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Full Length Research Paper

Phosphorus fractionation and crop performance on an alfisol amended with phosphate rock combined with or without plant residues

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The effects of Sokoto phosphate rock (PR) and plant residues on soil phosphorus (P) fractions and crop performance was studied in the field on an alfisol in the derived savanna of southwestern Nigeria. The plant residues studied were leaves of *Dactyladenia barteri*, *Flemingia macrophylla*, *Gliricidia sepium*, *Leucaena leucocephala*, maize (*Zea mays*) stover and rice (*Oryza sativa*) straw. They were applied alone or in combination with phosphate rock. The PR was applied at a rate of 60 kg P ha^{-1} and the plant residues at 5 ton dry matter ha^{-1} during the onset of the major rainy season. Plots without PR and plant residues application were included as control. After four weeks incubation period of PR and plant residues, *Crotalaria ochroleuca* (shrub legume) was planted in 1999 and maize (*Zea mays*) was planted in 2001 as test crops. When PR was not combined with plant residues, incubation of *Dactyladenia* residues increased resin P from 0.13 to 0.79 mg P kg^{-1} at 4 weeks after incubation (WAI). Other plant residues did not cause appreciable changes in resin P. Application of *Leucaena* residues increased NaOH-extractable inorganic P (Pi) from 14.36 to 20.47 mg P kg^{-1} at 4 WAI. Total extractable P increased under all the plant residues at 4 WAI but decreased at 8 WAI. When PR was combined with plant residues, there were increases in almost all the P fractions under the plant residues at 4 WAI followed by decreases at 8 WAI. Averaged across P levels, addition of *Leucaena* residues resulted in higher resin P, NaOH-Pi, residual P and total extractable P compared with the other plant residue treatments. Averaged across residue treatments, resin P increased from 0.12 mg P kg^{-1} to 0.75 mg P kg^{-1} at 4 WAI and decreased to 0.08 mg P kg^{-1} at 8 WAI. All other P pools showed similar trends but with less pronounced decreases at 8 WAI. When PR was not applied with plant residues, *Crotalaria* dry matter correlate positively with $NaHCO_3$-Pi (R^2 = 0.59), NaOH-Pi (R^2 = 0.53) and total extractable P (R^2 = 0.50), while *Crotalaria* P uptake correlate positively with $NaHCO_3$-Pi (R^2 = 0.50) at 4 WAI. Maize grain yield and P uptake did not correlate with any of the P fractions. However, when PR was applied with plant residues, maize P uptake was positively correlated with resin P (R^2 = 0.53) while *Crotalaria* dry matter (R^2 = 0.60) and P uptake (R^2 = 0.49) correlate positively with NaOH-Po at 4 WAI. Application of PR alone did not affect yields and P uptakes of *Crotalaria* and maize crops. Compared with the control without residues, *Crotalaria* dry matter production and P uptake increased significantly when residues were applied. Interaction effects between PR and *Leucaena* and rice straw residues on *Crotalaria* dry matter production and P uptake was significant. Interaction effects between PR and plant residues on maize yield and P uptake were not significant. Our results suggest that combined application of PR with selected plant residues may enhance P dissolution from PR and improve crop performance in some cases.

Key words: Phosphorus fractions, Phosphate rock, plant residues, *Crotalaria ochroleuca, Zea mays,* Nigeria.

INTRODUCTION

Phosphorus (P) deficiency is one of the major constraints to crop production on highly weathered upland savanna soils of West Africa. Consequently, they require the addition of P fertilizers for producing even moderate yields. The high cost and unavailability of soluble phosphate fertilizers such as single or triple super phosphate has generated considerable interest in the utilization of phosphate rock (PR). Phosphate rock is a satisfactory source of P in acid soils (Hue et al., 2001). However, the use of PR for direct application for short-term crops have not shown good promise on non-acid and near neutral soils in the savanna of West Africa (Tossah, 2000). In view of this, numerous studies have been conducted amending PR to increase their immediate P availability and also to possibly enhance their rate of dissolution after application to soil. Among these methods is the combined application of plant residues with PRs (Zaharah and Bah, 1997). Medhi and De Datta (1997) reported that PR could be as effective as soluble P fertilizer for rice when combined with green manure, and this could be due to the solubilization of PR by acids produced from the decomposition of plant residues (Singh and Amberger, 1998). In addition, plant residues could improve plant P availability by reducing P sorption by soil (Zaharah and Bah, 1997; Ferreira, 1998). The chelation of P-fixing elements by low-molecular-weight (LMW) organic acids could be another mechanism governing the role of plant materials in P solubilization in the rhizosphere or decomposition system (Fox and Comerford, 1990).

While processes controlling the availability of N following residue amendments are relatively well understood, the release of P is so far not describable by quality characteristics in the same way (Merckx et al., 2001). In analogy to what is known for N, a relation between P showing up in an available fraction (resin extractable P, Olsen-P) and the C/P ratio of the organic amendment was put forward by Nziguheba et al. (2000). The authors indicate an added value with the use of some organic sources of P as compared to inorganic sources, where the organic amendment increased the amounts of P recovered as resin-P, for the same amounts of total P added. Only recently has awareness grown about the occurrence of different P species in soil solution, differing in mobility and hence in availability. The components in question are complexes of organic matter, Fe or Al and P. The increased concentrations of different P species in soil solutions and extracts of the strongly depleted upland soils of Vietnam after amendment with *Tithonia diversifoloia*, highlighted their potential importance (Phan, 2000). Most P fractionations are based on the so-called Hedley fractionation (Hedley et al., 1982), which consists of a sequential extraction, illustrating rather than identifying or characterizing changes in P availability. However, quite a few authors have been linking the changes in some of these fractions with a change in P availability. Nziguheba et al. (1998, 2000) has demonstrated the changes in resin-extractable P after amendment with organic residues. Some residues were able to increase resin-extractable P over that of comparable amounts of inorganic P, whereas others did not. Tossah (2000) confirmed the modifying role of the legume *Mucuna pruriens* on changing P availability in a system where maize is grown with *Mucuna* vs. a maize monocrop, having measured increases in two fractions (resin and $NaHCO_3$ extractable inorganic P) following a Hedley fractionation scheme.

In West Africa, there is a wide range of plant residues currently recommended as nutrient (mainly N) sources in low external input agricultural systems, including those from agroforestry and fallow species, and agricultural crops. Decomposition of different plant residues may produce organic acids of different concentrations and chemical structure/functional groups, which are directly related to the degree of P solubilization (Kpomblekou and Tabatabai, 1994). The present study quantifies the soil P fractionation, biomass and P uptake of test plants after the incubation of PR with plant residues. Our study will therefore increase our understanding of biological approaches of PR solubilization, and provide guidance for selecting plant residues to be combined with PR to improve its P availability to short-term crops in non-acid and near neutral savanna soils in the tropics.

MATERIALS AND METHODS

Study materials and site description

The PR was collected from Sokoto state, northern Nigeria, and contained 144 P, 218 Ca, 8.1 Mg, 0.9 K, 16.0 Fe and 7.5 Al (g kg^{-1}) (Fayiga and Obigbesan, unpublished data). The leaves of *Dactyladenia barteri*, *Flemingia macrophylla*, *Gliricidia sepium*, *Leucaena leucocephala*, maize (*Zea mays*) stover and rice (*Oryza sativa*) straw were collected at the International Institute of Tropical Agriculture (IITA) research farm. The choice of the above plant residues was based on earlier investigations on the chemical composition of several agroforestry and fallow species and crop residues (Tian et al., 1992). *Dactyladenia* and *Flemingia* leaves had high lignin content, but *Dactyladenia* leaves contained more polyphenols and less N. *Leucaena* and *Gliricidia* leaves had a high N concentration, though the polyphenols were higher in *Leucaena* than *Gliricidia*. Rice straw and maize stover had a low N, however, the former had an extremely high silicon concentration. The above plant residues decomposed at different rates largely due to variations in their chemical compositions (Tian et al., 1992).

The experiment was carried out at the main station of the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria (3°54'E longitude, 7°30'N latitude, 213 m altitude). The area has a bimodal rainfall pattern with an annual mean of 1278 mm and a mean annual temperature of 26.2°C. The experiment was conducted during the 1999 and 2001 rainy season. The soils for the field experiment were alfisols, and had the following properties (0 - 15 cm) for 1999 site: soil organic carbon (6.0 g kg^{-1}), Olsen-extractable P (7.5 mg kg^{-1}) and pH-H_2O (6.2). Soil properties for 2001 site were soil organic carbon (14.1 g kg^{-1}), Olsen extractable P (23.5 mg kg^{-1}) and pH-H_2O (5.9).

The trial involved the incorporation of PR into surface soil with plant residues 4 weeks before planting test crops in a randomised complete block design with 3 replicates. The PR was applied at a

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rate of 60 kg ha^{-1} P and plant residues at 5 ton ha^{-1} at the onset of the rainy season. Phosphorus added from plant residues was lower as compared to that from only 3.5 kg ha^{-1} P from *Dactyladenia*, 8.0 from *Flemingia*, 6.0 from *Gliricidia*, 8.0 from *Leucaena*, 3.5 from maize stover and 6.0 from rice straw. Plot size was small (3 x 3 m) due to the large number of treatments. The plots were kept weed-free for the first four weeks in order to eliminate plant uptake as a factor affecting soil P. Further details on trial establishment and management are described by Tian and Kolawole (2004).

Laboratory analysis

Composite soil sample was taken in each plot (0-15 cm depth) before the application of the treatments and at 4 and 8 weeks after application. Each composite sample consisted of 5 sampling points taken across the diagonals in a plot. The soil from each plot was bulked and a subsample was taken. Subsamples were air-dried and ground to pass through a 2- and 0.5-mm sieve for analysis.

Soil organic carbon was determined by the wet combustion method (Nelson and Sommers, 1975). The pH was determined in 1:1 H_20 (McLean, 1982). Soil available P was measured using the Olsen method (Olsen and Sommers, 1982), as the soil was rich in Ca. A modified version of the Hedley et al. (1982) procedure as described by Tiessen and Moir (1993) was used to sequentially fractionate soil P. In the sequential extraction, five inorganic (P_i) and three organic P (P_o) fractions were removed by anion exchange resin (BDH No. 55164), 0.5 M $NaHCO_3$, 0.1 M NaOH, 1 M HCl and concentrated HCl in that order. The 0.5 M $NaHCO_3$ extracted labile and NaOH extracted moderately labile P forms (Stewart and McKercher, 1982), while 1 M HCl extracted Ca-bound P. Phosphorus not recovered in these successive extractions was the residual fraction determined by digesting the soil residue in H_2SO_4-H_2O_2. Inorganic P in 0.5 M $NaHCO_3$ and 0.1 M NaOH extract was determined by taking 10 ml aliquots into 50 ml centrifuge tubes. The extracts were acidified to pH 1.5 with the addition of 6 ml (0.5 M $NaHCO_3$) and 1.6 ml (0.1 M NaOH) of 1.8 M H_2SO_4 and refrigerated for 30 min. The aliquots were centrifuged at 10 000 rpm for 10 min and the supernatants decanted into 50 ml volumetric flasks without disturbing the sedimented organic matter. The tubes were lightly rinsed with distilled water and P_i was determined by the method of Murphy and Riley (1962). Organic P in $NaHCO_3$, NaOH and concentrated HCl extracts was determined by the difference between P_i and total P (P_t.) The P_t in $NaHCO_3$, NaOH and concentrated HCl extracts was determined by transferring 5 ml aliquots into 50 ml Erlenmeyer flasks to which were added 0.63 g ($NaHCO_3$ extract), 0.86 g (NaOH extract) and 0.43 g (conc. HCl extract) ammonium persulphate. The pH of $NaHCO_3$ and NaOH aliquots was adjusted to 1.5 by adding 10 ml 1.8 M H_2SO_4. For the concentrated HCl aliquot, 10 ml distilled water was added. Aliquots of the bicarbonate, hydroxide, and concentrated sulphuric acid extracts were digested in the autoclave (103.4 kPa, 121°C for 1.5 h) by acidified ammonium persulphate oxidation (Environmental Protection Agency, 1971), and analyzed for total P. Inorganic phosphate in the extracts was determined colorimetrically with the molybdate-ascorbic acid procedure (Murphy and Riley, 1962). Organic P was calculated as the difference between total P and inorganic P. The total P in plant materials was determined using the molybdate-blue-colorimetric procedure after acid digestion (Okalebo et al., 1993).

Statistical analysis

Phosphorus uptake was calculated as: P concentration x Dry matter yield at harvest. Analysis of variance of data collected was performed as split plot in randomised complete block design using Statistical Analysis Systems programmes (SAS, 1985).

RESULTS

P fractions

When PR was not combined with plant residues, incubation of *Dactyladenia* residues increased resin P from 0.13 mg P kg^{-1} to 0.79 mg P kg^{-1} at 4 WAI. Other plant residues did not cause appreciable changes in resin P (Table 1). Application of *Leucaena* residues increased NaOH- extractable inorganic P (Pi) from 14.36 to 20.47 mg P kg^{-1} at 4WAI. Total extractable P increased under all the plant residues at 4 WAI but decreased at 8 WAI. When PR was combined with plant residues, there were increases in almost all the P fractions under the plant residues at 4 WAI followed by decreases at 8 WAI. For example, under *Dactyladenia,* resin P increased from 0.19 mg P kg^{-1} to 1.11 mg P kg^{-1} at 4 WAI and decreased to 0.02 mg P kg^{-1} at 8 WAI. $NaHCO_3$-Pi under *Leucaena* increased from 6.45 mg P kg^{-1} to 20.63 mg P kg^{-1} at 4 WAI and decreased to 14.25 mg P kg^{-1} at 8 WAI. Similarly, residual P under rice straw increased from 47.45 mg P kg^{-1} to 66.83 mg P kg^{-1} at 4 WAI and decreased to 40.02 mg P kg^{-1} at 8 WAI.

Averaged across P levels, addition of *Leucaena* residues resulted in higher resin P, NaOH-Pi, residual P and total extractable P compared with the other plant residue treatments. Averaged across residue treatments, resin P increased from 0.12 mg P kg^{-1} to 0.75 mg P kg^{-1} at 4 WAI and decreased to 0.08 mg P kg^{-1} at 8 WAI. All other P pools showed similar trends but with less pronounced decreases at 8 WAI.

Interaction effect between PR and plant residues was significant for 1 M HCl-Pi, while PR and time of sampling interaction was significant for most of the P fractions except for NaOH-Pi and soil pH. Similarly, plant residues and time of sampling interaction effect was significant for most of the P fractions except for resin P, $NaHCO_3$-Pi and soil pH. Plant residues, PR, and time of sampling interaction effects were significant for resin P, 1 M HCl-Pi and total extractable P.

Crop yields and P uptake

When PR was not applied with plant residues, *Crotalaria* dry matter correlate positively with $NaHCO_3$-Pi (R^2 = 0.59), NaOH-Pi (R^2 = 0.53) and total extractable P (R^2 = 0.50) while *Crotalaria* P uptake correlate positively with $NaHCO_3$-Pi (R^2 = 0.50) at 4 WAI (Table 2). Maize grain yield and P uptake did not correlate with any of the P fractions. However, when PR was combined applied with plant residues, maize P uptake was positively correlated with resin P (R^2 = 0.53) while *Crotalaria* dry matter (R^2 = 0.60) and P uptake (R^2 = 0.49) correlate positively with NaOH-Po at 4 WAI.

Application of PR did not significantly affect yields and P uptakes of *Crotalaria* and maize crops (data not shown). Addition of plant residues enhanced biomass production and P uptake of *Crotalaria* than the control

Table 1. Selected P fractions (mg kg^{-1} soil) and pH of an Alfisol amended with Sokoto phosphate rock combined with or without plant residues at Ibadan, 1999.

Residues/P levels	Time of sampling (WAP)	Resin P	$NaHCO_3$-Pi	NaOH-Pi	Residual P	1 M HCl-Pi	Total P	pH-H_2O	Olsen ext. P
(0 Kg P ha^{-1})									
No residues	0	0.04	5.86	14.57	42.01	4.48	104	5.35	9.65
Gliridia	0	0.12	6.02	14.73	41.61	5.54	104	5.37	10.12
Leucaena	0	0.16	5.81	14.36	41.87	4.96	106	5.38	10.18
Flemingia	0	0.02	5.07	12.50	40.68	5.86	97.1	5.43	9.76
Maize stover	0	0.30	5.44	12.82	36.83	6.34	91.0	5.43	9.53
Rice straw	0	0.13	7.83	14.89	45.86	6.13	112	5.43	12.07
Dactyladenia	0	0.13	7.19	15.16	40.68	5.92	113	5.48	10.47
No residues	4	0.14	6.08	15.63	50.64	5.12	119	5.20	8.70
Gliricidia	4	0.04	6.34	15.85	46.39	5.17	114	5.13	10.30
Leucaena	4	0.10	8.78	20.47	53.56	6.08	135	5.32	13.20
Flemingia	4	0.30	7.62	13.99	47.45	6.02	119	5.37	11.89
Maize stover	4	0.30	8.04	16.06	47.32	5.33	128	5.37	12.60
Rice straw	4	0.16	7.88	15.26	45.99	5.92	121	5.42	14.14
Dactyladenia	4	0.79	7.08	13.88	54.89	5.70	122	5.88	11.53
No residues	8	0.02	6.71	13.78	45.59	6.71	111	5.65	10.62
Gliricidia	8	0.08	6.02	12.77	42.80	5.28	97.5	5.53	11.68
Leucaena	8	0.09	7.08	12.50	41.87	5.92	104	5.62	17.74
Flemingia	8	0.13	7.72	14.04	37.36	6.87	103	5.63	12.24
Maize stover	8	0.09	7.62	14.36	39.62	5.81	103	5.77	19.30
Rice straw	8	0.06	7.40	13.88	40.41	3.95	108	5.87	15.24
Dactyladenia	8	0.06	6.82	13.24	35.50	5.17	98.6	5.72	13.74
(60 Kg P ha^{-1})									
No residues	0	0.10	6.34	17.12	43.34	6.98	106	5.20	11.18
Gliricidia	0	0.06	6.08	15.48	39.22	4.69	104	5.23	9.65
Leucaena	0	0.23	6.45	16.27	41.74	5.39	107	5.42	10.71
Flemingia	0	0.08	4.69	14.73	45.33	5.39	113	5.33	8.70
Maize stover	0	0.06	5.07	11.81	38.02	5.17	92.9	5.43	8.11
Rice straw	0	0.06	5.39	13.19	47.45	5.44	113	5.43	9.82
Dactyladenia	0	0.19	4.59	11.76	42.94	4.11	102	5.43	5.98
No residues	4	0.55	10.27	15.79	62.59	7.40	138	5.52	9.75
Gliricidia	4	1.75	15.48	18.87	73.47	13.09	168	5.55	10.79
Leucaena	4	1.93	20.63	22.49	72.68	16.52	174	5.47	11.59
Flemingia	4	0.97	8.41	15.21	55.02	6.08	124	5.70	9.93
Maize stover	4	1.25	13.67	17.02	67.23	18.50	160	5.65	11.16
Rice straw	4	1.11	12.93	17.55	66.83	14.78	155	5.93	9.51
Dactyladenia	4	1.11	17.39	18.02	65.37	4.80	153	5.82	8.34
No residues	8	0.24	23.34	15.79	52.63	7.40	126	5.57	12.37
Gliricidia	8	0.02	15.63	15.16	44.53	6.93	118	5.53	13.68
Leucaena	8	0.04	14.25	16.11	44.00	8.04	114	5.57	13.68
Flemingia	8	0.11	17.87	16.27	44.80	7.88	126	5.57	11.43
Maize stover	8	0.17	21.74	16.91	49.58	6.77	133	5.65	11.16
Rice straw	8	0.02	11.39	13.94	40.02	7.30	113	5.75	16.62
Dactyladenia	8	0.02	13.40	14.52	44.13	6.23	122	5.58	16.49
Means									
0 kg P ha^{-1}		0.16	6.88	14.51	43.78	5.63	110	5.49	12.13
60 kg P ha^{-1}		0.48	12.14	15.91	51.47	11.77	131	5.54	11.14

Table 1. Contd.

No residues		0.18	9.27	15.45	49.47	11.90	123	5.41	10.38
Gliricidia		0.35	9.26	15.48	48.00	6.78	117	5.39	11.04
Leucaena		0.42	10.50	17.03	49.29	15.32	132	5.46	12.84
Flemingia		0.27	8.56	14.46	45.11	6.35	114	5.50	10.66
Maize stover		0.36	10.26	14.83	46.43	7.99	118	5.55	12.52
Rice straw		0.26	8.80	14.78	47.83	7.25	121	5.64	12.90
Dactyladenia		0.38	9.41	14.31	47.25	5.32	119	5.65	11.09
0 WAP		0.12	5.84	14.24	41.97	5.46	105	5.38	9.71
4 WAP		0.75	10.76	16.86	57.82	11.82	142	5.52	10.96
8 WAP		0.08	11.93	14.52	43.09	8.83	115	5.64	14.23
LSD $_{(0.05)}$									
P level (P)		0.09	1.93	ns	ns	1.14	17.54	ns	ns
Residues (R)		0.19	ns	1.48	3.48	1.43	7.97	0.08	1.62
Time of sampling (T)		0.13	2.03	0.97	2.28	0.94	5.22	0.05	1.06
Probabilities (P = (0.05) of the F test for the ANOVA (interaction effects) for P, R and T									
P x R		ns	ns	ns	ns	<0.0001	ns	ns	ns
P x T		<0.0001	<0.0001	ns	<0.0001	<0.0001	<0.0001	<0.0001	ns
R x T		ns	ns	0.0065	0.0052	<0.0001	<0.0001	0.0018	ns
P x R x T		0.0100	ns	ns	ns	<0.0001	<0.0001	ns	ns

Table 2. Correlation coefficients (R^2) among selected P fractions and *Crotalaria* dry matter, P uptake, maize grain yield and P uptake.

P fractions	No PR				With PR			
	Crotalaria		**Maize**		***Crotalaria***		**Maize**	
	Dry matter	**P uptake**	**Grain yield**	**P uptake**	**Dry matter**	**P uptake**	**Grain yield**	**P uptake**
Resin P	ns[c]	ns	ns	ns	ns	ns	ns	0.53 (0.0131)
$NaHCO_3$-Pi[a]	0.59 (0.0050)	0.50 (0.0204)	ns	ns	ns	ns	ns	ns
NaOH-Pi	0.53 (0.0126)	ns	ns	ns	ns	ns	ns	ns
NaOH-Po[b]	ns	ns	ns	ns	0.60 (0.0037)	0.49 (0.0245)	ns	ns
Total P	0.50 (0.0213)	ns	ns	ns	ns	ns	ns	ns

[a]Pi = inorganic P; [b]Po = organic P; [c]ns = not significant.
Figures in parenthesis are probabilities = ≤ 0.05.

(without residues addition). Similarly, addition of *Gliricidia*, *Leucaena* and *Flemingia* residues enhanced higher maize grain yield and P uptake than the control. Interaction effects between PR and *Leucaena* (negative) and rice straw (positive) residues were significant for biomass production and P uptake of *Crotalaria*. Interaction effects between PR and plant residues were not significant for maize.

DISCUSSION

Correlation analysis among P fractions and yields and P uptakes of test crops at four weeks of field incubation of PR with plant residues showed that $NaHCO_3$-extractable inorganic P and NaOH-extractable organic and inorganic P fractions were positively related with *Crotalaria* dry matter and P uptake while resin P was related to maize P uptake. The increase in resin, $NaHCO_3$-extractable inorganic P and NaOH-extractable organic and inorganic P fractions after four weeks of field incubation of PR with plant residues should enhance P utilization from PR. The mineralization of NaOH-extractable organic P pool supplies P to the growing plant (Agbenin and Goladi, 1998). This pool has been shown to be an important source of P for crop growth in low-input systems (Beck and Sanchez, 1994).

Plant readily available, labile and moderately labile P fractions were improved when PR was applied alone or in combination with plant residues. However, there were little or no significant changes in yields and P uptake of test crops when PR was applied alone, in contrast to when PR was combined with some plant residues. This suggests that the yield and P uptake increase was observed when residues were combined with PR due to availability of other nutrients, especially N and Mg (Bezzola et al., 1994).

The observation that PR applied alone did not enhance the performances of the test crops is in agreement with the findings of previous workers (Adediran and Sobulo, 1998; Tossah, 2000). The near-neutral pH of the soils used in this trial might have contributed to the ineffectiveness of the PR. The addition of PR probably caused precipitation of soluble P in soil solution by Ca, Al and Fe from PR. Mishra and Bangar (1986) confirmed that the presence of excess calcium in the rock phosphate complexed the soluble P. Plant residue addition improved yields and P uptakes of the test crops compared with situation where no residues were added, which may be due to priming effects of the residues. Among other nutrients, such as N and Mg, the decomposition of the amended residues releases phosphorus. Nziguheba et al. (1998), working with a high-quality organic residue of *Tithonia diversifolia* and a low-quality input maize stover in western Kenya, found an increase in labile and moderately labile soil P fractions following application of *Tithonia*, but not after application of maize stover. The positive interaction effects of some of the residues when combined with PR on yield and P uptake of *Crotalaria* especially, provides the evidence that plant residues can be used as an amendment to promote the direct use of PR on near-neutral soils. This cannot be directly linked to improved soil acidity enhancing P dissolution of PR as we did not observe significant effects of plant residues on soil pH after incubation with PR. Other mechanisms, such as, reduction in soil P sorption by added organic matter and silicon, and P chelation by organic acids produced during the decomposition of residues may be suspected. The decomposition products of organic materials have significant chelation capacity that lowers the activity of polyvalent cations (Ca, Fe, and Al) which form insoluble salts with P and so liberate phosphorus. The positive interactive effect between rice straw and PR on yield and P uptake of *Crotalaria* could be related to its high SiO_2 (Tian et al., 1992). Shariatmadari and Mermut (1999) observed that Si addition increases desorption of P sorbed on both palygorskite-calcite and montmorillonite-calcite. Pardo and Guadalix (1990) confirmed that silicate strongly competed with phosphate for sorption site.

In conclusion, amendment of the near-neutral soils of West Africa with PR combined with or without selected plant residues increased most of the P fractions after the four weeks incubation period. However, application of PR alone was not beneficial to the test crops. This indicates that other nutrients apart from P alone were responsible for the post incubation response of test crops to the combined application of PR with plant residues.

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