Influence of Soil Properties on P Sorption Characteristics and Yield of Soybean (Glycine Max (L.) Merr.) In Some Alfisols in Benue State, Nigeria

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Abstract:
Studies were conducted using somealfisols in Benue state to evaluate the influence of soil properties on P sorption characteristics and yield of soybean (Glycine max (L.) Merr.).Significant and positive relationships existed between the soil organic matter content and the phosphate adsorption capacity (K) of these soils (r= 0.981). There was also a significant and positive relationship between the aluminum oxides and the clay content of the soils (r= 0.974). There was a negative but significant relationship between the Bray-1 P and the phosphorus buffer capacity (PBC) of these soils (r= -0.975) while the Olsen P related negatively and significantly with the iron oxide content (r= - 0.978) and the calcium P fraction (r= - 0.987) .No significant relationship existed between the solution phosphate concentration(SPC), standard phosphate requirement(SPR) and any of the yield parameters. PBC related negatively and significantly with total P in the plant biomass (r= -0.667) and showed a positive and significant relationship with the seed weight (r= 0.605). K showed a positive and significant relationship with P in plant biomass (r= 0.661). Clay content showed negative and significant relationships with pod number, seed weight and dry matter yield (r= -0.602, - 0.650 and – 0.658) respectively. The relationship between the iron P fraction and the total P in plant biomass was positive and significant (r = 0.587) while that with the seed weight was negative and significant (r= - 0.579). There was no significant relationship between the aluminum P fraction and any of the yield parameters but the calcium P fraction showed significant and positive relationships with the pod number and seed weight. (r = 0.633 and 0.687). Bray -1 P also showed a positive and highly significant relationship with the dry matter yield (r = 0.736). Understanding the phosphorus adsorption chemistry of these soils would be essential in the estimation and management of fertilizer rates and practices aimed at obtaining an optimum yield of soybean on these soils.

Key words: Alfisols, Soil Properties, P Sorption Characteristics, Yield, Soybean, Relationships, Benue state, Nigeria

1. Introduction

Soybean, *Glycine max (L) Merr.*is an annual leguminous crop grown mainly for its oil and protein content. In Nigeria, an estimated 50,000 hectares of the crop are cultivated annually, most of this being in Benue State (Aduayi*et al.,*eds. 2002). Farmers' yields average 300 – 1,030 kg ha^{-1} of threshold grain. Higher yield values and better quality of the crop are probable if phosphate interaction in soils is well understood and properly managed as P is the limiting nutrient element for the production of this crop.

Phosphorus (P) is the most important nutrient element, after nitrogen, limiting agricultural production in most regions of the world (Holford 1997; Udo and Ogunwale 1977; Uzu*et al.,* 1975; Enwezor and Moore 1966, Hue *et al.,* 2000). This is particularly so in tropical soils that are variously described as well weathered that have the ability to fix phosphorus (Adetunji, 1997). The high capacity of tropical soils to fix soluble P has contributed to a very low level of P in solution (Anyanduba and Adepetu, 1983). For this reason, it is essential to integrate sorption influenced indices such as quantity, intensity and buffering capacity in the measurement of P availability and P fertilizer requirement of soils.

This study was therefore undertaken to determine the relationships between soil properties and P sorption characteristics of the soils under study and its effect on the P fertilizer requirement for optimum yield of the crop.

2. Materials and Methods

The study involved laboratory, pot and field experiments. The laboratory experiment consisted of routine soil analysis, phosphorus fractionation study, total oxides and P sorption experiment.

Surface soil samples (0-20 cm) were collected from four benchmark soils in Benue State classifiedas Alfisols, (FDALR, 1990). All the sampled locations fall within the southern Guinea savannah zone of Nigeria.

The soil samples were air dried and passed through a 2 mm sieve for laboratory and pot experiments. Soil pH was determined by the glass electrode in a 1:2 soil: water ratio and in a 1:1 soil:KCl suspensions. Particle size analysis was determined by the hydrometer method of Bouyoucos, (1951), organic carbon by the chromic acid oxidation procedure of Walkley and Black, (1934). Exchangeable bases by the neutral ammonium acetate saturation. Sodium and K in the extracts were determined by the flame photometer while Ca and Mg were determined by the Atomic Absorption Spectrophotometer (AAS). Exchange acidity by the 1M KCl extraction and 0.01M NaOH titration. Nitrogen in the samples was determined by the macro- Kjeldahl method.

Phosphorus fractionation was done by the modified procedure of (Chang and Jackson, 1957) as modified by (Peterson and Corey, 1966) and reported by (Page *et al.,* 1982). Total and organic P was determined by the NaOH digestion method (Mehra*et al.,* 1954). Available P was extracted by 0.5 M NaHCO$_3$ buffered at pH 8.5, (Olsen *et al.,* 1954) and by 0.03M NH$_4$F + 0.025 M HCl,(Bray and Kutz, 1945). Phosphorus in the extracts was determined colorimetrically by the Ascorbic acid method of (Murphy and Riley, 1962) as modified by (Watanabe and Olsen, 1965) and reported by (Page *et al.,* 1982). Free Fe and Al oxides (Total oxides) were extracted by the citrate dithionate-bicarbonate method, (Mebra and Jackson, 1960). Iron and aluminum oxides in the extracts were determined with an atomic absorption spectrophotometer.

Phosphate sorption characteristics of the soils were determined by placing eight separate 5 g sub- samples of the 2 mm size sieved soils in 50 ml polypropylene centrifuge tubes. Volumes of 40 cm^3 of 0.01 M CaCl$_2$ solution containing 0, 15, 25, 40, 100, 200, 400 and 800 mg l^{-1} P as KH$_2$PO$_4$ were distributed to the tubes as described by (Dear *et al.,* 1992). The samples were then shaken for 24 hrs and then centrifuged for ten minutes at 1200 rpm at 4°C in a refrigerated centrifuge. The supernatant was filtered through a Whatman's number 42 filter paper. Phosphorus in solution was determined by a modification of the Murphy and Riley method (Watanabe and Olsen, 1965) and reported by (Page *et al.,* 1982). A plot of P in equilibrium (supernatant) solution was constructed against the amount of P added. For each soil the amount of P that gave the following levels of solution P concentration in the soils 0.025, 0.05, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.225, 0.250 mg kg^{-1}, was estimated from these plots. Phosphate sorbed (Ps) was calculated as the difference between the concentration of the added P and the P in solution

The Freundlich adsorption equation which expresses an empirical relation between the amount of a substance adsorbed (K) per unit mass of the adsorbent (Q) and the aqueous concentration (C) was used to evaluate the adsorption data. The Freundlich equation is given by:

- Log Q = Log K + 1/n Log C (Russel and Prescott, 1916)

Where:

- Q is the amount of P adsorbed in mg kg^{-1}
- C is the equilibrium concentration in mg l^{-1}
- K and n are empirical constants, as K is a measure of the adsorption capacity.

Phosphorus Buffering Capacity (PBC) was calculated from sorption curves as the slope of the regression equation relating P sorbed to the logarithm of the P concentration of the supernatant solution (Moody *et al.,* 1990;Moody, 2007).

Four kg of the 2 mm sieved soil from each location was placed in plastic pots used in the pot study. For each soil the amount of P that was equivalent to the following levels of solution P concentration in the soils;   0.025, 0.05, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.225, 0.250 mg kg^{-1}, was added to the pots as KH$_2$PO$_4$ in 50 cm^3 of distilled water and mixed thoroughly. The amounts of P were estimated for each soil. All the pots initially received equivalents of 60 kg N ha^{-1} as urea, and 30 kg ha^{-1} K (Yusuf and Idowu, 2001) as KCl. There were pots without P addition that served as control bringing the total number of pots to one hundred and thirty two (132). Three soybean seeds of the variety TGX 1448-2E were planted per pot and later thinned to two and the pots were laid out in a Randomized Complete Block Design (RCBD) and the crop was grown to maturity with the normal agronomic practices carried out.

At harvest (12 WAP), the above ground plant material was dried and weighed. The plant materials were milled and digested in a 4:1 HNO$_3$:HClO$_4$ mixture and analyzed for P using the method of (Murphy and Riley, 1962). The optimum solution concentration was determined for each soil both in terms of grain and dry matter yield by subjecting the yield data to the analysis of variance. The critical equilibrium solution P concentration (SPC) was estimated as the amount of P in an equilibrium concentration needed to achieve maximum yield. The Standard Phosphate Requirement (SPR) was estimated as the amount of fertilizer P that gave the equilibrium solution concentration required to achieve maximum yield. The quantity of P required to achieve the SPC for each soil was taken as the SPR.

Field trial was conducted at Nor. The experimental site was ploughed and harrowed. The size of each treatment plot was 5 m X 5 m (or 25 m^2)and each plot was treated with equivalents of 60 kg ha^{-1} N as Urea, 30 kg ha^{-1} K as KCl. For each location, phosphate fertilizer quantity that resulted in 0.0, 0.5 SPC, 1.0 SPC, and 2.0 SPC (as estimated from the pot experiment) was added per plot as KH$_2$PO$_4$ and the four treatments were replicated three times in a randomized complete block design (RCBD). Soybean seeds of variety TGX 1448-2E were drilled into the various plots at the rate of 50 kg ha^{-1} (Aduayi*et al.,* eds. 2002) and Planted on the 18th of July, 2010.

At harvest, the soybean grains were dried and weighed. For each location, data generated were subjected to analysis of variance and the solution concentration that gave the best yield was taken as the SPC. The solution phosphate concentration (SPC) that gave a

maximum grain yield was evaluated for each soil and the quantity of P required (SPR) to achieve this solution concentration was calculated for each soil.

3. Data Collection
The following Agronomic data was collected:
- Dry matter yield at harvest in both the pot and field experiments.
- Number of pods per plant
- Weight of seeds per pot/plot.

4. Statistical Analysis
Data generated in both the pot experiment and the field trial was subjected to the analysis of variance. Means were separated using the Duncan multiple range test (DMRT). Correlation analysis was carried out to determine the association between the studied (sorption) parameters and some soil properties. Regression analysis was carried out to study the relationship between the P sorbed and the logarithm of P concentration in the supernatant solution in the laboratory experiment. The SAS statistical package was used for these analyses.

5. Results and Discussion

5.1. Physical and Chemical Properties of the Soils
Some selected properties of the soils studied are shown in Table 1. The soils are acid ranging in pH (H_2O) from 5.7 at Utonkon to 6.3 at Nor. Clay content varied widely with the least value of 3% at Katsina-Ala while the highest value of 26% was obtained at Nor with an average value of 13.75%. The soils are sand (Katsina Ala), sandy clay loam (Utonkon and Nor) and loamy sand (Akoodo, Mbakor). The organic matter content of these soils however did not vary much with a least value of 1.22% at Katsina-Ala to 1.69% at Akoodo and Nor. All the soils had organic matter contents of at least 1.6% except Katsina-Ala. Total nitrogen values followed the same trend with the least value of 0.03% at Katsina-Ala, Nor had 0.05% while Utonkon and the Akoodo, Mbakor soils had the highest value of 0.06%. The ECEC of the soils also did not vary much with the least value of 3.05 c mol kg^{-1} at Nor. This was followed by 3.08 c mol kg^{-1} at Akoodo, 3.18 c mol kg^{-1} at Katsina-Ala and 4.72 c mol kg^{-1} at Utonkon. Total oxide content of the soils ranged from 1.5% at Katsina-Ala to 2.4% at Akoodo, Mbakor. These values were however not highly variable. Variations in organic matter content, clay content, pH, phosphate added as fertilizer has been responsible for variations in P adsorption in soils,(Litaor*et al.,*2005; Brady and Weil, 2008). In the present study, the variation could not be ascribed to such factors as pH as the pH of all the soils ranged between 5.8 and 6.3 with a very small difference and might have not affected the variation in phosphate adsorption to a greater extent. Similarly, phosphate added as fertilizers might have little effect as most of the farmers use no (phosphatic) fertilizers. Variations in P adsorption between the soils could have been due to various reasons such as the initial P contents of the soils, their clay contents which could have provided the active sites for the adsorption, the organic matter content etc. Holford and Patrick, (1979) however, reported that lower adsorption in such surface samples might be owing to occupation of sites in the surface soils by organic anions.

Location	pH (H_2O)	pH (KCl)	Clay (%)	Textur	O.M (%)	Tot N (%)	K	Na ↓	Ca (cmol	Mg kg^{-1}	E.acid	ECEC ↑	Fe$_2$O$_3$ (%)	Al$_2$O$_3$ (%)
K/Ala	5.8	5.2	3	S	1.22	0.03	0.24	0.12	2.03	0.77	0.03	3.18	0.8	0.7
Utonkon	5.7	4.9	16	SCL	1.6	0.06	0.41	0.22	3.05	1.02	0.02	4.72	0.9	1.2
Akoodo	5.9	5.2	10	LS	1.69	0.06	0.23	0.19	2.00	0.66	0.03	3.08	1.5	0.9
Nor	6.3	5.4	26	SCL	1.69	0.05	0.23	0.13	2.00	0.70	0.02	3.05	0.9	1.1

Table 1: Some Properties of the Experimental Soils

Selected P fractions of the experimental soils are shown in Table 2. The total P varied from 338.4 mg kg soil^{-1} at Akoodo, Mbakor to 447.9 mg kg soil^{-1} at Nor. Organic P ranged from 162.4 mg kg soil^{-1} at Akoodo to 214.9 mg kg soil^{-1} at Nor and constituted about 48% of the total P of these soils. Fe-P fraction of the soils varied from 101.2 mg kg soil^{-1} at Akoodo to 143.1 mg kg soil^{-1} at Utonkon. This fraction constituted about 32% of the total P content of the soils. Al-P values ranged from 40.94 mg kg soil^{-1} at Katsina-Ala to 61.8 mg kg soil^{-1} at Nor and constituted about 13% of the total P content of these soils. Ca-P in the soils was low and varied from 26.2 mg kg soil^{-1} at Utonkon to 32.9 mg kg soil^{-1} at Nor constituting about 8% of the total P content of the soils under study. The acid pH of this soils could be responsible for the low Ca-P fraction as this favored the accumulation of Fe and Al oxides, thus P retention and

sorption behavior in these soils could be attributable to the presence of a predominance of oxides of iron. Oxides of aluminum could also play a secondary role, leaving those of calcium with a negligible role in P retention and sorption behavior. Thus formation of strengite, vivianite and variscite are probable in these soils. Formation of phosphates of calcium such as monocalcium phosphate, dicalcium phosphate and dicalcium phosphate dihydrate are not very likely. The acid pH of these soils favored the accumulation of these oxides. Bray-1 P content of the soils was also variable and ranged from 2.3 mg kg soil[-1] at Utonkon to 7.0 mg kg soil[-1] at Nor while the Olsen-P values ranged from 2.3 mg kg soil[-1] at Nor to 4.9 mg kg soil[-1] at Akoodo, Mbakor.

Location	Total P	Organic P	Fe-P	Al-P	Ca-P	Bray-1P	Olsen-P
K/Ala	364.5	174.9	119.1	40.94	29.5	2.8	3.2
Utonkon	420.6	201.8	143.1	47.4	26.2	2.3	4.8
Akoodo	338.4	162.4	101.2	48.5	26.3	5.4	4.9
Nor	447.9	214.9	138.2	61.8	32.9	7.0	2.3

Table 2: Selected Phosphorus Fractions of the Experimental Soils (mg kg^{-1})

5.2. Phosphorus Sorption Parameters and yield of soybean on the Selected Soils
Table 3 shows the phosphorus sorption parameters of the soils. Maximum yield was attained at the SPC value of 0.075 mg kg^{-1}.The standard phosphate requirement also varied widely and ranged from 0.48 g kg^{-1} soil in Nor and Akoodo-Mbakor to 0.57 g at Utonkon with an average value of 0.52 g. The PBC values did not vary much. The Freundlich constant (K) which is a measure of the adsorption capacity of the soils was also determined and did not vary widely. However, the average adsorption capacity of the soils was 22.5. Since alfisols predominate the tropics due to extensive weathering, their capacity to fix P is usually very high. Adetunji, (1997), had earlier described tropical soils as well weathered that have the ability to fix phosphorus. The high capacity of tropical soils to fix soluble P has contributed to a very low level of P in solution (Anyanduba and Adepetu, 1983).

S/NO	LOCATION	SPC (mg kg^{-1})	SPR (g kg^{-1})	PBC (mg kg^{-1})	K	Pod No	Seed wt (g pot^{-1})	DMY (g pot^{-1})
1	KATSINA-ALA	0.075	0.53	46.36	13.9	76.0	25.89	17.26
2	UTONKON	0.075	0.57	49.82	24.8	51.67	13.02	14.35
3	AKOODO	0.075	0.48	40.37	24.6	96.67	16.56	7.55
4	NOR	0.075	0.48	44.56	26.7	56.33	15.47	16.45

Table 3: Phosphorus Sorption Parameters and yield of soybean (g pot^{-1}) on the Selected Soils

5.3. Relationships between Sorption Parameters and Soil Properties in the Experimental Soils
Significant and positive relationship existed between the soil organic matter content of the Alfisols and the phosphate adsorption capacity (K) of these soils (r= 0.981) (Table 4). There was also a significant and positive relationship between the aluminum oxides and the clay content of the soils (r= 0.974) indicating that the clay could probably provide the adsorption sites in these soils.Barrow, (1974 [b]) had attributed P retention to organic C, pH, calcium carbonate and sand content (Yuan and Lucas, 1982; Leclerc *et al.,*2001). Because of these close relationships, efforts have been made to predict P retention capacity from these soil properties using various combinations (Lookman*et al.,* 1996; Burt *et al.,* 2002; Ige*et al.,* 2003). Ige*et al.,* (2003) predicted P retention capacity of tropical soils from aluminum oxide, soil pH, and the clay content. Borling*et al.,* (2001) and (Maguire *et al.,* 2001) suggested the combination of iron and aluminum oxides for the prediction of soil P sorption capacity in non-calcareous soils. Also, (Maguire *et al.,* 2001) reported that sorption of P was strongly correlated with the amounts of Al and Fe. In addition, (Wang *et al.,* 2001) mentioned that many soils with high P retention were related to high levels of oxalate extractable Fe and Al.
Various soil properties have been reported to be closely related to the P retention capacity of soils. Such properties include the extractable Fe and Al oxides (Toor*et al.,* 1997; Freese*et al.,* 1992), clay content (Johnston *et al.,* 1991; Toor*et al.,* 1997), in the present study, P retention could be ascribed to such properties as clay content,extractable Fe and Al oxides. The organic P fraction of the soils related positively and highly significantly with the total P content of the soils (r= 0.99). The calcium P fraction also related positively and highly significantly with the iron oxide fraction of the soils (r= 0.999). There was a negative but significant relationship between the Bray-1 P and the phosphorus buffer capacity of these soils (r= -0.975) thus indicating that soils with high Bray-1P values will release P more easily into solution than those with low values. Olsen P related negatively and significantly with the iron oxide content (r= - 0.978) and the calcium P fraction (r= - 0.987) in these soils.

	SPC	SPR	PBC	K	pH	Clay	O.M	Fe_2O_3	Al_2O_3	TotalP	Org.P	FeP	AlP	CaP	Bray	Olsen
SPC																
SPR																
PBC		.900														
K		-.286	-.171													
pH		-.771	-.420	.448												
Clay		.218	.284	.873	.064											
O.M		-.410	-.347	.981*	.447	.790										
Fe_2O_3		-.497	-.091	.030	.863	-.222	-.023									
Al_2O_3		.224	.383	.844	.186	.974*	.731	-.029								
TotalP		.164	.545	.487	.487	.580	.321	.553	.748							
Org.P		.164	.545	.487	.487	.580	.321	.553	.748	1.000**						
FeP		.510	.810	.297	.146	.562	.106	.317	.716	.932	.932					
AlP		-.559	-.220	.773	.895	.502	.731	.657	.600	.694	.694	.394				
CaP		-.454	-.046	-.005	.837	-.236	-.064	.999**	-.037	.564	.564	.342	.629			

Table 4: Correlation coefficients (r) between sorption parameters and soil properties in the Alfisols
* Significant at 1 %, ** significant at 5 %

5.4. Relationships between Sorption and Yield Parameters in the Soils

Correlation coefficients between the sorption and yield parameters in the experimental soils are shown in Table 5. There was no significant relationship between the SPC and the SPR with any of the yield parameters. However, the PBC related negatively and significantly with total P in the plant biomass (r= -0.667) and showed a positive and significant relationship with the seed weight (r= 0.605). The phosphate adsorption capacity, K showed a positive and significant relationship with the total P in the plant biomass (r= 0.661).

	P biomass	Pod No.	Seed wt.	DMY
SPC	0.509	-0.226	-0.52	-0.41
SPR	0.172	-0.455	-0.421	-0.568
PBC	-.667*	0.28	0.605*	0.473
K	0.661*	-0.077	-0.198	-0.042

Table 5: Relationships between Sorption and Yield Parameters in the soils

5.5. Relationship between Soil Properties and Yield Parameters in the Soils

Correlation coefficients between the properties of the experimental soils and the yield parameters studied are shown in Table 6. Clay content showed negative and significant relationships with the pod number, seed weight and the dry matter yield (r= -0.602, - 0.650 and – 0.658) respectively. The relationship between the iron P fraction and the total P in plant biomass was positive and significant (r = 0.587) while that with the seed weight was negative and significant (r= - 0.579). There was no significant relationship between the aluminum P fraction and any of the yield parameters but the calcium P fraction showed significant and positive relationships with the pod number and seed weight. (r = 0.633 and 0.687). The relationship with the dry matter yield was positive and highly significant (r= 0.755). Bray -1 P also showed a positive and highly significant relationship with the dry matter yield (r = 0.736).

From the foregoing, phosphorus availability could be considered as a direct function of quantity of P in the solid phase but a negative function of P buffering capacity. The combination of buffering indices with quantity or intensity factors could improve the accuracy of P fertilizer recommendations, which in turn affect production costs and environmental quality. The importance of buffering capacity in P uptake by plants is likely to be greater in field conditions because of lower root densities in the field compared with those under pot conditions (Nair and Mengel, 1984).

	P biomass	Pod No.	Seed wt.	DMY
pH	0.241	0.31	0.218	0.379
Clay	0.55	-0.602*	-0.650*	-0.658*
Fe-P	0.587*	0.045	-0.579*	-0.023
Al-P	0.31	0.077	0.145	0.085
Ca-P	-0.278	0.633*	0.687*	0.755**
Bray-1P	-0.257	0.538	0.439	0.736**
Olsen-p	0.453	-0.025	-0.266	-0.258

Table 6: Correlation Coefficients between Soil Properties and Yield Parameters

6. Conclusion

It was concluded that soil properties are closely related to the P retention capacity of soils. Such properties include the extractable Fe and Al oxides clay content organic C, and pH. Because of these close relationships, efforts have been made to predict P retention capacity from these soil properties using various combinations. Understanding the phosphorus adsorption chemistry would be essential in the estimation and management of fertilizer rates and practices aimed at obtaining an optimum yield of soybean on these soils.

7. References

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