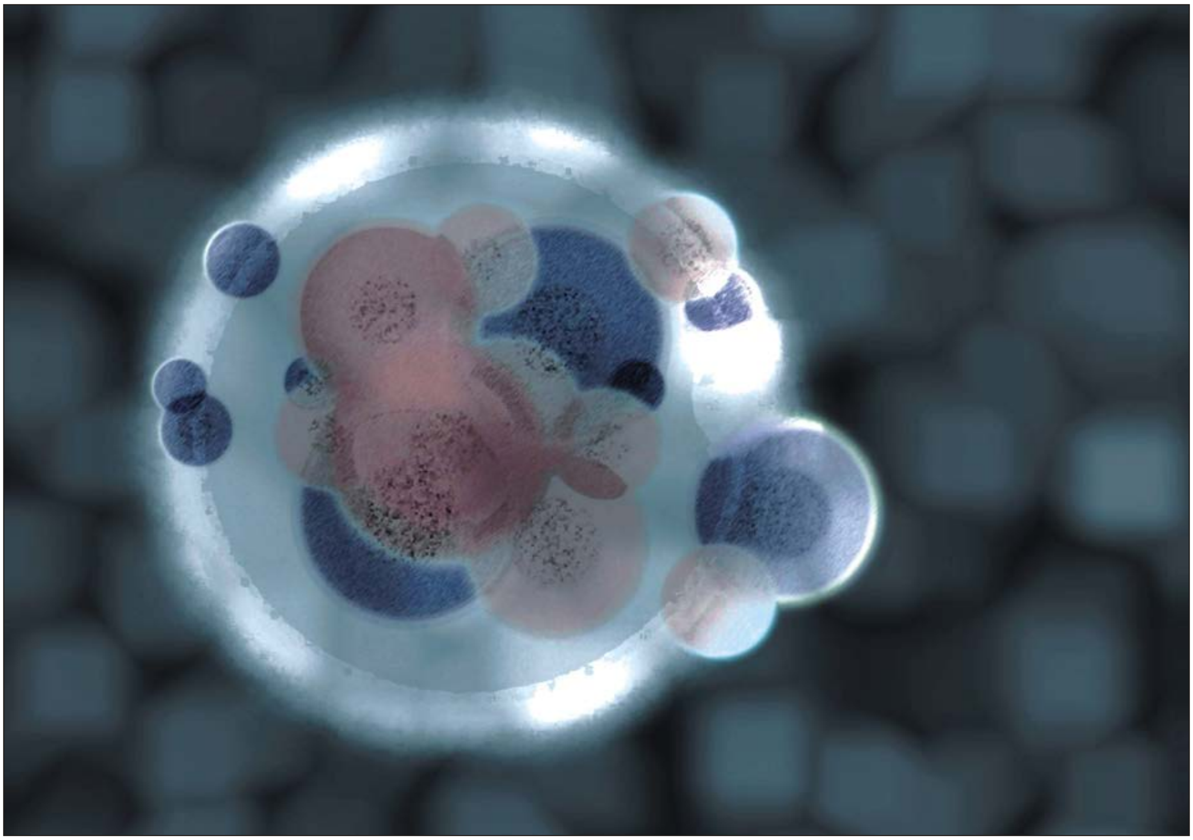

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Benefits of Phosphate Rocks in Crop Production: Experience on Benchmark Tropical Soil Areas in Nigeria

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Abstract: Paucity of research information on the agronomic effectiveness of Nigerian phosphate rocks had until recently hindered their direct application by farmers. We have investigated the behaviour of some indigenous phosphate rocks (Ogun Phosphate Rock, ORP and Sokoto Phosphate Rock, SRP) under laboratory; greenhouse and field plot conditions. Their physico-chemical and mineralogical properties as well as phosphate release in strongly acidic and mildly acid soil types and different moisture regimes were determined. Their suitability for direct application as phosphorus (P) fertilizer for maize (*Zea mays*), millet (*Pennisetum glaucum*) and oil palm (*Elaeis guineesis*) seedlings were tested in comparison with single super phosphate. Here, their agronomic efficiency in field studies at selected agro-ecological zones and soil types is reviewed. The results of chemical and crystallographic tests revealed the carbonate fluorapatite nature, the high total P content (ORP = 30.50% P_2O_5; SRP = 32.5% P_2O_5) and their soil ameliorating (liming) potential (ORP = 19.2% CaO; SRP = 44.2% CaO). ORP and SRP are reactive phosphate rocks, since more than 30% of P content are soluble in 2% citric acid. Unlike SRP with low Fe_2SO_4 and Al_2O_3 contents, ORP by virtue of its high Al and Fe oxides (6.9 and 7.3%) might be less suitable for partial acidulation. The chelating effect of the admixture of ground rock phosphate with poultry manure facilitated the solubilization of rock P and resulted into higher agronomic effectiveness. The results showed that SRP and ORP could be conveniently used for direct application in the humid and sub-humid zones with rainfall above 1200 mm. Low rainfall of semi-arid zone would be inadequate for their solubilization.

Key words: Phosphate rocks, residual effects, strongly acidic soil, mildly acid soil

INTRODUCTION

Soil fertility management in the West African sub-region, including Nigeria, poses the greatest constraint to sustainable agricultural production. Most of the soils are inherently infertile and phosphorus (P) is the most prominent after nitrogen. Compelled by dwindling foreign exchange, some governments in the sub-region have embarked on total or partial removal of fertilizer subsidy or have put in place enforced fertilizer import restrictions. This situation has stimulated the campaign for use of alternative local fertilizer materials, including Phosphate Rocks (PRs).

In Nigeria, the main deposits of rock phosphate are found in four sedimentary basins in Ogun State, Sokoto state, Edo state and Imo State (Tian and Kolawole, 1999; Ojo, 2003). However, only the Sokoto (and probably Ogun) sources occur in commercial quantities, with geologic estimates of 5 to 10 million and half tones, respectively. The Sokoto phosphate rock exists in forms of nodules and pellets (30.5-36.6% P_2O_5 by mass) while Ogun phosphate rocks (26.3-32.0% P_2O_5) occur in nodules, granular and vesicular forms (Adegoke *et al*., 1991; Sobulo, 1994; Adediran and Sobulo, 1998). These compare favourably with Togo phosphate (28.0-36.6% P_2O_5) imported by Nigeria for the manufacture of single super phosphate fertilizer.

Widespread P deficiency is exhibited by most Nigerian soils like others found in tropical Africa, with consequent sharp decreases in the yields of agricultural crops (Akinrinde *et al*., 2003, 2005). As export crops such as groundnut, cotton and cocoa remove enormous quantities of nutrients through crop harvest, the imperatives for P fertilizer use are indisputable. For instance, a groundnut export alone reaching 800,000 tonnes per annum removes an equivalent of 45,300 tonnes super phosphate (35,765 tonnes P), which should at least be returned to the soil in order to sustain productivity (Obigbesan and Udosen, 1995).

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Since the agronomic effectiveness of rock phosphate as fertilizer is favoured by soils that have low pH (Zapata and Axmann, 1995; Chien and Menon, 1995) and low calcium (Ca) and P status of the soil solution (Jones *et al*., 1991; Chapin and Van Cleve, 1992; Amapu *et al*., 1999) as well as P demanding crops such as maize, groundnut, cotton and cacao, direct application should have to be done for specific soil and crop.

Direct application of ground PRs has been the subject of several studies in Nigeria and West Africa sub-region with diverse reports on their agronomic efficiency and limitations in tropical and subtropical agro-ecosystems (Bromfield, 1975; Khasawneh and Doll, 1978; Mokwunye, 1979; Obigbesan and Mengel, 1981; Hammond, 1990).

The trends in the use of Nigerian phosphate rocks started with the discovery of new PRs deposits in Ifo (Ogun state, 1921); at Sokoto (1976), Edo (1977) and Imo States (1986). This stimulated scientists to evaluate the agronomic potential of these rocks as P fertilizer sources. In the early 1980s, the International Fertilizer Development Centre (IFDC) in collaboration with the International Institute of Tropical Agriculture (IITA), Ibadan and ICRISAT, set up numerous trials involving various forms of PRs in parts of sub-Saharan Africa, including several sites on the Alfisols and Ultisols in Nigeria. The results indicated positive and significant response of maize and millet to P application (Bationo *et al*., 1986) and that the rocks could be economically considered for direct application in certain soils. The Phosphate Research Group of the University of Ibadan has also carried out investigations on the potentials of Nigerian phosphate rocks (ORP and SRP) for direct use as P fertilizer sources suitable for various soil types and crop species (Obigbesan and Udosen, 1995; Obigbesan and Akinrinde, 2000; Akinrinde *et al*., 2003). Effects of the ground PRs were noticeable on cereal crops performance three weeks after planting.

Recent publications (Adediran and Sobulo, 1998; Akande *et al*., 1998) on the efficiency of SRP as fertilizer for maize production in Southwest Nigeria and agronomic evaluation of P fertilizer developed from SRP reflect the state of the art concerning the potentials of indigenous Nigerian PRs for direct application. Even though the several unknowns on the required technologies and economics involved are still being researched, enthusiastic Nigerian business entrepreneurs are already marketing compacted and bulk blended ground SRP in the country. This paper presents the results of laboratory and green house studies on indigenous PRs with benchmark soils and the field trials in a few agro-climatic zones of Nigeria are also reviewed.

MATERIALS AND METHODS

The investigations are grouped as follows:

- Laboratory study on the physico-chemical characterization of the PRs,
- Greenhouse evaluation of the effect of organic (poultry) manure on the solubilization of the phosphate rocks (PRs), as well as
- Greenhouse and field experimentation to elucidate the relative agronomic effectiveness of PRs on crop performance in different soils and agro-ecologies. The physico-chemical characterization in the laboratory establishes the base data on the PRs while the greenhouse study assesses the solubilizing effect of poultry manure on PRs and the investigation on the field determines the agronomic effectiveness of the PRs relative to SSP.

In characterizing the PRs, Ogun phosphate rock (henceforth ORP) was excavated by us (assisted by the staff of Geological Survey Department, Abeokuta) from pits dug at about 30-50 cm from the soil surface at Oja-Odan location in Ogun State, Sokoto phosphate rock (SRP) was obtained through the Raw Materials Research and Development Council staff at Sokoto. After thorough cleaning, the rocks were ground <1 mm and the physical and chemical properties were determined in quadruplicates using conventional methods (Table 1).

In elucidating the effect of poultry manure on the solubilization of PRs in the greenhouse, the fertilizer materials tested were poultry manure (0.6% P) at 5 and 10 t ha^{-1} as well as ORP, SRP and SSP at 13.1 kg ha^{-1}. The test crop was maize, grown in the rain forest zone at Ikorodu (Soil type: a Typic Hapludalf/Chronic Luvisols). The experiment was a factorial with Randomised Complete Block Design (RCBD) involving eight treatment

Table 1: Some physico-chemical properties of two major Nigerian phosphate rocks *and poultry manure used*

Characteristic	Ogun rock p (%)	Sokoto rock p (%)	Poultry manure (%)
Organic matter	N/A	N/A	2.59
Total N	N/A	N/A	2.66
Total P_2O_5	30.50	32.50	0.59
CaO	19.23	44.23	14.00
$CaCO_3$	34.30	79.00	ND
MgO	1.35	0.95	1.05
K	ND	ND	2.36
Na	ND	ND	3.56
Fe_2O_3	7.28	2.19	ND
Al_2O_3	6.91	1.79	ND
SiO_2	6.68	4.20	ND
Solubility in 2% citric acid	38.42	45.55	ND
Cd (mg kg^{-1})	9.70	0.63	ND

N/A, Not applicable; ND, Not determined

Table 2: Effect of poultry manure combined with ground phosphate rocks on grain yields of field grown maize in a Typic Hapludalf at Ikorodu, Nigeria

	Grain yield g per plant				
Treatment Combinations	1998	1999	Mean	Mean Yield tonnes ha^{-1}	RAE (%)
M_1P_0	75.25	92.57	84.91	4.53	52.8
M_2P_0	73.75	97.21	85.48	4.56	56.2
M_1 + ORP	77.75	93.28	85.51	4.56	56.2
M_2 + ORP	79.25	99.67	89.46	4.77	79.8
M_1 + SSP	76.00	96.37	86.19	4.60	60.7
M_2 + SSP	80.25	103.94	92.09	4.91	95.5
M_1 + SSP	74.50	99.84	87.13	4.65	66.3
M_2 + SSP	84.25	106.48	95.36	5.09	115.7
$LSD_{0.05}$	2.83	NS			
NPK + Urea	83.25	102.25	92.75	4.95	100.0

M1, M2 = Poultry manure at 5 and 10 t ha^{-1}, respectively, ORP and SSP = Ogun Rock -P and single super phosphate at 13.1 kg P ha^{-1}, NPK – 15-15-15 at 200 kg ha^{-1}; at 100 kg ha^{-1}, RAE = Relative Agronomic Effectiveness (relative to NPK + urea)

combinations of manure with PRs and SSP. There were two controls (No fertilization and 200 kg NPK - 15 - 15-15 plus 100 kg urea ha^{-1}) (Table 2).

The estimation of relative agronomic effectiveness of the PRs involved greenhouse and field experimentation with maize (*Zea mays*), forage grass (*Pennisetum glaucum*) and oil palm (*Elasies guineesis*) as test crops on the benchmark soil types of sedimentary and basement complex origin:

- Typic Paleustalf, basement complex, mildly acid and Dystic Nitosol, sedimentary origin, strongly acid used for *Zea mays* experiment (Table 3).
- Typic Kandiudalf, Ferric Luvisosl/Cambisol, basement complex, slightly acid used for *Pennisetum* experiment (Table 5).
- Rhodic Paleudalf and Plintic Tropudalf, sedimentary acid used for the oil palm seedling experiment (Table 4).

For the greenhouse pot experiment, two-kilogram sieved (2 mm) soils of low P level (Bray 1- P, 6.8-8.0 mg kg^{-1}) were used for the maize and *Pennisetum* experiments conducted for six weeks. Ten-kilogram soils samples were used for the polybag oil-palm experiment. ORP, SRP and SSP were applied at equivalents of 44 kg P ha^{-1} plus basal application of N and K. Each oil palm seedling received 3.33 g P at three weeks after transplanting (WAT) in the form of SSP, ORP and crystalliser and grown for 32 weeks. The treatments were replicated three times in a Randomised Complete Block Design (RCBD). Growth response parameters and biomass yield data were recorded.

Relative Agronomic Efficiencies (RAE) of the P sources were computed as the ratio of the yield response with the test fertilizer (PR) to the respective yield response of the reference fertilizer (SSP) at the same fertilizer rate.

$$RAE = \frac{(Y_{GRP} - Y_{control})}{(Y_{SSP} - Y_{control})} \times 100\%$$

where Y_{GRP}= Yield of ground rock phosphate treatments and Y_{SSP}= yield of single super phosphate treatment.

To evaluate the indigenous PR (SRP) and its partially acidulated form (PARP) under diverse agro-ecology, a multi-locational field experiment was conducted (Adediran and Sobulo, 1998) with the different P sources in the humid (Ikenne), sub-humid (Samaru) and semi-arid (Gumi) zones of Nigeria, using maize and sorghum as test crops. The RAE index was used to measure the effectiveness of the fertilizers as P sources, using the control as 0% and SSP as 100% (Table 5).

RESULTS AND DISCUSSION

Analysis of the two indigenous Nigerian phosphate rocks (Table 1), SRP and ORP showed that they contain appreciable quantities of P (31-33% P_2O_5) comparable to Togo phosphate rock (28.0-36.6% P_2O_5). Being reactive (38.4-45.6% of their total P is soluble in 2% citric acid), they could, therefore, present excellent P sources for soil fertility amelioration and by virtue of the carbonate content (19.2-44.2% CaO) they could serve as liming material in acid soils. However, ORP by virtue of its high contents of Fe and Al oxides (7.3 and 6.9%, respectively) might be less suitable for partial acidulation.

Organic manures combined with mineral fertilizers have proved to be beneficial to soil improvement and sustainable crop production (Akinrinde *et al*., 2003, 2005). Data on the effect of poultry manure combination with PRs (Table 2) confirm the possible interactions between the organic amendments and rock P (Bougor *et al*., 1985). For the maize crop, the RAE of the poultry manure combination with ORP increased from 56.5% to 79.8% and with SRP, it rose from 60.7% to 95.5% when the poultry manure rate was doubled from 5 tonne ha^{-1} to 10 tonne ha^{-1} (Table 2). With SSP, the chelation effect was remarkable, rising from 66.2% to 115.7% RAE, relative to application of NPK + Urea.

Table 3: Response of pot-grown maize to rock phosphates in sedimentary and basement complex soils relative to single super phosphate at six weeks after planting

Soil type characteristics	P sources	P (kgP_2O_5 area ha^{-1})	Mean leaf (cm^2)	RAE % biomass dry matter yield (g)		RAE %
Dystric Nitosol	Control	0	69.6	-	6.5	-
Benin Fasc,	SRP	0	123.9	85.2	9.9	38.7
pH (H_2O/KCl)	ORP	100	123.9	78.3	13.5	79.3
4.8/3.8	SSP	100	119.5	100.0	15.3	100.0
Typic paleustalf	Control	0	102.7	-	12.7	100.0
Basement complex	SRP	100	138.1	93.9	16.5	26.7
pH (H_2O/KCl)	ORP	100	125.7	61.0	15.8	22.1
6.3/5.6	SSP	100	140.4	100.0	27.0	100.0

Data recorded at six weeks growth period, SRP = Sokoto Rock; ORP = Ogun Rock P and SSP = Single Super phosphate

Table 4: Relative Agronomic Effectiveness (RAE) of rock phosphates for raising polybag oil palm seedlings in different soil types

Soil type	P Sources	Mean no of leaves per plant	RAE%	Mean leaf aera (cm^2)	RAE %	Mean plant weight (cm)	RAE %	Mean stem thickness (cm)	RAE %
Rhodic Paleudalf	SSP	20.7	100.0	1199	100	114	100	13.5	100
pH 5.1/4.2	ORP	20.7	104.8	1257	105	129	113	14.8	110
(H_2O/KCl)	CRY	20.7	110.0	1342	112	110	96	13.5	100
Plinthic	SSP	20.0	100.0	891	100	94	100	12.1	100
Tropudalf	ORP	20.0	101.9	834	94	103	110	13.0	107
PH 5.8/5.4 (H_2O/KCl)	CRY	20.0	100.0	1028	115	113	120	12.0	99

P application was based on recommended rate of 7.56 g P_2O_5 per palm seedling, SSP = Single super phosphate, ORP = Ogun Rock P and Cry = crystalliser, RAE = Relative Agronomic Efficiency (% of SSP), Data based on 12 months old seedlings

Table 5: Relative agronomic effectiveness of rock phosphate with respect to maize grain yields at selected agro ecological field locations in Nigeria

Location and soil type	P fertilizer source*	Average grain yield (t ha^{-1})	Relative agronomic efficiency (% of SSP)
Ikenne Humid zone (1200-1400 mm)	Control (Po)	2.50	-
Kandiudult pH 5.63	SRP	3.30	160.0
Exch Ca = 0.42	PARP	3.50	200.0
cmol kg^{-1}	SSP	3.00	100.0
Samaru	Control (Po)	1.25**	-
Sub-Humid zone (800-1100 mm) Paleustalf	SRP	1.80	73.3
pH, 5.6	PARP	2.25	133.3
Exch. Ca = 0.65 cmol kg^{-1}	SSP	2.00	100.0
Gumi	Control (Po)	1.20	-
Semi-Arid zone (600-800 mm)	SRP	1.80	17.6
Ustipsamment pH 5.82	PARP	3.20	58.8
Exch. Ca = 1.08 cmol kg^{-1}	SSP	4.60	100.0

*P was applied at 100 kg P_2O_5 ha^{-1}; **Sorghum yield, SRP = Sokoto Phosphate Rock; PARP = Partially (50%) Acidulated Rock Phosphate, SSP = Single Super Phosphate

Results of pot experiments with *Zea mays*, *Pennisetum glaucum* and *Elaeis guineensis* presented in Tables 3 and 4 confirm that the PRs are better utilised in non-calcareous soils of low pH ranges (Kagbo, 1991) whereby ORP performed better than SRP in the strongly acid Dystric Nitosol (RAE 79.3%>38.7%) (Table 3) but SRP performed better than ORP in the weakly acid sandy loam Typic Kandiudalf grown to millet and produced greater biomass with RAE values of 73.9 and 68.2%, respectively, relative to SSP (100%).

The superior agronomic effectiveness of PRs for raising polybag oil palm seedlings is reflected by the data in Table 4. ORP was much better (RAE, 102-113%) than SSP while Crystalliser, a blend of SRP and Talc magnesite ore, was equally as good (RAE, 96-120%) as SSP. The impact of these findings for the oil palm industry could be measured on the fact that Nigerian Institute for Oil palm Research (NIFOR) annually produces over a million seedlings for distribution to farmers.

Beside being dependent on several other soil properties (Chien and Menon, 1995), soil pH and Ca concentration in the soil solution as reflected by the data in Table 5, the effectiveness of PRs is closely tied to rainfall regimes. Solubilization of rock P could be hindered by inadequate soil moisture availability. Thus, SRP and ORP were consistently less effective with dwindling rainfalls from humid (1200 mm), sub-humid (800 mm) to semi-arid zones (600 mm) where SRP recorded 160, 73.3 and 17.6%, respectively, in comparison with SSP (100%).

CONCLUSIONS

The indigenous phosphate rocks, ORP and SRP considered in this paper constitute P fertilizer sources comparable to Togo PR and therefore of great agronomic potentials. The simplest and most effective use is to grind the material for direct application to the soil as a source of phosphate. Response by cereal crops already manifest as early as three weeks when applied one week before or one week after planting.

The enhancement of the agronomic effectiveness of the integrated application of PR with organic (poultry) manure is attributable to enhanced solubilization of the rock-P. This technique of chelation for agricultural purposes would also serve to sanitise the metropolis environments from pollution threats by poultry manure and city organic wastes. SRP and ORP can be used for direct application in the humid and sub-humid zones with rainfall regime above 1200 mm. The PRs would perform poorly in semi-arid zones unless with appropriate irrigation.

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