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Effects of Different Phosphorus Fertilizers on Rice (*Oryza sativa* L.) Yield Components and Grain Yields

Prosper I. Massawe[1*] and Jerome Mrema[2]

[1]Selian Agricultural Research Institute, P.O. Box 6024, Arusha, Tanzania.
[2]Department of Soil Science, Sokoine University of Agriculture, P.O. Box 3000, Morogoro, Tanzania.

Authors' contributions

This work was carried out in collaboration between both authors. Author PIM designed the study, wrote the first draft and managed the literature searches. Author JM managed the analysis of the study and made corrections to the first manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

A study to investigate the effects of phosphorus (P) from Minjingu Phosphate Rock (MPR), Minjingu mazao and Triple Super Phosphate (TSP) fertilizers under irrigated rice (*Oryza sativa* L.) production was conducted in two sites of Lekitatu village, Meru district, Arusha region, Tanzania. The fertility status of the soils and their suitability for rice production at two experimental sites were evaluated based on technical indicators of soil fertility. The major soil fertility limitations included low soil organic matter, low total nitrogen and medium available phosphorus hence the rice soils in Lekitatu village were categorized as of low fertility status and moderately suitable for rice production. A Randomized Complete Block Design (RCBD) with three replications was adopted. Phosphorus was applied at the rates of 0, 20, 40 and 60 kg P ha^{-1} as MPR, Minjingu mazao and TSP. Nitrogen was applied uniformly at a rate of 60 kg N ha^{-1} as urea to the MPR, Minjingu mazao and TSP treatments plots taking into account the 10% N contained in the Minjingu mazao fertilizer. The P fertilizers were broadcasted and incorporated into the soils before transplanting the rice seedlings and N was applied at two equal splits, namely at tillering and panicle initiation stages. The ranges in yield components between the control (0 kg P ha^{-1}) and the highest levels of P (60

**Corresponding author: Email: massawep17@gmail.com;*

kg P ha^{-1}) were 23.47 – 64.97, 23.47 – 66.17 and 23.47 – 60.03 cm plant heights, 12–22, 12–19 and 12–22 number of tillers per plant, 7.67–25.97, 7.67–26.83 and 7.67–30.20 tha^{-1} dry matter yields, 3.97 – 15.70, 3.97 – 17.03 and 3.97 – 15.77 tha^{-1} straw dry matter yields and 1.5–8.63, 1.5–9.23 and 1.5–10.43 tha^{-1} grain yields for MPR, TSP and Minjingu mazao, respectively. The P fertilizers applications increased rice yield components as the levels of P increased from 0 to 60 kg P ha^{-1} for all P sources. The yield components increased significantly ($P<0.05$) with increasing rates of P application. The increases were due to increased availability and uptake of plant nutrients particularly P. Based on the generated yields data, it was thus concluded that: Minjingu mazao at the rates of (40 to 60 kg P ha^{-1}), MPR and TSP at a rate of 60 kg P ha^{-1}, respectively could be adopted for increased and sustainable rice production in Lekitatu village.

Keywords: Rice; MPR; Minjingu mazao; TSP; yield components; soil fertility.

1. INTRODUCTION

Rice is among the major food crops of the world in terms of area under rice cultivation and the number of people depending on rice for their livelihoods [1]. For many years, rice after maize has been an important staple food for the majority of Tanzanians and will continue to be so for the foreseeable future [2]. Rice is grown in many parts of Tanzania covering an area of over 365000 hectares in varied ecosystems ranging from uplands to lowlands [3]. In Tanzania lowland and upland rice is mainly cultivated on large scale farms like the Kapunga Rice Farms which cover approximately 20000 hectares [1]. Small scale farmers' irrigation rice schemes like the Lower Moshi project also contribute substantially to rice production in Tanzania. The most important rice growing regions in Tanzania include Tabora, Morogoro, Mbeya, Shinyanga and Coast [4].

The importance of rice as a food crop calls for more efforts to increase the levels of rice production so as to ensure food security and income generation. However, previous data indicate that rice yields in most of the rice growing areas in Tanzania are low and decreasing with time with an overall average yield estimated at 1.74 t/ha [5]. The total production of 812000 tons is below the consumption needs of 872000 tons and therefore about 60000 tons per annum are imported to cover the shortfall [6]. A number of factors such as declining soil fertility, inadequate use of fertilizers, poor crop husbandry and inadequate rainfall have been reported to contribute to the low levels of rice yields in Tanzania [7]. Of these factors, soil fertility and nutrient management have a major influence on both the rice yields and quality [8]. Because Tanzania needs to raise the rice production levels so as to feed her growing population, soil fertility and nutrient monitoring in rice production systems should be given due consideration.

Over the years there has been a growing tendency of rice growers trying to raise rice yields by the application of nitrogenous fertilizers alone like for example in Lekitatu village, Meru district, Arusha region, Tanzania. However, rice, like any other crop requires balanced nutrients for optimum yields and one of the most deficient or limiting nutrients in rice production in Tanzania is phosphorus. Studies by Msolla [7], Mzee [9] and Shekifu [10] reported low levels of P in the rice growing soils of Tabora, Morogoro, Coast and Mbeya regions, respectively. The deficiency in available P is reported to be related to low soil organic matter, low soil pH, inherent low P contents in the parent materials of the soils and presence of P-fixing compounds in soils and inadequate application of P fertilizers [11]. Limited research has been done in respect of the inadequate P fertilization in the rice growing area of Arumeru district hence no sufficient data regarding P fertilizer use is available for sustainable rice production. Further, limited research has been undertaken to identify the most appropriate P-fertilizers (P-carriers) for rice cultivation in these areas (soils). Furthermore, the P in soils is to a very large extent controlled by the P-carriers that is the types, forms and kinds of the P-fertilizers or P sources [12]. Therefore, there is the need to assess the response of rice to P from different types of phosphatic fertilizer materials namely, Minjingu mazao, Minjingu phosphate rock and Triple super phosphate as sources of P for irrigated rice growing in Lekitatu village so as to identify the appropriate P-fertilizers for the soils and subsequently extrapolate to other rice growing areas with similar conditions in Tanzania. The three P sources named above have been chosen because they are locally available in Tanzania at affordable price to small scale rice farmers compared to other P fertilizers like for example diamonium phosphate (DAP).

The main objective of this study was to increase rice yields so as to attain food sufficiency and income generation through the use of the appropriate P-carrier (fertilizers) as a soil fertility management strategy. The specific objectives were to characterize the soils of Lekitatu village with respect to rice production, to establish the plant available P status in Lekitatu village soils, to determine the response of rice to different P fertilizers namely; Minjingu mazao, Minjingu phosphate rock and TSP.

2. MATERIALS AND METHODS

2.1 Site Location and Description

A study to evaluate the fertility status of soils for rice production and response of rice to different sources of phosphorus (P) was conducted in Lekitatu village, Meru district, Arusha region, Tanzania. The district lies between longitudes 36° 15 – 36° 55' E and Latitude 3°00 – 3° 40' S. The study was conducted in Lekitatu irrigation scheme (Meru district) at two sites/locations referred to as site 1 and site 2 in the current study. Based on Global Positioning System (GPS), the two trial sites in Lekitatu village are located between latitude 3° 23' 37.6" and 3° 23' 49" South of the equator and longitude 37° 9 '2.6" and 37° 9' 8.4" East of Great meridian at 1147 to 1143 meters above sea level, respectively. The Lekitatu village in Meru district was chosen because of intensive rice cultivation in the area and presence of an irrigation scheme. The district receives an annual rainfall ranging between 500 – 1200 mm and average temperatures of about 25°C (January – February) and 15°C (June – August).

2.2 Selection of Experimental Sites

Selection of the experimental sites in Lekitatu village involved reconnaissance survey of the rice growing areas of Lekitatu village where background information on the farming systems was collected through discussion with farmers and extension workers. The information and data collected include; how long the land had been cultivated, types and rates of fertilizers which had been used. Then two sites were finally selected based on the willingness of the farmers to participate in the research activities and devotion of areas for the trials and the very low rice grain yields realized by the farmers.

2.3 Soil Fertility Evaluation

Evaluation of the fertility status at the two selected trial sites was based on soil analysis. The soil analysis data assisted in the identification and establishment of the soil fertility and land suitability limitations for rice production in Lekitatu village.

2.4 Soil Sampling and Sample Preparation

Two composite soil samples (one from each site) were gathered from site 1 and site 2 of the rice growing areas of Lekitatu village. Soils were sampled from 0-30 cm depth (most of the rice plants roots concentrate in the 0-20 depth deep but significant numbers of roots extend to 30 cm hence the choice of 0-30 cm). Ten spot samples were collected randomly (because the soils were quite homogeneous) from each experimental site then mixed thoroughly to constitute one composite soil sample for each site (1 and 2). About 500g of the composite soil samples were air dried, ground to pass through a 2 mm sieve and analysed for some physical and chemical soil properties for the characterization of the soils at the two experimental sites.

The soil properties determined included soil pH, electrical conductivity (EC), organic carbon (OC), cation exchangeable capacity (CEC), total nitrogen (TN), available phosphorous, exchangeable bases, plant available zinc, copper, manganese and iron and particle size distribution.

The soil pH was measured electrometrically in 1:2.5 (weight/volume) soil:water suspensions in accordance with the procedure described by Thomas [13]. Organic carbon was determined by the wet digestion (oxidation) method of Walkley-Black [14]. Cation exchange capacity (CEC) was determined by the ammonium acetate (CH_3COONH_4) saturation method [15], while the leachates from the proceeding steps were used for determination of exchangeable Ca and Mg by atomic absorption spectrophotometer while K and Na were determined by flame photometer. Total nitrogen was determined by the Kjeldah method as described by Okalebo et al. [16]. Available phosphorus was determined by the Olsen method in accordance with the procedure described by Juo [17]. Particle size distribution was determined by the hydrometer method as described by Gee and Bauder [18] and textural classes of the soils were determined by the United States Department of Agriculture procedure [19]. Zn, Cu, Mn and Fe were extracted by DTPA and measured or quantified by atomic absorption spectrophotometer as described by Lindsay and Norvel [20].

2.5 Land Preparation and Layout of the Experiment

Land preparation involved clearing, ploughing and layout of the experimental plots. A Randomized Complete Block Design (RCBD) with three replications was adopted at each site. At each site there were thirty six treatment plots which were separated by bunds to restrict water movement from plot to plot and improve and sustain ponding.

Table 1. Rates of the different P treatments applied to the experimental plots

MM-Urea	MPR- Urea	TSP-Urea
P_0N_0	P_0N_0	P_0N_0
$P_{20}N_{60}$	$P_{20}N_{60}$	$P_{20}N_{60}$
$P_{40}N_{60}$	$P_{40}N_{60}$	$P_{40}N_{60}$
$P_{60}N_{60}$	$P_{60}N_{60}$	$P_{60}N_{60}$

The subscript numbers indicate the rates of the different treatments that were applied in kg ha$^{-1.}$
Where; MM = Minjingu mazao, MPR = Minjingu phosphate rock, TSP = Triple supperphosphate

One day before transplanting the rice seedlings, the plots were irrigated to saturation and then left for twenty four hours to drain off to about field capacity**.** Also prior to transplanting, triple superphosphate (TSP), Minjingu phosphate rock (MPR) and Minjingu mazao fertilizers were applied to each treatment plots at four levels (Table 1). Nitrogen as urea was applied uniformly except for the control plots (Table 1) taking into account 10%N contained in Minjingu mazao for each level of P.

2.6 Management of the Treatment Plots at the Trial Sites

Management of the treatment plots involved weeding, irrigating, bird scaring and harvesting. Weeding was done as the weeds appeared; three weedings were done. However, the high moisture status in site 2 suppressed weeds due to anaerobic conditions created by water ponding in the fields so no weeding was done. Water management was accomplished by ensuring that plot bunds were not broken hence the fertilizer treatment effects were not transferred to adjacent treatment plots. Bird scaring was done for the last 30 days before harvesting due to presence of trees and bushes in Lekitatu village, which saved as birds nesting habitats. Rice was harvested when 90% of grains in the panicle changed colour from greenish to light brown or hard when pressed. Harvesting was done by cutting the above ground plant portions then threshed by pounding with a stick to separate rice straw and rice grains.

2.7 Data Collection

Number of tillers per hill, the number of tillers per hill was obtained from an average of four hills selected randomly in each treatment plot at booting stage. Plant height, the average plant height in cm per four plants was measured in each treatment plot at maturity whereby plant height was measured using tape measure from ground level to the growing tip of the longest plant leaves and average data was recorded. Ten above ground rice plants portions selected randomly were taken at harvesting and sun dried for three days and then oven dried to constant weights at 70°C. After oven drying samples were weighed and data recorded as dry matter in t ha^{-1} and as straw yields after remove of grains yields. Grains yield were determined by randomly harvesting of 10 plants from each treatment plot and the grain yields per hectare determined by converting yields obtained per treatment plot to hectare (t ha^{-1}) at 14%MC.

2.8 Statistical Analysis of the Data

The data collected were coded into different variables and subjected to Analysis of Variance (ANOVA) using the Gen-Stat computer package version 12th. Treatments mean separation test was done using the Tukey's Test at 5% level of significance. The basic assumption in the ANOVA is that each observations (Yij) is constituted of the mean, treatment effect, block effect and random error. The statistical model used was:

$$Y_{ij}=U+Ti+Bj+Eij \quad (i)$$

Where;

U = Overall mean of the experiment
Ti = The effect of ith treatments among the treatments
Bj = Block effect for the blocks j
Eij = Random error effect for each observations in the ith treatment and jth block

3. RESULTS AND DISCUSSION

3.1 Characterization of the Soils at the Two Experimental Sites

The physical and chemical properties of the soils from the two experimental sites at Lekitatu village are as presented in Table 2.

3.2 Soils' Textural Classes

The soil textural classes of the soils ranged from sandy clay to clay for site 1 and 2, respectively. It has been reported that soils with high clay contents are suitable for rice production because of their high capacities to retain plant nutrients and soil water [1]. The high clay contents in these soils would further restrict the fast percolation of water through the soils, hence encouraging water ponding of the bunded fields. High clay content in soils extends and improves the water use efficiency by the rice plants. It has also been reported that rice plants perform well in fine to medium textured soils [21]. Based on the textural classes of the soils in Lekitatu village, the soils are suitable for rice production, if the other rice plant growth factors are optimal.

3.3 Soil pH

The soils' pH values for the two sites were 7.4 (very slightly alkaline soil reaction) (Table 2). The optimum soil pH for rice plants is 5.5 to 6.5 under dry conditions (non irrigated rice production system) and 5.5 to 7.2 under flooded conditions [21]. The observed soil pH value might favour the formation of disphosphate ions (HPO_4^{2-}), and also increases the activity of Ca^{2+} which reacts with HPO_4^{2-} to form insoluble calcium diphosphate and hydroxy-apatite. However, it has been reported that cultivation of rice is even possible in soils with pH up to 9.0 although yield levels will not be that high because of high exchangeable bases and P fixation by calcium and deficiencies of Cu, Zn, Mn and Fe [1]. The high pH values may also negatively affect some of the physical, chemical and biological properties of the soils like dispersion of soil organic matter which will negatively influence soil structure that control soil moisture and microbial decomposition in the soil hence negative contribution to soil fertility and consequently soil productivity. Based on the soil pH hence the soil reaction (slightly alkaline), the soils of Lekitatu village are suitable for rice cultivation.

Table 2. Some of the chemical and physical properties of the composite soil samples from the trial sites

Soil parameters	Site 1	Site 2	Mean	Rating[1]
pH (water)	7.40	7.40	7.40	Mild alkaline
EC (mS/cm)	0.14	0.16	0.15	Normal
Organic carbon (%)	2.53	2.10	2.32	Low
Organic matter (%)	4.40	3.60	4.00	Low
Total nitrogen (%)	0.07	0.08	0.08	Low
Extractable P (Olsen, mg kg^{-1})	9.10	11.20	10.15	Medium
Exchangeable Ca (cmol kg^{-1})	5.30	6.40	5.85	High
Exchangeable Mg (cmol kg^{-1})	3.90	4.20	4.05	High
Exchangeable Na (cmol kg^{-1})	5.30	4.40	4.85	High
Exchangeable K (cmol kg^{-1})	1.30	2.10	2.13	High
CEC (cmol kg^{-1})	16.70	19.30	18.00	Medium
Zinc ($mgkg^{-1}$)	1.50	1.20	1.35	High
Copper ($mgkg^{-1}$)	8.30	6.80	7.55	High
Manganese ($mgkg^{-1}$)	144.00	108.00	126.00	High
Iron ($mgkg^{-1}$)	143.00	306.00	224.50	High
Particle size distribution				
Sand (%)	8.00	20.00	14.00	
Silt (%)	48.00	39.00	43.50	
Clay (%)	44.00	41.00	42.50	
Textural class	SC	C	-	

Note: SC= Silty clay; C=Clay,
Soil parameters rating was done according to Landon [21]

3.4 Total Nitrogen

The percentage total nitrogen in the soils ranged from 0.07 to 0.08% with a mean percentage total nitrogen of 0.075% (Table 2). These values are rated as low (Landon, 1991) hence the soils are deficient in nitrogen for plant growth. A study by Pillai [22] reported that N requirement is categorized as low, medium and high when the percentage total nitrogen values are less than 0.1%, 0.1 – 0.2% and >0.2%, respectively. The low total nitrogen might have been caused by limited use of organic soil amendments, N uptake by plants, leaching, denitrification, sparse vegetation and burning of the crop residues and use of the crop residues as an animal feed. Therefore for high rice production in the Lekitatu village, nitrogen in the form of fertilizers and manures has to be applied to the soils to supplement the deficient levels of N in the soils. However, total nitrogen in soils is not a good index of nitrogen availability as the N in soils occur in complex organic compounds that have to be biochemically transformed to NH_4^+ and NO_3^- that can be taken up by plants.

3.5 Organic Carbon

The organic carbon contents in the soils ranged from 2.10% to 2.53% (Table 2) with mean organic carbon of 2.315%. These values are rated as low as they are less than 4 % [21]. The low percent organic carbon contents translate to low organic matter contents in the soils. Organic matter in soils influence both the physical, chemical and biological properties of soils, such as soil structure, water retention, nutrient contents and retention and micro-biological life and activities in soils. To improve and sustain rice productivity of the soils of Lekitatu village, organic soil amendments like manures or crop residues (rice straw and weeds) have to be applied/incorporated into the soils at rates ranging from 7.5 to 10 tha^{-1}.

3.6 Olsen Extractable Phosphorus

The olsen extractable phosphorus in the soils ranged from 9.1 to 11.2 mg P kg^{-1} soil (Table 2). The mean available phosphorus based on the rice producing areas (soils) of Lekitatu village was 10.15 mg P kg^{-1}. The soils' extractable phosphorus values would be rated as medium [21]. Pillai [22] reported that the P requirement for rice is low, medium and high when the available P (Olsen) values are less than 5, 5-10 and grater than 10 mg P kg^{-1}, respectively. In addition, the availability of phosphorus in ponded rice fields is a function of the soil reaction [23-24], hence the available soil P, might be fixed or precipitated as calcium phosphate because of the medium alkaline condition of the soils. However, reduction of Fe^{3+} to Fe^{2+} phosphates would cause a release into solution of adsorbed, chemically bound and occluded phosphate hence raising the P availability levels. Rice being a high P demanding crop, the observed soil available phosphorus values would not satisfy the phosphate demand or requirement by the rice crop, hence response by rice to phosphate application to these soils as inorganic or organic fertilizers would be expected. The amounts of P to be added should aim at raising the P availability status to the critical P concentration range of 15 – 20 mg P kg^{-1} soil [25-26].

3.7 Cation Exchange Capacity

The cation exchange capacities (CEC) of the soils at the two sites in the Lekitatu rice growing area ranged from 16.7 to 19.3 $Cmol_{(+)}$ kg^{-1} soil for site 1 and 2, respectively (Table 2) with a mean CEC of 18.0 $Cmol_{(+)}$ kg^{-1}. These CEC values would be rated as medium where 5-12.0 $Cmol_{(+)}$ kg^{-1} is rated as low, 12.1-25.0 $Cmol_{(+)}$ kg^{-1} as medium and 25-40 $Cmol_{(+)}$ kg^{-1} as high [21]. The medium CEC of the soils is attributed to the nature of the parent materials from which the soils were developed and the type of the layer or amorphous silicate clay minerals in the soils. The medium CEC of the soils is an indication of the moderate capacities of the soils to retain nutrients added to the soils in the form of fertilizers and manures. Based on the CEC of the soils, the dominant clay minerals in the soils include the 1:1 layer silicate clay minerals and hydrous oxides of Fe, Al and Si.

3.8 Exchangeable Bases

The exchangeable bases displaced by NH_4^+ through ion exchange process/ mechanism included calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+).

3.8.1 Calcium (Ca)

The exchangeable Ca levels in the two soils (Table 2) are categorized as very high, that is >2 Cmol Ca kg^{-1} soil [21]. Soils are considered to be deficient in Ca when the exchangeable Ca is less than 0.2 Cmol Ca kg^{-1} soil. The very high levels of exchangeable Ca in the soils could be attributed to high contents of Ca in the parent materials of the soils, the pH of the soils and concentration of Ca^{2+} in the surface horizons of the soils as a result of insignificant leaching due to inadequate rainfall. The high levels of Ca in the soil might affect P availability levels in the soils by causing the adsorption of appreciable quantities of P, especially in clay soils with high pH and precipitated as calcium phosphate [27] according to the reaction:

$$Ca^{2+} + HPO_4^{2-} + 2H_2O \longleftrightarrow CaHPO_4.2H_2O \quad \text{(ii)}$$
(Precipitation)

Therefore, the availability of Ca at the study area might be a soil fertility constraint to phosphate availability hence reduced response to applied P fertilizers.

3.8.2 Magnesium (Mg)

The exchangeable Mg in the soils (Table 2) are rated as high (>0.5 $Cmol_{(+)}\,kg^{-1}$ soil) according to Landon [21]. However, the availability of Mg of the soils might be reduced by the high Ca: Mg ratio greater than 5:1 due to antagonistic effects of calcium [21]. The high exchangeable Mg in the soils could be attributed to high contents of Mg in the parent materials of the soils and limited uptake by plants because of the limited plant /vegetation growth due to inadequate soil moisture and probably the presence of 2:1:1 layer silicate clay minerals (chlorites) in the soils. The soils in the study area, therefore, have adequate amounts of exchangeable Mg for rice production.

3.8.3 Sodium (Na)

The exchangeable Na values (Table 2) are rated as very high [21]. The exchangeable Na percentages (ESP) of the soils range from 25% to 34% indicating that the soils are sodic as the boundary between sodic and non-sodic soils is 15 ESP. It has been reported that soils with exchangeable Na greater than 1 Cmol Na kg^{-1} soil are regarded as potentially sodic. The high exchangeable Na contents in the soils could be attributed to high contents of Na in the parent materials of the soils and minimum leaching of the Na because of inadequate soil solution percolating down the soils. The high ESP of the soils would enhance the dispersion of the soils when the fields are flooded, hence restrict percolation of water thus increase the concentration of exchangeable Na in the surface horizon. Rice is moderately tolerant to sodic soil conditions (ESP = 20 – 40) hence the rice crop at the Lekitatu village would not be adversely affected by the high exchangeable Na values of the soils.

3.8.4 Potassium (K)

The exchangeable K in the soils (Table 2) is rated as high (> 0.4 cmol K kg^{-1} soil) according to Landon [21]. However, exchangeable K levels in soils are of limited value in predicting crop response to K as there is no direct relationship between soil K values and its availability to plants [21]. It has been reported that soils with large amounts of available K lose some of the K through fixation and those with low amounts have their exchangeable K increased through transformation of the non-available K to available/exchangeable forms under field conditions [22]. The availability of K uptake is thus controlled by the physico-chemical equilibrium between the soil solution K, exchangeable K and fixed K in the soils [22]. It has further been reported that the minimum absolute levels of exchangeable K in soils ranges between 0.07 and 0.2 cmol K kg^{-1} soil [22]. Thus the soil K values (1.3 to 2.1 $cmol_{(+)}\,kg^{-1}$ soil) of Lekitatu soils are above the minimum levels of 0.07 and 0.2 cmol K kg^{-1} soil, respectively hence not deficient.

3.9 DTPA Extractable Zn, Cu, Mn and Fe

The DTPA extractable Zn, Cu, Mn and Fe in the soils ranged from 1.2 to 1.5, 6.8 to 8.3, 108 to 144 and 143 to 306 mg kg^{-1} soil, respectively as shown in Table 2. The DTPA extractable micronutrients values in the soils are rated as high according to Landon [21] as they are > 1.0 mg Zn kg^{-1} soil, > 0.75 mg Cu kg^{-1} soil, > 1.5 mg Mn kg^{-1} soil, > 5 mg Fe kg^{-1} soil) hence sufficient for the rice plants.

Based on the soils analytical data, the soil fertility limitations with respect to rice production in Lekitatu village include low soil organic matter, low total nitrogen and medium soil phosphorus. These limitations can be corrected or addressed through application and incorporation of plant residuals in soils and application of nitrogen and phosphate fertilizers.

3.10 Response of Rice to P from MPR, TSP and Minjingu Mazao (P Sources)

The field data collected included plant heights, number of tillers per plant, total dry matter yields, straws dry matter yields and grain yields as shown in Table 3.

3.10.1 Effects of P sources and application rates on rice plant heights

For all of the three P sources namely MPR, TSP and Minjingu mazao applied, plant height increased with increasing P rates. The shortest plant heights (23.47 and 28.83 cm) were observed in plots without P (control plots) while the tallest plant heights (58.50 and 66.17 cm) were observed in plots with 60 kg P ha^{-1} as Minjingu mazao for site 1 and 2, respectively (Table 3). Plants heights in all P sources at a rate of 20, 40 and 60 kg P ha^{-1} were statistically similar at site 2 whereas at site 1 Minjingu mazao (20 kg P ha^{-1}), MPR (40 kg P ha^{-1}) and TSP (40 kg P ha^{-1}) were similar (Table 3). Also plant heights in site 1 with MPR, TSP and Minjingu mazao at 60, 60 and 40 kg P ha^{-1}, respectively, were similar.

Generally, Minjingu mazao had the tallest plants, followed by TSP and MPR at both sites. This is because Minjingu mazao and TSP are more soluble compared to MPR; hence P release and uptake by rice plants would be increased. Also the superiority of Minjingu mazao in increasing rice plant heights over the TSP and MPR might be due other nutrients contained in Minjingu mazao such as S and Bo. Plant heights differ significantly between the sites because of the water deficit that prevailed in site 1 thirty days after transplanting compared to site 2. However, in site 2 there was no statistical difference when P from all sources was applied at the rate of 20, 40 or 60 kg P ha^{-1} (Table 4). It has been reported that after rice plants have attained the vegetative stage, then the differences in P did not affect the plant height significantly [1]. It could be said that P can increase the plant height at initial stage of rice life cycle. A study Morgan [28] also reported similar effect of phosphorus on plant height. Plants grown without P fertilizer produced the shortest plant irrespective of growth stages. De Datta [1] reported stunted plant height due to deficiency of phosphorus. The increase in plant heights had positive effects on dry matter and grain yields. Therefore, there were significant difference among sites, P sources and rates of P applied on plant height at ($P<0.05$).

3.10.2 Effects of P sources and application rates on tillering of the rice plants

The effects of P sources and application rates on number of tillers per plant from the two sites are shown in Table 3. Irrespective of the P application rate, the highest number of tillers (18 to 22) were recorded where Minjingu mazao was applied at the rate of 60 kg ha^{-1} at all sites while the lowest number of tillers (10 to 12) were recorded in the control plots at both sites. However, in site 2 Minjingu mazao, MPR and TSP at 20, 40 and 60 kg P ha^{-1} respectively, were similar (Table 3). Number of tillers per plant increased significantly with increasing P rate up to 60 kg ha^{-1} from all P sources and were not significantly ($P<0.05$) different at site 1 while they differed significantly ($P<0.05$) with P sources and rates at site 2 (Table 4).

The low mean number of tillers per plant in the field on site 1 might be due to shortage of water and duration of ponding days compared to site 2 which attribute to the difference in the nutrients uptake by rice crops. Other studies in Northeast Thailand and Bangladesh [29-30] reported similar results where adequate water and nutrients positively influenced the number of tillers per plant. Therefore, the increased number of tillers per plant had positive influence on nutrient uptake, dry matter and grain yields (Table 3).

3.10.3 Effects of P sources and application rates on total rice dry matter yields

The response of rice plants to Minjingu mazao, TSP and MPR applications on dry matter yields are as presented in Table 3. The dry matter yields increased with increasing rates of Minjingu mazao, TSP and MPR. The trend in the increase in the dry matter yields was in the order of Minjingu mazao>TSP>MPR and the increases were statistically significant ($P<0.05$). The increases in dry matter yields for Minjingu mazao, TSP and MPR ranged from 7.67 to 30.20, 7.67 to 26.83 and 7.67 to 25.97 t ha^{-1}, respectively (Table 3).

Further, plants on both sites gave significant responses to P application indicating that soil available P which was medium was not adequate for the plants in this area as confirmed by the soil analytical data (Table 2). At high rates of P applications (60 kg P ha^{-1}) the performances of MPR and TSP on dry matter yields were similar but were inferior to Minjingu mazao at all sites. This was probably due to initial N, S and Bo applied as components of Minjingu mazao.

Furthermore, a study by Shekifu [10] in a glasshouse pot experiment obtained significant increases of rice dry matter yields from 7.83 to

24.9 g pot^{-1} when 30 mg P kg^{-1} (equivalent to 60 kg P ha^{-1}) were applied to soils of rice growing areas of Morogoro and Coast regions. The observations in the current study conform to those of Semoka and Shenkalwa [31] who obtained a significance increase in dry matter yields from the application of 60 kg P ha^{-1} in Dakawa rice soils. On average, at 60 kg P ha^{-1} at all sites and from all P sources gave the greatest increase in dry matter yield followed by 40 and 20 kg P ha^{-1}, respectively as in Table 3. The increase in dry matter yields followed the same trends to the increased plant heights and number of tillers per plant indicating that the medium available P in the soils (Table 2) was not sufficient for growth of the rice plants, hence the positive responses to the applied P from the three P-fertilizers sources.

3.10.4 Effects of P sources and application rates on rice straw yields

The response of rice plants to different P sources and application rates in terms of rice straw yields are as presented in Table 3. The rice straw yields increased with increasing rates of P for all the P sources. The trend in the increase in the rice straw yields was in the order of Minjingu mazao>TSP>MPR and the increases were statistically significant (P<0.05) (Table 4). The highest increases in straw yields for Minjingu mazao, TSP and MPR at the rate of 60 kg P ha^{-1} were 14.879 and 17.03, 12.678 and 15.77 and 13.090 and 15.70 tons ha^{-1} for site 1 and 2, respectively (Table 3). The response of rice plant in term of straw yields to P sources and application rates were statistically significant (P<0.05) (Table 4). From the analytical data in Table 3, phosphorus application rates from all P sources had a positive effect on rice straw yields and the increase was attributed to the increased soil P as the soils were initially medium in soil P (Table 2). Mongia et al. [32] reported significant positive effects on straw yields of rice when phosphate was applied and that the highest response of 6.8 tons/ha of rice grain was obtained at 80 kg P ha^{-1}. The increase in rice straw yields conforms to the trends of increases in plant heights and number of tillers with increasing P application rates. Landon [21] reported that rice response to applied P for soils with initial P (Olsen) between 12-20 mg kg^{-1} is highly questionable and if obtained it would not be that dramatic/high. The plant available P (Olsen) in the trial sites was 9 to 11.2 mg kg^{-1} which is below the above mentioned range leading to high response of rice in terms of straw yields upon addition of P.

3.10.5 Effects of P sources and application rates on rice grain yields

The response of rice to different P sources and application rates in terms of grain yields are as presented in Fig 1 and Tables 3 and 4. The grain yields increased with increasing rates of P applications from all sources at both sites. The trend in the increase in rice grain yields was in the order of Minjingu mazao>TSP>MPR (Table 3) and these increases were not statistically significant (P<0.05). The trend conforms to increased number of tillers and rice straw yields. The increase in grain yields due to the effect of P sources at the rate of 60 kg P ha^{-1} in site 1 and 2 were 7.842 to 10.433, 6.740 to 9.233, 6.839 to 8.633 tons ha^{-1} for Minjingu mazao, TSP and MPR, respectively (Table 3). Site 1 had significant lower mean grain yields in all P sources and rates than site 2. The highest increase in grain yields as a result of P application was due to increased number of tillers and dry matter yields (Table 3) consequently to the increased P-uptake by the plants.

Mongia et al. [32] reported significant positive effects on grain yields of rice when phosphate was applied and that the highest response of 6.8 tha^{-1} of rice grain was obtained at 80 kg P ha^{-1}. In addition, the availability of P influenced the uptake of other essential plants nutrients due to role of P in the rice plant roots. The lowest responses of P to grain yields in the control plots was due to initial medium soil P content at both sites (Table 2). Therefore, the grain yields variations for different treatments (P sources and rates) as shown in Table 3 indicated that increased grain yields were attributed to P rates and sources at both sites. Further, the observations from the current study showed that, plant heights, number of tillers per plant and dry matter yields were significantly correlated with grain yields at harvest (Table 3). This means that the performance of rice plant in terms of grain yield depends on increased yield components attributed to appropriate management of soil fertility and productivity. Based on the increased rice yields, the farmers should adopt the use of P fertilizers for sustainable productivity and soil fertility improvements.

Table 3. Effects of P Sources and application rates on plant height (cm), number of tillers, total dry matter yield (tha^{-1}), straw dry matter yield (tha^{-1}) and grain yield (tha^{-1})

Rate of P (kg P ha^{-1})	P sources	Site 1					Site 2				
		Plant height	No of tillers	TDM	SDMY	GY	Plant height	No of tillers	TDM	SDMY	GY
0	MPR1	23.47 d	5.80 d	5.67 e	3.974 e	1.318 e	28.83 b	12.00 c	7.67 e	5.80 e	1.500 e
	MM1	29.67 d	5.87 d	6.09 e	4.575 e	1.231 e	30.97 b	10.67 c d	7.67 e	5.87 e	1.467 e
	TSP1	25.90 d	6.00 d	5.91 e	4.191 e	1.404 e	29.73 b	11.67 c	7.83 e	6.00 e	1.533 e
20	MPR2	49.20 c	7.90 c d	11.02 d	6.783 d	3.369 d	56.43 a	21.33 a b	13.80 d	7.90 d	4.667 d
	MM2	46.53 c	12.10 b	16.50 c d	10.222 c	5.150 c	60.23 a	19.33 a b c	19.93 c	12.10 c	6.467 c
	TSP2	54.67 a b	7.60 c d	10.62 d	6.295 d	3.602 d	63.83 a	22.67 a	13.37 d	7.60 d	4.833 d
40	MPR3	46.20 c	11.70 c	19.97 c	12.671 b	6.135 a b	58.87 a	19.33 a b c	20.60 c	11.70 c	7.367 b c
	MM3	53.63 a b	13.03 b	19.86 c	12.145 b c	6.390 b	65.43 a	23.00 a	23.30 b c	13.03 b	8.267 b
	TSP3	46.93 c	12.17 b	19.20 c	11.678 b c	6.278 b	62.50 a	20.33 a b	21.23 c	12.17 b	7.667 b c
60	MPR4	53.27 a b	15.70 a	21.20 b	13.090 a b	6.839 b	64.97 a	22.00 a	25.97 b	15.70 a	8.633 a b
	MM4	58.50 a	17.03 a	24.38 a	14.879 a	7.842 a	66.17 a	22.00 a	30.20 a	17.03 a	10.433 a
	TSP4	54.13 a b	15.77 a	20.69 c	12.678 b	6.740 b	64.03 a	19.00 a b c	26.83 b	15.77 a	9.233 a
Mean		45.18	10.889	15.09	9.43	4.692	54.33	18.61	18.200	10.889	6.006
LSD		5.834	0.8420	1.099	1.105	0.5648	6.185	5.474	1.0088	0.8420	0.5204
CV (%)		7.6	4.6	4.3	6.9	7.1	6.7	17.4	3.3	4.6	5.1

Note: TDM = Total dry matter yield; SDMY = Straw dry matter yield; GY = Grain yield.
Means followed by the same letter(s) in the same column are not significantly different (P<0.05) according to Tukey Test

Table 4. Statistical analysis (means separation) of the rice plant height, number of tillers per plant, dry matter yields, straw dry matter yields and grain yields data for experimental site 1 and 2

Source of variation	DF	Site 1					Site 2				
		Plant height (cm)	Number of tillers	DMY (t ha^{-1})	SDMY (t ha^{-1})	Grain yields (t ha^{-1})	Plant height (cm)	Number of tillers	DMY (t ha^{-1})	SDMY (t ha^{-1})	Grain yields (t ha^{-1})
Replication	2	6.53n.s	3.444n.s	0.0939n.s	0.2570n.s	0.3101n.s	20.90n.s	1.36n.s	0.1225n.s	0.0169n.s	0.01778n.s
Treatments	11	433.74***	21.899***	139.3514***	47.6747***	17.3245***	678.69***	61.44***	189.5242***	51.2238***	30.25505***
Residual/Error	22	11.87n.s	1.384n.s	0.4214n.s	0.4260n.s	0.1112n.s	13.34n.s	10.45n.s	0.4539n.s	0.2472n.s	0.09444n.s
Total	35										

*Key: **= highly significant, ***= very highly significant, n.s = not significant*

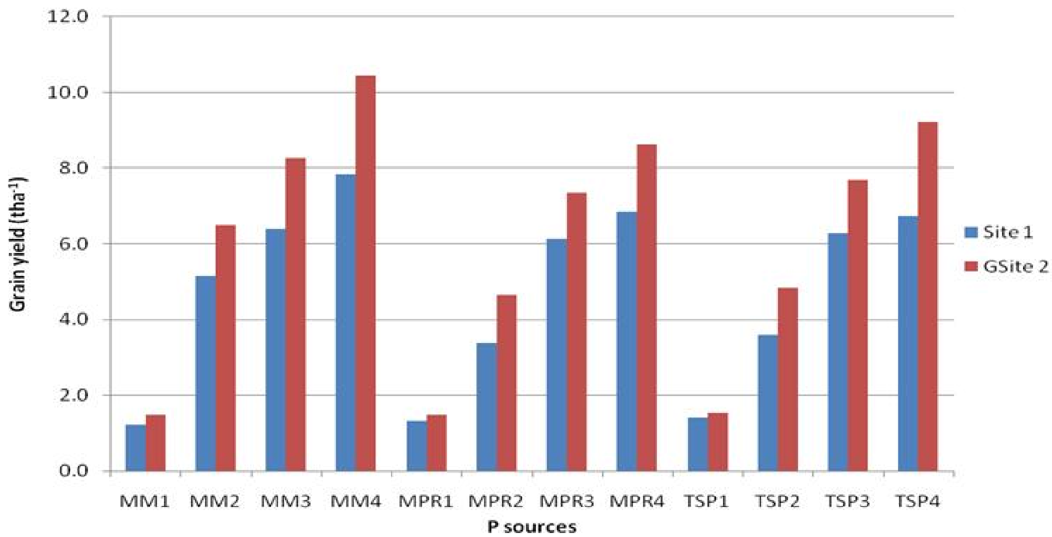

Fig. 1. Effects of P sources and application rates on grain yields (tha^{-1})
Note: P sources ending with 1, 2, 3 and 4 indicates 0, 20, 40 and 60 kg P ha^{-1} respectively

4. CONCLUSION

The application of phosphorus fertilizers as Minjingu mazao, MPR and TSP increased rice grain yields relative to the control at all rates and the response was in the order of Minjingu mazao>TSP>MPR. Phosphorus fertilizers should be applied two weeks before sowing seeds or transplanting seedlings into the rice fields to allow dissolution of P fertilizers. The three different P sources applied, a rate of 60 kg P ha^{-1} should be adopted in Lekitatu village with frequent reviews so as to take care of soil P depletion with time as well as the build-up of residual P in the soils.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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