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Effectiveness of Phosphate Rock Application Methods and Frequencies on Soil Available P and Uptake by the Leafy Vegetable Amaranth

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Authors' contributions

Authors RRM and JAN designed the study, performed the statistical analysis, and wrote the first draft of the manuscript. Authors NEM and LSK managed the pot experiment and recorded the data of the study. All authors read and approved the final manuscript.

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ABSTRACT

Low solubility of phosphate rock (PR) limits its direct application to leafy vegetables. However the low solubility and slow P releasing characteristics contribute to higher residual effect than water soluble P fertilizers. A pot experiment was conducted over three crop cycles at the Agricultural Research Institute Uyole (ARI Uyole) in Tanzania to determine the most appropriate PR application method and frequency for amaranth, a nutritious leafy vegetable. The experiment was laid out in a split plot design with three replications. Frequency of Minjingu phosphate rock (MPR) application constituted the main plots while the application methods were the sub plots. The methods were (i) control (no fertilizer material added), (ii) direct application of MPR, (iii) compost + MPR, (iv) crotalaria green manure + MPR, and (v) NPK (Nitrogen –Phosphorus-Potassium fertilizer) as standard. Frequencies were (i) once in the first crop cycle, (ii) during the first and third crop cycle, and (iii) during each crop cycle. Compost + MPR gave significantly higher fresh weight and dry matter amaranth yield than did other treatments. During the third crop cycle there was significant ($P \le 0.01$) interaction between frequency and method of MPR application on P uptake, plant P content, fresh weight and dry matter yield. There was positive and highly significant ($P \le 0.01$)

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correlation between soil available P, P uptake, concentration and amaranth yield. The results indicate that application of MPR once during three crop cycles especially when combined with manure could supply adequate levels of phosphorus thus replace the use of soluble P fertilizers in production of short season leafy vegetables such as amaranth.

Keywords: Phosphate rock; phosphorus; application frequency; application methods; leafy vegetables; amaranth.

1. INTRODUCTION

Addition of phosphate rock (PR) is recommended in areas with phosphate deficient soils for optimum crop yields. Phosphate rock is less reactive than water soluble P fertilizers [1] and hence it is more effective on perennial than short season crops. On the other hand, the low solubility and slow P releasing characteristics contribute to higher residual effect in soil and higher benefit-cost ratio [2] than water-soluble fertilizers, meaning a farmer may not need to apply P fertilizer every season [3]. Due to its natural characteristic it is accepted in organic farming [4]. Phosphate rock is locally mined in Minjingu mines in northern Tanzania. Its price is almost half that of other basal fertilizers available in the country [5].

Investigations have indicated that dissolution of PR can be enhanced by acids released by decomposing organic matter [6]. Therefore amendment of PR with organic materials is recommended to increase availability of P to plants [7-9].

Green leafy vegetables such as amaranth are good sources of calcium (Ca), iron (Fe), vitamin A, B and C which contribute to nutritional well-being of people. These short seasoned crops are grown in urban and rural areas and contribute significantly to food security and farmers income especially women. For normal growth and good yields leafy vegetables require adequate supply of soil nutrients especially N and P [10,11]. Since there is inadequate information on the effectiveness of PR on supply of P to short seasoned vegetables such as amaranth, this study was conducted to explore the most appropriate frequency and method of PR application to leafy vegetables. A pot experiment was conducted to evaluate different frequencies and methods of MPR application to vegetable amaranth. The results from the experiment will be tested under field conditions to give appropriate recommendations to farmers.

2. MATERIALS AND METHODS

A pot experiment was conducted between 2009 and 2012 at ARI Uyole located between latitude 8° 53‘02’’ and longitude 33° 39’11’’ in the Southern highlands of Tanzania. Amaranth was used as a test crop. The experiment was laid out in a split plot design with three replications. Frequency of MPR application constituted the main plots while the application methods were the sub plots. The methods of PR application were (i) control (no fertilizer material added), (ii) direct application of MPR, (iii) compost + MPR, (iv) crotalaria green manure + MPR, and (v) NPK (standard). Frequency of MPR application were (i) once in the first crop cycle, (ii) during the first and third crop cycle, and (iii) during each crop cycle.

The soil used in the pots was collected from a farmer field in Mbeya district. Before sowing soil samples were taken at random and were analyzed for pH, total N, available P, organic C, exchangeable levels of Mg, Ca, and CEC. Soil pH was measured in a 1:2.5 soil water ratio with a pH meter [12]. Organic carbon was determined by the wet combustion method [13]. Cation exchange capacity was determined by the ammonium acetate saturation method [14]. Exchangeable magnesium and calcium were measured by atomic absorption spectrophotometry [15]. Total nitrogen was determined using the Semi micro Kjeldahl method as described by Anderson and Ingram [16]. Extractable phosphorus was determined by the Bray- Kurtz No. 1 method [17].

Compost was prepared using a standard heap method as described by the Henry Doubleday Research Association [18]. Materials used include crop residues, cattle manure, wood ash, top-soil, green grass and MPR (49 kg P ha^{-1}). Seeds of *Crotalaria ochroleuca* were sown directly on a plot. Crotalaria plants were later uprooted at flowering stage, chopped, mixed with soil and MPR (49 kg P ha^{-1}) then filled in the experimental pots. The pots were irrigated for two weeks before sowing amaranth. Compost + MPR and NPK (168:49:139 kg ha-1) treatments were applied at sowing. The N in the NPK treatment was split applied. The rate of application for green manure and compost was based on N content of these materials and N requirement of amaranth crop.

Amaranth *(A. cruentus)* seed was sown directly on pots (3.5 kg size) in a screen house. Seedlings were thinned at two week stage leaving ten plants per pot. Each treatment was represented by a single pot replicated three times. In total there were 45 pots. The experiment was repeated for three crop cycles in the same pots. Application of fertilizer materials was repeated in the second and third crop cycles according to the treatment schedule.

2.1 Plant and Soil Analysis

Tissue P concentration in the amaranth plants was determined at harvest following procedures outlined by Okalebo et al. [19]. These values were then multiplied by the total dry matter of the plants to compute the P uptake. After three crop cycles soil samples from each pot were collected and analyzed for P content.

2.2 Yield Data

Amaranth plants were harvested four weeks after sowing. Plants were uprooted, washed to remove soil particles and then weighed to obtain total fresh weight per plant. The plants were oven dried at 65°C to constant weight for dry matter yield determination.

2.3 Data Analysis

Data collected from the experiment were analyzed using the MSTAT-C statistical package [20]. The analysis of variance (ANOVA) procedures were employed as described by Steel and Torrie [21]. Duncan's Multiple Range Test (DMRT) at $P = 0.05$ was used for mean separation procedures. Simple correlation coefficients between soil available P, and nutrient uptake parameters against yield were determined. Interaction between application methods and frequency of MPR application were also analyzed.

3. RESULTS AND DISCUSSION

3.1 Soil Properties

Before application of treatments analysis results indicated that the soil used for the experiment was acidic with medium levels of P, low organic carbon and calcium, (Table 1). Such properties make the soil used suitable for application of phosphate rock due to low levels of Ca, P and pH. However, low organic matter limits availability of nutrients to plants.

3.2 Effects of Treatments on Soil P

After three crop cycles there was no significant difference ($P \leq 0.05$) between the application frequency on soil available P (Table 2). The abscence of significant difference between the treatments indicates that, increasing the application frequency did not increase availability of P from PR significantly. It implies that, application of MPR once during three crop cycles will supply adequate levels of P for short seasoned vegetable crops like amaranth.

Significant ($P \leq 0.01$) difference was observed between the types of application methods on soil available P. The highest level of P was recorded in soil treated with compost + MPR while the lowest was obtained from the control. Compost + MPR was significantly more effective in increasing soil available P as compared with crotalaria + MPR, especially when the fertilizer materials were applied once or every after one season.

Availability of P from compost + MPR was comparable to that of NPK a soluble fertilizer. It means that application of MPR especially when combined with manure could replace the soluble P fertilizers. The results also suggest that addition of manure enhanced PR dissolution.

3.3 Uptake and Concentration of P in Amaranth Plants

There was significant interaction between frequency and method of MPR application on uptake and concentration of P in amaranth plants (Figs. 1 and 2).

Plant P concentration increased significantly ($P \leq 0.01$) as the frequency of application of the organic fertilizer materials (compost or crotalaria) was increased, while no significant increase was observed when MPR alone or NPK were applied at higher frequencies.

Table 1. Some chemical properties of the soil used in the study

Soil characteristic	Value	Remarks
PH (H_20) 1:2.5	5.54	Acidic*
Organic carbon g/kg)	0.86	Low
Organic matter	1.48	Low
Total N (%)	0.14	Medium
Extractable P (mg/kg)	13.58	Medium
Exchangeable bases (cmol(+) kg^{-1})		
Ca^{2+}	1.01	Very low
Mg^{2+}	2.20	Medium
CEC (cmol(+) kg^{-1})	14.36	Medium

**= According to Landon, [22]*

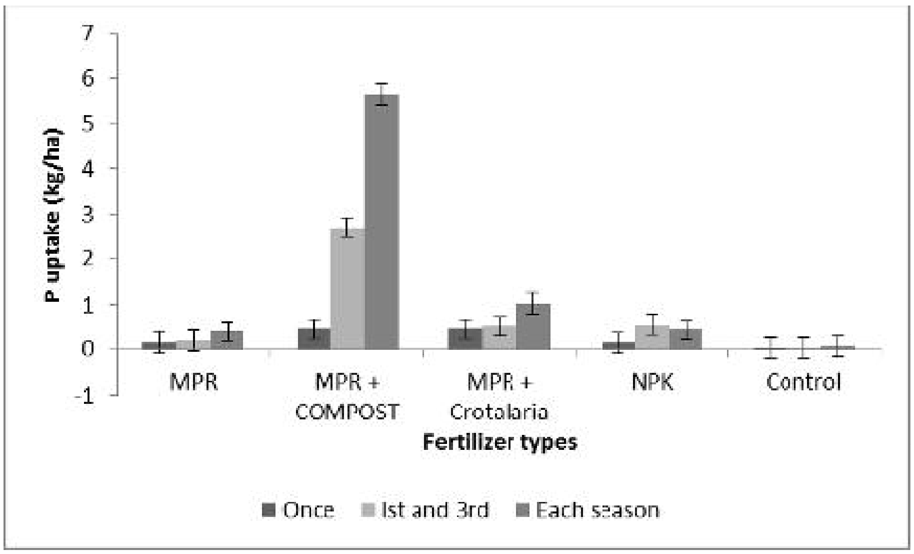

Fig. 1. Interaction of fertilizer types x application frequency on P uptake by amaranth plants

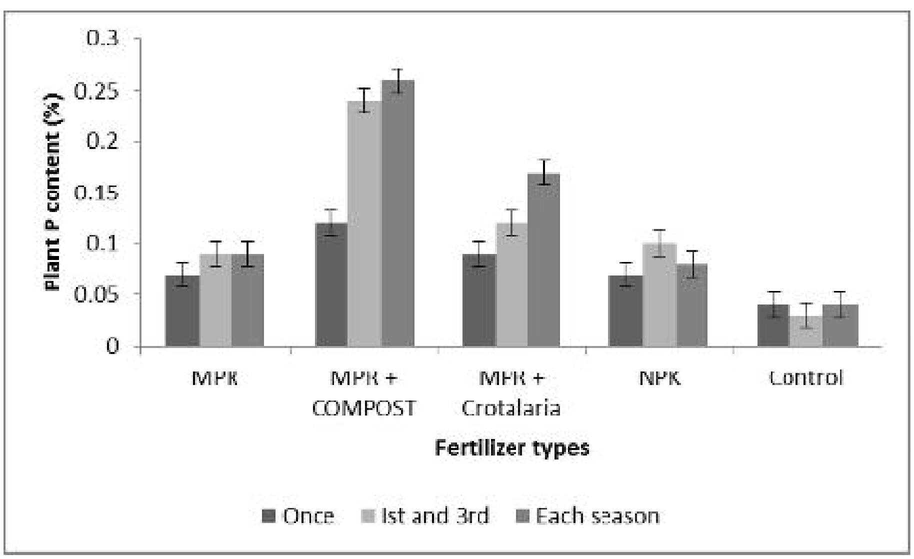

Fig. 2. Interaction of application methods x application frequency on plant P content

Table 2. Effects of fertilizer application method and frequency, over three crop cycles, on P in soil and amaranth plants, and on amaranth yield, as measured during the 3rd crop cycle

Fertilizer application frequency	Fertilizer application method	Soil P (mg/kg)	Amaranth			
			P (%)	P uptake(kg/ha)	Fresh weight (t/ha)	Dry weight (t/ha)
Once in the 1st crop cycle	MPR	38.5ab	0.07de	0.15fg	0.53fg	0.09gh
	Compost + MPR	40.37a	0.12cd	0.46def	1.48d	0.16ef
	Crotalaria + MPR	21.93c	0.09cde	0.46def	1.19de	0.14f
	NPK	42.23a	0.07de	0.14fg	0.71f	0.09gh
	Control	15.40d	0.04de	0.04g	0.24g	0.043i
During 1st and 3rd crop cycle	MPR	37.33ab	0.09cde	0.20efg	0.56fg	0.097g
	Compost + MPR	40.83a	0.24ab	2.70b	4.57b	0.49b
	Crotalaria + MPR	32.53b	0.12	0.51de	1.148d	0.18ef
	NPK	36.40ab	0.10cde	0.55d	1.99c	0.23cd
	Control	11.20d	0.03e	0.03g	0.21g	0.04i
During each of the 3 crop cycles	MPR	37.80ab	0.09cde	0.41def	0.94ef	0.19de
	Compost + MPR	42.47a	0.26a	5.64a	7.82a	0.93a
	Crotalaria + MPR	36.63ab	0.17bc	1.03c	2.28c	0.26c
	NPK	36.17ab	0.08de	0.44def	1.52d	0.25c
	Control	16.57cd	0.04de	0.05g	0.25g	0.05hi
Frequency (A)		ns	**	**	**	**
Fertilizer (B)		**	**	**	**	**
A X B		ns	**	**	**	**
CV (%)		23.37	19.12	46.73	30.76	24.09

*** = Significant at P ≤ 0.01 ns = Non significant*

The significant interaction between application methods and frequence of application implies that the impact of frequency on P-uptake and plant P concentration depended on the method of fertilizer application. As indicated in Figs. 1 and 2, there was significant ($P \leq 0.01$) increase of P-uptake and P concentration as the frequency of application of the MPR combined with organic materials (compost or crotalaria) was increased, while no significant increase was observed when MPR alone or NPK were applied at higher frequencies. The observation suggests that increasing organic matter influenced more P-uptake. The soil used in the present experiment was acidic with low organic matter (Table 1), which means addition of organic matter would increase P availability. Soils having high organic matter tend to have high P availability, P-uptake, followed by plant growth improvement [23]. The increased P availability is atributed to high biological activity in the soil caused by organic matter. In addition, organic matter reduces phosphate fixation a phenomenon that causes unavailability of P especially in acid soils.

Similarly, there was significant interaction between frequency and method of PR application on fresh weight and dry matter yield. (Figs. 3 and 4). Increasing frequence of MPR plus organic materials had positive effects on yield. The lower yield in NPK treatment could be attributed to low availability of nutrients caused by low organic matter.

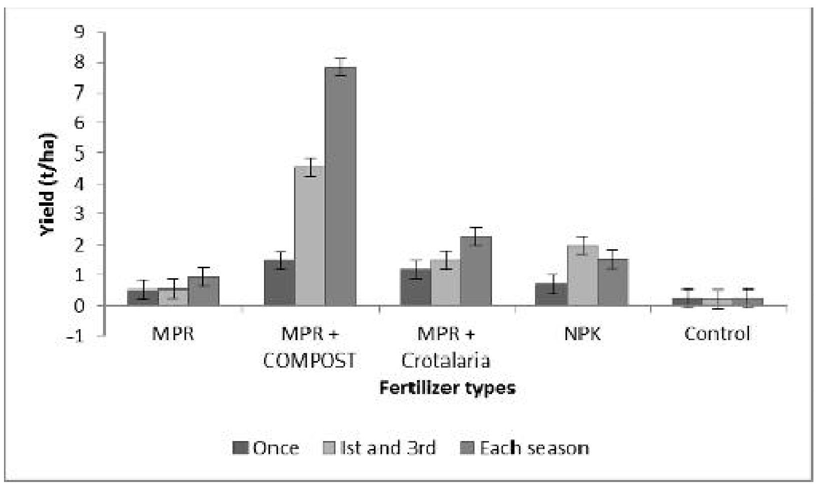

Fig. 3. Interaction of application methods x application frequency on fresh amaranth yield during the three crop cycles

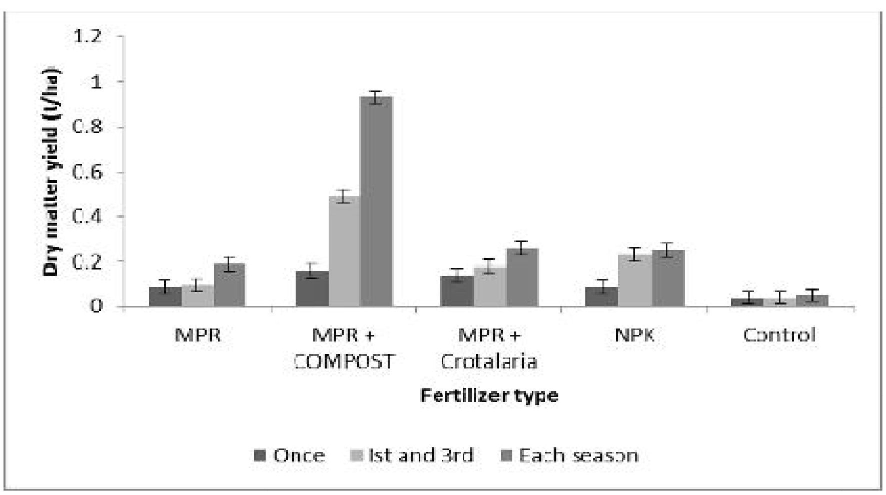

Fig. 4. Interaction of application methods x application frequency on amaranth dry matter yield during the three crop cycles

Table 3. Simple correlations between soil available P, P concentration, P uptake during the third crop cycle and amaranth yield over the three cycles

Variables	1	2	3	4	5	6	7	8	9
1. Fresh weight yield 1st	1.000								
2. Fresh weight yield 2nd	0.861**	1.000							
3. Fresh weight 3rd	0.627**	0.780**	1.000						
4. Dry weight 1st	0.991 **	0.831**	0.614**	1.000					
5. Dry weight 2nd	0.835**	0.981**	0.755**	0.807**	1.000				
6. Dry weight 3rd	0.586**	0.731**	0.983**	0.582**	0.704**	1.000			
7. P concentration 3rd	0.688**	0.793**	0.885**	0.683**	0.784**	0.856**	1.000		
8. Soil available P 3rd	0.459**	0.408**	0.353**	0.473 **	0.406**	0.352 **	0.466 **	1.000	
9. P uptake 3rd	0.428*	0.403*	0.968**	0.432*	0.383*	0.978**	0.854**	0.290	1.000

** = Significant at (P = 0.05) ** = Significant at (P = 0.01) n=45 Error df = n-2*

There was positive and highly significant ($P \leq 0.01$) correlation between soil available P, P uptake, concentration and amaranth yield (Table 3 above). The fact that soil available P was significantly correlated with P uptake and amaranth yield implies that the applied treatments influenced availability of P to amaranth plants which eventually contributed to observed plant growth and yield.

4. CONCLUSION

The results indicate that one time application of MPR can sustain three cropping of leafy vegetable crops such as amaranth. Application of MPR combined with manure increases availability of P due to enhanced dissolution and this treatment could replace the use of soluble P fertilizers in production of short season leafy vegetables. A field experiment is required to confirm these findings.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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