

Solution Phosphate Concentration as an Estimate of The Fertilizer P Requirement of Soybean (*Glycine max (L) Merr.*) in Some Inceptisols in Benue State, Nigeria

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Abstract

Some Inceptisols in Benue state were examined to determine the solution phosphate concentration (SPC) as a parameter for the estimation of the P fertilizer required to obtain optimum yield of soybean. Soil inorganic P was fractionated using standard procedures. Sorption characteristics were determined in 0.01 M $CaCl_2$ solutions of various P concentrations. For each soil, the amounts of P that gave 0.025, 0.05, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.225, 0.250 mg kg^{-1} solution concentration were estimated from adsorption curves. In the greenhouse, 4 kg of soil from each location was placed in plastic pots. Amount of P estimated from sorption study was added as KH_2PO_4. The treatments were laid out in Randomized Complete Block Design (RCBD) and soybean (TGx 1448-2E) was planted and observed to maturity. At harvest, the shoot was dried, weighed, milled and digested in a 4:1 HNO_3:$HClO_4$ mixture and analyzed for P. SPC was determined for each soil in relation to yield. Field trials were conducted at Otobi-Akpa and phosphate fertilizer quantity that resulted in 0.0, 0.5 SPC, 1.0 SPC, and 2.0 SPC (as estimated from pot experiment) was added per plot and replicated thrice in RCBD. Soybean seeds were planted by drilling. At harvest, SPC that gave highest grain yield was evaluated for each soil and the quantity of P required to achieve this concentration was calculated. High grain yield (t ha^{-1}) was obtained at 0.025 mg P kg^{-1} in Otobi-Akpa (12.5) and Abeda-Mbadyul (8.5) while Tor-Donga and Odoba produced 5.4 and 4.1 t ha^{-1} respectively at 0.10 mg kg^{-1} in the green house experiment. The estimated SPC value also gave high grain yield (5.0 t ha^{-1}) in the field trial at Otobi-Akpa. It was concluded that Odoba soil would require highest fertilization of 604.93 Kg P ha^{-1}, Tor-donga (112.31 Kg P ha^{-1}), Abeda-Mbadyul, 105.93 Kg P ha^{-1} while the Otobi-Akpa soil would require the least fertilization of 33.18 Kg P ha^{-1}.

Keywords: Solution phosphate concentration (SPC), Inceptisols, P-Requirement, Soybean

1. Introduction

The importance of phosphorus as a yield limiting nutrient element is well established (Udo and Ogunwale 1977; Uzu *et al.,* 1975; Enwezor and Moore 1966). This is particularly so in tropical soils that are variously described as well weathered that has the ability to fix phosphorus Adetunji, (1996). Soil solution contains very low concentrations of P as compared to plant requirements, continuous replenishment of this pool to avoid P deficiency is therefore, necessary. The labile P fraction serves this purpose. The labile soil P consists of P weakly adsorbed on to soil surfaces. This fraction is in equilibrium with solution P and is considered to be potentially available for plant use. Depending on time and soil P characteristics, the labile pool can become more stable and move into non labile pool (Barrow and Shaw, 1975). Since the labile P can easily revert to the non labile fraction, determination of the actual P concentration in solution that can sustain optimum yield is necessary avoid wastages and to continuously replenish the solution P pool throughout the growing season. This solution P concentration (SPC), is defined as the optimum solution P concentration required to achieve 95% maximum yield.

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 is 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. Under research conditions, yields of over 3000 kg ha^{-1} have been recorded. 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. This is particularly so as Benue State falls in the Northern Guinea Savannah area of the tropics and the soils are highly weathered with its attendant effect on phosphorus fixation.

This study is therefore undertaken with the following objectives:

To determine the solution phosphate concentration needed for optimum yield of soybean in some Alfisols in Benue state.

To determine the amount of fertilizer P that would be required to achieve this solution P concentration.

2. Materials and Methods

The study involved laboratory, pot and field experiments. Surface soil samples (0-20cm) were collected from four locations in Benue State described as Inceptisols as shown in Table 1.The soil samples were air dried and passed through a 2 mm sieve for Laboratory studies and pot experiment. pH was determined by the glass electrode in a 1:2 soil, water suspension. 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, Na and K in the extracts were determined by the flame photometer while Ca and Mg were determined by the Atomic Absorption Spectrophotometer. Exchangeable acidity by the 1M KCl extraction and 0.01M NaOH titration. Nitrogen in the samples was determined by the regular 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_4F + 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). Extractable Fe and Al in the extracts were determined with an atomic absorption spectrophotometer.

Phosphate sorption characteristics of the soils were determined by placing eight separate 5g sub- samples of sieved soils in 50 ml polypropylene centrifuge tubes. Volumes of 40cm^3 of 0.01 M $CaCl_2$ solution containing 0, 15, 25, 40, 100, 200, 400 and 800 mg l^{-1} P as KH_2PO_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^{o}C in a refrigerated centrifuge. The supernatant was filtered through a Whatman's filter paper. P in solution was determined by a modification of the Murphy and Riley method (Watanabe and Olsen, 1965). A plot of P in equilibrium (supernatant) solution was constructed against the amount of P added. Phosphate sorbed (ps) was calculated as the difference between the concentration of the added P and the P in solution.

2.1 Pot experiment

Four Kg of the 2 mm sieved soil from each location was placed in each of the 33 plastic pots. 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 as KH_2PO_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. Three soybean seeds 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 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 with the view to determine the solution concentration that gave maximum yield. The critical equilibrium 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.

2.2 **Field trials**

Field trials were conducted at Otobi-Akpa. The experimental site was ploughed and harrowed. The size of each treatment plot was 5 m X 5 m and each plot was treated with equivalents of 60 Kg ha^{-1} N as Urea, 30 Kg ha^{-1} K as KCl. Phosphate fertilizer quantity that resulted in 0, 0.5 SPC, SPC, and 2 SPC (as estimated from the pot experiment) was added per plot and the four treatments were replicated three times in a randomized complete block design (RCBD). Soybean seeds of the variety TGX 1448-2E were drilled into the various plots. At harvest, the soybean grains were dried and weighed. For each location, data generated was subjected to the analysis of variance and the solution concentration that gave the best yield was taken as the SPC. The solution P concentration that gave 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.

Agronomic data collected was: Dry matter yield at harvest in both the pot and field experiments, number of pods per plant, weight of seeds per pot/plot and one hundred seed weight per pot/plot. Data generated was subjected to the analysis of variance. Means were separated using the Duncan multiple range test (DMRT). The SAS statistical package was used for these analyses.

3. Results and Discussion

Properties of the experimental soils are shown on Table 2. The soils are acid with pH ranging from 5.5 at Abeda-Mbadyul to 5.9 at Tor-Donga. Clay content at Otobi-Akpa was least and stood at 4% while the Tor-Donga soil had the highest clay content of 17%. The soils are sand, sandy loam, sandy clay loam and loamy sand in texture. Organic matter content was highest at Otobi-Akpa (11.03%) and least at Tor-Donga with 0.98%. Total nitrogen values were generally low with the least value of 0.03% at Abeda-Mbadyul while the highest value of 0.30% was obtained at Odoba. Total oxide content was least at Otobi-Akpa (1.3%) and highest at Odoba (4.1%). Some selected P fractions of the soils are shown on Table 3. Total P was highest at Tor-Donga and least at Odoba with organic P constituting about 48% of the total. Bray-1 P was least at Odoba (2.1 mg kg^{-1}) and highest at Tor-Donga. The Olsen P was least at Otobi-Akpa and highest at Odoba (6.4 mg kg^{-1}). Response to P fertilization was thus probable.

The effect of P solution concentration on the yield parameters in the Abeda-Mbadyul soil is shown on Table 4. Response to P application in all the parameters varied significantly with the solution P concentration. The highest number of pods, seed weight and dry matter yield was achieved when the solution P concentration was 0.025 mg kg^{-1}. The yield of the crop in terms of all the parameters considered decreased significantly thereafter. Soybean grain yield of 8.5 t ha^{-1} at this level of P solution concentration was significantly higher than all the other treatment levels. 0.025 mg kgl^{-1} was therefore taken as the optimum solution concentration in this soil. The quantity of fertilizer P required to achieve this concentration 1 was calculated as 0.83 g kg^{-1} soil. This is equivalent to 105.93 kg P ha^{-1} and was therefore taken as the SPR value for the Abeda-Mbadyul soil. All the other plants at this location that received initial P treatments above 0.125 mg kg^{-1} died after three weeks of planting.
Effect of P solution concentration on some agronomic parameters in the greenhouse in the Otobi-Akpa soil is presented on Table 5. The pod number, dry matter yield and seed weight increased significantly with increase in solution concentration up to 0.025 mg kg^{-1} attaining the highest grain yield (seed weight) of 13.1 t ha^{-1} but decreased thereafter. 0.025 mg kg^{-1} was taken as the optimum solution P concentration for soybean yield in this soil and the quantity of fertilizer P required to achieve this solution concentration was calculated as 0.26 g kg^{-1} soil. This is equivalent to 33.18 kg P ha^{-1}.
Effect of P solution concentration on the yield parameters in the Tor-Donga soil is shown on Table 6. Response to applied P in all the parameters varied significantly with the solution P concentration. The highest number of pods, seed weight and dry matter yield was achieved when the solution P concentration was 0.10 mg kg^{-1}.

The soybean grain yield (seed weight) obtained at this level of P concentration was 5.4 t ha^{-1}. The yield of the crop in terms of all the parameters considered decreased significantly thereafter. Fertilizer P required to achieve this solution P concentration was calculated as 0.88 g kg^{-1} soil. This is equivalent to 112.31 kg P ha^{-1}. Effect of P solution concentration on the yield parameters in the Odoba soil is shown on Table 7. Response to applied P in all the parameters varied significantly with the solution P concentration. The highest number of pods, seed weight and dry matter yield was achieved when the solution P concentration was 0.10 mg kg^{-1}. The highest soybean yield obtained here was 12.71 g pot^{-1} and was equivalent to 7.1 tons per hectare. The yield of the crop in terms of all the parameters considered decreased significantly thereafter. Fertilizer P required to achieve this

level of solution P concentration in was calculated as 4.74 g kg^{-1} soil. This is equivalent to 604. 84 kg P ha^{-1}. Table 8 shows the effect of solution P concentration on yield parameters from the field trial at Otobi-Akpa. The highest yield of 15.967 kg per plot was obtained with a solution concentration of 2.0 SPC in terms of seed weight and this was equivalent to 6386.8 kg (6.4 tons) per hectare and was significantly higher than all the other treatments. This was followed by the 1.0 SPC treatments that produced 12.65 kg per plot which was equivalent to 5060 kg (5.01 tons) per hectare and differs significantly from the others. The 0.5 SPC and the control, (0.0 SPC) treatments were significantly not different from each other but were significantly lower than the other levels. In terms of dry matter yield, there was no significant difference between the 2.0 SPC and the 1.0 SPC treatments though the values obtained here were significantly different from both the 0.5 SPC and the control, (0.0 SPC) treatment that did not differ significantly from each other. Significant differences were observed across the treatments in terms of one hundred seed weight. The treatments can be ranked in the order of 1.0 SPC > 2.0 SPC> 0.5 SPC > control, (0.0 SPC).
The SPC values were generally very low and variable, ranging from 0.025 mg kg^{-1} a Abeda-Mbadyul and Otobi-Akpa, 0.050 mg kg^{-1} at Tor-Donga to 0.10 mg kg^{-1}at Odoba. This is within the range reported by previous workers, though with crops other than soybean (Fox *et al.,* 2006 ; Adetunji, 1995; Adetunji, 1997) and higher than what was reported for maximum yield of maize by (Kang and Juo, 1979). The value of 0.2 mg kg^{-1} reported by (Beckswith, 1965) and widely used for West African soils (Udo and Dambo, 1979) is high for the production of soybean in Inceptisols in Benue state. Soil properties like total oxides and clay content appeared to have influenced the solution P concentrations required for optimum yield as well as the amount of fertilizer P needed to achieve these concentrations. Abeda-Mbadyul and Odoba with the highest clay content achieved optimum yield at higher SPC values than the Tor-Donga and Otobi-Akpa soils. The total oxide content was also highest at Odoba and Tor-Donga. 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), organic C, pH (Barrow, 1974), 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.

Agbenin, (2003), had earlier reported evidence that clay mineral and extractable oxides of Fe and Al play an important role in P fixation in soils. In the same way, (Wiriyakitnateekul *et al.,* 2005) reported that in Thai soils, 81% of variability in P sorption was related with extractable Fe and Al by dithionate and oxalate extraction. 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.

The yield data of soybean under field conditions indicates that the estimated SPC from the pot experiment gave lower yield values at Otobi-Akpa. The highest seed weight was obtained at a solution concentration that was twice the SPC indicating that the SPC could have been higher than the value of 0.025 mg kg^{-1} estimated from the pot experiment. Generally, the variation in terms of the SPC between the pot experiment and the field was little. Dear *et al.,* (1992) had earlier reported little variations between the SPC in the green house and that of field. These variations were attributed to the more favorable moisture conditions prevailing in the green house which could be expected to increase the diffusion of P to the root hairs and lower the optimum level of solution P required(Adetunji, 1995).

4. **Conclusion**:

The critical value determined under the green house conditions in this study could also be applied to the field situation when similar laboratory procedures and the same crops are used. It was thus concluded that the Odoba soil would require the highest fertilization of 604.93 Kg P ha^{-1}. This was followed by Tor-donga soil (112.31 Kg P ha^{-1}), the Abeda-Mbadyul soil would require 105.93 Kg P ha^{-1} while the Otobi-Akpa soil would require the least fertilization of 33.18 Kg P ha^{-1}.

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Table 1: Description of the sampled sites

S/No	LOCATION	SOIL CLASS
1	Abeda-Mbadyul	Oxic ustropept (USDA) Eutric cambisol (FAO)
2	Otobi, Akpa	Oxic ustropept (USDA) Eutric cambisol (FAO)
3	Tor Donga	Ustoxic dystropept (USDA) Ferralic cambisol (FAO)
4	Odoba	Oxic ustropept (USDA) Eutric cambisol (FAO)

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Table 2: Some properties of the experimental soils

LOCATION	pH	Clay	Texture	O.M (%)	Total N (%)	ECEC (C mol kg^{-1})	Fe_2O_3 (%)	Al_2O_3 (%)
Abeda-Mbadyul	5.5	9	SCL	1.07	0.03	3.14	0.6	0.8
Otobi-Akpa	5.6	4	S	11.03	0.05	3.11	0.4	0.9
Tor Donga	5.9	17	SL	0.98	0.10	4.09	1.9	1.2
Odoba	5.7	12	LS	2.00	0.30	4.11	2.8	1.3

Table 3: P Fractions of the experimental soils (mg kg^{-1})

Location	Total P	Organic P	Fe-P	Al-P	Ca-P	Bray-1P	Olsen-P
Abeda-Mbadyul	276.8	132.9	62.82	41.88	28.3	2.0	3.6
Otobi-Akpa	296.1	139.3	73.1	46.2	31.5	3.7	2.3
Tor-Donga	298.3	143.2	112.8	22.3	11.6	3.8	4.6
Odoba	215.3	103.3	90.2	9.0	12.8	2.1	6.4

Table 4. Effect of P Solution Concentration on Yield parameters (g pot^{-1}) in Abeda-Mbadyul soil

Target conc. (mg kg^{-1})	Pod No	Seed wt	DMY	100 seed wt	Seed wt (t ha^{-1})
0	44.33abc	1.43d	3.36d	2.51d	0.8d
0.025	54.33a	15.12a	14.99a	13.49a	8.5a
0.050	50.33ab	10.40b	9.26b	10.63b	5.8b
0.075	38.33bcd	4.63c	3.30d	8.07c	2.6c
0.10	30.33cd	4.12c	6.38c	10.40b	2.3c
0.125	27.33c	1.16d	1.41d	2.85d	6.5d

Within each column, means with the same letters are not significantly different according to Duncan Multiple Range Test.

Table 5: P Solution Concentration and Yield Parameters (g pot^{-1}) in Otobi-Akpa Soil

Target conc. (mg kg^{-1})	Pod No	Seed wt	DMY	100 seed wt	Seed wt (t ha^{-1})
0	22.33bc	20.61a	14.99a	18.28c	11.5a
0.025	53.0a	22.34a	16.30a	26.14b	13.1a
0.050	25.67b	13.42b	8.11b	24.44b	7.5b
0.075	19.0bcd	4.44c	4.55d	9.98ed	2.5c
0.10	19.0bcd	12.04b	6.63bc	42.76a	6.7b
0.125	17.0bcd	5.13c	6.66bc	15.12cd	2.9c
0.150	12.0cde	4.14c	4.81cd	17.24^{c}d	2.3c
0.175	8.67de	2.67c	3.13d	14.88cd	1.5c
0.20	3.33e	1.37c	0.72e	13.95d	0.8c

Within each column, means with the same letters are not significantly different according to Duncan Multiple Range Test.

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Table 6: Effect of P Solution Concentration on Yield Parameters (g pot^{-1}) in Tor-Donga soil

Target conc. (mg kg^{-1})	Pod No	Seed wt	DMY	100 seed wt	Seed wt (t ha^{-1})
0	30.33d	5.31cd	4.84b	7.59d	3.0cd
0.025	30.33d	3.75de	4.78b	9.44c	2.1de
0.050	38.33c	5.86c	6.47b	13.87a	3.3c
0.075	52.67b	7.91b	10.22a	6.83e	4.4b
0.10	59.33a	9.67a	13.88a	6.46f	5.4a
0.125	28.0d	3.32e	4.25b	95.51g	1.9e
0.150	24.0e	2.11e	3.84b	11.19b	1.9e

Within each column, means with the same letters are not significantly different according to Duncan Multiple Range Test.

Table 7: Effect of P Solution Concentration on Yield Parameters (g pot^{-1}) in Odoba Soil

Target conc. (mg kg^{-1})	Pod No	Seed wt	DMY	100 seed wt	Seed wt (t ha^{-1})
0	7.33d	0.29e	1.15d	1.81f	1.6e
0.025	21.0c	1.56d	4.35c	5.78e	0.9d
0.050	34.0b	2.48cd	6.28b	7.28c	1.4cd
0.075	34.33b	3.46c	7.66a	5.91d	1.9c
0.10	48.67a	12.71a	8.17a	7.99b	7.1a
0.125	40.67ab	7.27b	7.71a	10.53a	4.1b

Within each column, means with the same letters are not significantly different according to Duncan Multiple Range Test.

Table 8: Effect of Solution P Concentration on Yield Parameters in the Field Trial at Otobi-Akpa

Target conc.	Seed wt (kg)	DMY (kg)	100 Seed wt (g)	Seed wt. (t ha^{-1})
0.0 SPC	6.67c	1.93b	11.41d	2.67c
0.5 SPC	8.83c	2.69b	12.70c	3.53c
1.0 SPC	12.65b	3.83a	13.75a	5.06b
2.0 SPC	15.97a	3.90a	12.85b	6.39a

Within each column, means with the same letters are not significantly different according to DMRT.