Hindawi Publishing Corporation
International Journal of Agronomy
Volume 2016, Article ID 6945024, 9 pages
http://dx.doi.org/10.1155/2016/6945024

Research Article

Response of *Sorghum* (*Sorghum bicolor* L.) to Residual Phosphate in Soybean-*Sorghum* and Maize-*Sorghum* Crop Rotation Schemes on Two Contrasting Nigerian Alfisols

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Received 12 February 2016; Revised 13 April 2016; Accepted 21 April 2016

Academic Editor: Iskender Tiryaki

The effectiveness of finely ground Sokoto Rock Phosphate and Morocco Rock Phosphate to enhance productivity of maize- (*Zea mays* L.) *Sorghum* (*Sorghum bicolor*) and soybean- (*Glycine max* L.) *Sorghum* crop rotation schemes was evaluated using Single Super Phosphate as reference fertilizer. The experiments were carried out in the screen house of the Department of Agronomy, University of Ibadan, in February and June 2013. The experiments involved 2 × 2 × 4 × 3 factorial in a Completely Randomized Design. In the first and second croppings, the slightly acidic loamy sand still produced higher biomass than the strongly acidic sandy clay loam. On average, MRP was more efficient than SSP for maize dry biomass but, for soybean dry biomass, MRP was less efficient than SSP in the two soils. Sokoto Rock Phosphate was less efficient in the two location soils compared to SSP for the test crops. There was no difference in performance of P-sources in the second cropping. Soybean-*Sorghum* crop rotation scheme produced greater *Sorghum* biomass than maize-*Sorghum* crop rotation scheme. It is evident that pH and clay contents of soils as well as the rotation crop concerned influence the efficiency of finely ground soluble phosphates in crop rotation schemes.

1. Introduction

Soil acidity is a major constraint to crop production throughout the world. It leads to low yields of arable crops [1]. Maize and *Sorghum* cannot do well with soil pH < 5.5. When the soil pH is around 6.7 it is slightly acidic but when it is less than 5.5 it is strongly acidic [2]. Crop performance could be adversely affected by Calcium (Ca), Potassium (K), Phosphorus (P), Magnesium (Mg), Sulphur (S), Zinc (Zn), and Molybdenum (Mo) deficiencies as well as Al, Mn, and Fe toxicities [3]. However, lime and fertilizer application is usually recommended to reduce these adverse effects. Phosphorus is a major plant nutrient (second only to nitrogen). Soils in Nigeria require moderate P-application for optimum crop growth [4]. The direct use of sparingly soluble, ground RP as substitute to the costly, more soluble P fertilizers is gaining widespread acceptance [5]. They provide slow-release P and residual effect for several years [6]. Residual effect is the carryover effect from preceding crops to the succeeding ones. The amount and longevity of the residual effect depends on rate, duration, and frequency of application, solubility, soil properties, crop type, yield level, and extent of P removal [7].

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 one of the ways of replenishing the soil with organic N, among others. According to Pedersen and Lauer [8], planting of soybean in rotation with cereals consistently gave higher yields than monoculture. Soybean (*Glycine max* L.) belongs to the legume family and is an important source of organic N fertilizer [9] because it fixes atmospheric nitrogen in the soil [10]. Atmospheric N fixation is a cheap, clean, renewable, and environmentally friendly source of nitrogen (N) for the non-N-fixing crop component of the cropping system [11].

The unavailability and high costs of lime and inorganic P fertilizers have led to research into low cost materials like rock phosphates, using SSP as reference. This study was to evaluate the effects of different P-sources, Single Supper Phosphate (SSP), Sokoto Rock Phosphate (SRP), and Morocco Rock Phosphate (MRP), on the performance of maize and soybean in two soil types, with the residual effects of the P-sources and the preceding crop on the performance of *Sorghum* in two crop rotation schemes.

2. Materials and Methods

2.1. Experimental Site. There were two experiments conducted between February and June 2013 in the screen house, Department of Agronomy, Faculty of Agriculture and Forestry, University of Ibadan, Nigeria. The greenhouse conditions were suitable for plants growth, where the wall and the door of the greenhouse were made up of metals with wire nets and roofed with transparent glasses. The floor was well cemented and there were metals tables inside on which the pots were kept. The planting date for Experiment 1 was February 23, 2013, and that of Experiment 2 was May 25, 2013. The university is located at latitude 7°24′N and longitude 3°54′E.

2.2. Experimental Design and Treatments. The experiments involved 2 (maize and soybean) × 2 (two soil types) × 4 (four levels of Phosphorus) × 3 replications (total of 48 treatments) in a Completely Randomized Design (CRD).

Experiment 1 (effect of different phosphorus fertilizer sources on the performance of maize and soybean grown on two contrasting Nigerian Alfisols). In the first experiment, treatments were as follows.

(i) Phosphorus Fertilizer. Absolute Control (0% P_2O_5), Sokoto Rock Phosphate (34.2% P_2O_5 by weight), Morocco Rock Phosphate (33.3% P_2O_5 by weight), and Single Super Phosphate (18% P_2O_5), the three Phosphorus fertilizers, were collected from Department of Agronomy, Faculty of Agriculture and Forestry, University of Ibadan, Nigeria.

(ii) Soil Locations. The two soils were collected from different locations. The sandy clay loam soil was strong acidic Alfisol collected from Leventis Foundation School of Agriculture, Imoo, Ilesa, Osun State. This area lies within the rainforest vegetation zone of Nigeria. According to Oyedele et al. [12], the parent rocks consist essentially of quartz with small amounts of white micaceous minerals. Also in this area, densely wooded quartz ridges rise abruptly from the surrounding country and are elongated north south following the strike of the rock. Akintoye et al. [13] stated that the soils round Ilesa are classified as Alfisols (mainly Paleustalf). The soil in this area belongs to the Okemesi series [12, 14], while the loamy sand soil was very slightly acidic Alfisol collected from Parry Road, Department of Agronomy Farm, University of Ibadan, Ibadan, Oyo State. According to USDA [15], the soils around Ibadan are classified as Alfisols (Typic Plinthustalf). The soil in this area belongs to the Gambari series.

(iii) Test Crops. Maize (*Zea mays* var. Swan-1) was collected from Department of Agronomy, College of Agriculture and Forestry, University of Ibadan, Nigeria, and soybean (*Glycine max* var. TGX 1448-2E) was gotten from International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, for first cropping.

2.3. Methodology. The two soils were crushed with mortar and pestle and passed through a 2 mm sieve separately. The chemical and physical properties of the two soils were determined in the laboratory according to Udo and Ogunwale [16] methods. For each of the soil locations, 4 kg was weighed using weighing balance into 24 bows and made a total of 48 bows of the two soils. 100 mg P_2O_5/kg soil of finely ground Sokoto Rock Phosphate, SRP (34.2% P_2O_5), Morocco Rock Phosphate, MRP (33.3% P_2O_5), Single Super Phosphate, SSP (18% P_2O_5), and Control (0% P_2O_5) was thoroughly mixed with the soil in each bow. The soil in each bow was later filled into forty-eight 4 kg of pots.

2.4. Water Field Capacity. Water field capacities of the two soils were determined in the laboratory. 50 g of each soil was weighed using sensitive scale. Two funnels were placed on two cylindrical flacks. Small tissue papers were put inside the funnels based to prevent soils pour-off. The 50 g of the two soils was separately put into each funnel placed on the cylindrical flasks. 50 mL each of water was poured on the two soils in the funnels. They were allowed to drain into the cylindrical flasks until they stopped dropping. The volumes of drained water in each cylindrical flask were subtracted from the actual volume of water poured. The water field capacity of the strongly acidic sandy clay loam was 2500 mL while the field capacity of slightly acidic loamy sand was 1500 mL. The two soils inside the 4 kg pots containing each phosphate fertilizer and Control were watered to 60% field capacity (FC) and allowed to equilibrate for 3 days.

2.5. Planting of Test Crops. Maize (*Zea mays* var. Swan-1) and soybean (*Glycine max* var. TGX1448-2E) were planted as the first crops. Three seeds of maize (*Zea mays*) and soybean (*Glycine max*) were planted per pot and two seedlings of the test crops were allowed to grow in each pot for 6 weeks.

2.6. Data Collected on Maize (Zea mays L.) and Soybean (Glycine max). Data on the following were taken weekly starting from first week after planting:

(i) Heights (cm): plant heights were measured from the soil level to terminal bud using a measuring tape for six weeks.

(ii) Dry biomass yield (g/kg): after harvest, the fresh biomass yields were thoroughly washed with water and air-dried. They were later oven-dried at 75°C for 24 hours to constant weight and the dry biomass yields were weighed using a sensitive scale.

Experiment 2 (residual effect of phosphorus- (P-) sources on dry biomass yield of *Sorghum* productions on two contrasting Nigerian Alfisols). In order to determine the response of *Sorghum* (*Sorghum bicolor* L. var. Sokoto local) to residual effects of the P-sources (SRP, MRP, SSP, and Control) in the two

Table 1: Precropping chemical and particle size analysis of the soils used in the study.

Properties	Soil A (strongly acidic Alfisol)	Soil B (slightly acidic Alfisol)
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 base (cmol/kg)		
K	0.2	0.3
Ca	1.6	1.8
Mg	0.7	0.7
Na	0.1	0.1
Exchangeable acidity (cmol/kg)	0.4	0.6
Exchangeable micronutrients (cmol/kg)		
Fe	0.3	0.2
Mn	0.3	1.3
Cu	0.04	0.01
Zn	0.01	0.01
Particle size distribution (gkg^{-1})		
Sand	628.0	871.0
Silt	150.0	40.0
Clay	222.0	89.0
Texture	Sandy clay loam	Loamy sand

soils, the biomass yield of *Sorghum* (*Sorghum bicolor* L var. Sokoto local) was also evaluated after air-drying and sieving of the first experimental soils and 50 seeds of *Sorghum* were sown inside each pot, that is, maize-*Sorghum* and soybean-*Sorghum* crop rotation schemes. The *Sorghum* plants were cut at 2 WAP and allowed to regenerate before they were cut in another 2 weeks.

2.7. Data Collected on White Sorghum (Sorghum bicolor L.) Fresh biomass yields of *Sorghum* plants were cut 2 cm above the soils surfaces every two weeks of growth. After harvest, the fresh biomass yields were thoroughly washed with water and air-dried. They were later oven-dried at 75°C for 24 hours to constant weight and the dry biomass yields were weighed using a sensitive scale.

2.8. Statistical Analysis. The data collected were subjected to Analysis of Variance (ANOVA) to determine the level of significance of the treatments using SAS (Statistical Analysis System) 2002 computer software (version 9.0). Treatment effects and magnitude of interactions were determined. LSD was used to detect differences between treatment means at 5% significant level.

2.9. Relative Agronomic Efficiency (RAE). The vertical comparison approach was used in this study to measure the relative agronomic efficiency (RAE) index of the Sokoto Rock Phosphate (SRP) and Morocco Rock Phosphate (MRP). This approach defines the RAE index as the ratio of the yield response above Control with the test fertilizer at the same rate [17].

Mathematically,

$$\mathrm{RAE} = \frac{\text{Yield of Rock Phosphate} - \text{Yield of Control}}{\text{Yield of Single Super Phosphate} - \text{Yield of Control}} \times 100. \quad (1)$$

3. Results

3.1. Experiment 1

3.1.1. Precropping Soil Characteristics. The particle size analysis and the chemical properties of the two soils used in this study are given in Table 1. The Ilesa location soil (Soil A) was strongly acidic sandy clay loams (pH 5.3) while the Ibadan location soil (Soil B) was slightly acidic loamy sand (pH 6.7). Available P in the strongly acidic sandy clay loam was lower (5 mg/kg) in slightly acidic loamy sand (9 mg/kg). The two soils had adequate amount of total nitrogen (2 g/kg). Organic matter content of the strongly acidic sandy clay loam (27.1 g/kg) was slightly higher than the slightly acidic loamy sand (26.5 g/kg). Exchangeable K was higher in strongly acidic sandy clay loam (0.04 cmol/kg) compared to that of slightly acidic loamy sand (0.03 cmol/kg).

There was no significant difference ($p < 0.05$) between the heights of maize plants grown on strongly acidic sandy clay loam and those grown on slightly acidic loamy sand until 4 weeks after planting (WAP). However, soybean plants grown on the two soils exhibited no significant difference ($p < 0.05$) throughout the growing period. Nevertheless, the

Table 2: Influence of soils on heights (cm) of maize and soybean plants (at successive growth periods) in the first cropping.

Treatment	Plants height Weeks after planting					
	1	2	3	4	5	6
Soil acidity level	*Maize plant*					
Strongly acidic	12.07	25.33	25.89	35.82	48.33	57.23
Slightly acidic	12.51	23.09	26.36	41.86	58.79	71.73
LSD (5%)	1.52	1.89	2.51	4.78	5.22	9.58
	Soybean plant					
Strongly acidic	9.52	16.99	19.74	23.95	30.78	35.39
Slightly acidic	10.04	18.31	21.49	27.01	35.05	40.05
LSD (5%)	1.20	1.81	1.72	2.96	3.42	4.27

LSD = least significant difference (5%).

Table 3: Influence of P-sources on heights (cm) of maize and soybean plants (at successive growth periods) in the first cropping.

Treatment	Plants height Weeks after planting					
	1	2	3	4	5	6
Phosphate fertilizers	*Maize plant*					
Control	11.78	24.17	24.50	34.47	46.35	59.88
Morocco Rock	12.50	26.00	26.33	41.33	59.05	67.83
Sokoto Rock	12.32	22.22	25.42	37.03	48.10	61.20
Single super	12.55	24.47	28.25	42.52	60.75	69.00
LSD (5%)	2.15	2.67	3.55	6.76	7.38	13.55
	Soybean plant					
Control	9.67	17.67	19.73	24.72	33.55	34.08
Morocco Rock	9.68	17.22	20.50	25.08	30.38	40.25
Sokoto Rock	9.63	16.83	20.23	23.68	30.78	34.23
Single super	10.13	18.88	22.00	28.43	36.93	42.32
LSD (5%)	1.70	2.57	2.43	4.18	4.84	6.04

LSD = least significant difference (5%).

slightly acidic loamy sand tends to produce taller plants compared to the strongly acidic sandy clay loam (Table 2).

The heights of plants treated with different Phosphorus treatments (sources) were significant ($p < 0.05$) different only at 5 WAP for maize, whereas for soybean significant differences were evident at both 5 and 6 WAP. The order of the magnitude of the performance of the P-sources was SSP > MRP > SRP > Control (Table 3).

There was no significant ($p < 0.05$) difference between the dry biomass yields of maize plants treated with SSP and MRP as well as SRP and Control. However, the dry biomass yield of maize plants treated with SSP or MRP was significantly different from those treated with SRP or Control (Table 4). The same trend was observed on dry biomass yield in plant tissue of soybean plants as those of the biomass yield of maize plants. The order of the effectiveness of P-sources on dry biomass yield of maize plants was MRP > SSP > SRP > Control while that of soybean was SSP > MRP > SRP > Control.

Table 4: Influence of P-sources on biomass yield (g/pot) and relative agronomic efficiency (RAE) (%) of maize/soybean plants in the first cropping.

Treatment	Dry biomass (g/pot)	RAE (%)
Phosphate fertilizers	*Maize plant*	
Control	11.67	
Morocco Rock	18.43	114.38
Sokoto Rock	12.65	16.58
Single super	17.58	100
LSD (5%)	2.39	
	Soybean plant	
Control	8.24	
Morocco Rock	11.42	85.03
Sokoto Rock	4.56	ND
Single super	11.98	100
LSD (5%)	2.49	

RAE = relative agronomic efficiency of the Phosphorus- (P-) sources = [((yield of GRP − yield of Control)/(yield of SSP − yield of Control)) × 100]%.
NS = nonsignificantly different at $p < 0.05$.
LSD = least significant difference (5%) and ND = not determined.

Table 5: Influence of soils and P-sources on dry biomass yield (g/pot) and relative agronomic efficiency (RAE) (%) of maize/soybean plants in the first cropping.

Treatment		Dry biomass (g/pot)	RAE (%)
	Maize plant		
Strongly acidic	Control	4.20	
	Morocco RP	12.40	88.17
	Sokoto RP	8.57	46.99
	Single SP	13.50	100
Slightly acidic	Control	19.13	
	Morocco RP	24.47	210.24
	Sokoto RP	16.73	ND
	Single SP	21.67	100
LSD (5%)		3.38	
	Soybean plant		
Strongly acidic	Control	4.65	
	Morocco RP	9.57	139.77
	Sokoto RP	4.02	ND
	Single SP	8.17	100
Slightly acidic	Control	11.83	
	Morocco RP	13.26	36.2
	Sokoto RP	5.11	ND
	Single SP	15.78	100
LSD (5%)		3.53	

RAE = relative agronomic efficiency of the Phosphorus- (P-) sources = [((yield of GRP − yield of Control)/(yield of SSP − yield of Control)) × 100]%.
NS = nonsignificantly different at $p < 0.05$.
ND = not determined.

There was significant ($p < 0.05$) difference between dry biomass yields of maize plants cut on slightly acidic soils treated with either SSP or MRP and those treated with SRP or strongly acidic soils treated with P-sources (Table 5). The

Table 6: Influence of the soils, P-source, or crop effects on biomass yield (g/pot) of *Sorghum* plants in the second cropping.

Treatment	Dry biomass (g/pot)	RY/RAE	Dry biomass (g/pot)	RY/RAE
	First cutting		Second cutting	
Crop effects				
Maize-*Sorghum*	1.68	5.17	0.05	0.15
Soybean-*Sorghum*	2.36	100	0.18	100
LSD (5%)	0.33		0.1	
Soil acidity level				
Strongly acidic	1.7	4.93	0.09	0.26
Slightly acidic	2.34	100	0.13	100
LSD (5%)	0.33		NS	
Phosphate fertilizers				
Control	2.1		0.12	
Morocco Rock	2	ND	0.11	50
Sokoto Rock	1.92	ND	0.13	ND
Single super	2.07	100	0.1	100
LSD (5%)	NS		NS	

RAE = relative agronomic efficiency of the Phosphorus- (P-) sources = [((yield of GRP − yield of Control)/(yield of SSP − yield of Control)) × 100]%.
RY = relative yield of test crop (maize or soybean) = [(yield of the crop on a particular soil type/maximum yield) × 100]%.
NS = nonsignificantly different at $p < 0.05$.
LSD = least significant difference (5%) and ND = not determined.

order of the effectiveness of the soils and P-sources on dry biomass yield of maize plants cut on strongly acidic soil was SSP > MRP > SSP > Control, while on slightly acidic soil it was MRP > SSP > Control > SRP. However, there was no significant ($p < 0.05$) difference between dry biomass yields of soybean plants cut on slightly acidic soil treated with SSP and those treated with MRP, whereas there were significant differences from those treated with SRP as well as those cut on strongly acidic soil. The order of the effectiveness of the soils and P-sources on dry biomass yield of soybean plants was SSP > MRP > Control > SRP on slightly acidic soil, while on strongly acidic soil it was MRP > SSP > SRP > Control (Table 5).

Sokoto Rock Phosphate was less than 50% efficient in the two location soils compared to SSP for the test crops. The MRP (relative agronomic efficiency, RAE, of 210.24%) was more efficient than SSP (100% RAE) in slightly acidic loamy sand but less efficient in strongly acidic sandy clay loam (88.17% RAE) compared to SSP (100% RAE) for maize (Table 5). However, for soybean (*Glycine max* L.), MRP (36.2% RAE) was less efficient than SSP (100% RAE) in slightly acidic loamy sand but more efficient (139.77% RAE) in strongly acidic sandy clay loam compared to SSP (100% RAE) (Table 5).

3.2. Experiment 2. It was also observed that slightly acidic loamy sand produced crops with higher dry biomass yield than strongly acidic sandy clay loam (Table 6). The soybean-*Sorghum* crop rotational scheme constantly produced dry biomass yield of *Sorghum* plants compared to that of maize-*Sorghum* crop rotational scheme (Table 6). Based on the residual effects of the various P fertilizer treatments, the dry biomass yields of *Sorghum* plants at first and second cuttings were not different (Table 6).

For the residual influence of the soils and P-sources, there were no significant differences ($p < 0.05$) among the *Sorghum* dry biomass yield produced on the two soils treated with the various P-sources and untreated ones at the first and second cuttings. However, similar trend was observed on the influence of the crop effects and soils on *Sorghum* dry biomass yield as those produced on soils and P-sources (Table 7).

The relative agronomy efficiency (RAE) of MRP in strongly acidic soil was 137.04% while SRP was 85.19% as efficient as SSP (100%) with regard to dry biomass production at first cutting of *Sorghum* plants while in the second cutting, RAE of P-sources were undefined (Table 7). However, in slightly acidic loamy sand only MRP was 85.71% as efficient as SSP at first cutting of *Sorghum* plants.

The relative yields of dry biomass yield of *Sorghum* in soybean-*Sorghum* crop effect are greater than those of maize-*Sorghum* crop effect at both first and second cuttings.

The various residual effects of crop effects and P-sources on dry biomass yield of *Sorghum* plants were significant ($p < 0.05$) at first cutting. The highest dry biomass yield of *Sorghum* plants was gotten from the influence of soybean-*Sorghum* treated with SSP while the least result was gotten from the influence of maize-*Sorghum* treated with SSP at the first cutting. At the second cutting, the influence of crop effects and P-sources had no significant difference on dry biomass yield of *Sorghum* plants. However, in maize-*Sorghum* only MRP was 78.13% as efficient as SSP at first cutting of *Sorghum* plants (Table 8).

The results of the influence of the various interactions among the experimental factors (soils, crops, and P-sources) show that there were no significant differences. The implication is that plant vigour and biomass yields did not differ at the various levels of each of the experimental factors.

Table 7: Influence of the experimental soils and P-source or crop effects and soils on dry biomass yield (g/pot) of *Sorghum* plants in the second cropping.

Treatment		Dry biomass (g/pot) Mean	Standard deviation	RAE (%)	Dry biomass (g/pot) Mean	Standard deviation	RAE (%)
			First cutting			Second cutting	
Soils acidity level	*Phosphate fertilizer*						
Strongly acidic	Control	1.92	±0.52		0.11	±0.16	
	Morocco Rock Phosphate	1.55	±0.69	137.04	0.07	±0.08	ND
	Sokoto Rock Phosphate	1.69	±0.25	85.19	0.06	±0.09	ND
	Single Super Phosphate	1.65	±0.55	100	0.12	±0.20	100
Slightly acidic	Control	2.28	±0.37		0.12	±0.18	
	Morocco Rock Phosphate	2.46	±0.81	85.71	0.14	±0.14	ND
	Sokoto Rock Phosphate	2.15	±0.60	ND	0.2	±0.28	ND
	Single Super Phosphate	2.49	±1.14	100	0.07	±0.09	100
LSD (5%)		NS			NS		
Crop effects	*Soils acidity level*						
Maize-*Sorghum*	Strongly acidic	1.39	±0.30	4.06	0.02	±0.03	0.06
	Slightly acidic	1.97	±0.29	100	0.07	±0.10	100
Soybean-*Sorghum*	Strongly acidic	2.01	±0.49	5.78	0.16	±0.17	0.46
	Slightly acidic	2.71	±0.88	100	0.2	±0.22	100
LSD (5%)		NS			NS		

RAE = relative agronomic efficiency of the Phosphorus- (P-) sources = [((yield of GRP − yield of Control)/(yield of SSP − yield of Control)) × 100]%.
NS = nonsignificantly different at $p < 0.05$ and ND = not determined.

Table 8: Influence of crop effects and P-sources on biomass yield (g/pot) of *Sorghum* in the second cropping.

Treatment		Dry biomass (g/pot)	RAE (%)	Dry biomass (g/pot)	RAE (%)
		First cutting		Second cutting	
Crop effects	*Phosphate fertilizer*				
Maize-*Sorghum*	Control	1.81		0.03	
	Morocco Rock	1.56	78.13	0.06	ND
	Sokoto Rock	1.86	ND	0.06	ND
	Single Super	1.49	100	0.03	100
Soybean-*Sorghum*	Control	2.39		0.2	
	Morocco Rock	2.44	ND	0.15	ND
	Sokoto Rock	1.98	ND	0.2	ND
	Single Super	2.64	100	0.16	100
LSD (5%)		0.66		NS	

RAE = relative agronomic efficiency of the Phosphorus- (P-) sources = [((yield of GRP − yield of Control)/(yield of SSP − yield of Control)) × 100]%.
NS = nonsignificantly different at $p < 0.05$.
LSD = least significant difference (5%) and ND = not determined.

4. Discussion

4.1. First Cropping

4.1.1. Visual Growth Observation. Crops (maize and soybean) grown in strongly acidic sandy clay loam were not as abundant in growth and yield as those grown in slightly acidic loamy sand where crops in untreated pots had the least plant height and biomass yield of 59 cm/11.67 g/pot for maize plant and 35.39 cm/8.24 g/pot for soybean plant, respectively. The maize plants grown in untreated pots also developed purple colouration which is a symptom of Phosphorus deficiency [18]. It was observed that SSP treatment supported most growth (plant height 74.83 cm) and biomass 21.67 g/pot in slightly acidic soil, whereas MRP treatment supported most growth (plant height 63.17 cm) and biomass yield 13.50 g/pot in strongly acidic soil for maize plants. However, for soybean plants, SSP treatment supported the most growth and yield with 43.63 cm/15.78 g/pot in slightly acidic soil as well as 41 cm/8.17 g/pot in strongly acidic soil, respectively.

4.1.2. Experimental Data. From the results above, it was observed that values of P in Table 1 imply that both soils were deficient in P contents since the critical levels range between 10 and 15 mg/kg P [19, 20]. The two soil types were adequately furnished with the same contents of total nitrogen 0.2% where the critical level of nitrogen is 0.15% [19]. The organic matter in strongly acidic sandy clay loam (27.1 g/kg) was slightly higher compared to that of slightly acidic loamy sand (26.5 g/kg). The exchangeable K was higher in strongly acidic sandy clay loam (0.04 cmol/kg) when compared to that of slightly acidic loamy sand (0.03 cmol/kg); both fall within the critical range 0.01–0.15 cmol/kg K [19]. The strongly acidic sandy clay loam had lower proportion of sand (62.8%) compared to slightly acidic loamy sand which had 87.1% sand, while Soil A had higher proportions of silt (15%) and clay (22.2%) when compared to Soil B with 4% silt and 8.9% clay.

Slightly acidic loamy sand constantly produced crops with higher plant height (Table 2) compared to crops grown on strongly acidic sandy clay loam. For example, crops grown on slightly acidic loamy sand were 58.89 cm, per plant height on the average, compared to crops grown on strongly acidic sandy clay loam with 46.31 cm after 6 weeks of growth. Slightly acidic loamy sand was able to support the growth of the crops as much as strongly acidic sandy clay loam because slightly acidic loamy sand was more fertile than strongly acidic sandy clay loam. The soil pH and clay content values for slightly acidic loamy sand were more suitable for crops growth compared to strongly acidic sandy clay loam. This is in agreement with the statement made by Akinrinde and Adigun [2] that crops performed better in slightly acidic soil when compared to medium acid Alfisol. Also, there is possibility of higher P-fixation of applied phosphate ions in strongly acidic sandy clay loam than slightly acidic loamy sand. This is similar to the experiment carried out by Akinrinde and Adigun, [2] quoting Borggard [21] that close linear relationship exists between clay content and phosphate fixation.

Furthermore, the Control and SRP had lesser values for all the growth component parameters (Tables 3 and 4). The conventional soluble P fertilizer (SSP) and one of the rock phosphates, that is, MRP, almost gave the same result compared to SRP. For instance, in Table 4, applied MRP significantly gave higher values of dry biomass 18.43 (g/pot) for maize plants than applied SSP with 17.58 (g/pot). SRP performed less in this experiment; this could be due to soils type because not all soils and cropping situations are suitable for direct use of the RPs from different sources [22]. For instance, this experiment showed that strongly acidic sandy clay loam treated with SRP gave higher soybean plants than slightly acidic loamy sand treated with the same SRP, though they were not significantly different at 6 WAP (Table 5). SRP's poor performance in this experiment could also be attributed to the higher amount of $CaCO_3$ it contains (79%) compared to SSP (35% $CaCO_3$) and MRP (14% $CaCO_3$) [23, 24]. This could increase the soil pH of the slightly acidic loamy sand from 6.7 to alkaline soil pH which could affect proper functioning of the roots of crops and lead to poor growth and yield. This is similar to the result gotten by Ojo [25] which stated that RPs have more Ca than SP; thus, when applied they tend to make the soil alkaline. While in strongly acidic sandy clay loam, the $CaCO_3$ in SRP helps to increase the soil pH from 5.3 to slightly acidic soil which is favourable to growth of plants. However, slightly acidic loamy sand treated with any of the P fertilizers gave better results in terms of growth and biomass yield of maize plants than strongly acidic sandy clay loam treated with the same fertilizer. This shows that maize plants could survive in wide range of soil pH compared to soybean plants. It also supports the fact that differences among P-sources enhancing growth and yield components or not are attributed to environmental, plant, and soil characteristic factors [2, 25, 26]. The order of the effectiveness of P-sources for the growth and yield of the crops (maize and soybean) is MRP ≥ SSP > SRP in the first cropping. This shows the P-sources superiority of P released and availability for plants metabolism.

For efficient utilization of RP, marked differences have been found in the ability of plant species to extract P from PRs [25, 27, 28]. Similar results were observed in this study where, on average, MRP (114.38% RAE) was more efficient than SSP (100% RAE) for dry biomass yield of maize (*Zea mays* L.) but, for soybean (*Glycine max* L.) dry biomass, MRP (85.03% RAE) was less efficient than SSP (100% RAE) in the two soils. Sokoto Rock Phosphate was less than 50% efficient in the two location soils compared to SSP for the test crops. The MRP (relative agronomic efficiency, RAE of 210.24%) was more efficient than SSP (100% RAE) in slightly acidic loamy sand but less efficient in strongly acidic sandy clay loam (88.17% RAE) compared to SSP (100% RAE) for maize. However, for soybean (*Glycine max* L.), MRP (36.2% RAE) was less efficient than SSP (100% RAE) in slightly acidic loamy sand but more efficient (139.77% RAE) in strongly acidic sandy clay loam compared to SSP (100% RAE).

4.2. Second Cropping. It was also observed that slightly acidic loamy sand produced crops with higher dry biomass yield than strongly acidic sandy clay loam. It could be due to similar reasons given in the first cropping of this experiment.

The soybean-*Sorghum* crop rotational scheme constantly produced biomass yield of *Sorghum* plants compared to maize-*Sorghum* crop rotational scheme. This might be as a result of nitrogen fixed by the leguminous plants which was used by the following *Sorghum* plants while cereal-cereal crop rotational scheme is nitrogen demanding. Legumes are used commonly in agricultural systems as a source of atmospheric N through symbiotic N_2 fixation for subsequent crops, maintaining soil nitrogen levels, and through subsoil retrieved [29]. Rotation of cereals and legumes is usually preferred to sole cropping of either crop because of higher yield [30]. Therefore, it is beneficial to alternate soybean with cereals and other plants that require nitrogen.

Based on the residual effects of P fertilizer treatment, the residual effects of the various P fertilizer treatments on the dry biomass yield of *Sorghum* plants at first and second cuttings did not differ. According to the experiment carried out by Akinrinde and Adigun, [2] stated that the P-sources produced significant differences in the height and fresh biomass yield but not in the dry matter production.

The relative agronomy efficiency (RAE) of MRP in strongly acidic soil was 137.04% while SRP was 85.19% as efficient as SSP (100%) with regard to dry biomass production at first cutting of *Sorghum* plants while in the second cutting, RAE of P-sources were undefined (Table 7). However, in slightly acidic loamy sand only MRP was 85.71% as efficient as SSP at first cutting of *Sorghum* plants. Rock phosphate of P dissociation improved with time which in turn improves P availability as well as increased yield [25].

The results of the influence of the various interactions among the experimental factors (soils, crops, and P-sources) showed that there were no significant differences. The implication is that plant vigour and biomass yields were not different at the various levels of each of the experimental factors.

5. Conclusions

The strongly acidic sandy clay loam produced crops with lower plant height than crops grown in slightly acidic loamy sand.

The relative agronomic efficiency (RAE) of MRP was more efficient than that of SSP in slightly acidic loamy sand but less efficient in strongly acidic sandy clay loam compared to SSP as reference fertilizer for maize plants. However, for soybean plants, MRP was less efficient than SSP in slightly acidic loamy sand but more efficient in strongly acidic sandy clay loam than SSP.

The residual effects of the various P fertilizer treatments on the dry biomass yield of *Sorghum* plants at first and second cuttings were not different.

The soybean-*Sorghum* crop rotational scheme constantly produced biomass yield of *Sorghum* plants compared to maize-*Sorghum* crop rotational scheme.

However, based on points made above, it is evident that pH and clay contents of soils as well as the crop concerned determine the efficiency of finely ground soluble phosphates in crop production as well as positive effects of the crop rotation schemes. It can serve as means of production of forage or hay for ruminant animal.

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

References

[1] M. E. Sumner and A. D. Noble, "Soil acidification: the world story," in *Handbook of Soil Acidity*, Z. Rengel, Ed., pp. 1–28, Marcel Dekker, New York, NY, USA, 2003.

[2] E. A. Akinrinde and I. O. Adigun, "Phosphorus-use efficiency by pepper (*Capsicum frutescens*) and okra (*Abelmoschus esculentum*) at different phosphorus fertilizer application levels on two tropical soils," *Journal of Applied Sciences*, vol. 5, no. 10, pp. 1785–1791, 2005.

[3] K. N. Fageria, "Soil acidity affects availability of Nitrogen, Phosphorus and Potassium," *Better Crops International*, vol. 10, pp. 8–9, 1994.

[4] A. Rashid, "Phosphorus use efficiency in soils of Pakistan," in *Proceedings of the 4th National Congress of Soil Science*, Soil Science Society of Pakistan, Islamabad, Pakistan, May 1992.

[5] E. A. Akinrinde and K. A. Okeleye, "Short- and long-term effects of sparingly soluble phosphates on crop production in two contrasting Nigerian Alfisols," *West African Journal of Applied Ecology*, vol. 8, no. 1, pp. 141–149, 2005.

[6] P. A. Sanchez, A. U. Mokwunye, F. R. Kwesiga, C. G. Ndiritu, and P. L. Woomer, "Soil fertility replenishment in africa. An investment in natural resource capital," in *Replenishment Soil Fertility in Africa*, R. J. Buresh, Ed., vol. 51, pp. 1–46, SSSA Special, 1997.

[7] H. L. S. Tandon, *Phosphorus Research and Agricultural Production in India*, 1987.

[8] P. Pedersen and J. G. Lauer, "Influence of rotation sequence and tillage system on the optimum plant population for corn and soybean," *Agronomy Journal*, vol. 94, pp. 968–974, 2002.

[9] A. R. J. Eaglesham, F. R. Minchin, R. J. Summerfield, P. J. Dart, P. A. Huxley, and J. M. Day, "Nitrogen nutrition of cowpea (*Vigna unguiculata*). 3: distribution of nitrogen within effectively nodulated plants," *Experimental Agriculture*, vol. 13, no. 4, pp. 369–380, 1977.

[10] A. Bationo and A. U. Mokwunye, "Alleviating soil fertility constraints to increased crop production in West Africa: the experience in the Sahel," *Fertilizer Research*, vol. 29, no. 1, pp. 95–115, 1991.

[11] C. P. Vance, P. H. Graham, and D. L. Allan, "Biological nitrogen fixation: phosphorus Ba critical future need?" in *Nitrogen Fixation from Molecules to Crop Productivity*, F. O. Pederosa, M. Hungria, M. G. Yates, and W. E. Newton, Eds., pp. 509–518, Kluwer Academic, Dordrecht, The Netherlands, 2000.

[12] D. J. Oyedele, O. O. Awotoye, and S. E. Popoola, "Soil physical and chemical properties under continuous maize cultivation as influenced by hedgerow trees species on an alfisol in South Western Nigeria," *African Journal of Agricultural Research*, vol. 4, no. 8, pp. 736–739, 2009.

[13] H. A. Akintoye, A. A. Adekunle, and A. A. Kintomo, "The role of training in urban and peri-urban vegetable production: the case study of Leventis Foundation Agricultural Schools in Nigeria," *Learning Publics Journal of Agriculture and Environmental Studies*, vol. 2, no. 2, pp. 21–40, 2011.

[14] A. J. Smyth and R. F. Montgomery, *Soils and Land Use in Central Western Nigeria*, Government Printer, Ibadan, Nigeria, 1962.

[15] United States Grain Council November, Sorghum, 2010, http://www.grains.org/sorghum.

[16] E. J. Udo and J. A. Ogunwale, *Laboratory Manual for the Analysis of Soil, Plants and Water Samples*, Department of Agronomy, University of Ibadan, Ibadan, Nigeria, 1981.

[17] O. P. Engelstad, A. Jugsujinda, and S. K. De Datta, "Response by flooded rice to phosphate rocks varying in citrate solubility," *Soil Science Society of America Journal*, vol. 38, no. 3, pp. 524–529, 1974.

[18] K. Mengel and E. A. Kirkby, *Principle of Plant Nutrition*, International Potash Institute Publisher, 1987.

[19] G. O. Adeoye and A. A. Agboola, "Critical levels for soil pH, available P, K, Zn and Mn and maize ear-leaf content of P, Cu and Mn in sedimentary soils of South-Western Nigeria," *Fertilizer Research*, vol. 6, no. 1, pp. 65–71, 1985.

[20] R. A. Solubo and A. O. Osiname, *Soils and Fertilizer Use in Western Nigeria*, Research Bullrtin no. 11, Institute of Agriculture Research and Training, University of Ife, Ife, Nigeria, 1981.

[21] O. K. Borggard, "Iron oxides in relation to phosphate adsorption by soils," *Acta Agriculturae Scandinavica*, vol. 36, no. 1, pp. 107–118, 1986.

[22] G. O. Obigbesan and E. A. Akinrinde, "Evaluation of the performance of Nigerian rock phosphates applied to millet in

selected benchmark soils," *Nigerian Journal of Soil Science*, vol. 12, pp. 88–99, 2000.

[23] E. A. Akinrinde and G. O. Obigbesan, "Benefits of phosphate rocks in crop production: experience on benchmark tropical soil areas in Nigeria," *Journal of Biological Sciences*, vol. 6, no. 6, pp. 999–1004, 2006.

[24] P. Van Straaten, *Rocks for Crops: Agro-Minerals of Sub-Saharan Africa*, ICRAF, Nairobi, Kenya, 2002.

[25] O. D. Ojo, *Growth development and yield of amaranth (*Amaranthus cruentus *L) varieties in response to different sources of phosphorus [Ph.D. thesis]*, University of Ibadan, Ibadan, Nigeria, 2001.

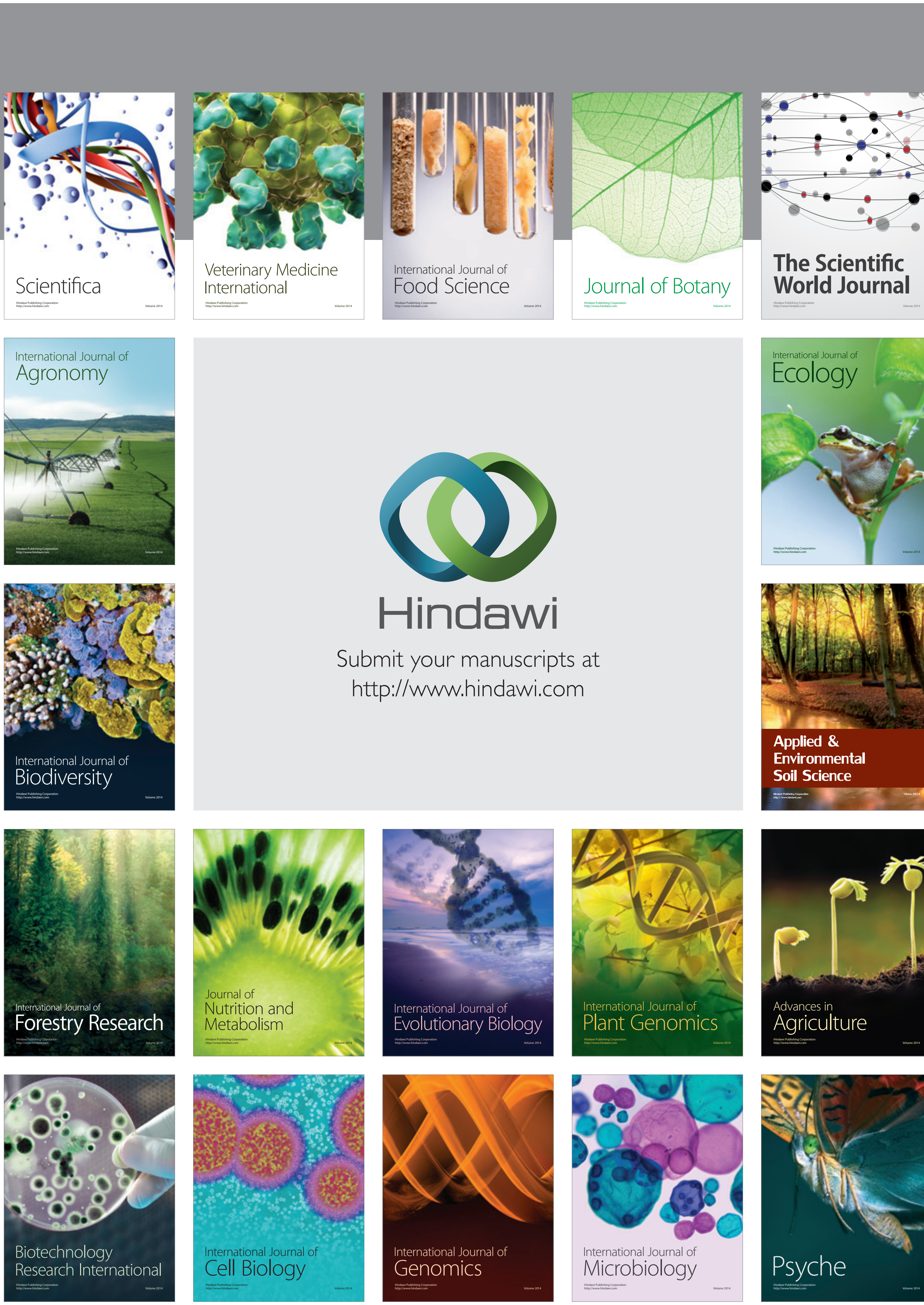
[26] D. P. Schachtman, R. J. Reid, and S. M. Ayling, "Phosphorus uptake by plants: from soil to cell," *Plant Physiology*, vol. 116, no. 2, pp. 447–453, 1998.

[27] E. N. Flach, "A comparison of the rock phosphate mobilizing capacities of various crop species," *Tropical Agriculture*, vol. 64, pp. 347–352, 1987.

[28] S. S. S. Rajan, J. H. Watkinson, and A. G. Sinclair, "Phosphate rocks for direct application to soils," *Advances in Agronomy*, vol. 57, pp. 77–159, 1996.

[29] S. M. Gathumbi, G. Cadisch, and K. E. Giller, "15N natural abundance as a tool for assessing N_2-fixation of herbaceous, shrub and tree legumes in improved fallows," *Soil Biology and Biochemistry*, vol. 34, no. 8, pp. 1059–1071, 2002.

[30] B. O. Baldock, R. L. Higgs, W. H. Paulson, J. A. Jackobs, and W. D. Shader, "Legume and mineral fertilizer effects on crop yields in several crop sequences in the upper Mississipi Valley," *Agronomy Journal*, vol. 73, no. 5, pp. 885–890, 1981.



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