg^{-1} application in Mbasa- 2 soil. In general, the findings shows that the application of P in all soils with low P increased DMY and grain yield, while the soils with relatively high P did not show the benefit of P application for either of the rates of P tested.

3.3.2 Grain yield response to potassium application

Absolute control yielded very low relatively to grains harvested from pots which were fertilized with K at different rates. An application of other nutrients rather than K produced much more grains compared to the absolute control. Comparing other treatments with K-without (K_0) treatment there was no a significant increase in rice grain yield observed for four potted soils namely Mngeta-1, Signal, Kisawasawa and Mang'ula -2. Plants grown in soils with low K namely Mkula-1, Magombera, Mbasa-1, Mbasa-2, Mkula-2 and Mang'ula-1 responded with fertilizer application. An application of 400 mg kg^{-1} soil did have a significant increase on grain yield when compared to 200 mg kg^{-1} soil for soils namely: Mkula-1, Mkula 2, Mang'ula -1, Magombera and Mbasa-2. This may indicate that 400 mg kg^{-1} soil is a suitable K application rate for soils with less than 2.0 cmol (+) kg^{-1} for high yield of rice.

The similar results were reported [31] that no significant increase in grain yield for the 50 mg kg^{-1} treatment applied in 0.4 cmol (+) kg^{-1} soil as observed in soils of Kisawasawa, Mngeta-1, and Signali. Similarly, an increase of grain yield in soils with < 2.0 cmol (+) kg^{-1} is justified by [27]

Table 5. Grain yield response to applied P in ten soils from Kilombero district

Village/site	P rates applied (mg kg^{-1} soil)				CV (%)
	ABC	P_0	P_{40}	P_{80}	
	Grain yield (g pot^{-1})				
Mngeta-1	8.3c	53.93b	58.53ab	67.4a	15.2
Signali	9.9 b	55.3a	54.33 a	60.83a	5.8
Kisawasawa	4.53b	39.7a	42.63a	45.53a	12.6
Mkula-2	9.13c	26.77b	44.97a	54.2a	23.6
Mbasa-1	4.53c	13.23c	31.63b	47.07a	17
Mbasa-2	2.88d	8.45c	31.60b	42.52a	4.9
Magombera	4.6b	6.4b	20.2a	46.67a	10.7
Mang'ula -2	7.5b	43.0a	42.1 a	51.47 a	7.8
Mang'ula -1	10.8b	14.13b	51.43a	68.2a	20.1
Mkula-1	8.63b	13.6b	36.93a	43.2a	19.4

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 P rates applied in mg kg^{-1} soil. ABC = Absolute control

Table 6. Grain yield response to applied K in ten soils from Kilombero district

Village/site	K rates applied (mg kg^{-1} soil)				CV (%)
	ABC	K_0	K_{200}	K_{400}	
	Grain yield (g pot^{-1})				
Mngeta-1	8.3b	59.8a	67.4a	53.97a	23.1
Signali	9.9b	58.4a	60.83a	58.4a	19.7
Kisawasawa	4.53b	40.0a	36.27a	45.53a	12.8
Mkula-1	6.63d	11.87c	33.57b	43.2a	25.0
Mkula-2	12.13d	37.13c	49.5 b	54.2a	17.1
Mbasa-1	4.53c	13.7 b	34.2 a	47.07a	27.6
Mbasa-2	2.88d	14.95c	30.13b	50.78a	10.7
Magombera	4.6d	15.13c	32.3 b	46.67a	20.1
Mang'ula -2	7.5b	46.57a	46.93a	51.47a	9.8
Mang'ula -1	10.8c	57.03b	55.43b	68.2a	12.4

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 K rates applied in mg kg-1 soil. ABC = Absolute control

reported a significant increase of rice grain yield after application of K in a soil containing 0.08 cmol (+) kg^{-1}. In general, from the current study, it can be concluded that an application of K in soils with K below 2.0 cmol (+) kg^{-1} increased grain and dry matter yields of rice plants.

3.4 Phosphorus and Potassium Critical Level in Soils

3.4.1 Phosphorus critical level in soils

The critical concentration of P in soils using Bray-I extractant was estimated to be 8.0 mg kg^{-1} (Fig. 1).

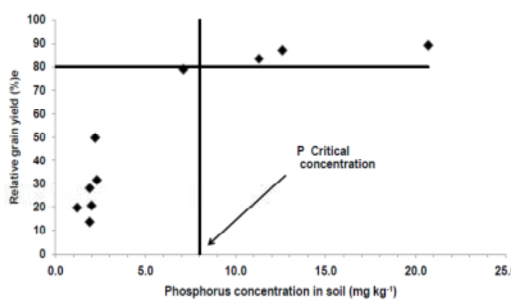

Fig. 1. The critical level of phosphorus in soil for rice production under flooded conditions

Plants grown in soils with P below the established critical concentration responded positively in terms of DMY and grain yields when P was applied in the current study.

A close value of 7.0 mg kg^{-1} was reported as a critical P level for soils under rice production in Eastern and Northern zones of Tanzania [11]. Another author [14] reported 7 mg kg^{-1} Bray -1 extracted P as a critical concentration for rice crop. He further suggested when targeting rice yield than 8 t ha^{-1} the response due to P fertilizer is probable for soils that contain extractable P levels below the range of 7 to 20 mg kg^{-1}.

3.4.2 Critical level of K in soils

The established soil critical concentration of K for soils collected from Kilombero was 0.20 cmol (+) kg^{-1} (Fig. 2). Below that value, positive response to application of K fertilizer was observed in terms of grain yield and DMY.

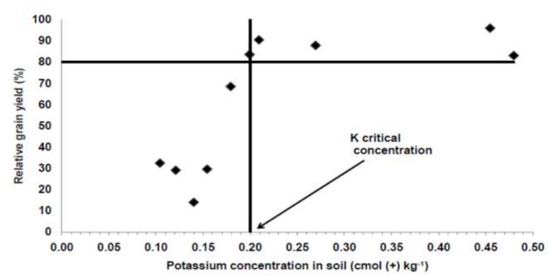

Fig. 2. The critical level of potassium in the soil for rice production under flooded conditions

Little information is reported on critical concentration of K in soils for the rice in Tanzania. [33] reported 0.3 cmol (+) kg^{-1} for maize grown in the *Typic rhodustalfs* family. The other [14] gave 0.15 cmol (+) kg^{-1} as a critical concentration for K in soils but suggested a wide range of 0.1 to 0.4 cmol (+) kg^{-1} as a critical range for rice depending on the soil texture, clay mineralogy and natural source of K.

3.5 Phosphorus and Potassium Fertility Categories/ Status

The extractable P levels and P fertility categories of rice-growing areas of Kilombero district are presented in Tables 2 and 7, respectively. Taking into consideration the established critical level in this study, eight (42.1%) out of 19 studied soils were deficient in P.

Previous studies by other researchers [11] reported that three (50%) out of six soils from Kilombero district had P lower than the established critical concentration. Similar results were also reported by [34], which indicated that 12 soils (60%) out of 20 soils from Kilombero valley contained P less than 8 mg kg^{-1}. This trend implies that P deficiency is emerging, as a major factor, limiting rice production in Kilombero district, and its application is would be important when targeting higher grain yields in Kilombero district.

The extractable K level and the K fertility categories of rice-growing areas of the Kilombero district are presented in Tables 2 and 8, respectively. Considering the established critical concentration of K, nine (47.3%) of the 19 studied soils in Kilombero district were deficient to K.

Similarly, a study by [11] reported that three (50%) out of six soil samples from Kilombero district contained K less than the established critical concentration while [34] found that 15 (75%) out of 20 soils in Kilombero valley contained K levels less than 2.0 (cmol (+) $kg^{-1)}$ which is deficient. This implies that K deficiency in soils is also becoming a major constraint to paddy production in Kilombero district.

3.6 Effects of P and K Fertilizer Application on Nutrient Concentration in Rice Shoots

3.6.1 Phosphorus concentration on rice shoots

Phosphorus application in soils with low P resulted in significant increase in shoots P concentration (Table 6). Soils that initially had P concentration below the critical level resulted in plants having low P concentration on rice shoots. The treatment with all other nutrients except P (P_o) had lower P concentration in plant tissues than P treatments and the absolute control.

Soils with higher levels of P did not increase tissue P concentration. The soil from Mngeta-1 village with 7.2 mg P kg^{-1} did not show any significant change in P concentration when P was applied although it had significantly high DMY.

Similarly, [26] reported a range of P concentration increasing from 0.10 to 0.18% when 655 kg ha were applied in soils. It has been reported [14] that the most observed range of P concentration in rice shoots from a wide range of fields was 0.07 to 0.12% with an average of 0.1% [14]. In another experiment [26], the treatment that did not receive P had 0.12% P while the one applied with 655 kg ha $^{-1}$ recorded 1.6% in rice tissues.

Table 7. Soil fertility categories for available P status of rice growing soils in Kilombero district

Fertility category	Extractable P (mg kg^{-1})		
	Critical level	Range	Percentage of sampled soils (n=19)
Deficient	< 8	1.9 – 7.1	42.1
Adequate	> 8	11.3-25.5	57.9

**n-number of soil samples*

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

Fertility category	Extractable K ($cmol_{(+)}$ kg^{-1})		
	Critical level	Range	Percentage of sampled soils (n=19)
Deficient	< 0.2	0.10 – 0.20	47.3
Adequate	> 0.2	0.21 – 0.48	52.7

**n-number of soil samples*

Table 9. Phosphorus concentration in rice shoots grown in ten soils applied with P

Village/site	P rates applied (mg kg^{-1} soil)				Cv (%)
	ABC	P_0	P_{40}	P_{80}	
	P concentration in rice shoots (%)				
Mngeta-1	0.17a	0.17a	0.18a	0.20a	19.6
Signali	0.18a	0.19a	0.19a	0.25a	15.3
Kisawasawa	0.19a	0.20a	0.189a	0.22a	12.6
Mkula-2	0.11b	0.09b	0.19a	0.20a	7.6
Mbasa-1	0.13c	0.07c	0.16b	0.25a	19.0
Mbasa-2	0.10b	0.09b	0.18a	0.22a	8.6
Magombera	0.11b	0.11b	0.18a	0.19a	8.4
Mangula -2	0.18a	0.21a	0.19a	0.21a	11.8
Mangula -1	0.12c	0.13c	0.19b	0.22a	9.1
Mkula-1	0.20b	0.10c	0.19b	0.23a	4.9

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 P rates applied in mg kg^{-1} soil. ABC = Absolute control

3.6.2 Potassium concentration on rice plants

Potassium application increased concentration of K in plant tissue especially for plants grown in soils with low K levels (Table 10).

The concentration of K in rice shoots in the control ranged between 0.75 and 1.49% for plants grown in soils with K below 0.21 cmol+ kg^{-1}. There was no significant increase in K concentration in shoots for plants grown in soils with exchangeable K above 0.21 cmol+ kg^{-1}. There was significant differences in K concentration in rice shoots between 200 and 400 mg K /kg treatments in soils from Mkula-1, Mangula -1, Magombera and Mbasa-2 villages which had low K.

The observed concentration in rice tissues of K_0 treatment is close to the findings of 1.06 observed in unfertilized plots, which were significantly lower to 2.07% K, obtained in the 75 kg K ha^{-1} fertilized plots [27], also supporting the higher K concentration in shoots for the K_{200} and K_{400} mg kg^{-1} treatments in the current study. Leaf K concentrations of unfertilized soils of Mkula-1, Mkula-2, Mbasa-1, Mbasa-2 and Magombera are similar to 0.48 to 0.91% values observed in plants grown in unfertilized alluvial soils of Mekong Delta, Vietnam [35].

3.7 Critical Levels of Phosphorus and Potassium in Rice Shoots

3.7.1 Critical levels of P in rice shoots

The estimated critical concentration of P in rice shoots was 0.16% (Fig. 3). The treatments that did not receive P and in the soils with initial low P resulted in shoot P concentration lower than the established critical concentration. Below the adequate range, the response to P was expected. All of the plants grown in soils with high soil P had adequate shoot P concentration. It was reported that P concentration in the leaf blade needed to be around 0.18% for the maximum tillering rate [14]. Another study [26] reported that the average P content of 0.16% in rice leaves is adequate for rice growth and yield.

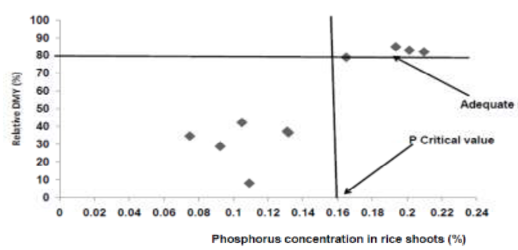

Fig. 3. Critical concentration of P in rice shoots

3.7.2 Critical levels of K in rice shoots

The critical concentration of K in shoots was estimated to be 1.4% (Fig. 4). Below the adequate range, the response to K was observed; all of the plants grown in soils with higher K were in the adequate range.

It can be generalized, that rice shoots with less than 1.4% K concentration will positively respond to application of K fertilizers. A researcher [14] reported 1.5% as critical concentration in rice tissues, which is close to the established value in this study.

Table 10. Potassium concentration in rice plants grown in ten soils applied with K

Village/site	K rates applied (mg kg^{-1} soil)				
	ABC	K_0	K_{200}	K_{400}	CV (%)
	K concentration in rice shoots (%)				
Mngeta-1	2.78a	2.8a	3.06a	3.2a	14.9
Signali	3.47a	2.48a	2.73a	3.59a	12.7
Kisawasawa	1.35a	1.70a	1.72a	1.76a	16.2
Mkula-2	1.37b	0.96b	1.79b	3.12a	7.6
Mbasa-1	1.09c	0.75c	1.52b	2.01a	12
Mbasa-2	1.00b	0.91b	1.67a	1.70a	9.9
Magombera	1.00b	0.86b	1.81a	2.09a	13.1
Mangula -2	2.51a	1.46c	1.78b	2.41a	17.1
Mangula -1	1.54b	1.48b	2.41a	2.47a	9.0
Mkula-1	1.24b	1.16b	1.95a	2.44a	4.9

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 K rates applied in mg kg-1 soil. ABC = Absolute control

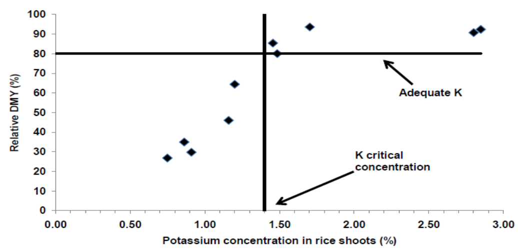

Fig. 4. Critical concentration of K in rice shoots

4. CONCLUSIONS

The following conclusions were made from this study.

- The soil critical concentration of P for flooded rice is 8.0 mg kg^{-1}, below which P fertilization will result in increase in rice yield The study revealed that eight out of 19 (42.1%) of the soils analyzed from Kilombero district are deficient in P for rice production. The critical concentration of P in rice shoots is 0.16%. An application of 40 mg P kg^{-1} soil was an optimum rate for soils deficient in P.
- The soil critical concentration of K for flooded rice is 0.2 cmol (+) kg^{-1}, below which a positive response to K fertilization is expected. Nine out of 19 (47.3%) of the soils analyzed were deficient in K for rice production. The critical concentration of K in rice shoots is 1.4%. An application of 400 mg K kg^{-1} soil was an optimum rate for soils deficient in K. These results indicate that P and K deficiencies are constraining rice production and their applications and management are crucial in the paddy soils of Kilombero valley.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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