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Research Article

Response of *Sorghum bicolor* L. to Residual Phosphate on Two Contrasting Soils Previously Planted to Cowpea or Maize

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Proper fertilizer nutrient management through adequate utilization of the residual value coupled with healthy crop rotation contributes significantly to sustainable crop production. This study was conducted to evaluate the direct and residual effects of two rock phosphate (RP) materials on two contrasting soils previously planted with either the cereal crop or the leguminous crop. The effectiveness of the RP materials as substitute for the conventional P fertilizers was evaluated using single superphosphate as reference at the Department of Agronomy, University of Ibadan, Ibadan, Nigeria. The experiments were $2 \times 2 \times 4$ factorial in completely randomized design. The test crops in the first cropping performed better on the slightly acidic loamy sand than on the strongly acidic sandy clay loam. Performance of each crop was improved by P supply in the first and second cropping. Single superphosphate proved to be more efficient than the RPs in the first cropping but not as effective as MRP in the second cropping. In the second cropping, sorghum performed better on the soil previously cropped to cowpea while Morocco RP had the highest residual effect among the P-fertilizer sources. It is evident that rock phosphates are better substitutes to the conventional phosphorus fertilizers due to their long term residual effect in soils. The positive effects of healthy rotation of crops as well as the negative effects of low soil pH are also quite obvious.

1. Introduction

Sustainable crop production aims at maintaining high crop yield without adversely affecting ecosystems to meet the need of current as well as future generations [1]. This is achievable with the use of organic fertilizers. Phosphorus (P) is the second most growth limiting macronutrient after nitrogen; it is an essential element for plant growth and is involved in many plant metabolic functions. It is among the most needed elements for crop production in most tropical soils, which tend to be P deficient [2]. Phosphorus, like nitrogen, is an important nutrient for plants, being an essential part of the process of photosynthesis; therefore, its proper management in the soil contributes significantly to sustainable crop production. Phosphorus often comes from different sources which are bone meal, rock phosphates, and superphosphates. Rock phosphates (RPs) are organic P sources which are good substitutes for the less available and expensive superphosphates. The use of RP is preferred to superphosphates because of its long term effect in the soil. Nitrogen (N) is another important nutrient element needed for crop production. However, in order to ensure sustainability, organic sources of N are preferred. Intercropping or rotation of legumes with cereals is a way of replenishing the soil with organic N among others. Cowpea (*Vigna unguiculata*) belongs to the legume family and it is an important source of organic N fertilizer [3] because it fixes atmospheric nitrogen in the soil [4]. It is a cheap, clean, renewable, and environmentally friendly source of nitrogen (N) for the non-N-fixing crop component of the cropping system [5]. Organic fertilizers are environmentally friendly and are within the reach of peasant farmers. The objectives of this experiment therefore were to evaluate the direct effects of two rock phosphate (RP) materials (Morocco RP, 33.3% P_2O_5, and Sokoto RP, 34.2% P_2O_5, by weight) on two contrasting soils (a strongly acidic sandy clay loam of pH 5.3 and another slightly acidic loamy sand of pH 6.7) and to determine the response of sorghum to the residual P in the soils previously planted to either the cereal crop (maize) or the leguminous crop (cowpea).

2. Materials and Methods

The experiment was carried out in the screen house of the Department of Agronomy, Faculty of Agriculture and Forestry, University of Ibadan, Ibadan, Nigeria (latitude 7° 24′ N and longitude 3° 54′ E), between February and June 2013. Two soils, A and B, were used for the experiments. Soil A was a strongly acidic sandy clay loam collected from Leventis Foundation School of Agriculture, Imoo, Ilesha, Osun State, while soil B was slightly acidic loamy sand collected from Parry Road, University of Ibadan, Ibadan. The chemical properties and particle size analysis of the soils were determined using laboratory methods described by Udo and Ogunwale [6]. The soils were crushed and passed through 2 mm sieve and were filled into 4 kg polythene bags. Each of the two phases of the experiment was $2 \times 2 \times 4$ factorial, with treatments replicated three times in a completely randomized design (CRD) to give a total of 48 pots. The treatments were as follows: soil A treated with MRP cropped with cowpea, soil A treated with MRP cropped with maize, soil A treated with SRP cropped with cowpea, soil A treated with SRP cropped with maize, soil A treated with SSP cropped with cowpea, soil A treated with SSP cropped with maize, untreated soil A cropped with cowpea, untreated soil A cropped with maize, soil B treated with MRP cropped with cowpea, soil B treated with MRP cropped with maize, soil B treated with SRP cropped with cowpea, soil B treated with SRP cropped with maize, soil B treated with SSP cropped with cowpea, soil B treated with SSP cropped with maize, untreated soil B cropped with cowpea, and untreated soil B cropped with maize. Each fertilizer was thoroughly mixed with the soils, watered to 60% Pot Capacity (PC), and allowed to equilibrate for four days. Three seeds each of cowpea and maize were planted in separate pots and later thinned to two stands per pot. Data collection commenced one (1) week after planting (WAP). Plant height was measured with meter rule from ground level to the tip of the leave and stem girth was taken 1 cm above ground level using vernier caliper. The aerial portions of the crops were harvested 6 WAP, weighed fresh using sensitive scale, oven-dried, and also weighed dry. The plant samples were later analyzed for their tissue phosphorus (P) contents and the P uptake was calculated by the following formula: P uptake = P content × Dry matter. In order to compare the residual effects of the three P sources in the two soil types, the first cropping soils were air-dried, sieved, watered to 60% PC, and then cropped with sorghum (*Sorghum bicolor*). The aerial parts of the crops were then harvested 4 weeks after planting. The forage yield of the sorghum was evaluated and the relative agronomic efficiencies (RAE) of the P sources were computed as the ratios of the yield responses with test fertilizer (ground rock phosphate) to the respective yield responses of the reference (single superphosphate) fertilizer at the same rate. That is,

$$\mathrm{RAE} = \left[\left(y\mathrm{GRP} - \frac{y\mathrm{CONTROL}}{y\mathrm{SSP}} - y\mathrm{CONTROL}\right) \times 100\right]\%, \tag{1}$$

where y is yield.

The data collected were subjected to Analysis of Variance (ANOVA) and significant means were separated using Least Significant Difference (LSD) at 5% level of probability.

Table 1: Precropping properties of the soils used.

Properties	Soil test values: Okemesi (Strongly acidic soil)	Gambari (Slightly acidic soil)
pH (1 : 1 soil/water ratio)	5.3	6.7
Bray-1-P (mg/kg)	5	9
Total N (g/kg)	2.0	2.0
Organic matter (g/kg)	27.1	26.5
Exchangeable cations (cmol/kg)		
K	0.2	0.3
Ca	1.6	1.8
Mg	0.7	0.7
Na	0.1	0.1
Exchangeable micronutrient (g/kg)		
Fe	0.3	0.2
Mn	0.3	1.3
Exchangeable acidity (cmol/kg)	0.4	0.6
Sand (g kg^{-1})	628.0	871.0
Silt (g kg^{-1})	150.0	40.0
Clay (g kg^{-1})	222.0	89.0
Texture	Sandy clay loam	Loamy sand

3. Results and Discussion

The chemical and particle size properties of the soils used are given in Table 1. Soil A (collected from the experimental site of Leventis School of Agriculture, Ilesha, Osun State) was strongly acidic with pH value 5.3 while soil B (collected from Parry Road, University of Ibadan) was slightly acidic with pH value 6.7. The two soils were low in available phosphorus (5 mg/kg and 9 mg/kg) considering 13 mg/kg being critical [7]. Total nitrogen was adequate in the two soils being 2 g/kg [7] while exchangeable potassium values were medium. Soil B (slightly acidic soil) had higher proportion of sand with less silt and clay particles than soil A (strongly acidic soil). The textural class of soil A was sandy clay loam while that of soil B was loamy sand.

Figure 1 shows the effects of soil acidity level and texture on plant height of maize and cowpea in the first cropping.

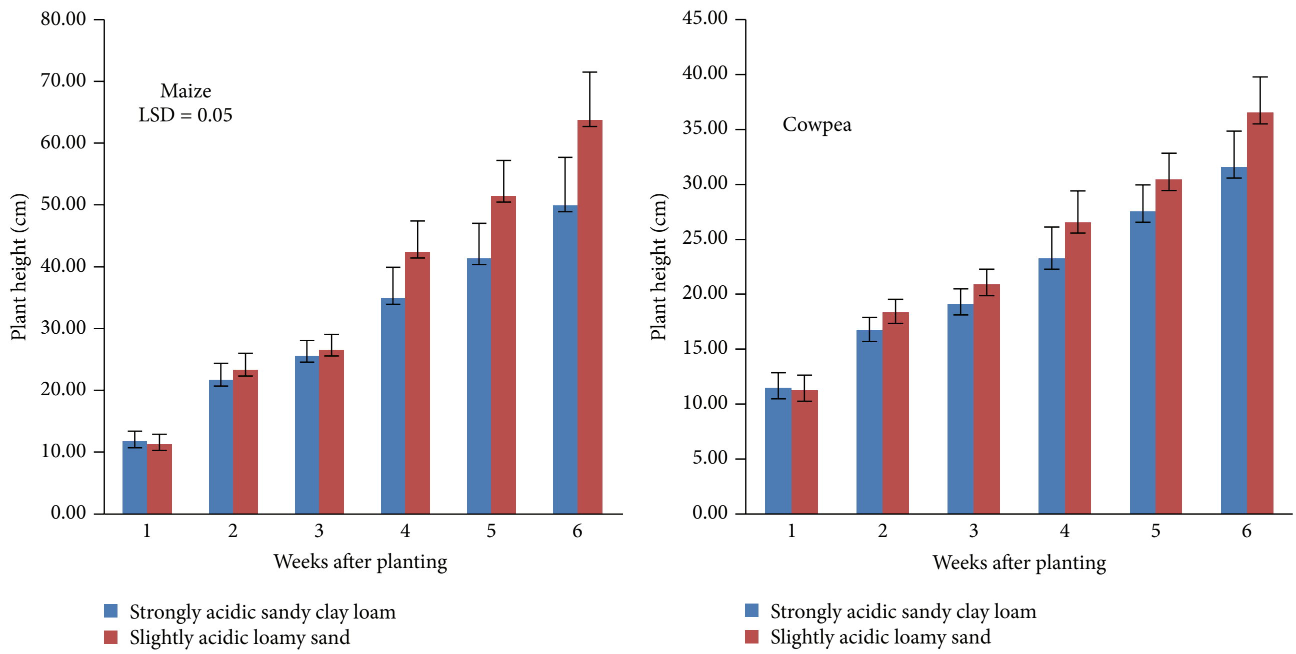

FIGURE 1: Effects of soil acidity level and texture (strongly acidic sandy clay loan and slightly acidic loamy sand) on plant height of maize and cowpea in the first cropping.

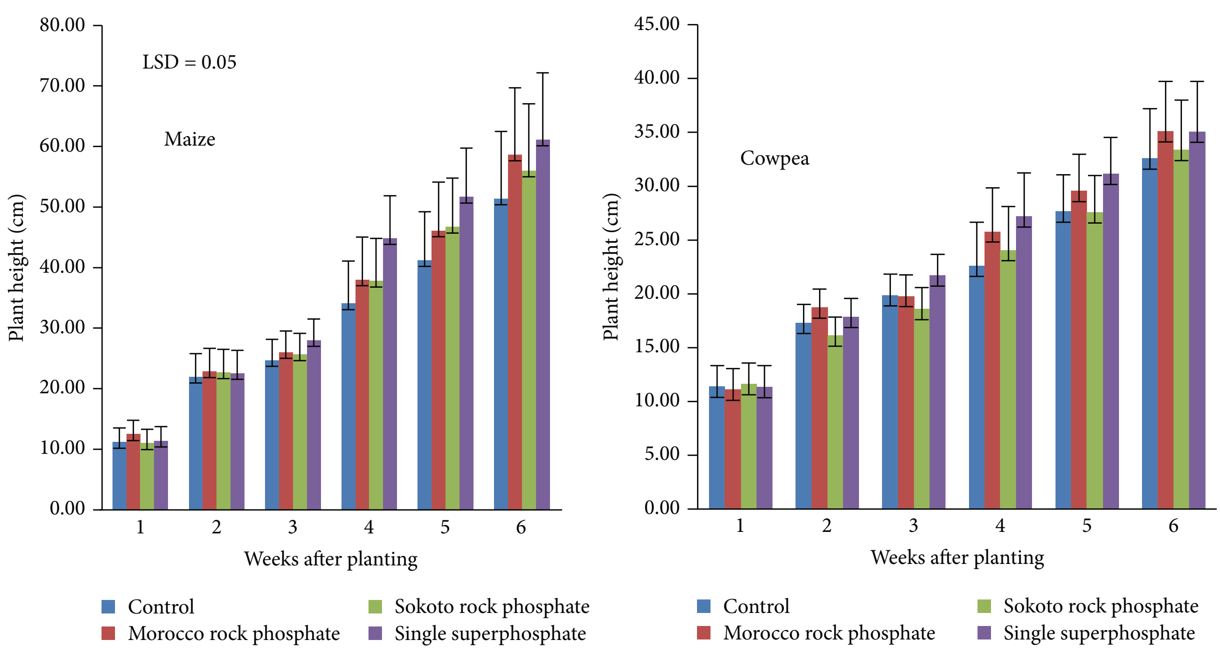

FIGURE 2: Effects of the different phosphorus fertilizer sources on height of maize and cowpea during the first cropping.

Starting from two Weeks after Planting (WAP), the slightly acidic loamy sand consistently produced taller plants than the strongly acidic sandy clay loam. Maize grown on slightly acidic soil was significantly taller than that grown on strongly acidic soil at 4, 5, and 6 WAP. Cowpea grown on slightly acidic soil was only significantly taller than those grown on strongly acidic soil at 6 WAP. This is in line with the findings of Tisdale et al. [8] that the ideal pH for optimum crop growth and adequate nutrient release ranges between 6 and 7.

The effects of P sources on height of maize and cowpea at successive growth stages in the first cropping are summarized in Figure 2. Phosphorus sources did not have significant effect on height of maize throughout the growth period except at 4 WAP, when plants treated with single superphosphate were similar to those treated with Morocco rock phosphate and Sokoto rock phosphate but significantly taller than the untreated (control) plants. On the other hand, cowpea plants treated with the different P sources were not significantly

Table 2: Effects of soil characteristics and phosphorus sources on plant height, stem girth, and leaf area of maize in the first cropping.

Treatment	Height (cm)	← Stem girth (cm) →			Leaf area (cm^2)
	Weeks after planting				
	6	4	5	6	6
Soil description/characteristics					
Strongly acidic sandy clay loam		0.42	0.64	0.77	121.15
Slightly acidic loamy sand		0.63	0.94	1.09	169.42
LSD (5%)		0.08	0.09	0.10	22.15
P sources					
P0		0.43	0.65	0.83	139.31
MRP		0.57	0.83	0.98	149.23
SRP		0.51	0.77	0.89	132.78
SSP		0.59	0.90	1.03	159.82
LSD (5%)		0.11	0.13	0.14	NS
Soil ∗ P sources					
Strongly acidic soil ∗ P0	39.10	0.23	0.37	0.51	78.77
Strongly acidic soil ∗ MRP	52.80	0.52	0.77	0.87	128.99
Strongly acidic soil ∗ SRP	52.07	0.43	0.65	0.80	122.04
Strongly acidic soil ∗ SSP	55.53	0.50	0.78	0.92	154.82
Slightly acidic soil ∗ P0	63.67	0.62	0.93	1.15	199.86
Slightly acidic soil ∗ MRP	64.47	0.62	0.90	1.10	169.46
Slightly acidic soil ∗ SRP	59.90	0.58	0.89	0.98	143.53
Slightly acidic soil ∗ SSP	66.67	0.68	1.02	1.13	164.82
LSD (5%)	15.67	0.15	0.19	0.19	44.31

P0: control, MRP: Morocco rock phosphate, SRP: Sokoto rock phosphate, SSP: single superphosphate, and NS: not significant ($p < 0.05$).

different at 1, 4, 5, and 6 WAP. However, at 2 WAP, plants treated with MRP though not significantly taller than plants treated with SSP and the untreated (control) plants were significantly taller than plants treated with SRP. At 3 WAP also, plants treated with SSP were the tallest but were only significantly taller than plants treated with SRP.

The effects of soil characteristics (acidity and texture), P sources, and their interaction on height, stem girth, and leaf area of maize at different stages of growth are summarized in Table 2. The interaction of soil characteristics and P sources was significant on the height of maize only at 6 WAP when plants grown on slightly acidic loamy sand treated with SSP were significantly taller than that grown on untreated strongly acidic sandy clay loam only. Maize grown on slightly acidic loamy sand had significantly bigger stem than those grown on strongly acidic sandy clay loam starting from 4 WAP. At 4, 5, and 6 WAP as well, plants treated with SSP had significantly bigger stems than those grown on untreated (control) soils although not significantly bigger than those grown on soils treated with MRP and SRP. The interaction of soil characteristics and P sources was also significant on stem girth from 4 WAP when the plant grown on slightly acidic loamy sand treated with SSP was significantly bigger than those grown on treated and untreated strongly acidic sandy clay loam but not significantly bigger than those grown on slightly acidic loamy sand treated with the two rock phosphates. At 6 WAP, plants grown on slightly acidic loamy sand had larger leaf area than those on strongly acidic sandy clay loam. Soil characteristics ∗ P sources interaction was significant on leaf area also only at 6 WAP when plants grown on slightly acidic loamy sand treated with MRP had the largest leaf area. Generally, the positive response of the crops to P application confirms stunted growth as one of the general symptoms of P deficiency. This could be attributed to the metabolic function of P as a key component of energy releasing molecules [9]. Consequently, plants cannot grow well without a reliable supply of P. Among the phosphorus sources, however, plants treated with SSP performed better than those treated with ground rock phosphates during the first cropping; this agrees with the assertion of Sample et al. [10] that rock phosphates are less effective than superphosphates in the year of application due to their limited solubility.

Table 3 shows the effects of P sources and soil characteristics by P sources interaction on the fresh and dry shoot weights, RAE, and P uptake of maize and cowpea in the first cropping. Maize treated with SSP had the highest fresh shoot weight which was only significantly higher than the untreated (control) plants; the dry shoot weight of plants treated with SSP on the other hand was significantly higher than the plants treated with SRP and the untreated (control) plants. The effectiveness (as indicated by the estimated RAE) shows that MRP which was 98.33% as efficient as SSP with respect to dry shoot weight of maize was more efficient than SRP being 49.29%. The fresh and dry shoot weights

Table 3: Effects of phosphorus sources as well as soil characteristics ∗ P sources interaction on fresh and dry shoot weight, relative agronomic efficiency, and P uptake of maize and cowpea in the first cropping.

Treatment	Fresh weight (g/pot)	RAE (%)	Dry weight (g/pot)	RAE (%)	P uptake (mg/pot)
P sources					
Maize					
P0	76.27	—	11.50	—	0.23
MRP	95.83	68.97	15.63	98.33	0.27
SRP	96.48	71.26	13.57	49.29	0.28
SSP	104.63	100.00	15.70	100.00	0.25
LSD (5%)	17.14		1.77		NS
Cowpea					
P0	58.86	—	7.38	—	0.12
MRP	69.53	120.29	9.73	112.98	0.16
SRP	43.21	−176.44	5.62	−84.62	0.10
SSP	67.73	100.00	9.46	100.00	0.17
LSD (5%)	13.74		2.51		0.66
Soil ∗ P sources					
Maize					
Strongly acidic soil ∗ P0	31.20	—	4.30	—	0.06
Strongly acidic soil ∗ MRP	65.10	69.57	10.60	78.07	0.22
Strongly acidic soil ∗ SRP	69.33	78.25	9.67	66.54	0.25
Strongly acidic soil ∗ SSP	79.93	100.00	12.37	100.00	0.18
Slightly acidic soil ∗ P0	121.33	—	18.70	—	0.39
Slightly acidic soil ∗ MRP	126.57	65.50	20.67	596.97	0.31
Slightly acidic soil ∗ SRP	123.63	28.75	17.47	ND	0.31
Slightly acidic soil ∗ SSP	129.33	100.00	19.03	100.00	0.32
LSD (5%)			2.50		0.13

P0: control, MRP: Morocco rock phosphate, SRP: Sokoto rock phosphate, SSP: single superphosphate, NS: not significant ($p < 0.05$), ND: not determined, and RAE = $[(y\text{GRP} - y\text{CONTROL}/y\text{SSP} - y\text{CONTROL}) \times 100]\%$.

of cowpea crops treated with MRP were significantly higher than plants treated with SRP and the untreated plants but not significantly higher than those treated with SSP. The efficiency of MRP (as estimated by RAE) on the fresh and dry shoot weight of cowpea was greater than that of SSP which in turn was greater than the efficiency of SRP. The effect of the interaction of soil and P sources on dry shoot weight of maize shows that plant grown on slightly acidic loamy sand treated with MRP had the highest weight which was significantly higher than the other interactions except slightly acidic loamy sand treated with SSP. The untreated strongly acidic sandy clay loam had the least dry weight. Slightly acidic loamy sand favoured phosphorus uptake by the two plants; this could be because P tends to be most available in soil pH that centered around 6.5 [8].

The effects of soil characteristics, previous crop, and their interaction on fresh shoot weight, dry shoot weight, and RY of sorghum in the second cropping is summarized in Table 4. The fresh and dry shoot weights as well as the RY of the plant were higher on slightly acidic loamy sand than on strongly acidic sandy clay loam. Previously grown crop had significant effect on succeeding sorghum as the plants grown on soils previously cropped to cowpea had higher fresh and dry shoot weights than that grown on soils previously cropped to maize. Relative yield of sorghum also was higher on soil previously cropped to cowpea than on soil previously cropped to maize. Previous crop ∗ soil characteristics were significant on the dry shoot weight and RY of sorghum. Plants grown on slightly acidic loamy sand previously cropped to cowpea had significantly higher dry weight than other interactions. Likewise, the RY of sorghum grown on slightly acidic loamy sand previously cropped to cowpea was higher than those of the other previous crop ∗ soil interactions. This result agrees with the existing fact that cowpea is an important source of organic fertilizer and fixes atmospheric nitrogen thereby enhancing the performance of the succeeding crop [4].

Table 5 shows the effects of previous crop ∗ soil characteristics ∗ P sources on fresh and dry shoot weight and RAE of sorghum in the second cropping. Sorghum grown on slightly acidic soil treated with SSP previously planted to cowpea had the highest fresh weight which was higher than other interactions while sorghum grown on strongly acidic soil treated with SSP previously planted to maize had the least fresh weight. Sorghum grown on slightly acidic soil treated with MRP previously planted to cowpea had the highest dry weight. This was not significantly higher than that grown on slightly acidic soil treated with SSP previously planted to cowpea but was significantly higher than other interactions. Sorghum grown on untreated strongly acidic soil previously planted to maize had the least dry weight.

Table 4: Effects of soil characteristics and previous crop on fresh and dry shoot weight (g/pot) and relative yield (%) of sorghum in the second cropping.

Treatment	Fresh shoot weight (g/pot)	Relative yield (%)	Dry shoot weight (g/pot)	Relative yield (%)
Soil characteristics				
Strongly acidic sandy clay loam	10.98	67.16	1.57	75.12
Slightly acidic loamy sand	16.35	100.00	2.09	100.00
LSD (5%)	0.94		0.16	
Crop effect on succeeding sorghum				
Cowpea-sorghum	14.19	100.00	2.13	100.00
Maize-sorghum	13.14	92.60	1.52	71.36
LSD (5%)	0.94		0.16	
Previous crop ∗ soil				
Cowpea ∗ strongly acidic soil	11.47	67.79	1.73	68.38
Cowpea ∗ slightly acidic soil	16.92	100.00	2.53	100.00
Maize ∗ strongly acidic soil	10.50	62.06	1.41	55.73
Maize ∗ slightly acidic soil	15.79	93.32	1.64	64.82
LSD (5%)	NS		0.22	

P0: control, MRP: Morocco rock phosphate, SRP: Sokoto rock phosphate, SSP: single superphosphate, NS: not significant ($p < 0.05$), and relative yield (RY) = (Yield of crop on a particular soil)/(Maximum yield) × 100%.

Table 5: Effects of previous crop ∗ soil ∗ P sources on fresh and dry shoot weight (g/pot) and RAE (%) of sorghum in the second cropping.

Treatment	Fresh shoot weight (g/pot)	RAE (%)	Dry shoot weight (g/pot)	RAE (%)
Previous crop ∗ soil ∗ P sources				
Cowpea ∗ strongly acidic soil ∗ P0	12.92	—	2.30	—
Cowpea ∗ strongly acidic soil ∗ MRP	8.87	250.00	1.36	120.51
Cowpea ∗ strongly acidic soil ∗ SRP	12.77	9.26	1.75	70.51
Cowpea ∗ strongly acidic soil ∗ SSP	11.30	100.00	1.52	100.00
Cowpea ∗ slightly acidic soil ∗ P0	14.33	—	1.85	—
Cowpea ∗ slightly acidic soil ∗ MRP	16.79	36.55	3.03	231.37
Cowpea ∗ slightly acidic soil ∗ SRP	15.49	17.24	2.36	50.00
Cowpea ∗ slightly acidic soil ∗ SSP	21.06	100.00	2.87	100.00
Maize ∗ strongly acidic soil ∗ P0	10.98	—	1.21	—
Maize ∗ strongly acidic soil ∗ MRP	12.17	ND	1.42	123.53
Maize ∗ strongly acidic soil ∗ SRP	10.62	13.09	1.61	235.29
Maize ∗ strongly acidic soil ∗ SSP	8.23	100.00	1.38	100.00
Maize ∗ slightly acidic soil ∗ P0	14.57	—	1.63	—
Maize ∗ slightly acidic soil ∗ MRP	17.02	371.21	1.78	ND
Maize ∗ slightly acidic soil ∗ SRP	16.34	268.18	1.68	ND
Maize ∗ slightly acidic soil ∗ SSP	15.23	100.00	1.48	100.00
LSD (5%)	2.66		0.44	

P0: control, MRP: Morocco rock phosphate, SRP: Sokoto rock phosphate, SSP: single superphosphate, NS: not significant ($p < 0.05$), ND: not determined, and RAE = $[(y\text{GRP} - y\text{CONTROL}/y\text{SSP} - y\text{CONTROL}) \times 100]\%$.

4. Conclusions

The three crops used in the experiment performed better on slightly acidic soils than on strongly acidic soils; hence, optimum crop performance cannot be obtained on strongly acidic soils. Morocco rock phosphate performed better than Sokoto rock phosphate and even better than the readily soluble single superphosphate during the second phase of the experiment. This suggests that residual effect of the rock phosphates could make them better than the conventional superphosphate. The performance of Sokoto rock phosphate was better on strongly acidic sandy clay loam than on the slightly acidic loamy sand; its use is therefore encouraged on the former than the latter. In general, crop growth and the eventual yield are highly dependent on available phosphorus in the soil being a primary macronutrient and due to its role in metabolism. The sorghum in cowpea-sorghum cropping sequence performed better than that in maize-sorghum cropping sequence confirming the importance of legumes in crop rotation.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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