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Organic Residues Affect Soil P Availability, Cowpea Yield And Nutrient Uptake on a Near Neutral P-Deficient Alfisol in Southwestern Nigeria

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Abstract

In the moist savanna zone of West Africa, it has been suggested that application of organic residues may play central roles in increasing the availability of inherent soil phosphorus and the dissolution and utilization of phosphate rock (PR) by food crops. Laboratory incubation study was carried out with plant residues of different chemical compositions (leaves of Flemingia macrophylla, Leucaena leucocephala, and maize stover (Zea mays L.) in pots containing a P-deficient Alfisol from SW Nigeria with ground Togo PR for 3 months to determine the dynamics of Olsen extractable P in the absence of growing plants. Cowpea (Vigna unguiculata L. Walp) was planted in the incubated soils thereafter to evaluate treatment effects on cowpea yield and P uptake. A control treatment (no PR, no plant residues) was included for comparison. The pot trial was laid out as completely randomised design replicated four times. Generally, soil P availability increased with increasing length of incubation. Compared with the initial soil P value of 3.14 mg kg^{-1}, after 12 weeks of incubation Leucaena +PR had the highest soil P (9. 9 mg kg soil^{-1}), followed by Flemingia (7.9 mg kg soil^{-1}) and Flemingia + PR (7.3 mg kg soil^{-1}). Phosphorus availability following incubation of PR was 5.11 mg kg soil^{-1}, 4.2 mg kg soil^{-1} for the control treatment, and 3.37 mg kg soil^{-1} for maize stover, which rather immobilized P throughout the incubation period. Cowpea plants grown on Flemingia and Leucaena incubated soils with and without PR produced higher number of pods, grain yield, and shoot dry matter than those grown on PR and maize+PR incubated soils. Total N uptake was not significantly different among the treatments but P and K uptake was significantly higher in plants grown on Leucaena+PR, Leucaena, Flemingia, and Flemingia+PR incubated soils than those grown on the control, PR, and maize+PR incubated soils. These results suggest that plant residues can be selected and incubated in near neutral P-deficient soils to enhance P availability and increase crop yield and P uptake.

Key words: Alfisol, cowpea dry matter, length of incubation, Olsen extractable P, plant residues, Togo rock phosphate, West Africa

Introduction

In the moist savanna zone of West Africa, organic residues may play central roles in halting the alarming soil fertility decline in the impoverished soils. Organic inputs can have fertilizer equivalency values of 50 to 100 kg N ha^{-1} (Ladha et al., 1988) and may meet crop demands for N but are not likely to meet P demands because of the low P concentration in most organic materials (Palm, 1995). Increasing P availability on these soils would require addition of large amounts of mineral fertilizer, an expensive venture not affordable by most resource poor farmers in the region. Due to the low P in organic materials and low rates of mineral fertilizer P applied by farmers, it may be necessary to use mineral fertilizers to supplement organic materials in order to achieve better crop yields. Studies have shown that organic residues incorporated into the soil are effective in increasing the availability of native soil phosphate and the dissolution and utilization of phosphate rock (PR) by subsequent crops (Kamh *et al*., 1999; Somado *et al*., 2003). With 28.5 percent of the world's production of phosphate rock (PR), Africa ranks first among the P-mining continents, but it has with 2.8 percent of the world's consumption, the lowest P use (FAO, 2004). Despite their abundant availability in certain parts of the continent, Africa's PR resources are not sufficiently used to enhance the productivity of its often severely P-deficient soils (McClellan and Notholt, 1986; Baudet *et al*., 1986). Direct use of PR has been propagated as a promising alternative to the use of processed mineral P fertilizers, because it potentially involves lower production costs and investments than the production of water-soluble P fertilizers from indigenous PR sources (Hammond *et al*., 1986; Rajan *et al*., 1996). However, on near neutral or alkaline savanna soils of West Africa the effectiveness of directly applied PR for short duration crops is severely hampered (Mokwunye, 1979; Akande *et al*., 1990; Oladeji *et al*., 2006). The use of organic materials, including plant residues, to amend rock phosphate has been found to increase availability of P from the PRs in soils (Iyamuremye and Dick 1996; Buresh *et al*., 1997; Tian and Kolawole, 2004; Akande *et al*., 2005). It is hypothesized that organic acids produced during decomposition of the residues prevent precipitation of phosphate by iron (Fe) and Aluminium (Al) oxides out of the soil solution (LeMare *et al*., 1987), and as a result, P concentration in the equilibrium solution increases. Competition for P-sorption sites between P and the released organic acids as well as complexation of Fe and Al oxides/hydroxides by organic acids have been suggested as the key factors controlling reduction of soil P-sorption capacity and P availability in soil solution (Sighn and Jones, 1976; Nziguheba *et al*., 1998). However, plant P availability does not always increase following incorporation of plant residues (Somado *et al*., 2007). The magnitude of the effect of plant residues on soil P availability may depend on the organic residues quality, especially the C:P ratio (Zaharah and Bah, 1997) and as well on the soil characteristics (Nwoke *et al*., 2004). Generally, the choice of organic residues for use on a particular soil type may be crucial for the improvement of the fertility.

This study was undertaken to determine the effects of soil amended with plant residues of different chemical compositions and Togo PR on soil extractable P, yield and nutrient uptake of cowpea grown on the amended soil.

Materials and Method

Study materials and site description

Incubation study

The experiment was conducted in the laboratory of the Department of Agronomy, Ladoke Akintola University of Technology (LAUTECH) in Ogbomoso (Longitude 4^o 10' E, Latitude 8^o 10' N and altitude 213 m asl), Oyo state, Nigeria, during May-August 2005.

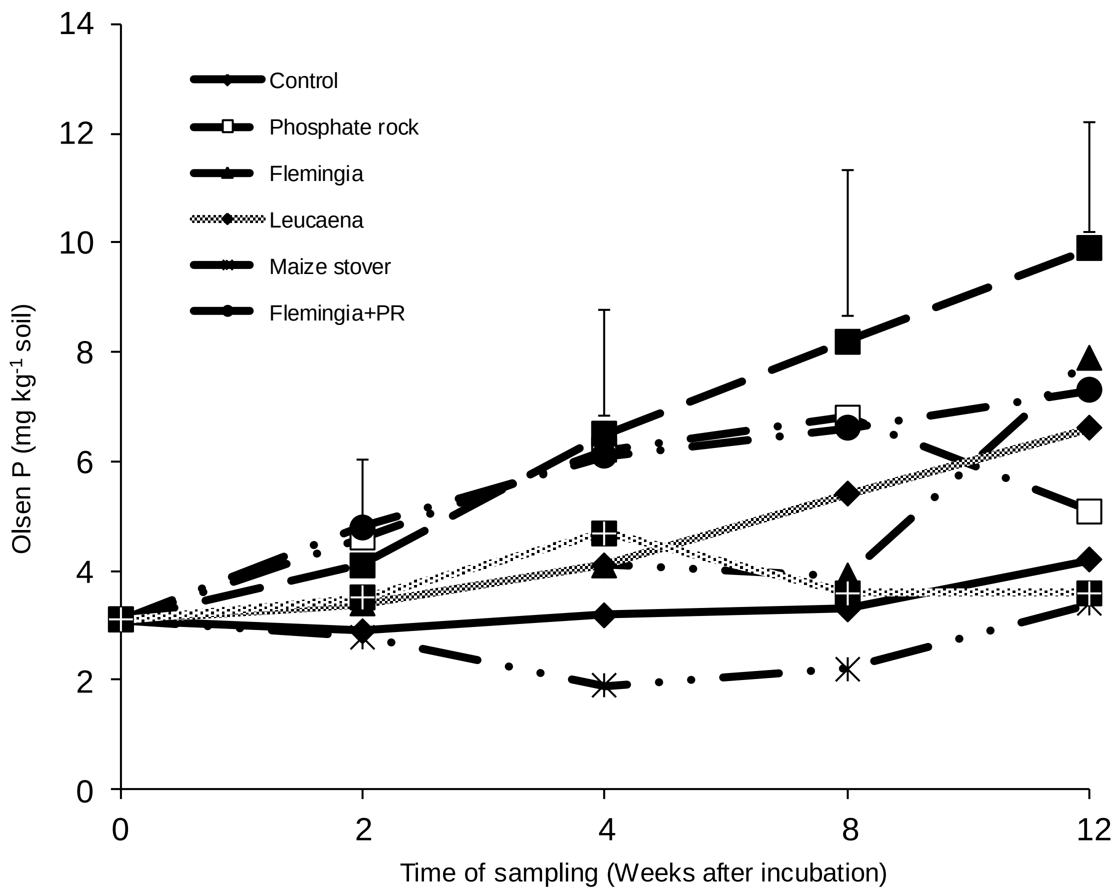

Fig. 1. Effects of incubation of plant residues with or without PR on Olsen P availability

Surface soil (0-15cm depth) of a near neutral P-deficient Alfisol was collected from the University Teaching and Research Farm. The soil was air-dried, sieved through a 2 mm mesh sized sieve and a sub sample was taken for laboratory analysis. The soil has the following characteristics; pH-H_2O 6.0, organic carbon 8.4 g kg^{-1} soil, N 0.61 g kg^{-1} soil, Olsen extractable P 3.14 mg kg^{-1}, exchangeable K 0.15, Ca 1.86, and Mg 0.54 in cmol kg^{-1} soil. Particle size distribution was sand 850, clay 60, and silt 90 in g kg^{-1}.

Phosphate rock and plant residue

The PR used came from southern Togo and contained 36% P_2O_5, 52% Ca, 0.5% H_2O, 0.1% S and 3.7% F (Lehr and

McClellan, 1972). The leaves of *Flemingia macrophylla*, *Leucaena Leucocephala*, and maize (*Zea mays*) stover were collected from the research farm of International Institute of Tropical Agriculture (IITA), Ibadan. The choice of the above plant residues was based on earlier investigations on the chemical composition of several agroforestry and fallow species and crop residue (Tian *et al.*, 1992 and 1995). *Flemingia* leaves had a high lignin concentration, *Leucaena* had a high N concentration, with high polyphenols and maize stover has a low N and a wide C:N ratio. Due to variations in their chemical composition the above plant residue decomposed at different rates largely (Tian *et al.*, 1992).

Table 1. Effects of plant residues and Togo phosphate rock on selected chemical properties of an Alfisol from SW Nigeria after 12 weeks incubation period

Soil amendment	pH– H_2O	Ca (cmol kg^{-1})	K (cmol kg^{-1})
Control	5.23	2.65	0.10
Phosphate Rock	5.26	2.00	0.10
Flemingia	4.76	3.41	0.14
Leucaena	4.96	2.31	0.14
Maize Stover	6.20	2.98	0.17
Flemingia+PR	4.90	2.39	0.12
Leucanea+PR	5.03	2.22	0.17
Maize+PR	6.23	2.37	0.14
LSD $_{(0.05)}$	0.48	1.36	0.08

Fully expanded medium-aged leaves were collected from the above plant species, dried at 65°C for 72 hrs and ground to pass through a 2 mm sieve. The ground plant residues (5 tDM ha^{-1}) and Togo PR in powdery form (39 kg P ha^{-1}) were thoroughly mixed with 6 kg of air-dried soil in each pot and laid out in a completely randomized design replicated four times. The treatments were Togo PR, *Flemingia*, *Leucaena*, Maize stover, *Flemingia*+PR, *Leucanea*+PR, and Maize+PR

Four control pots with no PR and no plant residue application were added for comparison. At the onset of the experiment, each pot received 1.2 l of distilled water to adjust the soil moisture content to 50% water holding capacity. The pots were covered with a double layer of 0.05 mm thick polyethylene film (to allow gas but not water exchange) and kept at 25°C with a day/night cycle of 12h/12h. At the end of each incubation period (2, 4, 8, and 12 weeks), the incubated soil was sampled with the aid of an iron pipe (diameter 24 mm) and analyzed for Olsen extractable P (Olsen and Sommers, 1983). After the 12 weeks incubation period, the polythene films were removed and the pots were arranged on benches in the open.

Pot trial

In September 2006, three cowpea seeds (var. TVX 3236, erect type) were planted in each of the 32 pots used for the incubation study described above. Two weeks after planting, the seedlings were thinned to one per pot. The plants were watered regularly as necessary. Weeds were hand pulled as they emerged and left in the pots to decompose. Insect attack was controlled by mixing one ml of karate® 2.5 E.C. (a.i. 25 g lambda-cyhalothrin per liter) insecticide into 500 ml of water to spray the plants. This was done four times before the harvesting of cowpea.

At physiological maturity, the number of pods was counted, the pods were harvested and the grains removed. The shoot was cut at ground level with a sharp knife. Litter was collected as part of the shoot biomass. All plant parts were placed in separate paper bags and oven dried at 65^oC for 72 hours to determine their dry weights. The shoots and grains were ground to pass through a 2 mm mesh sized sieve and analysed for the N, P, K, Ca, and Mg concentrations. All data were subjected to analysis of variance (ANOVA). Where F-values were significant, the treatment means were separated with an LSD test at the 5% probability level. All statistical analyses were performed using SAS software (Littell et al., 1996).

Results

Effects of incubation of plant residues on P availability and selected soil properties

At 2 weeks after incubation, *Flemingia* + PR, PR alone, and *Leucaena* + PR amended soils had the highest phosphorus contents, while maize stover amended soil and the control had the lowest P contents (Fig. 1). At 4 and 8 weeks after incubation, *Leucaena* + PR, PR alone and *Flemingia* + PR treatments still had the highest P contents while the control and maize stover treatments still had the lowest P contents. Incubation of maize stover rather immobilized soil P (Fig. 1). However, at 12 weeks, *Leucaena* + PR treatment had significantly highest P content. Incubation of *Flemingia* alone, *Flemingia* + PR and *Leucaena* residue alone were next to *Leucaena* + PR treatment in their effects on soil P content. The control, maize + PR, and sole maize treatments had the lowest soil P concentrations.

At 12 weeks after incubation, maize + PR and sole maize stover treatments had significantly higher pH values than the other treatments. PR alone had significantly higher pH than *Flemingia* while *Flemingia* and the other treatments had similar pH (Table 1). Incubation of *Flemingia* residues alone led to significantly higher Ca value than PR alone. All the other treatments led to similar Ca concentrations in the soil. All the treatments did not affect soil K concentrations significantly (Table 1).

Pot trial

Yield and yield parameters

Cowpea plants grown on *Flemingia* and *Leucaena*-incubated soils with and without PR tended to produce higher number of pods than those grown on PR and maize+PR incubated soils (Table 2). Shoot dry matter data followed a similar trend to that of pod number. For grain yield, plants grown on *Leucaena*, *Flemingia*, and *Leucaena*+PR incubated-soils had significantly higher yields than those grown on the control, PR, and maize stover incubated soils (Table 2).

Table 2. Pod number, shoot and grain dry weights of cowpea grown on an Alfisol from SW Nigeria incubated with plant residues and Togo phosphate rock

Soil amendment	Number of pods	Dry shoot weight (g/pot)	Dry grain weight (g/pot)
Control	8	5.7	4.7
Phosphate Rock	6	5.0	3.7
Flemingia	11	8.6	8.0
Leucaena	9	9.5	8.3
Maize Stover	7	5.3	4.3
Flemingia+PR	8	8.1	6.1
Leucanea+PR	10	9.9	7.5
Maize+PR	5	5.1	4.7
LSD $_{(0.05)}$	3	3.9	2.3

Nutrient concentrations and uptake

Nitrogen concentrations in cowpea shoot were not significantly affected by the treatments (Table 3). However, plants grown on *Leucaena*+PR and *Flemingia* incubated soils had higher P concentrations in the shoots than those grown on the control and *Leucaena* incubated soils. Plants grown on PR incubated soils had significantly higher K concentrations in their shoots than all the others. Nitrogen concentration in the grains of plants grown on the control soil was significantly higher than those of plants grown on *Leucaena*, maize stover and *Flemingia*+PR incubated soils (Table 3). Plants grown on PR and *Leucaena*+PR incubated soils had significantly higher P concentrations in grain than those grown on maize stover incubated soil. Potassium concentration in grains of plants grown on PR, *Flemingia*, and *Flemingia*+PR incubated soils was significantly higher than those of plants grown on *Leucaena* incubated soil.

Total N uptake was not significantly different among the treatments but P uptake was significantly higher in plants grown on *Leucaena*+PR, *Leucaen*a, *Flemingia*, and *Flemingia*+PR incubated soils than those grown on the control, PR, and maize+PR incubated soils (Table 3). Total K uptake was significantly higher in plants grown on the *Flemingia*, *Leucaena*, and *Leucaena*+PR incubated soils than those grown on the control, maize, maize+PR, and PR incubated soils.

Discussion

Incorporation of *Flemingia* and *Leucaena* plant residues into the soil increased soil available P concentration, cowpea yield and nutrient uptake compared with the situation where PR alone was incubated with the soil and the situation without plant residues amendment. On the other hand, maize stover immobilized soil P and led to lower cowpea yield and nutrient uptake. 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. Maize stover had low P and N concentrations (Tian *et al*., 1992). Somado *et al*. (2007) reported that the incorporation of green manure residues with low P concentration does not lead to net P release. Incubation of maize stover alone or with PR and PR alone caused increased soil pH. The increase in soil pH could be due to the contribution of base elements such as Ca, Mg, and K in plant residues and PR. Moreover, this could also be responsible for the immobilization/low mineralization of P in these treatments.

Table 3. Nutrient concentrations in shoot and grain, and total nutrient uptake of cowpea grown on an Alfisol from SW Nigeria incubated with plant residues and Togo phosphate rock

	N	P	K	N	P	K	N	P	K
	----------------------	(%)	----------------------				----------	(mg/pot)	------
Soil amendment	Shoot			Grain			Total nutrient uptake		
Control	1.47	0.08	0.50	3.02	0.27	0.52	23.1	1.74	5.28
Phosphate Rock	1.63	0.10	0.64	2.64	0.32	0.58	18.0	1.64	5.32
Flemingia	1.84	0.11	0.55	2.30	0.28	0.58	35.0	3.11	9.54
Leucaena	1.69	0.08	0.53	1.54	0.29	0.48	30.3	1.13	9.01
Maize Stover	2.48	0.09	0.48	1.66	0.25	0.52	19.5	1.58	4.80
Flemingia+PR	2.53	0.10	0.51	1.94	0.29	0.57	31.4	2.61	7.57
Leucanea+PR	1.99	0.12	0.47	2.40	0.32	0.54	37.3	3.53	8.81
Maize+PR	1.75	0.10	0.47	2.88	0.28	0.55	22.0	1.72	4.83
LSD $_{(0.05)}$	ns	0.03	0.05	1.38	0.06	0.08	ns	0.77	3.15

The possible improvement in root growth with the application of *Flemingia* and *Leucaena* plant residues might have enhanced the utilization of P by the test crop. That plant residue addition improved yields and P uptakes of the test crop compared with situation where no residues were added may also be due to priming effects of the residues. Among other nutrients, such as N and Mg, the decomposition of the amended residues releases phosphorus. The observation that cowpea crop grown on PR incubated soil performed poorest on the near neutral P-deficient Alfisol in this trial conform to the findings of previous workers (Akande *et al*., 1990; Tian and Kolawole, 2004; Oladeji *et al*., 2006). Apparently, the near-neutral pH of the soil used in this trial had contributed to the ineffectiveness of the PR. Carsky *et a*l. (2001) demonstrated that application of PR without legumes may have little effect in improving crop yields but combination of PR with legumes could increase them. The amending effect of plant residues to PR clearly depended on the plant species based on the contrasting effects of *Flemingia* and *Leucaena* with maize stover on P availability from PR (Fig. 1), and on crop yield and nutrient uptake (Tables 1 and 2). The general contention that application of plant residues increases the availability of native soil P and promotes the dissolution and utilization of PR should be taken with caution.

Flemingia and *Leucaena* residues amendments led to reduce soil pH (Table 1). It is worth to note that not only the organic acids are important for mobilization of P from rock phosphate; the N dynamics of plant residues has also a great impact on the P mobilization too. These residues had higher N concentrations and when organic N is mineralised to nitrate, a strong acid as HNO_3 is produced. This probably caused the lower soil pH under these amendments. The lower pH probably enhanced soil P mineralization under these treatments.

The products of plant residue decomposition could help PR acidulation (Hammond *et al*., 1986; Troeh and Thompson, 1993). The organic compounds released from decomposing materials may also complex inorganic P released from PR into the organic pools, which can be taken up by plants after mineralization (Khasawneh and Doll, 1978; Kpomblekou and Tabatabai, 1994).

The use of organic materials, including plant residues, to amend rock phosphate has been found to increase availability of P from the PRs in soils (Iyamuremye and Dick, 1996; Buresh *et al*., 1997; Tian and Kolawole, 2004; Akande *et al*., 2005; Oladeji *et al*., 2006).

Based on the results of this trial, the direct use of PR without any amendment is not recommended on the near neutral soils in savanna of West Africa and plant residues can be selected and incubated or composted with PR in near neutral P-deficient soils to enhance soil P availability, crop yield and P uptake.

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