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Full Length Research Paper

Solution phosphate concentration as a means of estimating the fertilizer phosphate requirement of soybean (*glycine max (l) merr.*) in some alfisols in Benue State, Nigeria

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Abstract

Four Alfisols in Benue state were examined to determine the solution phosphate concentration required to obtain optimum yield of soybean with the view of employing the SPC as a tool for the estimation of the P fertilizer requirement for soybean production on these soils. 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 seed variety (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. Optimum solution P concentration (SPC) was determined for each soil in relation to yield. Field trials were conducted at Nor 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 (SPR) to achieve this concentration was calculated. High grain yield (t ha^{-1}) was obtained at 0.075 mg P kg^{-1} in Katsina-Ala (15), Utonkon (7.3), Akoodo-Mbakor (9.3) and Nor (8.7) in the green house experiment. The estimated SPC value also gave high grain yield (t ha^{-1}) in the field trial at Nor (4.3). It was thus concluded that the highest P fertilization would be required at Utonkon (72.75 Kg P ha^{-1}), Katsina-Ala (67.64). Akoodo-Mbakor and Nor (61.26) would require the least.

Keywords: Solution, phosphate, concentration, fertilizer, requirement, soybean, alfisols.

INTRODUCTION

Phosphorus is one of the major nutrient elements. Its importance 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, (1995).

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. The concentration of P in this fraction could be10 to 100 times greater than that in solution. 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

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the actual P concentration in solution that can sustain optimum yield is necessary so as to 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. Farmers' yields average 300 – 1,030 kg ha^{-1} of threshold grain (Aduayi et al.,eds. 2002). 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 study was 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.

MATERIALS AND METHODS

The study involved laboratory, pot and field experiments. Surface soil samples (0-20cm) were collected from four locations in Benue State from the soil type of Alfisols 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^oC 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. Amounts of P required meeting the target concentrations were estimated from this curve.

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. 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.

Field trials

Field trials were conducted at Nor. 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

Table 1. Description of the sampled soils

S/No	LOCATION	SOIL CLASS
1	Katsina-Ala	Arenic haplustalf (USDA)
		Orthic luvisol (FAO)
2	Utonkon	Aquic haplustalf (USDA)
		Orthic luvisol (FAO)
3	Akoodo-Mbakor	Typic haplustalf (USDA)
		Orthic luvisol (FAO)
4	Nor	Typic haplustalf (USDA)
		Orthic luvisol (FAO)

Federal Department of Agricultural Land Resources (FDALR, 1990)

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(%)
Katsina-Ala	5.8	3	S	1.22	0.03	3.18	0.8	0.7
Utonkon	5.7	16	SCL	1.60	0.06	4.72	0.9	1.2
Akoodo	6.3	26	SCL	1.69	0.05	3.05	0.9	1.1
Nor	5.9	10	LS	1.69	0.06	3.08	1.5	0.9

Table 3. Selected Phosphorus Fractions of the Experimental Soils (mg kg^{-1})

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

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).

RESULTS AND DISCUSSION

Some properties of the experimental soils are shown on Table 2. The soils are acid with pH ranging from 5.7 at Utonkon to 6.3 at Akoodo, Mbakor. Clay content was lowest at Katsina-Ala (3%) and the Akoodo- Mbakor soil had the highest clay content (26%). The soils are sand, sandy clay loam and loamy sand. Organic matter content was lowest at Katsina-Ala while the highest values were recorded at Akoodo and Nor. The soils were generally poor in their total nitrogen status with the least value of 0.03% recorded at Katsina-Ala and the highest value of 0.06% recorded at Utonkon and Nor. Response to applied nutrients was thus probable. Total oxide content was also lowest at Katsina-Ala (1.5%) and highest at Nor (2.4%).

Selected P fractions of the soils under study are shown on Table 3. Total P was least at Katsina-Ala and highest at Nor with the organic P constituting about 48% of total P. Bray-1 P was highest at Nor and least at Utonkon while Olsen- P values were highest at Akoodo, Mbakor

Table 4. Effect of P solution concentration on yield parameters (g pot^{-1}) in Katsina-Ala Soil

Target conc. (mg kg^{-1})	Pod No	Seed wt	DMY	100 seed wt	Seed wt (t ha^{-1})
0	12.0de	3.87f	4.02de	11.98a	2.2f
0.025	16.0de	6.01de	5.44cd	13.85a	3.4de
0.05	25.33cd	8.16c	6.82c	13.87a	4.6c
0.075	76.0a	25.89a	17.26a	14.20a	15.0a
0.10	49.0b	11.39b	9.76b	14.21a	6.4b
0.125	57.67b	13.12b	10.72b	12.48a	7.3b
0.15	30.67cde	7.41cd	6.21c	9.77b	4.1cd
0.175	19.0cde	7.35cd	5.35cd	8.16bc	4.1cd
0.20	13.0de	5.07ef	3.15ef	8.24bc	2.8ef
0.225	16.33de	7.15cd	5.02cde	6.21c	4.0cd
0.25	7.0e	0.68g	1.92f	7.07c	0.4g

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

Table 5. Effect of P solution concentration on yield parameters (g pot^{-1}) in Utonkon Soil

Target conc.(mg kg^{-1})	Pod No	Seed wt	DMY	100 seed wt	Seed wt (t ha^{-1})
0	20.0d	2.58d	4.42c	5.92d	1.5d
0.025	31.0c	6.36c	8.65b	10.13a	3.6c
0.050	40.67b	9.05b	9.83b	11.46a	5.1b
0.075	51.67a	13.02a	14.35a	10.85a	7.3a
0.10	13.0e	2.12d	4.42c	8.12b	1.2d
0.125	7.0e	0.75d	3.87c	3.45d	0.4d

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

and the least values were recorded at Nor. Response to P fertilization was expected due to the generally low P status of the soils.

Effect of P solution concentration on mean yield data in the pot experiment

The effect of P solution concentration on some agronomic data in the greenhouse in the Katsina-Ala soil is presented on Table 4. The pod number, dry matter yield and seed weight increased significantly with increase in solution concentration up to 0.075 mg l^{-1} and decreased thereafter. Consequently, 0.075 mg l^{-1} appears to be the optimum solution P concentration for soybean production in this soil. The highest soybean grain yield (seed weight) obtained in this soil was 25.89 g pot^{-1} and was equivalent to 15 tons per hectare. The quantity of fertilizer P required to achieve this level of solution P concentration was calculated as 0.53 g kg^{-1} soil. This is equivalent to 67.64 kg P ha^{-1}.

The effect of P solution concentration on the yield parameters in the Utonkon soil is shown on Table 5. Yield of 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 0.075 mg l^{-1}. At this level of P concentration, the grain yield obtained was equivalent to 7.3 tons per hectare. The yield of the crop in terms of all the parameters considered decreased significantly thereafter. Amount of fertilizer P required to achieve this level of solution P concentration was calculated as 0.17 g kg^{-1} soil. This is equivalent to 72.75 kg P ha^{-1}. All the other plants at this location that received initial P treatments above 0.125 mg kg^{-1} died after three weeks of planting.

The effect of P solution concentration on the yield parameters in the Akoodo-Mbakor soil is shown on Table 6. Yield in all the parameters varied significantly with the solution P concentration. The highest number of pods, seed weight (9.3 t ha^{-1}) and dry matter yield was achieved when the solution P concentration was 0.075 mg l^{-1}. The yield of the crop in terms of all the parameters considered decreased significantly thereafter. Quantity of fertilizer P required to achieve this level of solution P concentration is equivalent to 61.26 kg P ha^{-1}.

Table 6. Effect of P solution Concentration on Yield Parameters (g pot^{-1}) in Akoodo –Mbakor

Target conc. (mg kg^{-1})	Pod No	Seed wt	DMY	100 seed wt	Seed wt (t ha^{-1})
0	10.33e	1.56e	2.74b	6.72d	0.9e
0.25	16.0e	3.90cd	7.11a	11.68ab	2.2cd
0.50	40.67b	5.22c	7.71a	11.55ab	2.9c
0.075	96.67a	16.56a	7.55a	11.79a	9.3a
0.10	24.67c	9.87b	3.87b	11.34b	5.5b
0.125	22.67cd	2.66de	2.71b	10.06d	1.5de

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 Nor Soil

Target conc.(mg kg^{-1})	Pod No	Seed wt	DMY	100 seed wt	Seed wt (t ha^{-1})
0	11.0^{d}	0.98^{f}	7.44^{d}	16.19^{d}	0.6f
0.025	14.67^{d}	4.28^{e}	11.02^{c}	15.16^{e}	2.4e
0.05	29.67^{c}	6.18^{d}	13.68^{b}	16.05^{d}	3.5d
0.075	56.33^{a}	15.47a	16.45^{a}	16.66^{c}	8.7a
0.10	36.0^{b}	12.32^{b}	16.04^{a}	19.58^{b}	6.7b
0.125	33.33^{b}	9.06^{c}	13.11^{b}	21.25^{a}	5.1c
0.150	24.0^{c}	2.22^{ef}	11.10^{c}	16.90^{c}	1.2ef
0.175	10.67^{d}	1.31^{f}	7.27^{d}	14.36^{f}	0.7f

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

Table 8. Effect of Solution P Concentration on Yield Parameters in the Field Trial at Nor

Target conc. (mg kg^{-1})	Seed wt (kg plot^{-1})	DMY (kg)	100 Seed wt (g)	Seed wt.(t ha^{-1})
0.0 SPC	2.78b	0.77b	9.04c	1.11b
0.5 SPC	3.64b	0.99b	11.19a	1.46b
1.0 SPC	10.67a	2.64a	11.35a	4.27a
2 .0 SPC	9.80a	1.37b	10.00b	3.92a

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

The effect of P solution concentration on some agronomic data in the greenhouse in the Nor soil is presented on Table 7. The pod number, dry matter yield and seed weight increased significantly with increase in solution concentration up to 0.075 mg l^{-1} and decreased thereafter. Soybean grain yield (seed weight) of 8.7 tons per hectare which was the highest in this soil was obtained at this level of solution P concentration. 0.075 mg l^{-1} appears to be the optimum solution P concentration for soybean in this soil and the quantity of fertilizer P required to

Achieve this level of solution concentration was calculated as 0.48 g kg^{-1} soil. This is equivalent to 61.26 kg P ha^{-1}.

Effect of solution P concentration on yield parameters in the field experiment

Yield data obtained from the field trial conducted at Nor is presented on Table 8. For the seed weight the highest value of 10.667 kg per plot was recorded when a solution concentration of 0.075 mg kg^{-1} (1.0 SPC) was added. This is equivalent to 4266.8 kg (4.27 tons) per hectare. This was however not significantly different from the value of 9.8 kg per plot which is equivalent to 3920 kg (3.92 tons) per hectare obtained with a solution P concentration of 0.15 mg kg^{-1} (2.0 SPC). A solution concentration equivalent to 0.5 SPC produced 3.643 kg per plot, which is equivalent to 1457.2 kg (1.46 tons) per hectare, a value that is not significantly different from the control that produced 2.78 kg per plot that is equivalent to 1112 kg (1.11 tons) per hectare that was the least value in this parameter.

For the dry matter yield, 2.6367 kg per hectare per plot or 1054.68 kg (1.06 tons) was obtained with a solution concentration equivalent to 1.0 SPC. This value was significantly different from all the other treatments that did not show any significant difference among themselves.

In terms of one hundred seed weight, the 1.0 SPC again produced the highest value of 11.353 kg which however was not significantly different from 11.19 kg obtained with 0.5 SPC. This was followed by 9.9967 kg of SPC treatment that was significantly different from all the other treatment levels. Control, (0.0 SPC) produced the least amount of 9.04 kg that was significantly lower than all the other treatments.

CONCLUSION

Highest soybean yield was obtained with the Katsina-Ala soil (15 t ha^{-1}) and was followed by the 9.3 t ha^{-1} obtained with the Akoodo-Mbakor soil. Nor followed with 8.7 t ha^{-1} while the Utonkon soil produced the least yield of 7.3 t ha^{-1}. Optimum yield in all the soils was obtained with a solution P concentration of 0.075 mg kg^{-1}. Amount of fertilizer P required to achieve the SPC however varied among the soils due probably to the native P content and the soil properties. It was concluded that the highest P fertilization would be required at Utonkon (72.75 Kg P ha^{-1}), Katsina-Ala (67.64). Akoodo-Mbakor and Nor (61.26) would require the least.

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