Original Research Article

Influence of phosphorus forms on growth and yield of cowpea, Kales and Amaranth vegetable species

Abstract

Maximum production potential of leafy vegetable is limited by phosphorous deficiency in the soils. This is due to the high cost of the phosphate fertilizer and the fixed form of the available phosphorous in the soil. There is therefore, need for farmers to use alternative and cheaper sources of P that are economic friendly to supply the required mineral nutrition to their crops. Rock phosphate is widely available but has a challenge in solubilization to make P available to the crops. In the current study, the aim was to evaluate the effect phosphate forms and acidulate rock phosphate on growth and yield of selected leafy vegetables. The experiment was laid out in Randomized Complete Block Design in split-plot arrangement, with three leafy vegetables (cowpeas, kales and amaranth) being the main plots, and various sources of P (Triple super phosphate (TSP) Mijingu Phosphate Rock (MPR), Mijingu phosphate Rock + sulphur (MPR) PR+S and control) constituting the subplots with three replicates. The collected data included the root dry weight, leaf area, shoot fresh weight and leaf area and was subjected to SAS for ANOVA and where there were significant differences between means were further separated using the Fischer's LSD at 5% level of significance. The results revealed that there were significant increase in the growth parameters of the vegetables as an effects of phosphorus application compared with the control. TSP elicited the best results in all the tested parameters in 5 WAP, 6 WAP and 7 WAP respectively in both seasons The highest value of root dry weight (11.2 g), leaf area (1905.0 cm^2), number of branches (40.67) shoot fresh weight (236.8 g) as influenced by TSP application in the vegetable species. The MRP +sulphur also followed in superiority of increasing the growth parameters which is an indication that sulphur can be used in solubilizing rock phosphate and making it a suit alternative for farmers. Thus, farmers are advised to directly apply rock phosphate and sulphur to soil as a possible alternative to the more expensive soluble phosphate fertilizers in tropical cropping system.

Key words: Rock phosphate, Available Phosphorous, sulphur, soil fertility

1.0 Introduction

Phosphorus is one of the most needed elements for crop production in many tropical soils. Phosphorus has been reported to have a tremendous effect on proper root formation, establishment and formation for the absorption of mineral salts and water from the soil [1]. Regardless of its imperative role in plant growth, its deficiency in the soils has limited farmers from achieving maximum yield. The situation is aggravated in smallholder agriculture where use of mineral fertilizers is limited or even non-existent, as peasant farmers, due to their low purchasing capacities, cannot afford high costs of these fertilizers [2,3]. Specifically, vegetable farmers have experienced great challenges in increasing yield due to the fact that vegetable species consume significant amount of phosphorus that is way beyond their potential to purchase the chemical fertilizers [4]. There has been a rising demand of African Leafy vegetables (ALV) in the recent past in Kenya. The priority species marketed include leafy amaranth (Amaranthus spp), cowpeas (*Vigna unguiculata*), Ethiopian kale (*Brassica carinata*), African black nightshades (*Solanum* spp), pumpkin leaves (*Cucurbita maxima)* [5]. African leafy vegetables have gained commercial importance over the past 15 years as a result of the enormous growth in market [5]. The production of ALVs has its advantages because of the uniqueness such as short production cycles, are resistant to pests and diseases and are quite acceptable to local tastes [5]. This could be contributed by their perceived nutritional and medicinal values on diseases and alleviation of conditions such as diabetes, high blood pressure, cancer and HIV/AIDS. Due to this high demand there is need to look for alternate supply of phosphorus nutrients to the vegetable and consequently increase yield. Rock phosphate (PR) provides an alternative to the expensive soluble P. Unfortunately, use of Rock phosphate (PR) to alleviate P deficiency in the soils remains a great challenge due to their low solubility [6]. The PR is water-insoluble but acid-soluble indigenous P source, that may be more relevant for these resource-limited farmers, in comparison to the prohibitive expensive soluble P [7]. The PR is acid-soluble and any activities that increase rhizosphere acidification increase its solubility. However, studies have shown that elemental sulphur has high dissolution rate of phosphorus from rock phosphate that is locally available and can be used in reducing the problem of phosphorus deficiency in soils and increase the yield of leafy vegetables. Therefore, in this study, the focus was to compare the performance of the synthetic phosphorus forms with rock phosphate on the selected African leafy vegetables on their growth responses.

2.0 Materials and methods

2.1 Description of the study site

The experiment was carried out at Kenyatta University farm, Kiambu County, Kenya. The site lies at an altitude of 1745 meters above sea level and is within latitude 110 0.012 S and longitude 3649 59.880 E. The average amount of rainfall received is 989 mm per year (where 1200 mm rains were recorded during the long rains whereas 780 mm recorded during the short rains). Temperature ranges between 12.8^0 C during the cold months and 24.6^0 C during the hot seasons. The soils are loamy, acidic, well drained and moderately deep [8].

2.2 Experimental Layout and Design

The experiment was arranged in a split-plot arrangement, with three leafy vegetables (cowpeas, kales and amaranth) being the main plots, and various sources of P (TSP, MPR, MRP+S and control) constituting the subplots with three replicates. Each experimental plot measured 2m x 2m. Individual blocks were spaced 1 m apart while the plots within the blocks were separated by a 0.5 m path. The kale and amaranth seedlings were first raised in a nursery and transplanted at six leaf stage (4 weeks) into a seedbed prepared to a medium tilth at a spacing of 30 cm x 15 cm for amaranth, 45 cm x 15 cm for cowpeas, and 45 cm x 15 cm for kales. The seedlings were subjected to treatment during transplanting to the field. Four treatments used consisted of; control (zero fertilizer input), Mijungu rock phosphate (120 kg P_2O_5 /ha), MRP +S (120 kg P_2O_5 /ha) using 240g of elemental sulphur, and TSP (60 ~~Kg~~ kg p /ha). The rate of 120 kg P_2O5/ha used in this experiment was adapted from the recommendations of FURP & KARI (1994). Appropriate rates of Calcium Ammonium Nitrate (26%N) at 60 kg N/ha and Muriate of potash (60% K_2O) at 30 kg/ha were uniformly administered and incorporated into the soil to supply sufficient amounts of N and K to ensure the two nutrients were not limiting factors on plant growth when studying the effects of P. The fields were kept weed free by manual weeding. Pests and diseases were also controlled.

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2.3 Data collection and Analysis

Data on plant height, fresh weight, dry weight, leaf area and root area were recorded. A well-calibrated ruler in centimetres, electronic weighing balance in grams and physical counting were used. Plant height was measured from the ground level up to the apex of the youngest leaf. Fresh weight measurement entailed picking all the leaves and tender shoots and weighing them immediately using an electronic weighing balance. The collected data was subjected to analyses of variance (ANOVA), using the General Linear Model (GLM) procedure of SAS-computer software (SAS 2002, version 19.0). Mean separation was done using least significant difference (LSD) test at 5% significant level.

3.0 Results and Discussions

3.1Root Dry weight

Significant differences ($P \leq 0.05$) were observed between the phosphorus treatments in the three root dry weight of the vegetable species in season 1 and season 2. Kales recorded the highest root biomass in 5 WAP, 6WAP and 7 WAP in both season 1and season 2 with the 7WAP being superior with 9.84 g and 9.83 g in season 1 and 2 respectively. This could be due to high growth rate of the kales as a result of phosphorous nutrition. Cowpea had the least biomass accumulation in root in both seasons as shown in Table 1. Phosphorous forms also exhibited significant differences in root biomass with TSP being superior during the whole growth period with the highest being recorded at 7WAP with 11.2 g in the two season. The RP+sulphur was the second best in terms of root growth which is an indication of high availability of phosphorus from this particular source of phosphorous. The control recorded the least root biomass compared to other sources of phosphorous.

Table 1: Influence of phosphorous forms and vegetable species on root dry weight

	Season 1			**Season 2**		
Species	**5WAP**	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kales	3.65^{a}	7.08^{a}	9.84^{a}	3.73^{a}	7.25^{a}	9.83^{a}
Amaranth	2.79^{ab}	4.60^{ab}	5.46^{b}	2.80^{ab}	4.59^{ab}	5.46^{b}
Cowpea	1.80^{b}	3.06^{b}	3.77^{b}	1.79^{b}	3.06^{b}	3.77^{b}
LSD	**1.40**	**2.61**	**3.56**	**1.40**	**2.72**	**3.56**
Treatments						
Control	1.12^{c}	1.92^{c}	2.78^{b}	1.12^{b}	1.92^{c}	2.78^{b}
TSP	4.76^{a}	8.47^{a}	11.22^{a}	4.65^{a}	8.69^{a}	11.22^{a}
RP+S	3.22^{b}	5.59^{ab}	6.88^{ab}	3.44^{a}	5.59^{ab}	6.87^{ab}
RP	1.88^{bc}	3.66^{bc}	4.54^{b}	1.88^{b}	3.66^{bc}	4.54^{b}
LSD	**1.10**	**2.42**	**3.70**	**1.15**	**2.56**	**3.70**
SXPF	*	*	*	*	*	*

Means followed by the same letter within the same column are not significantly different (P≤0.05). TSP- Triple –super phosphate, RP+S-Rock Phosphate and sulphur, RP- Rock phosphate, S-vegetable species, PF-phosphorous sources

Interaction effects between the vegetable species and phosphorus source at various growth stages in the two experimental sites. During the first season , amaranth supplied with TSP was superior in root biomass in three sampling stages recording 2.64 g, 4.62 g and 5.50 g in 5WAP, 6 WAP AND 7 WAP respectively as shown in table 2. In the second season, significant differences were observed in the interaction of the vegetable species and phosphorus with amaranth supplied with rock phosphate having the highest root dry weight of 6.12 g, 6.14 g and 6.03 in 5 WAP, 6 WAP and 7 WAP respectively. (Table 2) RP+S followed in root biomass accumulation which was an indicator of vibrant root growth as influenced by phosphorus from dissolved rock phosphate. There was a significant influence on the all-vegetable species compared to the control which could be as a result of promoted growth of young cells and rapid cell division as a result of phosphorus nutrition. Phosphorous has also been associated with increased root formation which is confirmed from the current study.

Table 2: Interaction effects on vegetable species and phosphorous sources on root dry weight in season 1 and season 2

Treatments	Season 1			Season 2		
	5WAP	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kale control	1.24^{f}	1.86^{g}	2.69^{f}	1.24^{h}	1.85^{i}	2.69^{h}
Amaranth control	0.24^{i}	0.58^{h}	1.13^{i}	5.86^{ab}	5.83^{b}	5.83^{ab}
Cowpea control	0.81^{h}	1.79^{g}	2.17^{h}	5.12^{d}	4.99^{d}	5.25^{cd}
Kales TSP	2.61^{a}	3.81^{b}	4.87^{b}	2.60^{f}	3.81^{f}	4.87^{e}
Amaranth TSP	2.64^{a}	4.62^{a}	5.50^{a}	5.38^{cd}	5.31^{c}	5.27^{cd}
Cowpea TSP	1.39^{e}	2.46^{e}	2.84^{e}	5.51^{c}	5.48^{c}	5.49^{bc}
Kale RP	1.97^{c}	2.29^{e}	3.89^{d}	1.97^{g}	2.76^{h}	3.89^{g}
Amaranth RP	1.49^{d}	2.83^{d}	3.82^{d}	6.12^{a}	6.14^{a}	6.03^{a}
Cowpea RP	1.01^{g}	2.10^{f}	2.46^{g}	5.63^{bc}	5.69^{b}	5.76^{ab}
Kale RP+S	2.34^{b}	3.43^{c}	4.51^{c}	2.33^{f}	3.43^{g}	4.51^{f}
Amaranth RP+S	1.91^{c}	3.65^{b}	4.40^{c}	5.10^{de}	4.60^{e}	5.02^{de}
Cowpea RP+S	1.24^{f}	2.29^{e}	2.70^{f}	4.77^{e}	4.74^{e}	4.81^{ef}
LSD	0.12	0.17	0.11	0.35	0.18	0.34

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). TSP- Triple –super phosphate, RP+S-Rock Phosphate and sulphur, RP- Rock phosphate,

The current study agrees with the findings of Ojo *et al*. [9] who reported an increase in root biomass on grain amaranth when supplied with phosphorus forms. Application of phosphorus sources in cowpea has also reported to increase nodulation which is a sign of vibrant root growth as reported by Kyei-Boahen *et al*. [10] particularly for cow pea. On the other hand the effective utilization of rock phosphate in combination with sulphur was obvious where by the S seem to play a role in decreasing soil pH, and consequently helped in transformation of insoluble P to available form for plant uptake [11] Moreover, mixing the RP with elemental S caused a significant increase in the available P over those applied without S. As stated by Huang Rankine

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et al. [12], phosphorus is an essential element for plant growth and is particularly important for root growth during the establishment and early growth stages. The current study thus, indicates that growers can embark on rock phosphate utilization in farming as an alternative in provision of phosphorous nutrition in vegetable species.

3.2 Leaf area

Vegetable species exhibited significant differences ($P \leq 0.05$) in leaf area in the two study seasons. Kales recorded the largest leaf area in season 1 and season 2 with the greatest values being recorded during the 7 WAP with 2088.0 cm^2 in season one and 1905.0 cm^2 at 7 WAP in season 2 as illustrated in table 3. The significant high leaf area in kales could be as a result of proper utilization of the applied phosphorous to match the shoots and root demand. Cowpea had the lowest leaf area in the entire growing season for both season 1 and season 2. The TSP treatment elicited the greatest leaf area followed by the rock phosphate plus sulphur treatment. The control had the least effect on leaf area in vegetable species during the season 1 and season 2. There were significant interactions observed between the vegetable species and phosphorous species.

Table 3: Leaf Area as affected by vegetable species and phosphorous sources during season 1 and season 2

	Season 1			**Season 2**		
Species	**LA5WAP**	**LA6WAP**	**LA7WAP**	**LA5WAP**	**LA6WAP**	**LA7WAP**
Kales	775.4^{a}	1221.0^{a}	2088.0^{a}	573.7^{a}	1129.3^{a}	1905.0^{a}
Amaranth	263.0^{b}	691.2^{ab}	1141.0^{ab}	263.0^{b}	607.9^{ab}	1149.0^{ab}
Cowpea	189.9^{b}	285.4^{b}	596.0^{b}	189.9^{b}	267.9^{a}	525.0^{a}
LSD	**279.2**	**560.9**	**866.3**	**241.9**	**510.0**	**860.00**
Treatments						
Control	131.3^{b}	187.1^{c}	333.0^{c}	109.1^{b}	176.0^{b}	329.0^{c}
TSP	760.8^{a}	1543.2^{a}	2472.0^{a}	649.7^{a}	1442.1^{a}	2393.0^{a}
RP+S	553.8^{ab}	910.1^{ab}	1665.0^{ab}	431.6^{ab}	710.1^{b}	1420.0^{ab}
RP	191.9^{b}	289.7^{bc}	630.00^{bc}	178.5^{b}	345.3^{b}	630.0^{bc}

LSD	**329.2**	**518.8**	**810.00**	**246.1**	**485.3**	**815.5**
SXPF	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Means followed by the same letter within the same column are not significantly different (P≤0.05). TSP- Triple –super phosphate, RP+S-Rock Phosphate and sulphur, RP- Rock phosphate, S-vegetable species, PF-phosphorous sources

Application of phosphorous promotes growth and differentiation of major organs such as leaf s hence results to increase in leaf area. According to Yan *et al.* [13], adequate phosphorus nutrition has been reported to lead to an increase in leaf growth and consequently recording a high leaf area in brassica family which also supports the findings of this study. Additionally, phosphorus helps in the conversion of other nutrients into usable building blocks for growth and photosynthesis. It is also indispensable for cell differentiation and for the development of the tissues that form the growing points of the plants [14]. This study conforms to the findings of Singh *et al*. [15] who reported phosphorus that leads to an increase in leaf expansion that's result into high leaf area hence increasing the photosynthetic area of various crops.

3.3 Shoot Fresh weight

Shoot fresh weight had significant differences (P ≤ 0.05) between the vegetable species and also phosphorus forms in season 1 and season 2. Kales had the highest accumulation of shoot fresh weight in all the sampling stages in both seasons; with 7 WAP having the highest value of 175.03 g and 174.96 g in season 1 and season two respectively as shown in table 4. Cowpea accumulated the least shoot fresh weight in all the growth stages. Phosphorous forms also showed significant (P ≤ 0.05) increase in shoot fresh weight of vegetable species TSP recorded the highest shoot fresh weigh I in both season 1 and 2 at all the growth stages with the highest in 7 WAP (236.88 g) in season 1 and (228.0 g) in season 2. The high shoot fresh weight could be as a result of more available phosphorus that promoted vibrant growth of the vegetative parts. The control had the least shoot fresh weight in all the growth stages.

Table 4. Shoot Fresh weight as influenced by vegetable species and phosphorous sources

	Season 1			**Season 2**		
Species	**5WAP**	**6WAP**	**SFW7WAP**	**SFW5WAP**	**SFW6WAP**	**SFW7WAP**
Kales	51.48^{a}	107.49^{a}	175.03^{a}	50.80^{a}	107.49^{a}	174.96^{a}
Amaranth	25.25^{ab}	46.42^{ab}	91.54^{ab}	25.25^{ab}	53.09^{ab}	81.54^{ab}
Cowpea	13.32^{b}	22.34^{b}	31.26^{a}	13.66^{b}	23.01^{b}	32.53^{b}
LSD	**23.79**	**49.38**	**93.0**	**24.17**	**48.40**	**92.2**
Treatments						
Control	6.31^{b}	11.87^{b}	17.44^{b}	5.58^{c}	12.76^{b}	18.91^{b}
TSP	60.71^{a}	135.43^{a}	236.88^{a}	61.38^{a}	130.98^{a}	228.0^{a}
RPS+S	37.28^{ab}	64.93^{b}	96.06^{b}	37.39^{ab}	64.93^{b}	96.06^{b}
RP	15.76^{b}	36.12^{b}	46.86^{b}	15.26^{bc}	36.12^{b}	42.41^{b}
LSD	**23.99**	**48.42**	**89.0**	**23.66**	**49.10**	**91.2**
SXPF	*	*	**NS**	*	*	**NS**

Means followed by the same letter within the same column are not significantly different (P≤0.05). TSP- Triple –super phosphate, RP+S-Rock Phosphate and sulphur, RP- Rock phosphate, S-vegetable species, PF-phosphorous sources

Interactions effects between the phosphorus forms and vegetable species on the influence of shoot fresh weight during 5 WAP and 6 WAP in season 1 and 2 are illustrated in figure 1. Kales applied with TSP had the highest shoot fresh weight (106.91 g) in season one for both 5 WAP and 6 WAP respectively and 233.91 g in 5 WAP and 6 WAP in season 2. Like other parameters, the control recorded the least shoot fresh weight.

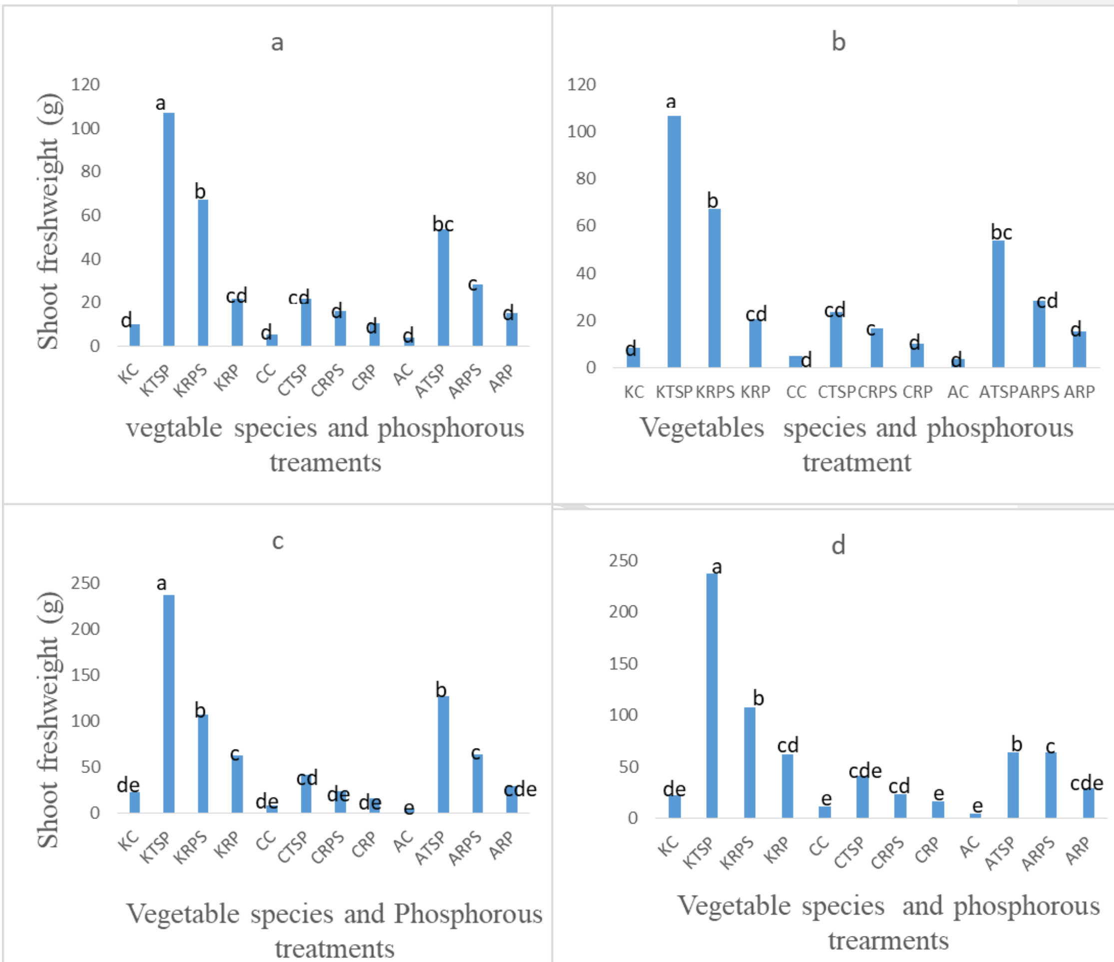

Figure 1: Interaction effects of phosphorus forms and vegetable species on shoot fresh weight in season 1 5WAP (a), 6WAP (b) season 2 5WAP (c), 6WAP (d). KC- kales control, KTSP- Kales TSP, KRPS- kales RPS, KRP- Kales RP, CC- Cowpea control, CTSP- cowpea TSP, CRPS- cowpea RPS, CRP- cowpea RP, AC- Amaranth control, ATSP- Amaranth TSP, ARPS- Amaranth RPS, ARP- Amaranth RP.

The findings of this study agree with those of Chen *et al.* [16] who reported an increase in the shoot biomass in Chinese kale upon application of phosphate fertilizers. In another study by Kim *et al*. [17] application of high phosphorous form led to high growth of the above ground biomass as well as the roots. In soils where P-is deficient in plants, shoot growth was found to be more affected than root growth due to assimilate partitioning towards the roots and this led to a decrease in the shoot: root dry matter ratio [18]. The authors also observed a reduction in trunk diameter, bunch size and a pronounced pyramid shape of the palm due to the progressive depletion of soil P. The superior effect of TSP fertilizer shoot biomass produced could be ascribed to high solubility of phosphate in TSP [19].

3.4 Number of branches

There were significant differences $P \leq 0.05$) on the number of branches between the vegetable species and phosphorus forms treatments in both season 1 and season 2. Amaranthus recorded the highest number of branches in both season with an increment from 5WAP, 6 WAP and 7 WAP. The highest number of branches was recorded in 7 WAP with 30.88 and 45.58 in season 1and season 2 respectively (table 5). Cowpea had the least number of branches due to the P treatments effect for both seasons. In phosphorous forms the highest number of branches per plant were observed on the TSP treatment for both seasons while the lowest was on the control. The rock phosphate plus sulphur treatment showed higher number of branches than that on the sole rock phosphate treatment.

Table 5: Number of branches as affected by vegetable species and phosphorous sources

	Season 1			**Season 2**		
Species	**5WAP**	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kales	9.25^{b}	11.75^{a}	14.00^{b}	9.08^{b}	12.12^{b}	14.00^{b}
Amaranth	17.75^{a}	27.50^{a}	30.83^{a}	17.75^{a}	30.00^{a}	45.58^{a}
Cowpea	9.00^{b}	11.50^{b}	13.75^{b}	9.00^{b}	11.35^{b}	13.75^{b}

LSD	**3.48**	**5.98**	**6.94**	**3.51**	**7.64**	**14.46**
Treatments						
Control	7.00^{b}	8.72^{b}	10.33^{b}	7.0^{b}	8.72^{b}	10.44^{b}
TSP	16.44^{a}	23.56^{a}	27.78^{a}	16.44^{a}	26.89^{a}	40.67^{a}
RPS+S	13.56^{a}	19.83^{ab}	22.22^{ab}	13.56^{a}	19.72^{ab}	27.78^{ab}
RP	11.00^{ab}	15.56^{ab}	17.78^{ab}	10.78^{ab}	15.83^{ab}	18.89^{ab}
LSD	**4.67**	**8.82**	**9.60**	**4.71**	**10.75**	**19.95**
SXPF	*****	*****	*****	*****	*****	*****

Means followed by the same letter within the same column are not significantly different (P≤0.05). TSP- Triple –super phosphate, RP+S-Rock Phosphate and sulphur, RP- Rock phosphate, S-vegetable species, PF-phosphorous sources

These results are in conformity with the findings of Shivakumar *et al*. [20] who reported that the increasing levels of phosphorus in the form of rock phosphate significantly increased the plant height, number of branches per plant, buds per plant, grain and stover yield during both the years indicating that application of higher levels of phosphorus. Similarly Shaktawat *et al*. [21] reported that, higher phosphorus dose through rock phosphate either alone or in combination with acidulates were better than the control in soybean-mustard cropping system.

4.0 Conclusions and Recommendations

Application of phosphorus forms influenced growth parameters of the vegetable species including cowpea, kales and Amaranthus compared to the control. The triple superphosphate treatment led to the highest fresh shoot weight, leaf area, root dry weight, and root dry weight especially under the amaranth and kale crop then followed by the rock phosphate plus sulphur treatment which at some instances under the cowpea they were not significantly different with the industrial fertilizer however being superior. Direct application of phosphate rock to soil is a possible alternative to the more expensive soluble phosphate fertilizers in tropical cropping system. Therefore, the acidulated rock phosphate (RP+sulphur) increased the growth parameters of amaranth, cowpea and kale as well as their yield parameters though less than the TSP treatment which was superior. Thus the use of acidulated rock phosphate is a viable option in the smallholder farmers who may not be able to afford the industrial fertilizer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

References

1. Gouda, S., Kerry, R. G., Das, G., Paramithiotis, S., Shin, H. S., and Patra, J. K. (2018). Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture. *Microbiological research*, *206*, 131-140.
2. Abdulai, A. D. A. M. S. (2006). *Resource use efficiency in vegetable production: The case of smallholder farmers in Kumasi metropolis* (Doctoral dissertation, Kwame Nkrumah University of Science and Technology).
3. Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A., and Tribedi, P. (2017). Biofertilizers: a potential approach for sustainable agriculture development. *Environmental Science and Pollution Research*, *24*(4), 3315-3335.
4. Jouzi, Z., Azadi, H., Taheri, F., Zarafshani, K., Gebrehiwot, K., Van Passel, S., and Lebailly, P. (2017). Organic farming and small-scale farmers: Main opportunities and challenges. Ecological Economics, 132, 144-154.
5. Irungu C.J, Mburu J, Maundu P, Grum M and Hoescle-Zeledon I (2007). Analysis of markets for African leafy vegetables within Nairobi and its environs and implications for on- farm conservation of Biodiversity. A consultancy report for Global facilitation Unit for underutilized species, Rome, Italy.
6. Borie, F., Aguilera, P., Castillo, C., Valentine, A., Seguel, A., Barea, J. M., and Cornejo, P. (2019). Revisiting the Nature of Phosphorus Pools in Chilean Volcanic Soils as a Basis

for Arbuscular Mycorrhizal Management in Plant P Acquisition. Journal of Soil Science and Plant Nutrition, 1-12.

7. Zapata F and Roy R.N (2004). Use of phosphate rock for sustainable food and agriculture: United Nation. 12-121.

8. Ogembo (2015). Laboratory Methods of Soil and Plant Analyses: A Working Manual (2nd Ed.). Nairobi, Kenya. Partey of Africa in relation to productivity. Geoderma, 77:1- 18.

9. Ojo, O. D., Kintomo, A. A., Akinrinde, E. A., and Akoroda, M. O. (2007). Comparative effect of phosphorus sources for grain amaranth production. Communications in soil science and plant analysis, 38(1-2), 35-55.

10. Kyei-Boahen, S., Savala, C. E., Chikoye, D., and Abaidoo, R. (2017). Growth and yield responses of cowpea to inoculation and phosphorus fertilization in different environments. Frontiers in plant science, 8, 646.

11. Koch, M., Kruse, J., Eichler-Löbermann, B., Zimmer, D., Willbold, S., Leinweber, P., and Siebers, N. (2018). Phosphorus stocks and speciation in soil profiles of a long-term fertilizer experiment: evidence from sequential fractionation, P K-edge XANES, and 31P NMR spectroscopy. Geoderma, 316, 115-126.

12. Huang, K. L., Wang, H., Wei, Y. L., Jia, H. X., Zha, L., Zheng, Y., and Li, X. B. (2019). The high-affinity transporter BnPHT1; 4 is involved in phosphorus acquisition and mobilization for facilitating seed germination and early seedling growth of Brassica napus. BMC plant biology, 19(1), 156.

13. Yan, Z., Kim, N., Han, W., Guo, Y., Han, T., Du, E., & Fang, J. (2015). Effects of nitrogen and phosphorus supply on growth rate, leaf stoichiometry, and nutrient resorption of Arabidopsis thaliana. Plant and Soil, 388(1-2), 147-155

14. Kunene, E. N., Masarirambi, M. T., Gadaga, T. H., Dlamini, P. S., Ngwenya, M. P., and Vilane, V. S. (2017, November). Effects of organic and inorganic fertilisers on the growth and yield of amaranth (Amaranthus hybridus). In African Vegetables Forum 1238 (pp. 31-38).

15. Singh, S. K., Reddy, V. R., Fleisher, D. H., and Timlin, D. J. (2018). Phosphorus nutrition affects temperature response of soybean growth and canopy photosynthesis. Frontiers in plant science, 9.

16. Chen, R., Song, S., Li, X., Liu, H., and Huang, D. (2013). Phosphorus deficiency restricts plant growth but induces pigment formation in the flower stalk of Chinese kale. Horticulture, Environment, and Biotechnology, 54(3), 243-248.

17. Kim, H. J., and Li, X. (2016). Effects of phosphorus on shoot and root growth, partitioning, and phosphorus utilization efficiency in Lantana. HortScience, 51(8), 1001-1009.

18. Goh, K. J. and Härdter, R. (2003). In Fairhurst, T.H., and R. Härdter (Eds.), Managing oil palm for large and sustainable yields. PPI/PPIC-IPI, Singapore. p. 191-230.

19. Imogie, A. E., Oviasogie, P. O., Udosen, C. V., Ejedegba, B. O. and Nwawe, A. (2011). Evaluation of some locally sourced phosphate rocks for oil palm production. Journal of Soil Science and Environmental Management. 2(6): 153-158.

20. Shivakumar, B. G., Ballari, S. S. and Saraf, C. S., 2004, Effect of sources and levels of phosphorus with and without seed inoculation on the performance of rainfed chickpea (Cicer arietinum L.). Ann. Agric. Res. New Series, 25(2): 320-326.

21. Shaktawat, M. S., Sharma, D. D. and Mehta, Y. K., 2006, Rock phosphate applied along with acidulants under soybean-mustard cropping system in alkaline soils. In: Phosphate Rich Organic Manure: An Alternate to Phosphate Fertilizers, Himanshu Publications. pp. 56-58