American-Eurasian J. Agric. & Environ. Sci., 16 (3): 487-493, 2016
ISSN 1818-6769

DOI: 10.5829/idosi.aejaes.2016.16.3.12854

Estimation of Phosphorus Requirement of Mungbean (*Vigna radiata* L.) Wilezek in the Acid Soils of South Eastern Nigerian Using P-Sorption Isotherm

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Abstract: This study was conducted to determine the phosphorus requirement of mungbean (*Vigna radiata*) in two soil types in South Eastern Nigeria Amaeke (Sandstone and Bende (Shale formation) using sorption isotherms. Soil samples were collected at 0-15cm depth and the processed method used involved equilibrating 3 g of soil in 30 ml of 0.01 m $CaCl_2$ containing 0.5, 10, 15, 20, 25 µg g^{-1} P at room temperature for 5 days. From the P sorption curves, the standard P requirement for the two soils was calibrated and phosphorus requirement of the soils for optimum growth and yield of mungbean were found to be low. Difference phosphorus rates were calibrated from the isotherm curves and used in fertilizing mungbean in a split-plot potted experiment in completely randomized design (CRD) with three replications. The soil types occupied the main plots while the P rate was assigned to the subplots. The results obtained indicated that solution P concentration level of 0.2 µg g^{-1} equivalent to 8.38 kg ha^{-1} gave the best grain yield in Bende and concentration of 0.3 µg g^{-1} equivalent to 26.5 kg ha^{-1} in Amaeke soil gave the best grain yield. The high relative yield was recorded in the soils of Bende compared to that of Amaeke

Key words: Phosphorus · Freundlich · Model · Sorption · Parent materials · Fertilizer

INTRODUCTION

Phosphorus (P) is an essential nutrient element for plant growth and development [1, 2]. It is necessary for the formation and translocation of all intermediate end products. Also it plays a major role in stimulating early root growth, thus encourages P mineralization by plant as well as hastening plant maturity and improving good quality seed. [3, 4].

Phosphorus has been identified as one of the most limiting nutrient elements in crop production in tropical soils [5, 6]. Widespread P deficiency has been reported in the acid sands of Nigeria [7-9]. The major problem in these soils is the low P availability which may be attributed to low P in the parent materials and high fixation by soil factors; thereby making applied P unavailable for crop. High P fixation had been reported in these soils [10, 11].

A sorption isotherm for P is the curve which describes the relationship between phosphate taken up by a solid surface and concentration of phosphate remaining in solution measured after addition of phosphate in a laboratory experiment [12]. It has been found that this relationship can differ greatly between soils. As reported by Warren [12], phosphate sorbing sites and components of soils. However, P sorption isotherm which relates P concentration in the solution with P sorbed by the soil has been used to predict fertilizer P requirement of crops [12-14].

Mungbean is grown widely in Southeast Asia, Africa, South America and Australia [15]. It is a warm-season crop, requiring about 80-150 days to maturity. Mungbean is widely used as human food, green manure and forage for livestock. It also serves for medicinal purpose[16, 17].

Legumes require relatively high amounts of phosphorus for nodulation, yield and high quality seed [1, 17].

Information on phosphorus requirements of mungbean in the soils of southeastern Nigeria is limited. This study was therefore carried out to provide information on phosphorus requirements of mungbean in selected soils of South Eastern Nigeria using sorption isotherm studies.

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MATERIALS AND METHOD

Location of the Study Area: Southeastern Nigeria lies between latitude 4° 20[1] and 7° 25[1] N and longitudes 5° 25[1] and 9° 51[1] E [18]. The climate is essentially humid tropical rainforest with an average annual precipitation of 2163mm. There are two distinct seasons, the rainy season (April-October and dry season (November-March). Temperatures are high, maximum temperature range from 33 to 35°C, while minimum temperature ranges from 28 to 29°. The vegetation is essentially secondary forest tending toward derived savanna because of population pressure and repeated annual bush burning [19].

Soil formed on shale parent material have high clay content and are poorly drained. The clay type is mainly smectite. They are acidic with high exchangeable cations and are generally fertile. Soils formed on sand stones are usually acidic have low CEC, low base saturation and of low fertility status. The prominent clay type is kaolinite [20, 121].

Soil Sampling and Analysis: The soil samples for the study were collected from Amaeke, Sand Stone (SS) and Bende, Shale formation (SH). The samples were collected at 0-15cm depth to represent each of the parent materials at different locations. Bulk soils sample were also collected for pot experiments. Soil samples were collected from about ten points and bulked, from which sub samples were obtained.

The samples were air dried and sieved through 2mm mesh. Particle size distribution was determined by the Bouyoucos hydrometer method [22]. Soil pH was determined in 1:2.5 soil/water ratio and soil/$Cacl_2$ ratio using a glass electrode pH meter. Soil organic C, total N, available P, exchangeable bases (Ca, Mg, K and Na) were determined as described in Sparks [23]. Exchangeable acidity was measured as described by Udo *et al*., [24]. Effective cation exchange capacity (ECEC), percent base saturation and carbon to nitrogen ratio (C/N) were obtained by calculation.

Sorption Study: The sorption isotherm were determined by equilibrating 3g of soil in 30 ml of 0.01m, $CaCl_2$ containing 0.5, 10, 15, 20 and 25 μg g^{-1} P in 50ml centrifuge tubes for five days at room temperature as described by Fox and Kamprath [25].

The samples were shaken twice daily for 30 minutes. Three drops of toluene were added to each of the samples suppress microbial growth. At the end of five days, the suspension was centrifuged at 1600 rpm for 15miniutes and P in the supernatant solution determined by the method of Murphy and Riley [26]. Standard P requirement were then obtained. The amounts of P adsorbed by the soil were determined by the change of concentration in solution.

Table 1: Phosphorus Rate (μg g^{-1}) Calibrated from Isotherm Curves and its Equivalent Rates ($Kgha^{-1}$) in Different Locations

	EQUIVALENT P RATE	
Solution P (μg g^{-1})	Amaeke	Bende
0.0	0.00	0.00
0.1	20.3	1.40
0.2	23.4	8.38
0.3	26.5	15.2
0.4	29.5	22.0

The isotherm data were interpreted in terms of Freundlich sorption equation (Log x/m = log a + n log c). Where the slopes were obtained by plotting x/m against logc. [27]. Maximum adsorption and maximum buffering capacity were calculated and affinity coefficient obtained

where

x/m = Amount of P sorbed per gram of soil (mgP kg^{-1} soil)

a and n = Sorption constants

= P concentration in equilibrium solution.

Pot Experiment: The pot experiment was sited at Umudike (5° 29[1]) N[1], 7° 33[1]E). The treatments were arranged in a split plot experiment in a completely randomized design (CRD) with three replications. The soil types occupied the main plot while the P rates were assigned to the sub plots.

Mungbean (*Vigna radiata*) was used as the test crop in the experiment. Six kilograms of each of the soil samples were weighed into a 12-litre plastic pot and moistened to field capacity. Mungbean at the seed rate of 3 seeds per pot were sown and later thinned down to one seedling per pot 2 weeks after planting. The soils were kept moist for 2 weeks within which the crop was fully established.

The phosphorus rates calibrated from the isotherm curves at 0, 0.1, 0.2, 0.3 and 0.4 μg g^{-1} equivalents to values shown in Table 1 were applied to the pots at 2 weeks after germination at different levels. The pots were irrigated on daily basis. Plant height was measured with a meter rule, as the height from the abse of the crop to the tip of the inflorescence. Leaves number was measured as all the fully opened leaves per plant and numbers of seeds per pod were assessed by counting, while stem determiners was measured with a vernier caliper. Pod weights per plant and grain yield per plant were determined with a sensitive electronic balance [24, 28].

Nodules number was determined by carefully uprooting the plants and washing soil from the roots of the plants and the nodule number counted [29]. Data on yield and growth parameters were analyzed statistically using the method outline by Wahua [30]. Regression analysis was also done using the Genstat [31] statistical programme.

RESULTS AND DISCUSSION

Soil Properties: The physicochemical properties of the soils are shown in Table 2. The soil texture varied as loamy sand for Bende and sand for Amaeke, respectively. The variation in texture reflects the differences in the parent materials. Uzoho and Oti [32] observed that the texture of soils is greatly determined by the parent materials.

Enwezor *et al.* [33] also observed that texture plays dominant role in soil behaviour as it affects water and nutrient retention as well as suitability of soils as a rooting medium.

Soil pH values in $CaCl_2$ were very acidic 3.87 (Bende) and 3.60 (Amaeke) lower than pH measured in water (4.94 & 4.80). Indicating that the two soils are negatively charged [34] and can leads to significant yield reduction. Ibia [5] also observed that aluminum toxicity occurs in soils with pH less that 5.0. The available P in the soils was higher than the critical level 12-15 mg kg^{-1} for crop production in Southern Nigeria [35]. The high P values in Bende soil agree with findings of [32, 36] that soils of the Shale are generally high in available phosphorus.

The total nitrogen, Organic matter CEC, for both soils fall within the critical levels proposed by Aduayi *et al*; [37]) for the soils of South Eastern Nigeria. Enwezor *et al*., [33] indicated that the fertility status of the soil is related to soil organic matter content. The values of the exchangeable bases were high, also reflect the differences in the soil organic matter. Exchangeable mg, ca, K and Na were low. These results are in agreement with the finding of Enwezor *et al.* [35], who observed that the soils of South Eastern Nigeria are low in these ions. The ECEC were low (8.50 Bende and 4.79 $Cmolkg^{-1}$ for Amaeke). The values remaining below 12 $cmolkg^{-1}$ propose for these soils [37].

The release of nutrients by soils is influenced by the carbon to nitrogen (C/N) ratio, the values ranged from 12.3 (Bende) and 9.91 (Amaeke), indicating net mineralization. Breman and Reuler [38] stated that when the C/N ratio is below 25, application of low rate of N will accelerate mineralization.

Table 2: The physiochemical characteristics of the soil

	Location	
Soil Parameters	Amaeke	Bende
Sand	83.4	72.4
Silt	9.80	16.2
Clay	6.80	11.4
Texture	Sand	Sandy- Loam
pH (H_20)	4.80	4.94
pH ($CaCl_2$)	3.60	3.87
Organic matter (g/kg)	19.2	33.0
Total N (g/kg)	2.00	3.60
Available P (mg kg^{-1})	16.5	33.0
Mg (Cmol kg^{-1})	0.85	2.54
Ca	2.42	4.90
K	0.18	0.06
Na	0.13	0.04
Ex. Acidity (cmol kg^{-1})	1.20	0.96
ECEC (Cmol kg^{-1})	4.79	8.50
Base saturation%	71.7	87.7
C/N ration	9.91	12.3

SS – Sand stone, SH – Shale

Phosphate Sorption Characteristics: The phosphate sorption isotherm curves are presented in Fig. 1 and 2. These curves related the amount of P sorbed by the soil to the concentration of P in equilibrium solution.

The curves indicated that with continuous, addition of P and higher P concentrations in equilibrium solution, each of the curves tend to flatten and approach a maximum indicating that the soil is saturated. Similar curves were reported by Osodeke [1]. The highest P sorption capacity at the different levels of P applied followed the order Bende (516 mg kg^{-1}) and Amaeke 282 mg kg^{-1}) as shown in Table 3. The variation could be due to the organic matter content and the intensity of weathered conditions of the soils of the regions, which resulted in high concentrations of various oxides of iron and aluminum [7].

The Freundlich Phosphate Sorption Isotherms for the Soils Are Shown in Fig. 3: In the two soils, more P was adsorbed. The sorption capacity calculated from the Freundlich plotted (Table 3) was 282 mg kg^{-1} in Amaeke and 516 mg kg^{-1} Bende. The high P sorption capacity in Bende soils indicated the presence of more active sites for P sorption which in turn, may be attributed to the type and amount of clay present but affinity coefficient (K) which relate the bonding energy of the soil is low, indicating that leaching would occur easily (1.13 mg kg^{-1})

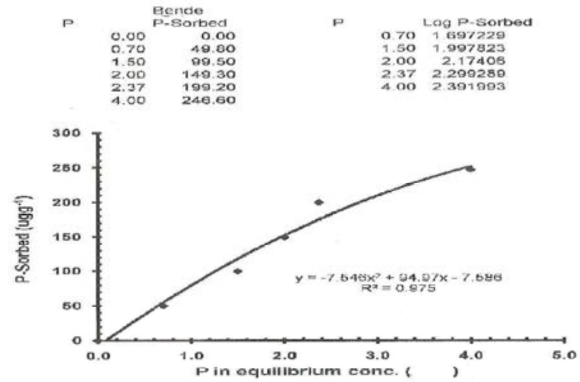

Fig. 1: Phosphate sorption Isotherms for soils of Bende (0-15 cm)

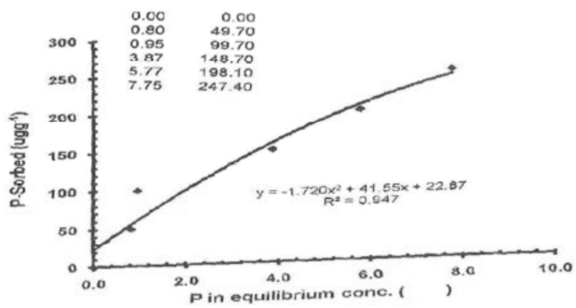

Fig. 2: Phosphate sorption Isotherms for soils of Amaeke (0-15 cm)

while Amaeke is (3.52 mg kg^{-1}). Udo [13] and Osodeke [6] reported similar results for this soils. The buffering capacity (MBC) of the soils is high ranging between 993 (mg kg^{-1}) Amaeke and 582 mg kg^{-1} respectively.

The least values in Bende may be attributed to the high content of organic matter in that soil which block the adsorption sites. Uzoho and Oti [32] reported that relatively large organic molecules or competition of the organic anions with the phosphate ions blocks the adsorption sites. The buffering capacities are affected by soils texture, clay content, exchangeable aluminum content and clay mineralogy [9] and [39].

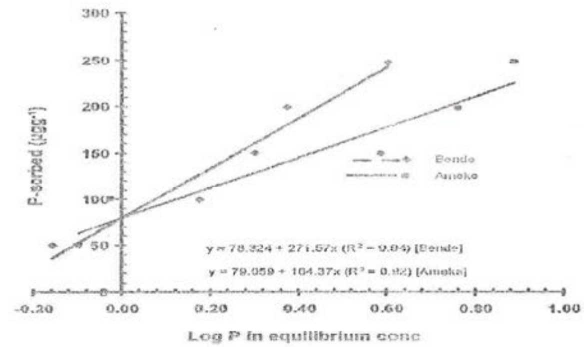

Fig. 3: Freundlich phosphate sorption isotherms for soils of Bende and Amaeke (0-15cm)

Effects of Soil types on Growth and Yield Parameter: From the Table 4, Bende had the highest plant highest with mean of 32.8cm, while Amaeke is 25.2cm. The two values fall within the range reported by AVRDC [40]. In terms of growth and yield parameter for the two soils, Bende performed better than Amaeke. The variation may be attributed to the inherent fertility of the parent materials and the degree of soil acidity [9]. There was a significant relationship between the soil types and growth/soil parameters.

Effect of Phosphorus Rates on Growth and Yield Parameter: Table 5 shows the effects of phosphorus rates on growth and yield parameters. The highest plant height, number of leaves, stem diameter and number of seeds per plant were recorded at solution P concentration of 0.3 μug^{-1}, while the maximum numbers of pods per plant and pod weight were at the equilibrium solution concentration of 0.2 μug^{-1}. The highest number of nodules was recorded at solution P concentration of 0.4 μug^{-1} with a mean of 44.5 μug^{-1}. This indicates that phosphorus is needed in large quantity for the process of biological nitrogen fixation as reported by Sanginga [41]. There was a significant yield response of mungbean to phosphorus fertilizers. Similar trend had been reported by Uzoho and Oti [32], Osodeke [1] and Mehdi [2].

Table 3: Sorption Parameters of the Freundlich

Location	P sorption capacity (a) (mg kg^{-1})	P sorption energy (a) (mg kg^{-1})	Maximum buffering capacity (axn) (mg kg^{-1})	Co-efficient of determination R^2 values
Amaeke	282	3.52	993	0.92
Bende	516	1.13	582	0.94

Table 4: Effect of soil types on growth and yield parameters

Soil Types	Plant height (cm)	Number of leaves/plant	Stem diameter (cm)	Pod length (cm)	Number of pods/pant	Pod weight g/plant	Number of seeds/ plant	Grain yield g/plant	Number of modules/ plant
Amaeke	25.2	14.3	0.32	6.75	5.67	3.23	9.00	2.26	8.14
Bende	32.8	17.6	0.58	6.50	13.4	6.38	8.73	4.40	45.7

Table 5: Summary of the Effect of Phosphorus Levels on Growth and Yield Parameters

P. solution Con. (µg g^{-1})	Plant height (cm)	Number of leaves/plant	Stem diameter (cm)	Pod length (cm)	Number of pods/pant	Pod weight g/plant	Number of seeds/ plant	Grain yield g/plant	Number of modules/ plant
0	21.3	14.1	0.37	4.49	5.87	3.21	5.68	2.15	30.5
0.1	24.6	16.5	0.42	5.23	8.07	4.58	7.16	3.31	20.2
0.2	24.6	16.9	0.39	6.20	10.1	5.25	7.95	3.72	39.0
0.3	27.2	18.0	0.42	5.79	10.0	5.54	7.83	4.02	24.2
0.4	25.5	16.5	0.39	5.63	8.00	4.55	7.25	3.29	44.5
$LSD_{0.05}$	2.75	2.49	0.06	0.93	2.20	1.05	1.42	0.75	23.5

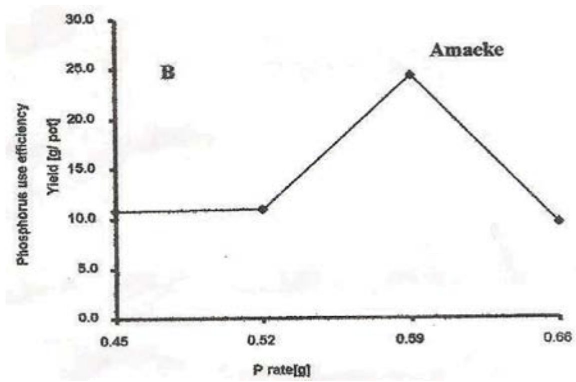

Fig. 4: Phosphorus Use Efficiency (PUE) for soils of Amaeke

Phosphorus Use Efficiency (PUE) in the Soils: Figure 4 and 5, shows the phosphorus use efficiency (PUE) for the two soils studied. The higher P application rate, the lower the PUE for the soils. Similar observations have been reported by Kogbe and Adediran [42]; and Uzoho and Oti, [32]. This shows that the efficiency of P utilization of Mungbean decreased as the P fertilizer rate increased. The highest P use efficiency occurred in Bende at 8.38 kg ha^{-1} P.

Uzoho and Oti [32] reported 9 kg ha^{-1} for maize on Bende soil and Amaeke at 26.5 kg ha^{-1}. Additional use of P fertilizer beyond this rate reduced the yield the relative yield increases were 1448 kg ha^{-1} (Bende) and 928 kg ha^{-1} (Amaeke). The relatively high grain yield in Bende soil correspond to phosphorus concentration of 0.2 µug^{-1} in equilibrium solution while the optimum yields in Amaeke were at 0.3 µug^{-1} solution concentration of phosphorus. Efficiency of P utilization was highest in Bende and could be explained by its low P adsorption capacity as well as the low affinity co-efficient with which adsorbed P was held, making it more readily available for the crop uptake. The low efficient P utilization in the others soil suggests the needs for incorporation of organic matter as management strategy for crop production.

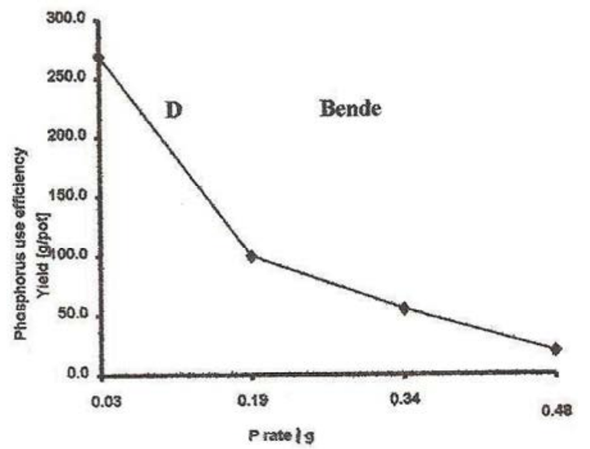

Fig. 5: Phosphorus Use Efficiency (PUE) for soils of Bende

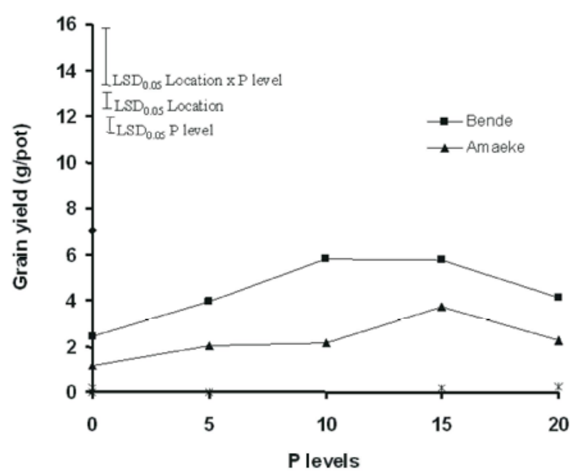

Fig. 6: Effect of soil types on mungbean yield

Effect of Soil Types and Phosphorus Rates on Grain Yield (g/plant): Figure 6 shows the effects of soils types and phosphorus rate on grain yield (g/plant). Grain yield per plant varied within the two soils studied. The yield was not significantly different in other location at (P>0.05) level. Bende soil had higher grain yield than Amaeke. The yields at zero P (control) rate were however significantly lower than yields at other P rates, indicating response of the crop to P application. The optimum mungbean yield in the soils could be achieved at a P fertilizer rate of 8.38 kg ha^{-1} in Bende and 26.5 kg ha^{-1} in Amaeke. This is equilibrium solution concentration of between 0.2 μug^{-1} and 0.3 μug^{-1}. These rates are in agreement with those reported by Uzoho and Oti [32] and are lower than the maximum rate of 40 kg ha^{-1} P proposal for soils of southeastern Nigeria [33, 37]. Osodeke [1] reported P rate of 65 kg ha^{-1} in Bende to be adequate for cowpea production. The greater seed weight in Bende could be as a result of high organic matter content in the soil as shown in Table 4. Organic matter tends to suppress phosphate fixation by adsorbing ions, or forming complexes with Ca^{2+} ion or by producing H^{+}. The lower yield in Amaeke may be due to aluminum toxicity, which normally occurs in soils with pH values less than 5.5 [43]. The interaction between the soils types and P rates was significant at ($P < 0.05$).

CONCLUSION

The study showed that the soils were acidic and light textured. The soil had very low phosphorus adsorption capacity. The mungbean also responded to the applied phosphorus with concentration solution 0.20 μug^{-1} equivalents to 8.38 kg ha^{-1} giving the best grain yield in Bende soil. While, 0.3 μug^{-1} P solution gave the optimum grain yield at P rate of 26.5 kg ha^{-1} in Amaeke soil. Therefore, these P rates are recommended for the soils studied. The use of P isotherm technique for P fertilizer determination is therefore recommended for efficient P fertilization practice in soils of Southern Eastern Nigeria.

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