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Effects of Phosphate Rock on Phosphorus Availability for Vegetable Crops in Cropping Sequence

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Authors' contributions

This work was carried out in collaboration between all authors. Authors RRM and JN designed the study, managed the field experiments, literature searches, performed the statistical analysis and wrote the first draft of the manuscript. Authors NM and SK managed the field experiments and collected data. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

This study was conducted to investigate the effects of cropping sequence and Minjingu Phosphate Rock (MPR) on soil phosphorus (P) availability and yield of selected vegetable crops. The study involved a researcher managed on farm field experiment conducted in Mbeya, Tanzania using a split plot design with three replications. Crop sequence (i) Cabbage - tomato - maize (ii) Maize - tomato -cabbage (iii) Cabbage - cabbage - maize (iv) Maize - tomato – maize, constituted the main plots. The P sources (i) control (no fertilizer), (ii) MPR, (iii) compost + MPR, (iv) crotalaria green manure + MPR (v) NPK (standard), were sub plots. The experiment was repeated three times on the same plots. In the fourth season, bean was planted in all plots without fertilizer to capture residual nutrients. Results indicated more percent increase in soil available P in plots where cabbage was included in the sequence (207.9%) as compared to when it was ommited (85.39%). Compost + MPR treatment significantly increased soil pH from 5.8 to 6.33 while in NPK treated plots it decreased to 5.49. After three seasons there was higher residual P in MPR treated plots (33.33 mg/kg) as compared with NPK (27.65mg/kg). Plots treated with NPK produced the highest maize yield while plots treated with MPR alone or combined with compost or crotalaria produced significantly ($P \le .01$) higher cabbage and

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tomato yield especially during the first and second seasons. Bean pod yield was higher in MPR treated plots. Therefore, the use of PR and including cabbage in crop rotations should be encouraged in organic vegetable farming systems to restore P on phosphorus deficient soils.

Keywords: Phosphorus; crop sequence; phosphate rock; cabbage; organic farming.

1. INTRODUCTION

One of the factors limiting production of organic crops is low supply and availability of phosphorus nutrient [1]. The problem is more serious in Sub-Saharan Africa because of the low content of soluble P on bedrock in many regions [2]. This suggests that, the sole use of organic materials and recycling nutrients on the farm may not supply adequate amounts of P for optimum plant growth. Manure and compost, for example, provide relatively low P content in comparison to chemical fertilizers.

Agricultural soils in the Southern Highlands of Tanzania are inherently low in P. The area is potential for vegetable growing. In order to avoid depletion of nutrients and sustain organic vegetable production in these areas, there is need to apply P from external sources such as phosphate rock (PR). Tanzania has two principal deposits of PR; one located at Minjingu area along lake Manyara with a proven 10 million tons deposit of rock phosphates and the other at Panda hill in Mbeya. However, due to low solubility, PR is less effective when applied to short-term annual crops such as vegetables. Previous studies by [3,4,5,6] have shown that amendment of organic materials with PR increases soil available P through enhanced dissolution. Also, crops in the *Cruciferae* family, such as cabbage can enhance P availability from PR by the excretion of acids, formation of root hairs, and high uptake of Ca [7]. Inclusion of such crops in rotations can therefore increase the PR use efficiency. However there is scanty information and inadequate field studies to test these approaches. This study was therefore designed to integrate and test effectiveness of PR within organic vegetable crops rotations. The intended impact was to improve productivity and restoration of P on phosphate deficient soils of smallholder farmers using locally and naturally available materials.

2. MATERIALS AND METHODS

The study was conducted between 2009 and 2012. The field experiment was located in Inyala Ward, Mbeya Rural district along the Mbeya to Dar es Salaam road on the slopes of Uporoto Mountains toward the Usangu plains. The altitude at the site is 1700 m above sea level. The general climate of the area is a transition between arid and wet climate. The mean annual minimum and maximum temperatures are 9ºC and 25ºC, respectively, while the mean annual rainfall ranges from 650 mm and 1400 mm. The soils are reddish brown sandy loams or sandy clays, well drained with a weak structure and profile development. The natural soil fertility of the site is low with pH between 5.5-6.1. The soils have a moderate to poor moisture storing capacity. The major soil types are Vitric Andosols and Haplic Leptosols.

The experiment was laid out in a split plot design with three replications. Crop sequence constituted the main plots ,while the sources of P were the sub plots. The two commonly grown vegetable species in the study area, cabbage and tomato were used.

The cropping sequences included (i) Cabbage - tomato - maize (ii) Maize - tomato - cabbage (iii) Cabbage - cabbage - maize, and (iv) Maize - tomato - maize. The P sources included (i) control (no fertilizer material added), (ii) Direct application of MPR, (iii) compost + MPR, (iv) crotalaria green manure + MPR and (v) NPK (standard).

Soil characterization was conducted at the beginning of the experiment. Top soil samples were randomly collected using soil auger to a depth of 20 cm. Samples were analyzed for soil pH, total N, available P, organic C, exchangeable levels of K, Mg, Ca, Al and CEC.

Soil pH was measured in a 1:2.5 soil water ratio with a pH meter [8]. Organic carbon was determined by the wet combustion method [9]. Cation exchange capacity was determined by the ammonium acetate saturation method [10]. Exchangeable potassium, magnesium and calcium were measured by atomic absorption spectrophotometry [11]. Total nitrogen was determined using the Semi micro Kjeldahl method as described by Anderson and Ingram [12]. Extractable phosphorus was determined by the Bray- Kurtz No. 1 method [13], whereas exchangeable Al was determined by the KCl method [14].

Compost was prepared using the heap method as described by the Henry Doubleday Research Association [15]. Materials used include crop residues, cattle manure, wood ash, a thin layer of top-soil and green grass. MPR (dust) 49 kg P ha^{-1} was added to the layers of the compost heap to make phospho-compost.

Seeds of *Crotalaria ochroleuca* were sown directly on a separate plot at a rate of 50 kg ha^{-1} [16]. Crotalaria plants were uprooted at flowering stage, chopped and incorporated into the soil. Depending on the type of crop, the MPR (49 or 20 kg P ha^{-1}) was broadcasted evenly on the green manure at the time of incorporation into the soil, to come up with green manure + MPR treatment. The rate of application for green manure and compost was based on N content of these materials and N requirement of the crop species.

Seeds of tomato variety mwanga were sown on seedbeds and after one month seedlings were transplanted into field plots at a spacing of 60cm within and 60cm between the rows. The plot size was $10.1m^2$. Seedlings of cabbage variety glory of enkhuizen were transplanted at 50 cm within and between rows. Weeding and irrigation were done as timely as required. Diseases and insect pests in tomato and cabbage plants were controlled using a neem product (Nimbecidine EC (Azadirachtin 0.03%, Neem oil 90.57%).

Data collected include soil nutrients levels and crop yield. Soil samples were collected from the plots after each harvest and analyzed for pH, available P and organic carbon. Yield data for cabbage was obtained by weighing the heads cut close to the soil. Tomato fruits were harvested at red ripening stage. Total fruit yield was estimated based on the weight of fruits harvested from each plot. This was then expressed in t ha^{-1}. Maize yield per plot was obtained by weighing dry grains at harvesting stage.

The experiment was repeated three times on the same plots. In the fourth season, bean crop was planted in all plots without fertilizer application to capture the residual nutrients.

Data collected from the experiment were analyzed using the MSTAT-C statistical package [17]. The analysis of variance (ANOVA) procedures were employed as described by Steel and Torrie [18]. Duncan's Multiple Range Test (DMRT) at P = .05 were used for mean separation procedures.

3. RESULTS AND DISCUSSION

3.1 Initial Soil Analysis Results

Initial soil analysis results at experimental site indicated low P (10.47 mg/kg), low OC (1.43%), low Ca (1.09 cmol(+) kg^{-1}) and low CEC (18.2 cmol (+) kg^{-1}) (Table 1). Total nitrogen content of the soil and the CEC are regarded as medium.

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

Soil characteristic	Value	Remarks*
PH (H_20) 1:2.5	5.80	Medium
Organic carbon (%)	1.43	Low
Total N (%)	0.18	Medium
Extractable P (ppm)	10.47	Low
Exchangeable bases (cmol(+) kg^{-1})		
Ca^{2+}	1.09	Low
Mg^{2+}	1.13	High
K^{+}	1.39	High
CEC (cmol(+) kg^{-1})	18.2	Medium

**= According to Landon [19]*

3.2 Effect of Cropping Sequence on Availability of Phosphorus

During the first crop cycle performance of crops was poor. The situation was worse in cabbage plots especially where NPK was applied. Cabbage plants in those plots expressed Ca deficiency symptoms. Low levels of Ca, P and organic matter before application of fertilizer materials (Table 1) and slow release of P from MPR during the first season may have contributed to poor performance of crops in the first season. However, during the second and third seasons crops responded well especially in plots treated by MPR alone or combined with organic materials. This can be explained by the fact that release of P increases with time of contact between soil and PR. PRs in soil dissolve gradually and supply P at a steady rate. According to results obtained by Al-oud [20], availability of P from rock phosphate was increased by increasing incubation period up to 90 days. This suggests that for more efficient use of phosphate rock in cropping systems low P demanding crops should be planted in the first season and higher P demanding crops later in the rotations.

Although not significant higher levels of soil available P were recorded in plots where cabbage was included in the rotation as compared to when cabbage was omitted (Table 2). This suggests that cabbage had influence on availability of P. In the plots where cabbage was omitted from the cropping sequence, final P levels during the third season had increased only by 85% as compared to 207% where cabbage was included. This is due to the fact that cabbage can enhance P availability from calcium phosphates through excretion of citric and malic acids that actively solubilize PRs to release the bound P and Ca. Also, cabbage form extensive fine root hairs that facilitates the exploration of a large soil volume for P. The uptake of high amounts of Ca also contributes to enhanced availability of P [21]. Therefore subsequent crops in rotation can benefit from the increased availability of phosphorus [22]. More evidence is shown by the results presented in Fig. 1 whereby the lowest bean pod yield was recorded in plots where cabbage was omitted. Normally common bean (*Phaseolus vulgaris* L.) crop exhibits a generalized response to P fertilization, as demonstrated by several experiments conducted in Tanzania and elsewhere in the world [23]. This could be the reason why higher pod yield was recorded in plots with higher residual P and probably where there was more Ca supplied by MPR (Fig. 2). Although not significantly deferent the soil P improvement results caused by inclusion of cabbage in the crop rotation indicate a long term advantage of this practice.

Table 2. Changes in soil available Phosphorus in the plots as influenced by crop sequence during the study

Treatment (crop sequence)	Initial P (mg/kg)	Final P (mg/kg)	Difference (%)
Cabbage— tomato— maize	10.47	32.24a*	207.93
Maize—tomato—Cabbage	10.47	24.18a	130.95
Cabbage—cabbage—Maize	10.47	26.6a	154.06
Maize —tomato —Maize	10.47	19.41a	85.39

** = Means in the same column followed by the same letter are not significantly different at ($P \leq 0.05$) according to DMRT*

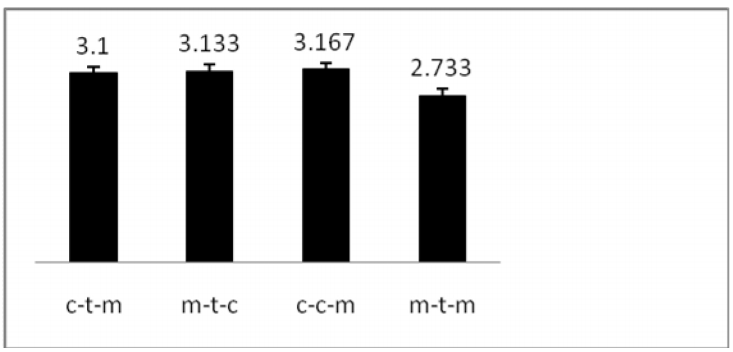

Fig. 1. Bean pod yield (kg/plot) as influenced by cropping sequence
Key: C=Cabbage, t = tomato, m = maize

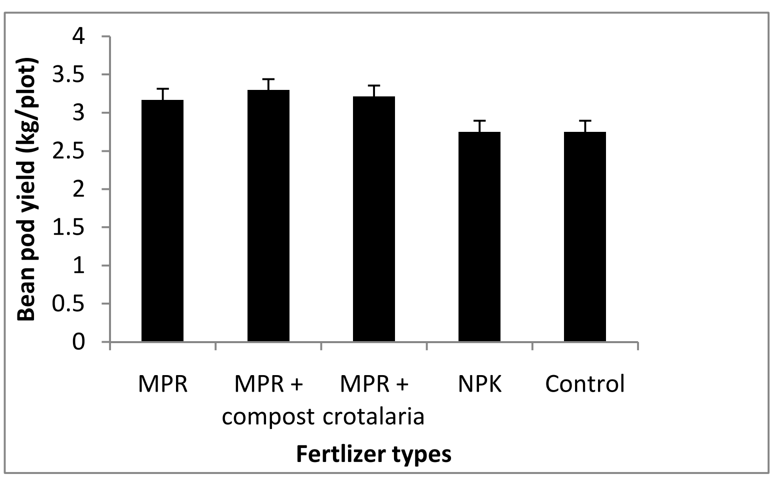

Fig. 2. Pod yield (kg/10m^2) as influenced by fertilizer types and cropping sequence

3.3 Effects of MPR and Organic Amendments on Soil Properties

3.3.1 Soil pH

There was an increasing trend on soil pH levels in plots treated with MPR applied alone or combined with organic materials during the three cropping cycles (Table 3, Fig. 3). On the other hand a decreasing trend was observed in plots treated with NPK. The higher pH levels may have been attributed by the released cations (Ca++) by the phosphate rock. Phosphate rock treated soils had higher available calcium than other treatments due to the release of calcium from phosphate rock [24]. In Kenya [25] higher pH levels were observed in the plots treated with MPR as compared to those treated with DAP. Similarily, significantly lower levels of pH were obtained where NPK was applied as compared to plots treated with NPK combined with manure [26]. In another study a mean pH of 5.2 was obtained in fertilizer treated soils as compared to pH 6.03 in untreated soils [27]. Persistent use of acid-forming fertilizers can cause soil acidification [28].

One of adverse effects of long run decreasing soil pH is creation of chemical and biological conditions which are harmful to plants [29]. In acid soils, biological activities decline, soil aggregation becomes poorer and availability of nutrients to plants is affected. In some cases, acid soils encourage the growth of certain plant pathogens such as club root [30] which affect cabbage. The results from this study therefore suggest that, application of MPR and organic amendments in the Southern Highlands region where soils are generally acidic and deficient in P [31] may improve the pH conditions of the soil.

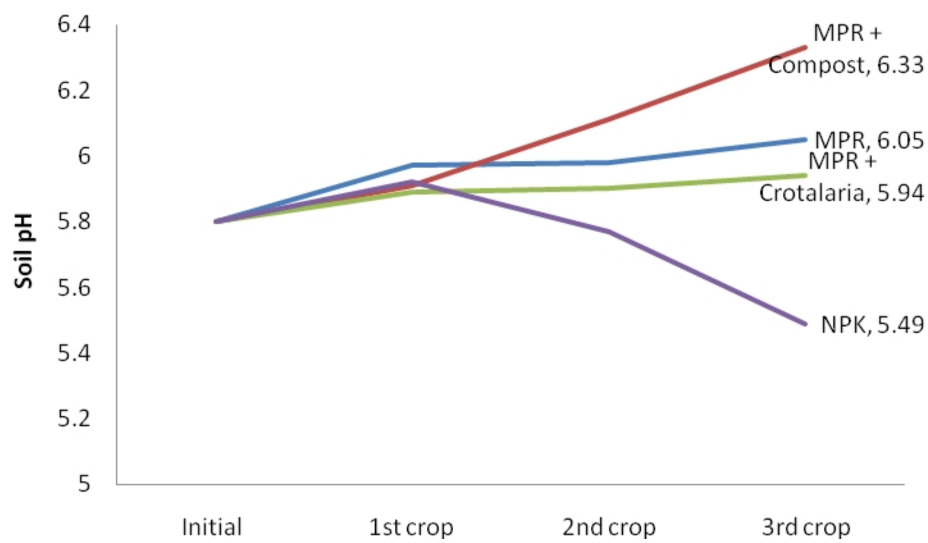

Fig. 3. Changes in soil pH during the three cropping cycles

Table 2. Soil available P, OC and pH in the plots during three crop cycles

Treatments	P After 1st crop	P After 2nd crop	P After 3rd crop	OC After 3rd crop	pH After 1st crop	pH After 2st crop	pH After 3st crop
Cropping sequence (A)							
Cabbage—tomato— maize	11.96a	26.66a	33.38a	1.42a	6.01a	5.99a	6.17a
Maize—tomato—Cabbage	13.17a	22.89a	24.18a	1.49a	6.02a	5.83a	5.94a
Cabbage—cabbage—Maize	9.68a	21.43a	26.61a	1.35a	5.90a	5.93a	5.84a
Maize —tomato —Maize	11.29a	20.89a	19.41a	1.38a	5.90a	5.93a	5.89a
SE±	1.37	1.49	3.68	0.04	0.04	0.06	0.06
Fertilizer types (B)							
MPR	12.29a	23.33ab*	31.43ab	1.37b	5.97a	5.98ab	6.05b
Compost + MPR	14.42a	29.93a	33.33a	1.54a	5.91a	6.11a	6.33a
Crotalaria + MPR	11.78a	20.75bc	23.26b	1.37b	5.89a	5.90ab	5.94b
NPK	10.64a	26.21ab	27.65ab	1.43b	5.92a	5.77b	5.49c
Control	8.50a	14.63c	13.81c	1.34b	6.10a	5.86ab	5.99b
Mean	11.52	22.97	25.90	1.41	5.96	5.92	5.96
SE ±	1.30	1.72	1.87	0.03	0.08	0.04	0.07
CV (%)	39.12	25.94	24.95	8.48	4.66	2.13	3.84

** = Means in the same column followed by the same letter are not significantly different at ($P \leq 0.05$) according to DMRT*

3.3.2 Soil phosphorus

Adequate soil phosphorus enables plants to store and transfer energy, promotes root, flower and fruit development, and allows early maturity. For most vegetables phosphorus is also required for production of quality transplants by improving the leaf area, shoot and root mass [32]. In the present study, different fertilizer materials differed significantly on their influence on availability of soil P. Plots treated with MPR + compost had significantly ($P \leq .01$) higher P as compared to other treatments (Table 3). Higher levels of P in Compost + MPR treated plots may have been attributed to higher organic matter content as compared to MPR applied alone or combined with crotalaria. The high cation exchange capacity of organic matter, formation of Ca-organic-matter complexes; and organic acids leads to enhanced PR dissolution [33,34].

Soil analysis results after three crop cycles have indicated highest residual P in plots treated with compost + MPR as compared with other treatments including NPK. Compost + MPR treatment increased soil available P by 218% (Table 4). Compared to industrial mineral fertilizers, rock phosphates have long-term residual effects and contribute to recapitalization of P in the soils.

Table 4. Changes in soil available P in the plots during the study

Treatment	Initial P (mg/kg)	Final P (mg/kg)	Difference (%)
MPR	10.47	30.60ab*	192.26
Compost + MPR	10.47	33.33a	218.34
Crotalaria + MPR	10.47	23.26b	122.16
NPK	10.47	27.65ab	164.09
Control	10.47	13.81c	31.90

** = Means in the same column followed by the same letter are not significantly different at ($P \leq 0.05$) according to DMRT*

3.3.3 Soil organic matter

Soil organic matter is regarded as the main contributor to soil fertility. It acts as a reservoir of soil nutrients such as nitrogen, phosphorus and sulphur. Compost + MPR treatment increased soil organic carbon by 7.69% while crotalaria + MPR, MPR applied alone and NPK did not increase organic carbon (Table 5). The highest organic carbon observed in compost treatment could be attributed to more humus synthesis in those plots. The decreased organic carbon observed in the control, MPR, and Crotalaria + MPR plots could be attributed to low synthesis of organic matter and previous cultivation without adding organic amendments.

Table 5. Changes in organic carbon in the plots during the study

Treatment	Initial (%)	Final (%)	Difference (%)
MPR	1.43	1.37b	-4.19
Compost + MPR	1.43	1.54a	7.69
Crotalaria +MPR	1.43	1.37b	-4.19
NPK	1.43	1.43b	0.00
Control	1.43	1.34b	-6.29

** = Means in the same column followed by the same letter are not significantly different at ($P \leq 0.05$) according to DMRT*

Studies have reported organic matter declines of between 25 and 75% with continued cultivation. A study conducted in the semi-arid parts of Tanzania revealed a 50% loss of SOC after 50 years of cultivation [35]. Increased soil disturbance breaks down soil aggregates and exposes residues and other SOM to microbial decomposition and oxidation, accelerating the rate of SOM decline. Tillage mixes oxygen into the soil and raises its average temperature, thereby contributing to an increased rate of organic matter decay [36]. Organic matter in virgin soils is usually higher than in cultivated soils and furthermore when cultivation of such soils begins organic matter content usually declines. Other causes of declining organic matter include inadequate use of organic amendments, burning or removing of crop residues, soil types, topography and soil erosion.

Normally, vegetable crops demand high levels of soil organic matter ranging from 5-8% [37]. Restoration of the declining soil organic matter can be achieved through frequent application of organic soil amendments and to limit losses due to erosion, cultivation or management [38].

3.4 Effects of Fertilizer Materials on Yield

There were differences in response of different crops to applied fertilizer materials (Fig. 4a–c). Normally plant species differ in their P and Ca uptake demand and pattern as well as in their ability to absorb soil nutrients [39,40]. Application of MPR only slightly increased maize and pigeon pea, but nearly tripled cabbage [41]. In the present study plots treated with NPK produced the highest maize yield while plots treated with MPR alone or combined with compost or crotalaria produced significantly ($P \leq .01$) higher cabbage and tomato yield especially during the first and second seasons. The yield performance may have been partly attributed to ability of MPR to regulate the pH thus increasing availability of nutrients such as Ca and P.

While Ca is an essential element for all plants, crops such as cabbage, tomatoes and legumes have been found to be responsive. In a study, medium and high levels of calcium increased cabbage yield [42]. In calcium deficient soils these vegetables demonstrate symptoms such as Blossom End Rot in tomatoes and tipburn in cabbage. In the present study tipburn symptoms were observed in cabbage plots during the first season in plots treated with NPK due to low Ca. Application of rock phosphates in such soils may be an advantage. Fig. 4b indicates higher cabbage yield during the first season in plots where MPR was applied as compared to NPK and the control. An explanation for this could be that, MPR containing 30% Ca as its constitutent may have supplied adequate Ca to cabbage and tomato crops.

Therefore frequent application of MPR in the Southern Highlands and other areas with similar soils will increase yields of vegetables substantially while building soil Ca and P capital. In small holder vegetable farming system this endeavor is possible because MPR fertilizers are easily available in shops and at an affordable price.

Application of compost + MPR gave significantly higher cabbage and tomato yield as compared to other fertilizer treatments. This may be attributed by the ability of compost to modify the soil physicalchemical characteristics which in turn improved the availability of nutrients thus increasing the vegetable yields. Compost increases humus and microbiological activity in soil.

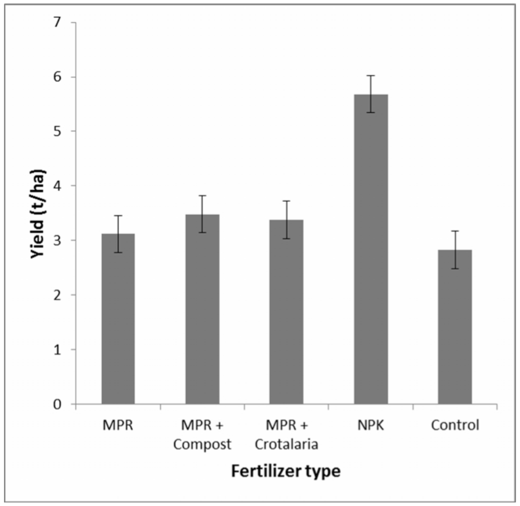

Fig. 4a. Maize yield (t/ha) as affected by different fertilizer treatments

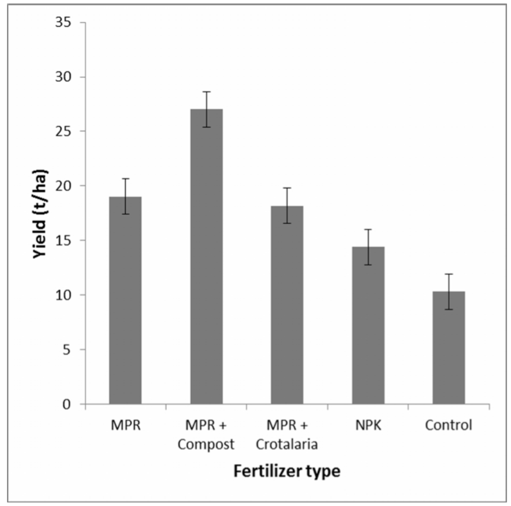

Fig. 4b. Cabbage yield (t/ha) as affected by different fertilizer treatments

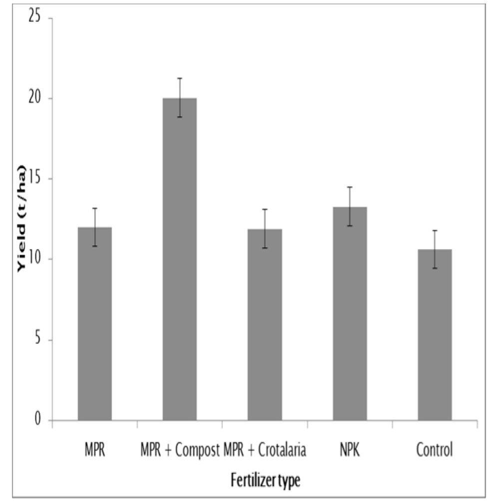

Fig. 4c. Tomato yield (t/ha) as affected by different fertilizer treatments

4. CONCLUSION

The results revealed that there is great potential in using PR in organic vegetable farming. Combining PR with organic fertilizer materials increases soil available P due to enhanced PR dissolution thus making it available to short seasoned crops like vegetables. The results also suggest that including cabbage in the cropping sequence increases effectiveness of PR for subsequent crops. The use of PR in vegetable farming, supplies both calcium (Ca) and P nutrients which are essential for growth and yield. Promotional activities should be conducted to increase the number of farmers accessing the product and adopting the use of MPR in vegetable production especially in the southern highlands of Tanzania and other areas where soils have low pH, Ca and P.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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