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Effects of Phosphorus Sources and Application Rates on Nitrogen and Phosphorus Concentrations and Phosphorus Use Efficiency in Rice Plant

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

A study was conducted to determine the effects of nitrogen (N) and phosphorus (P) concentrations and P use efficiency from Minjingu phosphate rock (MPR), Minjingu mazao and Triple Super Phosphate (TSP) fertilizers under irrigated rice (O*ryza sativa* L.*)* production in Lekitatu village, Meru district, Arusha region, Tanzania. The initial soil pH in the two experimental sites was slightly alkaline while total N and available P was low and medium respectively. Randomized Complete Block Design (RCBD) with three replications was adopted and 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 taking into account the 10% N contained in the Minjingu mazao fertilizer. Phosphorus application increased N and P contents in the rice plants and phosphorus use efficiency (PUE) with the increase of P levels from 0 to 60 kg P ha^{-1} for all P sources. The site 1 had more PUE than site 2 due to higher moisture content. These effects were due to increased availability and nutrients uptake by plants, particularly P. Based on the results, it is recommended 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 have to be adopted for sustainable soil P use in rice production areas of Lekitatu village.

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1. INTRODUCTION

The responses of rainfed lowland rice to phosphorus (P) fertilizer applications are not as frequent as those of upland rice even in soils deficient in P [1]. This is due to the fact that rice is usually grown under flooding conditions where availability of P is higher than in upland soils because of higher dissolution under flooded conditions [2]. Nitrogen is the most important nutrient for rice and is universally limiting the rice productivity. Fertilizer N use efficiency in lowland rice may be maximized through a better timing of application to coincide with the stages of peak requirement of the crop, and placement of N fertilizer in the soil [2]. Phosphorus (P) is an essential element for plant growth, but many soils lack sufficient P in a form that is readily available to crops, especially in acidic soils of the tropical and subtropical regions [3]. For example, some soils in upland rice are acidic and very low in available phosphorus since aluminium phosphate is the dominant fraction controlling the P sorption index [4].

Soluble P fertilizers applied to correct such deficiencies are immediately transformed to forms unavailable to plants as shown in the reaction below:

$$\text{Oxide-M-OH}_2{}^{x+} + H_2PO_4{}^{-} \longrightarrow \text{Oxide-M-O-PO}_3H_2{}^{(1-x)-} + H_2O \quad \text{(i)}$$

Phosphorus is needed for tillering, but the total P requirement is small relative to nitrogen because of its mobility in plants [1]. In addition, if sufficient P is absorbed at the early stages of growth of the rice plants, it can be redistributed to the growing organs as growth progresses [5]. The major P-fertilizers for rice cultivation in Tanzania include ordinary super phosphate, triple super phosphate and ammonium phosphate. Due to its high solubility in water (about 98% water soluble) triple super phosphate is a preferred phosphate fertilizer for rice in Tanzania. Under reduced, anaerobic soil conditions, Fe plays a major role in P dynamics in soils. Reduction of Fe and its re-precipitation to form ferrous (Fe^{2+}) minerals are dominant processes under anaerobic soil conditions [6]. Studies by Einsele [7] and Mortimer [8] reported that there was a reduction of ferric ion (Fe^{3+}) to more soluble ferrous (Fe^{2+}) forms in anaerobic lake sediments according to the reaction;

$$FePO_4 \longleftrightarrow Fe^{2+} + PO_4{}^{3-} + e^{-} \quad \text{(ii)}$$

Phosphorus fertilizers can be applied to the rice soils as surface broadcasting, drilling at seedling stage, or by dipping the rice seedling roots in superphosphate slurry. In Tanzania, surface broadcasting is the most common method of phosphate fertilizer applications because it is less labour demanding as compared to other application methods. However, it has been reported that there is no significant difference in terms of yields among the application methods due to enhanced release of native P in water logged soils [1,9].

Relative agronomic effectiveness (RAE) is defined as the crop yield per kilogram nutrient taken by plants [9]. The practices used in the management of P fertilizers and soil can also influence the relative agronomic effectiveness (RAE) of phosphate rock (PR) with respect to soluble P sources. The two important factors in this regard are methods and time of application because P fertilizers need long time to dissociate and release P [10]. Chien and Menon [11] found that the response of flooded rice to TSP was not substantially influenced by placement method but with time of application because of its high solubility in the soil. Fertilizer use efficiency is the product of any crop per unit of fertilizer nutrient applied under specified soil and climatic conditions [9]. Phosphorus use efficiency (PUE) in rice therefore, refers to an increase in yield of harvested portion (grain) per unit of fertilizer P used. However, the PUE vary with the stage of the growth of the plants, hence the stage of growth at which the PUE was determined has to be specified [12]. Rock phosphates and partially acidulated rock phosphates have been suggested as possible substitutes for water-soluble sources of phosphorus where TSP is not available because they release P slowly in the soil for plant uptake and maintain the P equilibrium in the soils [13,14]. This slow and continuous release of P from phosphate rock increases the PUE because the P nutrient is available in the soil solution at any time required for plant uptake. Since 1940, there have been many investigations on the effectiveness of rock phosphates as P sources and in the past 30 years, the principles controlling their availability to crops have been determined [15].

It has also been observed that changes in the values of P fractions in soils were significantly affected by soil type, P source and rate of P application [11]. To compare the effectiveness of two fertilizers, it is thus necessary to apply several levels of each fertilizer and measure the response in terms of yield or P uptake. Further, the P-use efficiency 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 [16]. Furthermore, the relationships between rice P and N accumulation and PUE with P applications from different P sources are not quite clear. A better understanding on P nutrition of rice, P response of rice plant, P availability in rice soils and P adsorption in rice soils is necessary before deciding P fertilization in rice culture. Therefore, there is a need to determine the effects of different types of phosphatic fertilizer materials namely, Minjingu mazao, Minjingu phosphate rock and Triple super phosphate as sources of P on N and P concentrations, and the P- use efficiency for irrigated rice growing areas of Lekitatu village in order to identify the appropriate P-fertilizers for the soils and subsequently extrapolate to other rice growing areas with similar conditions in Tanzania.

2. MATERIALS AND METHODS

A study to determine the effects of different sources of P and application rates on N and P concentrations and PUE was conducted in Lekitatu village, Meru district, Arusha region, Tanzania. The two sites were selected based on the intensive cultivation of rice in Laketatu village. Two composite soil samples were sampled from 0-30 cm depth from the two sites for determination of initial soil pH, total nitrogen and available soil phosphorus. The soil pH was measured in 1:2.5 (weight/volume) soil:water suspension in accordance with the procedure described by Thomas [17]. Total nitrogen was determined by the Kjeldah method as described by Okalebo et al. [18]. Available phosphorus was determined by the Olsen method in accordance with the procedure described by Juo [19]. Experimental design followed a Randomized Complete Block Design (RCBD) with three replications and thirty six treatment plots which were separated by bunds to restrict water movement from plot to plot were established.

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.

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

2.1 Plant Material Collection and Preparation for Analysis

Above ground portions of ten plants were randomly collected at booting stage from each treatment plot for the determination of nutrient uptake or contents, namely percent N and P. Prior to analysis, the fresh plant samples were washed using distilled water and drip dried. Thereafter, the samples were oven dried at 70ºC to constant weights and ground to a fine powder (0.5 mm sieve) for plant tissue analysis of N and P. The plant analysis for N and P were done based on the procedures described by Okalebo et al. [18] and Juo [19].

Phosphorus use efficiency (PUE) was computed by the formula:

$$\%PUE = \frac{P_1 - P_2}{P_3} \times 100 \qquad \text{(iii)}$$

Where; P_1 = P uptake by plants in the treatment plots, P_2 = P uptake by plants in the control plots and P_3 = total amount of P applied

The analyzed N and P were coded into different variables and subjected to Analysis of Variance (ANOVA) using the GenStat computer package. Treatments mean separation test was done using the Tukey's Test at 5% level of significance.

3. RESULTS AND DISCUSSION

The initial chemical and physical soil properties are presented in Table 2. Soil pH greatly affects the availability of P to plants, with P being tied up by Ca at high pH and by Fe and Al at low pH. The textural classes of our study sites ranged from silty clay to clay soil (Table 2). According to Massawe and Mrema [10], the soils with high clay content tend to fix more P than sandy soils with low clay content. Thus, more P needs to be added to raise the soil test level of clay soils than loam and sandy soils.

3.1 Effects of P Sources and Application Rates on Nitrogen Concentrations in Rice Plant Shoots

The results of N concentration in rice plants as influenced by P sources and application rates are presented in Fig. 1 and Table 3. The N concentrations increased with increasing rates of Minjingu mazao, MPR and TSP and the trends in the increase in N concentrations were in the order of Minjingu mazao > TSP > MPR (Fig. 1 and Table 3). The effect of MPR, TSP and Minjingu mazao at the rate between 0 to 60 kg P ha^{-1} on the N concentration in the rice plants ranged from 1.6 to 3.5%, 1.8 to 3.8% and 1.8 to 3.6%, respectively. The response of the rice plants (above ground portions) in terms of N contents for the three P sources (Fig. 1 and Table 3) were significant at ($P<0.05$). Mikkelsen [21] rated nitrogen concentrations in the rice plants at tillering stage, < 2.4% as deficient, 2.4-2.8% as low, 2.8-3.6% as sufficient and > 3.6% as high. Based on the results by Mikkelsen [21], the N contents in the rice plants in this study ranged from deficient (1.60% control) to high (3.80%) for all P sources at a rate of 20 to 60 kg P ha^{-1}). Similar responses of increased N uptake as a result of P application in N deficient soils were reported by Seleque et al. [22]. Therefore, N content was significantly higher in all plots that received P fertilizers regardless of the P rates used from each P sources.

Table 2. Initial chemical and physical soil properties and rating

Soil parameters	Site 1	Site 2	Mean	Rating[1]
pH (water)	7.30	7.40	7.4	Mild alkaline
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})	5.20	6.60	5.90	High
Particle size distribution				
Sand (%)	9.00	21.00	15.00	
Silt (%)	50.00	39.00	43.00	
Clay (%)	41.00	40.00	42.00	
Textural class	SC	C	-	

Note: SC= Silty clay; C=Clay
Soil parameters rating was done according to Landon [20]

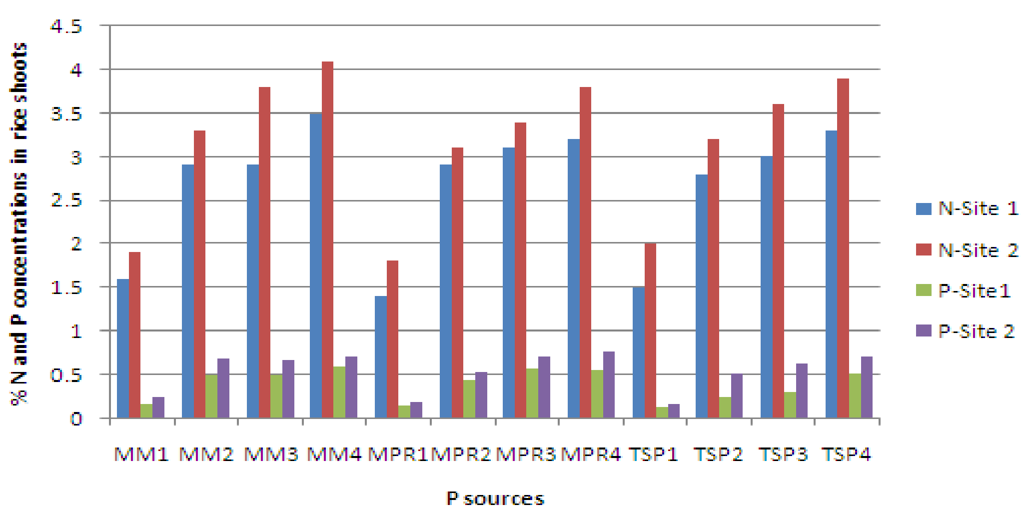

Fig. 1. Effects of P sources and application rates on N and P content in rice plants
Note: P sources ending with 1, 2, 3 and 4 indicates 0, 20, 40 and 60 kg P ha^{-1}, respectively

3.2 Effects of P Sources and Application Rates on Phosphorus Concentrations in Rice Plant Shoots

The effects of P sources and application rates on the mean P contents in the rice plant shoots are as presented in Fig. 1 and Table 3. The P concentrations increased with increasing rates of P from all P sources and the trend in the increase was in the order of Minjingu mazao > MPR > TSP (Fig. 1). The trend conforms to number of tillers per plant, straw and grain yields (data not shown). The effect of P applications on P contents in the rice plant above the soil levels ranged from 0.150 to 0.645%, 0.190 to 0.635% and 0.135 to 0.565%, at the rates of 0 to 60 kg P ha^{-1} for Minjingu mazao, TSP and MPR, respectively. Further, Pillai [23] categorized P concentration of 0.1% (1 g kg^{-1}) in the dry matter of rice plant at tillering stage as deficient. The P concentrations obtained in the current study (Fig. 1 and Table 3), the adequate concentrations of P was attained when phosphorus was applied at the rates of 20 to 60 kg P ha^{-1} from all P sources because of medium /adequate initial available P in the soil (Table 2), which possibly enhanced saturation of P adsorption index of the soil particles. Furthermore, Fageria [24] reported optimum phosphorus concentration in rice plants of 2.4 g kg^{-1} (0.24% P) at the active rice plant tillering stage.

Therefore, the P concentrations in the rice plants from the three P sources and rates applied ranged from deficient (control plots) to adequate (20 to 60 kg P ha^{-1}). Based on the categorization by Pillai [23] and according to Fageria [24], regardless of the medium initial availability of P in the soils (Table 2), the adequate P concentrations in rice plants have also been attributed to soil moisture content. In addition, the pH of the soils and exchangeable Ca could have to some extent reduced the availability of P to the rice plants through the transformation of the native and applied P to unavailable P forms. Such transformation includes the formation of insoluble Ca-phosphate in alkaline soils with high quantities of exchangeable Ca. Similar observations have been reported by Slaton et al. [25]. The conversion of available P to less available forms in soil is the reason for the low initial efficiency of P fertilizers. From this study, phosphorus contents was highly significant in rice plants from all P sources and application rates except in control plots indicating high P uptake from the soils in P treated plots.

3.3 Effects of P Sources and Application Rates on Phosphorus Use Efficiency (PUE)

The effects of P sources and application rates on P use efficiency by rice plants are presented in Fig. 2 and Table 4. There were differences between the three P sources and application rates on P use efficiency at both sites (Fig. 2 and Table 4). The P use efficiency ranged from 54 to 75%, 58 to 69% and 50 to 70% for MPR,

Table 3. Effects of P sources and application rates on nitrogen and phosphorus concentrations in rice plants

Rate of P (kg P ha^{-1})	P source	% N	% P
0	MPR1	1.600 a	0.1350 a
	MM1	1.750 a	0.1900 ab
	TSP1	1.750 a	0.1500 a
20	MPR2	3.000 b	0.3750 abc
	MM2	3.100 bc	0.5750 c
	TSP2	3.000 b	0.4950 c
40	MPR3	3.250 bc	0.4750 bc
	MM3	3.350 bcd	0.6250 c
	TSP3	3.300 bcd	0.5700 c
60	MPR4	3.500 bc	0.5650 c
	MM4	3.800 d	0.6450 c
	TSP4	3.600 cd	0.6350 c
Mean		2.917	0.453
LSD		0.2955	0.1625
CV (%)		4.6	16.3

Means followed by the same letter(s) in the same column are not significantly different (P<0.05) according to Tukey Test.

Minjingu mazao and TSP when applied at the rate of 60 kg P ha^{-1} in site 1 and 2, respectively. The P use efficiency increased with increasing P rates from all P sources (Table 4) for site 1 and 2, respectively. However, the MPR recorded the highest P use efficiency at all application rates in both sites followed by Minjingu mazao and TSP, respectively (Fig. 2 and Table 4).

A study by Choudhury et al. [26] indicated better efficiency of rock phosphate in rice and rice based cropping systems in acid soils. This is because the MPR releases P gradually into the soil solution for plant uptake attributed to its slow dissolution at the high soil pH compared to Minjingu mazao and TSP. Syers et al. [27] observed that the P use efficiencies of rice crop grown on different soils in different climates in Brazil, New Zealand, Western Canada, England, Peru, India, China and the USA were on the average of 43%, where many values exceeded 60%, some values exceeded 80% and on occasional instances values larger than 100% were obtained. PUE larger than 100% indicate that P taken up in the harvested crop exceeded the amounts of P applied and that the soil P reserves were being depleted [27]. To achieve a percent PUE frequently exceeding 60% and indeed up to and exceeding 80%, would not be possible if P was irreversibly fixed in soils, as was in this study. The high PUE of the rice plant at Lekitatu village could be attributed to the soil pH (slightly alkaline soil reaction), medium initial available P in soils (Table 2) and favourable moisture conditions of the soils.

Table 4. Effects of P sources and application rates on P use efficiency by rice plants

Rate of P (kg P ha^{-1})	P source	%PUE (Site 1)	%PUE (Site 2)
0	MPR1	0	0
	MM1	0	0
	TSP1	0	0
20	MPR2	42	51
	MM2	47	66
	TSP2	23	50
40	MPR3	56	68
	MM3	49	64
	TSP3	29	62
60	MPR4	54	75
	MM4	58	69
	TSP4	50	70

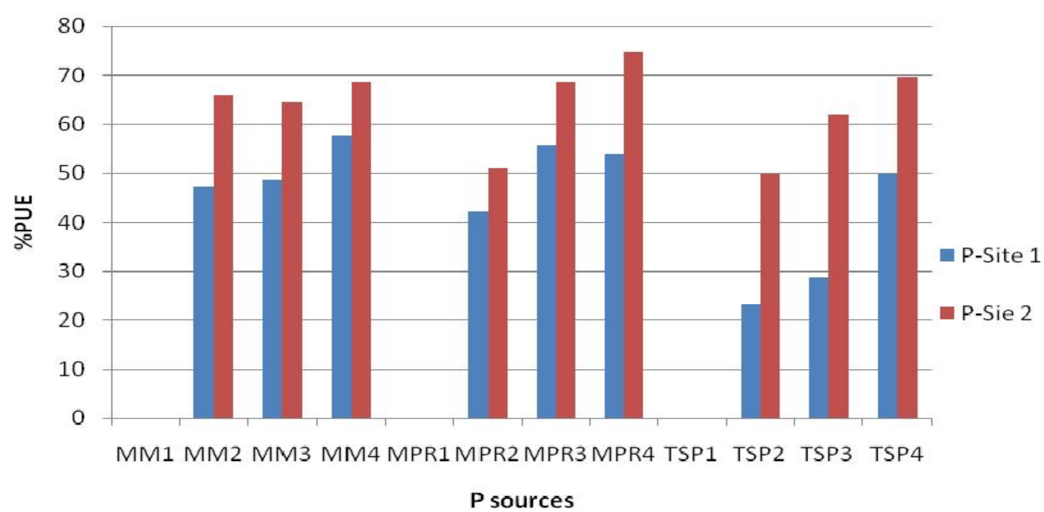

Fig. 2. Effects of P sources and application rates on P use efficiency by rice plants
Note: P sources ending with 1, 2, 3 and 4 indicates 0, 20, 40 and 60 kg P ha^{-1} respectively

Significant increases in fertilizer P use efficiency can also be achieved by different fertilizer formulations as the one used in this study but also by altering time of application, changing the rate of P applied and choosing crop species or varieties efficient at scavenging P from soils.

4. CONCLUSION

Phosphorus use efficiency was higher in MRP followed by minjingu mazao and TSP and increased with increasing levels of P fertilizers. The application of finely ground PR should be at least one month before planting in order to allow time for the PR dissolution. This applied rock phosphate develops a reserve of P in the soil, which results in higher availability of P for the succeeding crops. For TSP and minjingu mazao fertilizers must not be applied too long before planting, but at sowing so as to increase time of contact with soil to increase P availability quickly as well as to increase PUE. Based on the results, it is recommended 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 have to be adopted for sustainable soil P use in rice production areas of Lekitatu village.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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