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Full Length Research Paper

Effect of phosphate rock on selected chemical properties and nutrient uptake of maize and cowpea grown sequentially on three soil types in south western Nigeria

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Utilization of RP was investigated in incubation and greenhouse studies at the Institute of Agricultural Research and Training Ibadan, Nigeria to evaluate the effect of phosphorus (P) sources, their application rate and frequency of application on nutrient availability and uptake by maize and cowpea grown in sequence on three soil type. Two hundred grammes of soil was mixed with each of Ogun phosphate rock (OPR) (20.21% P_2O_5), Crystallizer super (CS) (31.4% P_20_5) and Single superphosphate (SSP (18% P_20_5) at the rate of 0, 50, 100 and 150 mg P kg^{-1} replicated thrice in an incubation study and was conducted for sixteen weeks in the laboratory. The greenhouse experiment consisted of four P rates (0, 20, 40 and 60 kg P ha^{-1}). Two frequencies of application (regular and alternate) were imposed on three soil types and was laid out as a split –split plot using randomized complete block design. Results of incubation study showed that phosphate application significantly increased soil available P and exchangeable Ca but no significant increase was observed in soil pH. The SSP treated soil consistently obtained the highest values of exchangeable Ca at each sampling period. The percentage changes in soil available P and exchangeable Ca when 100 mg P kg^{-1} was added to the soil as SSP, ORP and CS at the end of incubation period were 276, 184 and 203 % and 83, 87 and 73 % respectively. In the greenhouse phosphate application significantly enhanced the P uptake by maize and cowpea. The highest value of 3.3 and 3.5 mg kg^{-1} P uptake were obtained where maize has been planted thrice consecutively and where maize was alternated with cowpea in SSP treated plants respectively. Phosphorus uptake was increased by 133, 125 and 100% in the second cropping and 200, 80 and 250 % in the fourth cropping for Ilora, Ibadan and Epe soils respectively. The soil available P in regular frequency of application was consistently greater than alternate frequency of application in all the soil and throughout the four croppings. There were increases of about 57, 53 and 80% soil available P in Ilora, Ibadan and Epe, respectively at the end of final cropping.

Keywords: Available Phosphorus, rock-phosphate, nutrient uptake.

INTRODUCTION

Extensive tracts of land in the tropical and sub-tropical regions of Asia, Africa and Latin America contain highly weathered and inherently infertile soils. These areas generate low crop yields and are prone to land degradation as a result of deforestation, overgrazing and inefficient farming practices. Apart from socio-economic factors, the main constraints are soil acidity

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and low inherent nitrogen (N) and phosphorus (P) levels (Lal, 1990). While N inputs can be obtained from sources such as BNF (Biological nitrogen fixation), crop residues and other organic sources, P inputs need to be applied in the farms in order to improve the soil P status and ensure normal plant growth and adequate yields. Therefore, substantial P inputs are required for optimum growth and adequate food and fibre production (Date et al., 1995). Water soluble phosphate (WSP) fertilizers such as superphosphates are commonly recommended for correcting soil P deficiencies. However, most developing countries import these fertilizers, which are often in limited supply and represent a major outlay for resource-poor farmers. In addition, intensification of agricultural production in these regions necessitates the addition of P inputs not only to increase crop production but also to improve P status in order to avoid further soil degradation. Therefore, it is imperative to explore alternative P inputs. In this context, under certain soil and climate conditions, the direct application of rock phosphates (RPs) has been discussed as an agronomic and economically sound alternative to the more expensive superphosphates in the tropics (Akande et al., 2008; Zapata and Roy, 2004; Akinrinde et al., 2005; Akande et al 1998; Chien et al 1990). The direct application of rock P is an avenue to low input agriculture which fits well with emerging Green Revolution for Africa. The direct application of ground, natural RP as a source of P for crops is a practice that has been utilized with varying degrees of success over years. Numerous field and greenhouse experiments have been conducted to assess the capabilities of these materials to supply P to crops and to define the most favourable conditions for their application. The results obtained have been reported as erratic and sometimes conflicting, leading to confusion and disagreement on the utilization of RPs (Kwasawneh and Doll, 1978). The main reason for this stemmed from the lack of understanding of the various factors affecting the agronomic effectiveness of RPs. Since the work of (Kwasawneh and Doll, 1978), significant progress on evaluation of the main factors affecting agronomic effectiveness of RPs has been reported. These authors examined and summarized the influence of the inherent RP factors as: Soil factors (pH, texture, organic matter, P status, P fixation and Ca content) and plant factors (growth cycle, P demand and pattern of P uptake, root system and rhizosphere properties). It is now known that plants can enhance the dissolution of RP by acidification of the rhizosphere and high uptake of Ca (Hinsinger and Gilkes, 1996), secretion of organic acid anions that complex Ca (Hoffland, 1995), and depletion of P in soil solution. The rhizosphere pH changes are attributed to imbalances in cation –anion uptake [Marschner, (1995). Accordingly, nitrogen plays a prominent role in the cation-anion balance because it is the nutrient that is taken up at the highest proportion by most plant species (Marschner, 1995; Mengel et al., 2001). Root-induced acidification of the rhizosphere, or more precisely the H^+ release that originates in the roots, can thus dramatically increase the bioavailability of inorganic P whenever Ca phosphates are present, mostly in alkaline to mild acidic soils. Its effect in soils, which have an acidic pH, is more questionable, except when a source of Ca phosphates such as phosphate rock is added to the soil (Hinsinger and Gilkes 2011; Zoysa et al., 1998). The current research work attempts to investigate the direct application of phosphate rock on P and Ca availability and uptake in maize – cowpea grown in sequence.

MATERIALS AND METHODS

Incubation experiment

Incubation and greenhouse experiments were carried out at the Institute of Agricultural Research and Training (I.A.R and T), Moor Plantation, Ibadan (lat.7° 22½'N and long.3° 50½'E). Surface (0 - 15 cm depth) soils were collected from three locations namely: Epe, Ilora and Ibadan in South western Nigeria and are classified as Udipsamment, Arenic Haplustalf and Aquic Arenic Haplustalf respectively. Treatments consisted of three sources of P: Ogun phosphate rock (OPR), Crystallizer super (CS) and Single super phosphate (SSP); ORP contained 20.2% P_2O_5, CS was a homogenous blend of Sokoto rock phosphate and magnesite that contained 31.4% P_2O_5 and 0.1% MgO while the SSP contained 18% P_2O_5. The two sources of phosphate rock are low in re-activities. The availability of P in the three sources of P was determined by incubation method. Two hundred grammes (200g) of each of the soils were weighed into plastic cups and mixed thoroughly at the rate of 0, 50, 100 and 150 mg P kg^{-1} as SSP, OPR and CS. The treatments were arranged in completely randomized design (CRD) with three replicates. The soils were moistened to field capacity with distilled water and left for sixteen weeks. Soil samples were taken at monthly intervals and analyzed for pH, exchangeable Ca and available P.

Greenhouse experiment

Three kilogrammes (3 kg) of air-dried, sieved soil was weighed into black polyethylene bags. Each bag was supplied with drainage holes and saucer for watering. Treatments consisted of three sources of P (OPR, CS and SSP) used for incubation study. Four rates (0, 20, 40 and 60 kg P ha^{-1}) and two fertilizer application frequencies (Alternate and Regular) were studied. Three soil types were used for the study. The experimental set-up was a split-split plot design replicated three times and arranged in a completely randomized design. Soil type was the main factor. Frequency of fertilizer application was the sub factor while rate of application was the sub-sub factor. The fertilizers were thoroughly mixed with soil and water was supplied to field capacity. The soils were allowed to stabilize for seven days before planting. Each soil received a basal dressing of urea and muriate of potash at the rate 100 kg N and 50kg K per hectare respectively to the following cropping sequences:

1. Continuous maize for 4 cycles.
2. Maize and Cowpea in alternate croppings.

Four seeds of maize (*Zea mays* L: variety, DMR – ESR – Y) and cowpea (*Vigna unguiculata* (L) Walp: variety, Ife brown) were sown sequentially in each pot and thinned to two plants, at one week after planting. The soils were regularly moistened with water. Each cropping cycle lasted for four weeks. Total plants were uprooted and the shoots separated from the roots from the soil mark level.

Each portion was dried in the oven at 65℃ to a constant weight and cooled and the dry weights determined. Soil samples were taken per pot for post-cropping chemical analysis.

Laboratory analysis

Soil analysis

Particle size distribution was determined by the hydrometer method using sodium hexametaphosphate as the dispersing agent [Bouyoucos, 1962]. Soil pH was determined in distilled water at soil to water ratio 1:1 using glass electrode on an EIL 7020 pH meter. Exchangeable bases (K, Na, Ca and Mg) were determined by extraction with neutral normal NH_4OAc at soil: solution ratio 1:10. Potassium, calcium and sodium in the extract were read by flame photometry while magnesium was determined by atomic absorption spectrophotometer. Soil exchangeable acidity was determined by titration of normal KCl extracted acidity against 0.05N sodium hydroxide to a pink end point using phenolphthalein as indicator (Mclean, 1982). Cation exchange capacity was obtained by summation of exchangeable cations (K, Na, Ca, and Mg) and exchange acidity. Available P was determined using 0.03 N NH4F in 0.025 N HCl as extractant (Bray RM, Kurtz, 1945). Organic carbon was determined by wet oxidation (Walkley and Black, 1934). Total N was determined by macro Kjedahl.

Plant analysis

Chemical analysis of plant samples from greenhouse experiment was carried out in the laboratory. The plant samples were dried in an oven at 65^oC until a constant weight was obtained. The samples were ground in a Wiley mill of Arthur Thomas of USA equipped with stainless steel grinding chamber and passed through a 0.5 mm sieve. The plant sample was ashed in a muffle furnace at a temperature of 450℃. The nutrients in the ash were extracted by washing with 0.1 N HCl. Phosphorus was determined colorimetrically by the vanadomolybdate (yellow) method (Kitson RE, Mellon, 1944).

Nutrient Uptake

Nutrient Uptake was calculated by method of (Ombo, 1995) as

Nutrient Uptake = % Nutrient content x sample dry weight.

Statistics

Based on the experimental design data collected were subjected to analysis of variance using mixed model procedure of statistical analysis system (Chien, 1977).

RESULT

Characteristics of experimental soils

The physical and chemical properties of the experimental soils are presented in Table 1. Ilora and Ibadan soils are classified as Arenic Haplustalf and Aquic Haplustalf respectively and were loamy sand in texture, while Epe soil is classified as Udipsamment and was sandy loam. The pH was slightly acidic in Ilora and Ibadan soils while Epe was moderately acidic. Exchangeable bases, total N and available P were low implying that the soils were low in fertility level, justifying the need for additional fertilizer input to boost crop yield.

Incubation study

Soil pH, exchangeable Ca and available P

The results of changes in some selected chemical properties of soil samples collected in the three locations as influenced by different sources and rates of phosphate fertilizer incubated for 16 weeks followed the

Table 1. Some properties of the soil samples used prior to experimentation

	EPE	ILORA	IBADAN
pH (H_20)	5.00	6.00	6.10
Org. C (%)	1.00	2.02	1.82
Total N (%)	0.8	0.14	0.10
Ca $cmol^+Kg^{-1}$	0.50	2.30	3.20
Mg $cmol^+Kg^{-1}$	0.30	0.84	0.88
K $cmol^+Kg^{-1}$	0.15	0.25	0.34
Na $cmol^+Kg^{-1}$	0.20	0.10	0.14
H^+ $cmol^+Kg^{-1}$	1.40	0.10	0.19
CEC $cmol^+Kg^{-1}$	2.55	3.59	4.82
Avail. P $mgkg^{-1}$	1.92	4.71	5.89
Sand (%)	93.20	76.40	87.00
Silt (%)	1.60	18.80	8.80
Clay (%)	5.20	4.80	4.20
Textural class	Sandy Loam	Loamy Sand	Loamy Sand

Table 2. Effects of P sources and rates on soil pH (means of 3 soils)

P source	Rate (mg P kg^{-1})	Incubation period (Weeks)			
		4	8	12	16
Control	0	5.7*	5.7*	5.8*	5.8*
SSP	50	5.8	5.9	6.0	6.1
OPR	50	5.8	5.9	5.9	6.0
CS	50	5.8	5.9	6.0	6.1
SSP	100	5.8	6.0	6.1	6.2
OPR	100	5.8	5.9	6.0	6.1
CS	100	5.8	5.9	6.0	6.I
SSP	150	5.8	6.0	6.1	6.2
OPR	150	5.8	5.9	6.0	6.1
CS	150	5.8	5.9	6.1	6.2

*Mean within a column was not significantly different at P≤0.05

same trend. The mean values for the three soils are presented in Tables 2 to 4. The effect of P source and rate on soil pH is shown on Table 2. There was no significant treatment effect on soil pH, although soil pH slightly increased with type of phosphate fertilizer as incubation period progressed. Application of different rates had no significant effect on soil pH, even at the highest rates of application, differences were not significant. This implies that at high rates a larger quantity of phosphate would be required to affect a little increase in soil pH over time.

The effect of P source and rate on soil exchangeable Ca is shown in Table 3. The soil exchangeable Ca was significantly influenced by P sources. The SSP treated soil consistently showed the highest values of 2.70, 3.54 and 3.97 c mol kg^{-1} of exchangeable Ca at 4, 8 and 12 weeks respectively at the application rate of 150 mg P kg^{-1} but at 16 weeks of incubation the highest value of 4.46 c mol kg^{-1} was at application rate of 100 mg P kg^{-1}. The OPR and CS were similar in most cases while control had the lowest value. Increasing rates of phosphate increased soil exchangeable Ca at each

Table 3. Effects of P sources and rates on soil exchangeable Ca (cmol kg^{-1}) (means of 3 soils)

P source	**Rate (mg P kg^{-1})**	**Incubation period (Weeks)**			
		4	8	12	16
Control	0	2.0c	2.03c	2.01c	2.00b
SSP	50	2.63a	3.00ab	3.45ab	4.24a
OPR	50	2.14bc	2.33bc	2.76bc	3.39ab
CS	50	2.31b	2.53b	3.03b	3.43ab
SSP	100	2.68a	3.14ab	3.82a	4.46a
OPR	100	2.19b	2.58b	3.13b	3.69ab
CS	100	2.20b	2.73b	3.11b	3.59ab
SSP	150	2.70a	3.54a	3.97a	4.43a
OPR	150	2.25b	2.82b	3.37ab	3.94ab
CS	150	2.27b	2.85b	3.42ab	4.08a

Mean having the same letter(s) within a column are not significantly different at $P \leq 0.5$ according to Duncan Multiple Range Test

Table 4. Effects of P sources and rates on soil available P mg kg^{-1} (means of 3 soils)

P source	**Rate (mg P kg^{-1})**	**Incubation period (Weeks)**			
		4	8	12	16
Control	0	3.2b	3.2c	3.6c	3.7c
SSP	50	4.5ab	8.8ab	10.7ab	12.0ab
OPR		4.0ab	5.8bc	8..2b	9.9b
CS		4.1ab	6.8b	9.2ab	10.0b
SSP	100	5.3a	10.2a	12.1a	13.9a
OPR		4.1ab	5.9bc	9.5ab	10.5b
CS		4.4ab	7.2b	10.0ab	11.2ab
SSP	150	6.2a	12.0a	10.5ab	15.7a
OPR		4.3ab	7.1b	10.0ab	11.2ab
CS		4.5ab	8.0ab	7.3b	11.8ab

*Mean having the same letter(s) within a column are not significantly different at $P \leq 0.5$. According to Duncan Multiple Range Test

sampling period. The percentage changes in soil exchangeable Ca when 100 mg P kg^{-1} was added to the soil as SSP, ORP and CS at the end of 16 weeks of incubation period were 83, 87 and 73 % respectively.

Available soil P was significantly influenced by P sources (Table 4). The three sources of P were significantly higher than the control at every sampling period. However, among the P sources SSP was superior to OPR and CS in soil available P whereas OPR and CS were similar. The soil available P at the end of 16 weeks of incubation period has increased from initial value of 4.17 to 15.7 mg kg^{-1} at application rate of 100 mg P kg^{-1}. Increasing rates of Phosphate increased soil available P at each sampling period. The percentage changes in soil available P when 100 mg P kg^{-1} was added to the soil as SSP, ORP and CS at the end of 16 weeks of incubation period were 276, 184 and 203 % respectively.

Table 5. Effect of frequency, source and rate of P application on P (mg kg^{-1}) uptake

Soil	Treatment	1st cropping	2nd cropping		3rd cropping		4th cropping	
		Maize (m)	Maize (m^2)	Cowpea (mc)	Maize (m^3)	Maize (mcm)	Maize (m^4)	Cowpea (mcmc)
Frequency								
Ilora	2	1.4a	0.8b	0.3b	1.0b	1.2b	0.9b	0.5b
	4	1.6a	0.9b	0.6a	1.2a	1.5a	1.6a	0.8a
Ibadan	2	2.0a	0.7b	0.4b	0.9b	1.5b	0.9b	0.6b
	4	2.1a	1.2a	0.8a	2.1a	2.5a	2.0a	0.9a
Epe	2	0.2a	0.4b	0.2b	0.6b	0.7b	0.8b	0.5a
	4	0.2a	0.6a	0.4a	0.7a	0.9a	1.5a	0.6a
P Source								
Ilora	Control	0.8c	0.5c	0.3d	0.6d	0.7d	0.5c	0.4b
	SSP	1.9a	0.9a	0.7a	1.5a	1.9a	2.5a	0.9a
	OPR	1.5b	0.8b	0.5a	1.3b	1.6b	1.7b	0.5ab
	CS	1.5b	0.9a	0.6a	1.2c	1.4c	1.8b	0.6ab
Ibadan	Control	1.0c	0.8c	0.3c	1.1d	1.3c	0.9c	0.5b
	SSP	2.8a	2.4a	0.9a	3.3a	3.5a	3.3a	0.8a
	OPR	2.6b	2.2b	0.6b	3.0b	3.1b	2.3b	0.6ab
	CS	2.8a	1.9b	0.5b	2.3c	2.8b	2.0b	0.6ab
Epe	Control	1.0c	0.2c	0.2c	0.5c	0.7c	0.7c	0.3b
	SSP	0.9a	0.7a	0.5a	1.4a	1.9a	2.3a	0.6a
	OPR	0.4b	0.4b	0.4b	1.1b	1.4b	1.5b	0.5a
	CS	0.4b	0.3b	0.3b	1.1b	1.5b	1.5b	0.5a
Rate								
Ilora	0	0.8c	0.5c	0.3b	0.6d	0.7c	0.5d	0.3d
	20	1.2b	0.7b	0.5ab	0.9c	1.1c	1.4c	0.5c
	40	1.7a	0.9a	0.6a	1.3b	1.7b	2.0b	0.7b
	60	1.8a	0.9a	0.7a	1.5a	2.0a	2.3a	0.9a
Ibadan	0	1.0d	0.8d	0.4c	1.1d	1.2d	0.9d	0.5b
	20	2.1c	1.5c	0.6b	2.1c	2.3c	1.8c	0.7ab
	40	2.7b	2.1b	0.8a	2.8b	3.0b	2.5b	0.8a
	60	3.0a	2.4a	0.9a	3.4a	3.6a	3.1a	0.9a
Epe	0	0.1d	0.2b	0.2b	0.5c	0.7c	0.7c	0.2b
	20	0.4c	0.3b	0.3a	0.8b	1.0b	1.3b	1.5ab
	40	0.6b	0.5a	0.3a	1.2a	1.4a	1.7ab	0.6ab
	60	0.7a	0.5a	0.4a	1.4a	1.8a	2.2a	0.7a

Figures with the same letter(s) in a column are not significantly (P = 0.05) different according to Duncan Multiple Range Test. m, m2, m3, and m4: Maize in 1, 2, 3, and 4 consecutive croppings; mc: maize followed by cowpea; mcm / mcmc: maize and cowpea in alternatecroppings. 2 = Alternate Frequency (Applied to every other crop) 4 = Regular Frequency (Applied to every crop)

Greenhouse experiment

Phosphorus uptake

Phosphorus uptake by maize and cowpea was significantly influenced by frequency of P application (Table 5). Values were significantly higher in pots that received P at regular frequency of application than alternate frequency of application except at first cropping when no significant difference was observed in all the soils. The highest P uptake value of 2.1 mg kg^{-1} was obtained at regular frequency of application in Ibadan soil in first cropping whereas in second cropping the highest P uptake values of 1.2 and 0.8 mg kg^{-1} were

Table 6. Effect of frequency, source and rate of application on available P (mg kg^{-1}) at the end of each cropping

Soil	Treatment	1st cropping	2nd cropping		3rd cropping		4th cropping	
		Maize (m)	Maize (m^2)	Cowpea (mc)	Maize (m^3)	Maize (mcm)	Maize (m^4)	Cowpea (mcmc)
Frequency								
Ilora	2	4.61a	3.43b	2.23a	9.17a	10.24b	6.20b	6.24b
	4	4.60a	7.48a	2.62a	11.28a	12.46a	13.40a	8.43a
Ibadan	2	4.74a	4.24b	2.13a	8.02a	9.20b	5.86b	4.24b
	4	5.30a	7.17a	2.38a	10.68a	11.48a	12.06a	8.18a
Epe	2	5.11a	3.38b	2.45a	7.06b	8.36b	5.07b	4.34b
	4	5.16a	7.30a	2.62a	13.31a	14.41a	12.14a	8.24a
P Source								
Ilora	Control	2.16c	2.13c	2.21c	1.85c	1.80c	1.59b	1.60c
	SSP	6.33a	7.76a	5.20a	14.46a	16.32a	12.24a	8.42a
	OPR	4.47ab	5.39ab	4.54ab	10.31b	11.29b	10.62a	6.32b
	CS	4.37b	4.32b	4.60ab	8.966b	10.86b	9.27a	6.24b
Ibadan	Control	2.55c	2.20c	2.29c	1.55c	1.49c	1.41c	1.43c
	SSP	6.82a	7.68a	5.38a	12.86a	13.48a	12.44a	8.36a
	OPR	4.70b	5.68b	4.48b	9.87ab	10.92b	9.15b	6.29b
	CS	4.37b	4.93b	4.46b	8.21b	9.41b	7.80b	6.09b
Epe	Control	2.72bc	2.49c	2.13c	2.05d	1.84c	1.49c	1.50c
	SSP	5.79a	7.17a	5.21a	15.40a	15..96 a	10.81a	8.63a
	OPR	5.64a	5.69b	4.36b	9.88b	10.12b	9.50ab	6.44b
	CS	4.81ab	4.92b	4.30b	7.98c	9.16b	7.88b	6.50b
Rate								
Ilora	20	3.86b	4.48b	4.20b	9.04b	9.68b	7.51b	5.26b
	40	4.87ab	5.80a	4.86b	10.45ab	11.47a	10.77ab	7.32b
	60	5.32a	6.40a	5.24a	11.55a	12.62a	11.85a	9.42a
Ibadan	20	4.47b	4.63b	4.46a	6.98b	8.24b	6.68b	5.14b
	40	5.15ab	6.14a	4.92a	10.24ab	10.96a	9.89a	6.86a
	60	5.60a	6.68a	5.42a	11.87a	12.48a	11.03a	7.94a
Epe	20	4.43a	4.52b	4.38a	6.86c	8.42b	6.71b	4.96b
	40	5.26a	5.94a	4.82a	9.8b	10.24b	9.23a	5.84a
	60	5.96a	6.63a	5.54a	14.85a	15.96a	10.47a	6.24a

Figures with the same letter(s) in a column are not significantly (P = 0.05) different according to Duncan Multiple Range Test. m, m2, m3, and m4: Maize in 1, 2, 3, and 4 consecutive croppings; mc: maize followed by cowpea; mcm / mcmc: maize and cowpea in alternatecroppings. 2 = Alternate Frequency (Applied to every other crop) 4 = Regular Frequency (Applied to every crop)

obtained by maize and cowpea respectively at regular frequency of application. However, in third cropping the highest values of 2.1 and 2.5 were obtained where maize has been planted thrice in sequence and when maize was alternated with cowpea at regular frequency of application. In the fourth cropping, the highest P uptake values for maize and cowpea were 2.0 and 0.9 mg kg^{-1} P at regular frequency of application. The trend was almost similar in Ilora and Epe soils except in second and fourth cropping when there were no significant differences between regular and alternate frequencies of application.

The sources of P had significant effect on P uptake by maize and cowpea. The no P (control) plants had significantly lower value than treated plants in the three soils. Single super phosphate treatment had higher values than the two phosphate rocks sources in the three soils. The two PRs were almost similar in all the three soils except in Ibadan in second and third croppings when values from OPR and CS were significantly different from each other. The highest P uptake value of 2.8 mg kg^{-1} was obtained by maize treated with SSP in Ibadan soil in the first cropping whereas in the second cropping, highest P uptake obtained by maize and cowpea were 2.4 and 0.9 mg kg^{-1} respectively. In the third cropping, when P fertilizers were reapplied, pot where maize has been planted thrice consecutively had the highest value of 3.3 mg kg^{-1} P uptake, whereas when maize was alternated with cowpea P uptake was 3.5 mg kg^{-1} in SSP treated plants. A slight increase was observed in P uptake when maize was alternated with cowpea compared to where maize has been sown three times consecutively. However, in the fourth cropping the highest values of 3.3 and 0.8 mg kg^{-1} P were obtained for maize and cowpea respectively in SSP treated plants. The trend was almost similar in Ilora an Epe soils (Table 3) except in second and fourth croppings in Ilora and Epe soils respectively when there were no significant difference among the P sources.

The P uptake by maize was significantly increased as the rate of application increased. The P uptake was increased by 53, 48, and 73% in Ilora, Ibadan and Epe soils respectively at the highest rate of 60kg ha^{-1} in the first cropping. The three soils recorded over 28% increases in uptake even with as low as 20kg P ha^{-1}. Phosphorus uptake by maize in the second cropping in pots where maize was grown thrice consecutively was increased by 43, 32 and 215% for Ilora, Ibadan and Epe soils respectively whereas in pots where maize was alternated with cowpea in the second cropping, the increases were 16,100 and 14% for Ilora, Ibadan and Epe soils respectively. But in the fourth cropping the increase was by 47, 51 and 45% for Ilora, Ibadan and Epe soils respectively. Phosphorus uptake by cowpea in the second and fourth croppings followed the same trend like P uptake by maize. Phosphorus uptake was increased by 133, 125 and 100% in the second cropping and 200, 80 and 250% in the fourth cropping for Ilora, Ibadan and Epe soils respectively.

Soil available phosphorus

The trend observed in soil available P was similar to trends observed in P uptake by maize and cowpea. Frequency of application had significant effect on soil available P in all the soils except in the first and second cropping when maize was followed by cowpea (Table 6). The soil available P in regular frequency of application was consistently greater than alternate frequency of application in all the soil and throughout the four cropping. The highest value of 14.41 mg kg^{-1} available P in regular frequency was obtained in third cropping where maize and cowpea alternated in Epe soil while the lowest value (2.13 mg kg^{-1}) was obtained in the second cropping in alternate frequency in Ibadan soil. There were increases of about 57, 53 and 80% soil available P in Ilora, Ibadan and Epe soils respectively at the end of final cropping.

The source of P had significant effect on soil available P in all the soils. The no P treated soils were significantly lower than P treated soils. The SSP treatment in all the soils was significantly higher than the two PRs sources whereas the two PRS sources were similar in most cases. The highest value of 16.32 mg kg^{-1} available P was obtained in SSP in third cropping where maize and cowpea alternated in Ilora soil while the lowest value (1.41 mg kg^{-1}) was obtained in the fourth cropping in control where maize has been grown four time consecutively in Ibadan soil. The soil available P at the end of final cropping in all the soils has tremendously increased when compared to the initial soil available P.

The rate of P application also had significant effect on soil available P. The available P increased as the rate of application increased. The 20 kg P ha^{-1} rate was significantly lower from 40 and 60 kg P ha^{-1} in all the three soils whereas there was no significant difference between 40 and 60 kg P ha^{-1} rates throughout the cropping cycle.

DISCUSSION

The dissolution of PRs in the soils within the incubation period had a non significant effect on soil pH, for instance, there was an increase of 0.5 and 0.6 units respectively for 50 and 100 mg P kg^{-1} level of PR addition. These increases were partially due to the consumption of protons during the dissolution of apatite according to idealized reaction: $Ca_2 (PO_4)_3 (F_2CO_3) + 7 H$ ---- $5 Ca^{2+} + 3H_2PO_4- + H (F_2CO_3)$. Increase in pH resulting from dissolution of PR had also been associated with dissolution of free carbonate in rock phosphate [22]. This attests to the fact that phosphate apart from supplying P for crop use, also serves as a source of Ca supply. The increase in Ca occurred consistently over time. The interactive effects of sources and rates of P coupled with soil types over the period of incubation were significant.

The available P and exchangeable Ca status of the soil after addition of phosphate fertilizer significantly increased until the end of incubation period. This observation is in agreement with the work carried out by (Akintokun et al., 2003). This established the fact that extractable soil P status could be augmented through the use of phosphate materials. Phosphorus availability to plants in soil is governed by concentration of P in soil solution, sustainability of this concentration on its absorption of P by plants, and the ability of crops to utilize the element. In general, increased PR dissolution is expected to result in a measurable increase in soil solution P and therefore increased plant production (Rajan et al., 1991), but this is not always the case because of soil, crop and fertilizer management factors.

Maximum maize and cowpea yields are usually limited by inadequate availability of nutrients. The results highlighted the superiority of fertilized plants over non-fertilized plants in terms of nutrient uptake. The consistently poor performance of the non-fertilized maize and cowpea plants indicates the potentials of the crops to give optimal yields with adequate fertilization. In this study, P and Ca uptake by maize and cowpea was markedly increased by phosphorus application with the three phosphate materials.

Increase in yield has been reported as an overall benefit derived from phosphate application (Akande et al 1998; Yusuf et al., 2003). Frequency of P application had significant effect on P and Ca uptake by maize and cowpea in all the soils. Regular frequency of P application consistently gave significantly higher P and Ca uptake than alternate frequency. SSP has proved to be a superior P source to the other PR sources. Phosphorus application rate had significant effects on phosphorus and Ca uptake throughout the four croppings in all the soils. These findings agree with the observations of (Khasawneh and Sample, 1979) that the maximum yield attained with increasing rates of phosphate rocks varies among the sources. It was also observed that these maxima are less than the maximum yield attained with increasing rates of water-soluble P sources such as super phosphate (Engelstad et al., 1974).

CONCLUSION

Results from both incubation and greenhouse studies has shown that application of the two local phosphate rocks (OPR and CS) tested along with water soluble phosphate (SSP), both proved to be effective in enhancing the P and Ca uptake by maize and cowpea. A further study is required on the field to elucidate the findings before a valid recommendation.

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