Short- and Long-term Effects of Sparingly Soluble Phosphates on Crop Production in Two Contrasting Nigerian Alfisols

E. A. Akinrinde[1] and K. A. Okeleye[2]
[1]Department of Agronomy, University of Ibadan, Ibadan, Nigeria
[2]Department of Crop Production, University of Agriculture, Abeokuta, Nigeria

Abstract

The effectiveness of Sokoto and Ogun rock phosphates (RP) as substitutes for the conventional phosphorus (P) fertilizer sources in the production of tomato (*Lycopersicon esculentum*) and okra (*Hibiscus esculentus*) were evaluated using single super-phosphate (SSP) as reference. Their residual effects were also investigated using rice (*Oryzae sativa*) and soybean (*Glysine max*). The two experiments were $2 \times 2 \times 4$ factorial combinations with completely randomized design (CRD) involving two crops, two soils, three P-fertilizer sources and a control. The treatment combinations were replicated four times to give a total of 64 pots, each containing 5 kg of either a slightly acid (pH 6.3) alfisol (Typic Paleudalf) A, from Abeokuta (rainforest ecological zone) or a medium acid (pH 5.9) alfisol (Oxic Paleustalf) B, from Zaria (southern Guinea savanna zone). The soils represent a wide range of Nigerian soils with medium to low P-availability and cultivated to various food and economic crops. The rock phosphates (particularly SRP) were more efficient than SSP in soil A but had less than 50% relative agronomic efficiency (RAE) in soil B, especially when tomato was the test crop. They also had higher RAE in soil A than in soil B when okra was grown, though the efficiency was not as high as that of the reference fertilizer. In the slightly acid alfisol (A), ORP was less efficient than SRP whereas it had 47.8% RAE compared with 34.9% RAE for SRP in the medium acid soil. In the second cropping, the soil from the rainforest zone still produced greater biomass than soil B while soybean gave more biomass than rice. The results confirmed that, apart from crop species to be grown, organic matter and clay contents as well as pH of soils should be considered for efficient utilization of the sparingly soluble phosphates for both short- and long- term effects in crop production.

Introduction

Phosphorus (P) is an important limiting nutrient element in the production of vegetables, cereals and leguminous crops. It stimulates root growth, flower development and seed formation besides enhancing rapid and vigorous as well as early maturity in these crops. With inadequate P supply, leaves are often small in size and greenish red, reddish brown, purple or bronze-like colours while fruits and seeds are small and have reduced quality (Denton & Swarup, 1981; Al-Wandawi, 1983). The occurrence of excess available P is rare in soils since it is often adsorbed, sometimes strongly through fixation by colloidal (inorganic clay and organic materials) complexes formed with Al, Fe and Ca. It can also be lost through erosion, leaching and crop removal (Aduayi & Ekong, 1981).

Crops have become so expensive to grow that nutrient deficiencies should not be allowed to limit their yields. However, this goal is far from reality. The use of phosphatic fertilizers is beyond the reach of peasant farmers due to procurement difficulties, especially in developing countries of the world. This necessitates research to investigate alternative materials that can be used as P fertilizer sources. One of the possibilities is the direct use of sparingly soluble rock phosphates (RP). Yet, it is not all soils that are suitable for such direct applications (Obigbesan & Akinrinde, 2000). The objective for this work was, therefore, to investigate the direct and residual effects of two rock phosphate materials, namely Ogun rock phosphate (ORP) and Sokoto rock phosphate (SRP) applied directly as P-fertilizer sources in sequential cropping of okra and tomato, as well as rice and soybean in two contrasting soils.

Materials and methods

Two soils, A and B, were used for the experiments. Soil A was a slightly acid alfisol (Typic Paleudalf) collected from Abeokuta in the rainforest zone of south-west Nigeria (Soil Survey Staff, 1975; Agboola & Ogunkunle, 1993) while soil B was a medium acid alfisol (Oxic Paleustalf) collected from Zaria in the southern Guinea savanna zone of northern Nigeria (Soil Survey Staff, 1975; Akintunde *et al.,* 2000). Their physical and chemical properties were determined using laboratory methods described by Udo & Ogunwale (1981).

The soils were crushed, passed through a 2-mm sieve and 4 kg filled into 32 polyethylene bags for each soil type. A $2 \times 2 \times 2$ factorial completely randomized design with four replications was adopted, giving a total of 64 experimental pots. The treatments used were an absolute control and 100 mg P_2O_5/kg soil each of Ogun rock phosphate, ORP (31.4% P_2O_5), Sokoto rock phosphate, SRP (34.2% P_2O_5) and single super phosphate, SSP (18% P_2O_5). Each fertilizer was thoroughly mixed with the soils, watered to 60% field capacity (FC) and allowed to equilibrate for 3 days. Tomato (*Lycopersicon esculentum* var. Ibadan local) and okra (*Hibiscus esculentus* var. V-35) were planted as first crop followed by rice and soybean. Two seedlings of the test crops were allowed to grow in each pot for 10 weeks before the aerial portions (shoot, fruits and root) were harvested and weighed. Prior to this, however, the height of plants was measured and the leaves counted at 2, 4 and 6 weeks while flowers and fruits were counted at weekly intervals between the 7th and 10th weeks of growth.

In order to compare the residual effects of the P sources in the two soil types, the growth and forage yields of rice (*Oryza sativa* L.) and soybean (*Glycine max*) were also evaluated after air-drying and sieving of the first cropping

soil, but only for a 7-week-growth-period. The use of rice and soybean was in conformity with the cropping practice of the farmers around the experimental soil locations. The relative agronomic efficiencies (RAE) of the P sources were computed as the ratios of the yield responses with test fertilizer (GRP-ground rock phosphate) to the respective yield responses of the reference (SSP) fertilizer at the same rate (100 mg P_2O_5/kg soil), i.e.

RAE = [(yGRP – yCONTROL / ySSP – yCONTROL) × 100]%, where y = yield.

In all cases, analysis of variance (ANOVA) was performed based on the completely randomized design, CRD (Steel & Torrie, 1981), using the statistical analysis system (SAS, 1985) computer software. Treatment effects and the magnitude of interactions were determined and the F-LSD (Carmer & Swanson, 1971) was used to detect differences between treatment means at 5% significant level.

Results and discussion

The soils investigated represent a wide range of Nigerian soils with medium to low acidity and P availability. They are soils on which a wide range of food and economic crops such as oil palm, kola nuts, cassava, yam, maize, sweet potato, tomato and okra are cultivated.

Soil properties

The physical and chemical properties of the soils are given in Table 1. The Typic Paleudalf (soil A) had a higher proportion of sand (712 g/kg) than the Oxic Paleustalf (soil B) with 523 g/kg. On the other hand, soil B had higher silt (354 g/kg) and clay (114 g/kg) contents than soil A. Silt and clay contents of soil A were 214 g/kg and 74 g/kg, respectively. The two soils were, however, sandy loam in texture. Soil A had higher *p*H than soil B (i.e. 6.3 against 5.9). Soil A also had a higher available P than soil B. Based on the 6–20 mg/kg critical range (Agboola & Adeoye, 1985), soil A could be said to be adequately furnished with available P than soil B.

TABLE 1

Properties of the soils used prior to cropping

Soil test values

Properties	Soil A, Typic Paleudalf (Abeokuta location)	Soil B, Oxic Paleustalf (Zaria location)
pH (1 :2.5 soil/water ratio)	6.6	5.9
Organic matter (g kg⁻¹)	38.7	18.4
Total N (g kg⁻¹)	1.93	0.92
Bray-l-P (mg kg⁻¹)	25.56	5.99
Exchangeable-K (cmol kg⁻¹)	0.23	0.17
Sand (g kg⁻¹)	712	532
Silt (g kg⁻¹)	214	354
Clay (g kg⁻¹)	74	114

First cropping

Table 2 summarizes the effects of soil location or soil type, crop species and P fertilizer sources on plant height, numbers of leaves, flowers and fruits at successive growth stages. Soil type A from Abeokuta consistently produced crops with higher number of leaves, flowers and fruits, as well as taller plants than crops grown on soil B from Zaria. For instance, crops grown on soil A were 34.2 cm tall on the average compared with crops grown on soil B with 31.3 cm after 6 weeks of growth. Similarly, Soil A had an average of 4.6 and 1.2 flowers and fruits, respectively after 9 weeks of growth while crops grown on soil B had 4.7 and 0.9, respectively, at the same growth stage (Table 2).

TABLE 2

Effects of experimental soil location, crop species and phosphorus fertilizer sources on plant growth and development in the first cropping

Treatment	Plant height (cm)			Number of leaves			Number of flowers			Number of fruits		
						Weeks after planting						
	2	*4*	*6*	*2*	*4*	*6*	*7*	*8*	*9*	*8*	*9*	*10*
Soil location												
Abeokuta	7.4	13.7	34.2	6.2	13.9	28.8	3.0	4.0	4.6	16.1	1.2	1.6
Zaria .	6.2	13.6	31.3	5.5	11.8	22.5	2.8	3.9	4.7	13.1	0.9	1.0
LSD	0.5	1.2	2.2	0.4	1.0	1.9	0.8	0.9	1.3	2.7	0.3	0.3
Crop species												
Tomato	7.9	15.5	36.3	7.7	21.8	47.5	5.7	7.8	9.1	16.2	1.3	1.4
Okra	5.6	11.8	29.2	4.0	3.8	3.8	0.2	0.1	0.1	12.9	0.8	1.2
LSD	0.5	1.2	2.2	0.4	1.9	3.6	0.8	0.9	1.3	2.7	0.3	0.3
Phosphorus sources												
Control	5.9	9.7	27.4	5.8	10.3	19.6	2.3	3.2	4.1	10.8	0.9	1.0
0RP	6.5	12.6	34.1	5.6	11.6	26.2	2.7	4.3	5.2	15.2	1.0	1.3
SRP	6.9	15.2	35.4	6.0	13.6	26.9	3.1	3.5	4.3	15.3	1.1	1.4
SSP	7.7	16.9	34.1	6.2	15.8	29.9	3.5	4.7	5.0	16.9	1.2	1.5
LSD	0.7	1.5	2.9	0.6	2.5	5.0	1.3	1.4	2.4	4.0	0.6	0.6

It is noteworthy that soil B did not support the growth of the crops as much as soil A. This is due to the fact that soil A was more fertile than soil B. Soil A had higher organic matter and other plant nutrient elements than soil B. The soil pH and clay content values were also more conducive for crop growth in soil A than in soil B. This is in line with the report by Adepetu (1981) that rainforest soils generally have higher available P (8–15 mg/kg) than most others, particularly from savanna ecological zones. There is also the possibility of higher sorption of applied phosphate ions in soil B than in soil A as a result of the higher clay contents of soil B. This is in agreement with the submission of Borggard (1986) that close linear relationship exists between clay content and phosphate sorption. Additionally, Table 2 exposes variations in the performance of the test crops arising from their morphological differences.

Tomato produced relatively more root mass than okra (Fig. 1), implying that it was able to forage for essential plant nutrients in general (P in particular) more than okra. According to Ojo (2001) higher plant uptake rate usually create a P-deficient zone around the roots due to slow P diffusion rate (10^{-2}–10^{-15}m^2) in soils. The low availability of P in the bulk soil, therefore, limits plant uptake of the nutrients. As a result, plant root geometry and morphology are also important for maximizing P uptake. Lynch (1995) also noted that root system having high surface area to volume ratios will more effectively explore a large volume of soil than root systems with low surface area to volume ratio.
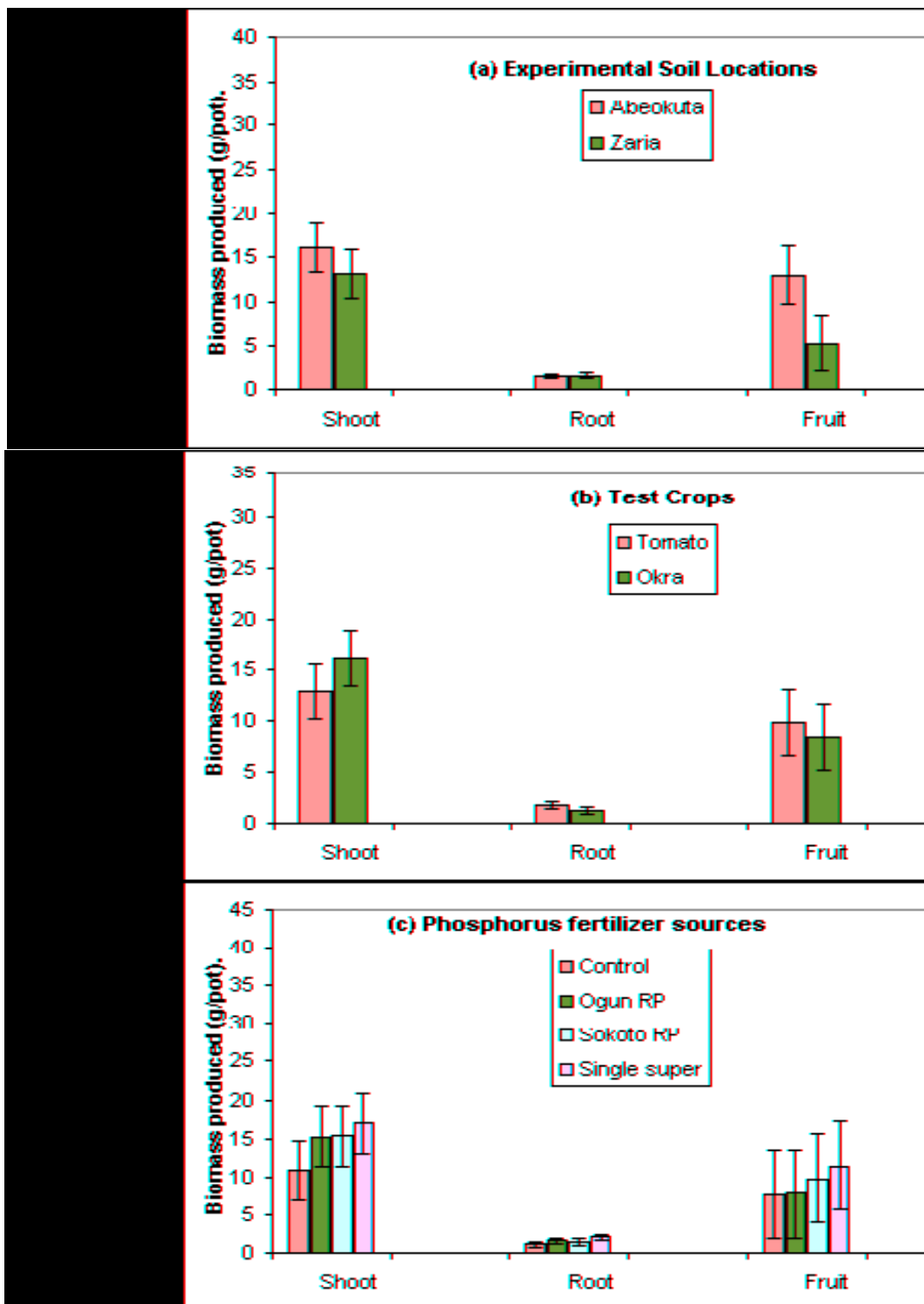
Fig. 1. Effects of experimental location soils, crop species and phosphorus fertilizer sources on biomass production

With regard to the P fertilizer treatments, the control plants had the least values for all the growth and yield component parameters (Table 2). The conventional soluble P fertilizer (SSP), however, gave the highest value in respect of the growth and yield component parameters. Among the rock phosphate fertilizer materials used, SRP proved to be generally more effective as P fertilizer than ORP (Table 2). This is in line with the submissions of Sobulo (1994) and Adediran and Sobulo (1998) that SRP increased crop yield and gave similar relative agronomic efficiency as SSP. Obigbesan & Akinrinde (2000) also observed that SRP was more effective in weakly than strongly acid soils.

The influence of the experimental factors (soil type, crop type and P fertilizer source) on total biomass yield and fresh material partitioning into shoot, root and fruits are illustrated in Fig. 1. While soil A enhanced greater biomass production (30 g/pot) than soil B (20 g/pot), there was no significant difference in the total biomass yield for tomato and okra (a range of 25.0–27.0 g/pot). Nevertheless, SSP still proved to be the most effective P source while the

untreated (control) plants had the least biomass yield. ORP and SRP were not very much different in their support for crop yield. The higher performance recorded by SSP in respect of growth and yield component parameters might be due to high solubility and ease of absorption of P (by the plants) from SSP relative to the other P sources.

The results of the effects of the various interactions between the experimental factors (soil type, crop type and P source) as they influenced the growth parameters are indicated in Table 3. The P source * Soil * Crop interaction was significant, indicating that plant vigor and biomass yield differed at the various levels of each of the experimental factors.   Thus, in line with the observed morphological differences between the test crops, shoot, root, fruit and biomass yields for tomato grown in soil A was significantly different from those of okra grown on the same soil (Table 3). Similarly, the effectiveness (as indicated by the estimated relative agronomic efficiency, RAE) of the ground rock phosphates with respect to biomass yields was different in the two soil types. For instance, ORP was 58.3% efficient in soil A, but only 45.6% efficient in soil B. In the same vein, SRP that was 149.2% as efficient as SSP in soil A was found to be just 11.3% as efficient in soil B. These RAE values are quite higher than the maximum of 100% obtained for millet (Obigbesan & Akinrinde, 2000).

TABLE 3

*Effect of P-source*Soil * Crop interaction on relative yields (%) of tomato and okra and relative agronomic efficiency, RAE (%) of the phosphorus fertilizer sources in the first cropping.*

Treatment	Biomass yield							
	Shoot		*Root*		*Fruit*		*Total*	
	(g/pot)	*R. Y*	*(g/pot)*	*R. Y*	*(g/pot)*	*R. Y*	*(g/pot)*	*R. Y*
Control/Abeokuta/Tomato	12.13	–	1.28	–	16.53	–	29.94	–
Control/Abeokuta/Okra	11.15	–	0.90	–	6.40	–	18.45	–
Control/Zaria/Tomato	8.10	–	1.13	–	4.18	–	13.41	–
Control/Zaria/Okra	11.93	–	0.98	–	3.60	–	16.51	–
0gun/RP/ Abeokuta/Tomato	12.65	17.81	2.05	192.50	8.48	125.80	33.18	66.53
0gun/RP/ Abeokuta/Okra	17.80	51.01	1.15	30.12	15.85	277.90	34.80	98.61
0gun/RP/Zaria/Tomato	12.10	53.12	1.40	11.07	4.93	7.39	18.43	25.04
0gun/RP/Zaria/Okra	18.33	136.17	1.73	62.50	3.65	2.73	23.71	108.27
Sokoto/RP/Abeokuta/T omato	20.60	290.07	1.78	125.00	18.25	17.00	40.63	219.51
Sokoto/RP/Abeokuta/Okra	18.68	60.97	1.23	39.76	20.40	411.80	40.31	131.90
Sokoto/RP/Zaria/Tomato	10.15	27.22	1.38	10.25	6.03	18.23	17.56	20.70
Sokoto/RP/Zaria/Okra	12.88	20.21	1.13	125.00	4.38	42.62	18.39	28.27
Single super/Abeokuta/Tomato	15.05	100.00	1.68	100.00	18.08	100.00	34.81	100.00
Single Super/Abeokuta/Okra	23.50	100.00	1.73	100.00	9.80	100.00	35.03	100.00
Single super/Zaria/Tomato	15.63	100.00	3.57	100.00	14.33	100.00	33.46	100.00
Single super/Zaria/Okra	16.63	100.00	1.10	100.00	5.43	100.00	23.16	100.00
LSD	0.64		0.40		5.81		6.85	

R.Y. = Relative yield (tomato or okra) = [Yield of the crop on a particular soil type/ Maximum yield] × 100] %

RAE = Relative agronomic efficiency of the phosphorus (P) sources = [(yGRP – yCONTROL / ySSP – yCONTROL) × 100]%, where y = yield.

Second cropping

In the second cropping, the P-source, soil type, crop type and the interactions of the three significantly influenced plant height and biomass yield. No interaction could, however, be established between P sources and either soil type or crop species. As in the first cropping, morphological differences between the alternative test crops (rice and soybean) caused significant differences in crop growth and yield on the soils (Table 4). The P source also produced significant differences in the height and fresh biomass yield but not in the dry matter production. SRP was 117.9% while ORP was 96.4% as efficient as SSP across the soils with regard to fresh biomass production (Table 4). With respect to dry matter production, however, SRP and ORP were 83.3% and 50% as efficient as SSP, respectively. The residual effect of P source * Soil * Crop interaction were also significant (Table 5). Soybean plants treated with SRP were 39.0 cm tall on the average when grown on soil A but only 34.0 cm tall when grown on soil B.

TABLE 4.

Effects of experimental location soils, crop species and phosphorus fertilizer sources on plant height, relative yields (%) and relative agronomic efficiency, RAE (%) in the second cropping.

Treatment	Plant height (cm)	Fresh biomass (g/pot)	R.Y/RAE (%)	Dry biomass (g/pot)	R.Y/RAE (%)
Experimental soil location					
Abeokuta	37.3a	12.2a	100.0	3.6a	100.0
Zaria	33.0b	7.0b	57.4	2.0b	55.6
LSD	2.3		1.8	0.5	
Crop species					
Rice	35.6a	5.3b	38.1	1.1b	25.0
Soybean	34.6a	13.9a	100.0	4.4a	100.0
LSD	2.3	1.8	0.5		
Phosphorus fertilizer sources					
Control	32.6b	7.4b		2.4a	
Ogun RP	35.5ab	10.1ab	96.4	2.7a	50.0
Sokoto RP	37.1a	10.7a	117.9	2.9a	83.3
Single super	35.4ab	10.2a	100.0	3.0a	100.0
LSD	3.7	2.8		0.9	

R.Y. = Relative yield of test crops (tomato or okra) = [Yield of the crop on a particular soil type/ Maximum yield) × 100] %

RAE = Relative agronomic efficiency of the phosphorus (P) sources = [(yGRP – yCONTROL / ySSP – yCONTROL) × 100]%, where y = yield.

TABLE 5

Effect of P-source*soil*crop interaction on plant height, biomass yield, relative yield, RY of rice and soybean and relative agronomic efficiency, RAE of the phosphorus fertilizer sources in the second cropping

Treatment		Plant height (cm)	Fresh biomass (g/pot)	R.Y/RAE (%)	Dry biomass (g/pot)	R.Y/RAE (%)
Control / Abeokuta/	Rice	33.1	5.6	–	1.3	–
	Soybean	35.1	12.5	–	5.4	–
Zaria	Rice	34.2	3.6	–	0.7	–
	Soybean	27.9	7.9	–	2.4	–
Ogun RP / Abeokuta /	Rice	38.3	7.7	420.0	1.7	0.0
	Soybean	38.1	18.0	73.3	5.6	25.0
Zaria	Rice	32.4	4.2	40.0	0.9	50.0
	Soybean	33.2	10.6	135.0	2.8	40.0
Sokoto RP /Abeokuta /	Rice	39.4	6.9	260.0	1.4	0.0
	Soybean	39.0	20.6	108.0	5.8	50.0
Zaria	Rice	35.1	3.4	13.3	0.7	0.0
	Soybean	34.8	11.7	190.0	3.7	130.0
Single super/Abeokuta/	Rice	36.9	6.1	100.0	1.3	100.0
	Soybean	38.3	20.0	100.0	6.2	100.0
Zaria	Rice	35.7	5.1	100.0	1.1	100.0
	Soybean	30.8	9.7	100.0	3.4	100.0
	LSD	3.7	2.8		0.9	

R.Y. = Relative yield of test crops (tomato or okra) = [Yield of the crop on a particular soil type/ Maximum yield) × 100] %

RAE = Relative agronomic efficiency of the phosphorus (P) sources = [(yGRP – yCONTROL/ySSP – yCONTROL) × 100]%, where y = yield.

Conclusion

The benefit of the sparingly soluble rock phosphates (RP) is soil type dependent. Across the soils and particularly for the medium acid Oxic Paleustalf, the order of effectiveness of the P sources for the growth and yield of the test crops is SSP > SRP > ORP. However, on the slightly acid Typic Paleudalf the order was SRP > SSP > ORP.

Among other crops, tomato and okra are produced on sites where the experimental soils were collected. Information on the relative agronomic efficiency (RAE) of various RP for the growth of these crops on the different soil types could assist in their economic production such that each crop is grown only under the most conducive soil – RP situation. The significant interactions among the experimental factors confirm that, apart from crop species to be grown, soils' physico-chemical properties (e.g. organic matter and clay contents, as well as *p*H) should be considered in the efficient utilization of the sparingly soluble phosphates. An economic analysis of the relative short- and long-term benefits of these phosphate fertilizers on field-grown crops would also be necessary.

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