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NUTRIENT USE EFFICIENCY OF SOYBEAN AS AFFECTED BY PHOSPHORUS FERTILIZATION IN THE SOUTHERN GUINEA SAVANNA OF NIGERIA

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ABSTRACT

The study was carried out at Teaching and Research Farm of the Federal University of Technology Minna to determine the effect of Phosphorous fertilization on the agronomic nutrient use efficiency (ANE) and partial factor of productivity (PFP) of P in soybean production. The treatments consisted of five P rates (0, 15, 30, 45, and 60 kg ha^{-1}), these were factorially arranged and laid out in a randomized complete block design (RCBD) with three replicates. Physicochemical properties of soil of the experimental site was assessed using a standard procedure described by IOAC. The result of soil analysis revealed that, soil of the study site was dominated by sand with slightly acidic reaction. The result further showed that, soil organic carbon was low while available P was moderate. There was response to P with the highest grain yield of 857 kg ha^{-1} obtained from soybean fertilized with 45 kg P^{-1}. The efficiency of applied nutrients in increasing grain or biomass yield (ANE) and increase in yield pertaining to an increase in only a single specific nutrient applied (PFP) were significantly affected by P fertilization and their values were significantly reduced as the P rate increased. Application of 15 kg P ha^{-1} had the highest ANE and PFP values of 9 kg grain kg P^{-1} and 42 kg grain kg P^{-1}respectively. Phosphorus fertilizer may be applied at rate of 15 kg ha^{-1} for economic and profitable yields and for efficient use of P to minimize environmental pollution by P. In conclusion, Phosphorus was more efficiently used by soybean at lower rate compared to a higher rate as indicated by ANE and PFP. The study recommends Lower rate of P should be applied for higher P use efficiency. Phosphorus fertilizer should be applied at the rate of 15 kg ha-1 for economic and profitable yields of soybean.

Key words: Efficiency, Fertilizer, Moist, Responsiveness and Phosphorus

INTRODUCTION

Soybean is an important leguminous crop widely cultivated in Nigeria for food, oil, and feed purposes. It is grown due to its inherent ability to fix nitrogen from atmosphere and improve soil fertility thereby boosting crop production (Samuel *et al.*, 2022).It provides dietary proteins for not only human but also animal feed in the form of soy meal, which makes up approximately 98% of global livestock feed (Dos Santos *et al.*, 2022). In Nigeria, soybean accounts for339 mt of the 578.7 mt of the total world oilseed production, which is approximately 59 % of the total world oilseed production (Soystats, 2021).Despite the numerous benefits of the crop, soybean grain yield per unit area in Nigeria is low, estimated at 970 kg ha^{-1} compared to the worldwide average yield of 2791 kg ha^{-1}(FAOSTAT 2018) and this can be attributed to inefficient use of fertilizer. The current fertilizer recommendations in the country are mainly blanket and often specified to the level of agroecological zone (AEZ) (Ichami *et al.*, 2019). As a result, there is low response of crops to fertilizer, which makes the recommendations to be of limited in relevance to the farmers (Tittoneil *et al.*, 2013).

Blanket fertilizer recommendations both in terms of type and amount can be assessed using indicators such as agronomic nutrient use efficiency (AEN) (Ichami *et al.*, 2019) and partial factor productivity (PFP). The AEN is a measure of the increase in crop yield for a given amount of nutrient added and can be used to evaluate the efficiency of a specific nutrient applied. It indicates how much productivity improvement was gained by the application of the nutrient and used as a short-term indicator of the impact of applied nutrients in productivity (Ichami *et al*., 2019). The PFP is determined by dividing the grain yield with the amount of nutrient applied; therefore, it is an indication of production per unit of nutrient applied. The PFP addresses show productive the cropping system is compared to its nutrient input. It is considered the most important index for on-farm studies, among the different indices of nutrient use efficiency, as it integrates the use efficiency of both indigenous and applied nutrients (Mandal *et al*., 2015).

Blanket fertilizer recommendation scan be improved upon when there are better understanding of the factors that affect variability in response to fertilizers. Environmental factors including climatic such as rainfall variability, soil-related such as low level of organic carbon, and secondary and micronutrient deficiencies affect response to fertilizers across smallholder farming systems in Sub Sahara Africa (SSA) (Ichami *et al*., 2019).

Phosphorus despite being the second most important plant nutrient after nitrogen, it is mostly deficient in most of the arable soils, thus its application is essential to minimize yield losses. More worrying, phosphorus unlike N and other major nutrients, its natural reserve resources are non-renewable and limited (Cordell *et al*., 2009). There is need therefore to use p efficiently so as to conserve the resource base and minimize its pollution of the environment while maintaining or improving crop productivity.

The low efficiency of P fertilization has been reported in different researchers (Dorahy *et al*., 2008; Takashi and Anwar, 2007; Murphy and Sanders, 2007; Sanders *et al*., 2012).However, in the southern Guinea savanna of Nigeria, there are few studies that determined the efficiency of P use as affected by P fertilization in soybean. Therefore, this study was carried out to determine the efficiency of P use when P fertilizer is applied using ANE and PFP of P.

MATERIALS AND METHODS

The Study Area

The study was conducted at the Teaching and Research Farm of the Federal University of Technology Minna during 2023 cropping season. The site is located on Latitude 9° 31'54.06" N; Longitude 6°27'20.5" E, 234 m above sea level in the southern Guinea savanna of Nigeria. The climate of Minna is sub-humid and the rainfall pattern is monomodal, with the rainy season starting from March and ending in October. The monthly rainfall during the period of the study is shown in Figure 1. The physical features around Minna consist of gently undulating high plains developed on basement complex rocks made up of granite, migmatites, gneisses and schists (Ojanuga, 2006). The soil of the site was classified as a Typic Plantstuff (Lawal *et al*., 2012). Prior to the study over the years, the field has been cultivated with maize with little or no fertilizer application.

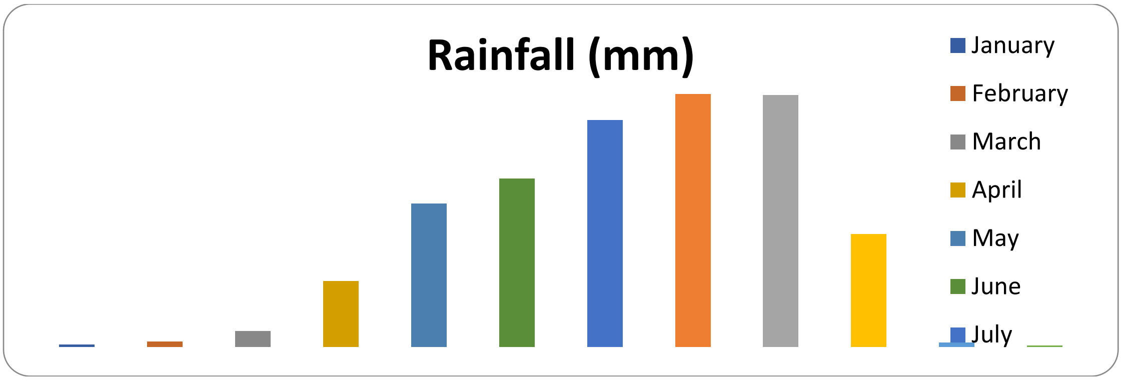

Figure 1: *Monthly rainfall distribution in Minna, during the period of the study.*

Treatments and Experimental Design

The treatments consisted of five phosphorous rates (0, 15, 35, 45, 60 P kg ha^{-1}), these were factorially arranged in a Randomized Complete Block Design (RCBD) with three replications given a total of 15 plots. The gross plot size was 6 m by 7 m and the net plot size was 5 m by 6 m (30 m^2) with an alley of 1 m.

Agronomic Practices

The field was manually cleared and ridged 75 cm apart. The soybean variety used TGX 1904-6F was sown (2 plants per stand) at 10 cm within the ridge. Thinning was done to one plant per stand at 3 weeks after sowing (WAS). All plots received basal application of 20 kg N ha^{-1}as urea and 30 kg K ha^{-1} as muriate of potash at 3 WAS. The P was applied as single superphosphate to required plots at 3 WAS. Fertilizers were applied by side banding, 5 cm away from the seedlings and about 5 cm deep. All plots were hoe-weeded at 3 and 6 WAS.

Soil Sampling and Analysis

Surface soil (0-15 cm) samples were collected before land preparation at regular interval from eight points along three diagonal transects. The samples from each transect were bulked together to give three composite samples, which was used to characterize the field before land preparation. The soil samples collected were air-dried, crushed gently, passed through 2-mm sieve and taken to the laboratory for physical and chemical analysis using the method described by ISRIC/FAO (2002) as follows; Particle size distribution was determined by the Bouyoucos hydrometer method. Soil reaction was determined potentiometrically in 1:2.5 soil to water and $CaCl_2$ suspension with the glass electrode pH meter. Organic carbon was determined by the Walkley and Black wet oxidation method. Total N was determined by the Kjeldahl digestion method. Available phosphorus was extracted using Bray No. 1 method and the P concentration in the extract was determined calorimetrically using spectrophotometer. Exchangeable bases were determined by extraction with 1N NH_4OAC. Potassium and Na in the extract were determined with a flame photometer, while calcium and magnesium were determined using an atomic absorption spectrophotometer. The Exchangeable Cation Exchange Capacity (ECEC) was determined by summing the exchangeable bases and the exchangeable acidity. Soybean grain yield analysis was carried out by harvesting five soybean plants from each plot. These plants were sun dried for 2 weeks, threshed, winnowed and weighed.

Analytical Technique

The AE and PFP were calculated using the formulae below

i. $AE_p = Y_p\text{-}Y/N$ (Ichami *et al.*, 2019) … (1)

Where,
AE_p = Agronomic efficiency
Y_p = Yield in kilogram of P fertilized crop
Y = Yield in kilogram of control or unfertilized crop
N = phosphorus applied in kilogram

ii. $PFP = Y_p/N$ (Doberman, 2007) …(2)

Where,
PFP = Partial factor productivity
Yp = yield in kilogram of fertilized crop
N = Phosphorus applied in kilogram.

The General Linear Model Procedure of Statistical Analysis System Software (SAS, 2015) was used for statistical analysis of the data including analysis of variance (ANOVA) and means separation where F values were significant was carried out by Student Newman Kuels (SNK) Test at 5 % level of probability unless otherwise stated.

RESULTS AND DISCUSSION

Physicochemical Properties of Soil of the Experimental Site

The result of the initial soil characteristics of the study area is presented in Table 1. Sand was the dominant fine earth fraction in the soil with a value of 679 g kg^{-1}. This confers on the soil a sandy loam texture. The coarse nature of the soil indicates low water holding capacity and availability, making the soil susceptible to drought stress during even short rainless period. The soil has a slightly acidic reaction, implying that nearly all plant nutrients are available in optimum amount. The soil organic carbon (SOC) and nitrogen (N) were low, while phosphorus (P) was moderate in the soil (Chude *et al.*, 2011). The low content of SOC implies low reserve of soil organic matter which is responsible for low N in the soil. The typically insufficient rates of organic inputs such as manure or crop residues applied to croplands due to low crop productivity and livestock density and alternative use of crop biomass for energy and construction are also partly responsible for the low content of organic matter in tropical soils (Koatterer *et al.*, 2011). The relatively low N compared to organic carbon will lead to stabilization of N in the soil and minimize it via nitrification coupled to nitrate leaching and denitrification due to high microbial N use efficiency (Zhang *et al.*, 2019).Available P content was moderate implying that the soil might not need application of phosphorus fertilizer in the short run for optimum yield of soybean. The exchangeable cationic plant nutrients; Ca^{2+} and K^{+} were low while Mg^{2+} was rated moderate (Chude *et al.*, 2011). The low content of these cationic nutrients is a reflection of the low organic matter content of the soil. The exchangeable acidity was 0.53 cmol kg^{-1} and was rated low. The effective cation exchange capacity of the soil was generally low and contains low amounts of exchangeable cations this means low fertility status of the soil (Ronner *et al.*, 2016).

Table 1. Means of initial soil properties prior to land preparation in 2023

Parameter	Value
Sand (g kg^{-1})	679
Silt (g kg^{-1})	166
Clay (g kg^{-1})	155
Textural class	Sandy loam
pH (H$_2$O)	6.7
Organic Carbon (g kg^{-1})	4.60
Total Nitrogen (g kg^{-1})	0.20
Available Phosphorus (mg kg^{-1})	15
Exchangeable Bases (cmol kg^{-1})	
Ca^{2+}	3.70
Mg^{2+}	1.70
K^{+}	0.24
Na^{+}	0.45
Exchangeable Acidity (cmol kg^{-1})	0.50
Effective Cation Exchange Capacity (cmol kg^{-1})	6.62

Effect of Phosphorus Fertilization on Grain Yield

Phosphorus fertilization had a significant effect on grain yield (Table 2). Treatment with 45 kg P ha^{-1} produced the highest grain yield of 857 kg ha^{-1} and lowest grain yield of 541 kg ha^{-1} was recorded from the control. Application of P fertilizer increased the grain yield significantly over the control. The treatment with 45 kg P ha^{-1} produced 58% grain yield more than the control. The findings are in agreement with Abbasi *et al.* (2012), who reported yield increases of up to 53% with increased P application. Aulakh*et al.* (2003) observed increasing seed yield following P rates of up to 80 kg ha^{-1}. However, yield at 80 kg ha^{-1} P was statistically similar to 100 kg ha^{-1} P on irrigated soybean.

Table 2. Effect of phosphorus fertilization on yield and yield component

Treatments	Grain yield (kg ha^{-1})
0 kg P ha^{-1}	540.6b
15 kg P ha^{-1}	629.7b
30 kg P ha^{-1}	670.4b
45 kg P ha^{-1}	857.1a
60 kg P ha^{-1}	708.3ab
SE±	50.4

Means within column followed by same letter are not significantly different at $P < 0.05$

Effect of Phosphorus Fertilization on Nutrient Use Efficiency

Effect of phosphorus fertilization on ANE and PFP of P is shown in Table 3. Phosphorus fertilization significantly affected agronomic use efficiency. Agronomic efficiency (kg grain per kg P applied) decreased with increasing P rate. The highest agronomic efficiency of 9 kg P^{-1} was observed in treatments with 15 kg P^{-1} and declined as the treatment increased up to 60 kg ha^{-1}. This is consistent with the findings of (Munthali *et al.,* 2017) who found AE to decrease with increasing P levels. Yadav *et al.* (2017) also found that increasing the phosphorus level from 0 to 20 kg ha^{-1} resulted in the highest agronomic efficiency and apparent recovery of phosphorus. The higher agronomic efficiency at lower P rates is likely a result of intense root competition, leading to the efficient utilization of the applied phosphorus. When P application rates are higher, plants tend to use a smaller proportion of the fertilizer P resulting in a lower P use efficiency (Ghafoor, 2016). The utilization efficiency of P has been reported to be affected by rate of P fertilization (Syers *et al*., 2008).

Partial factor of productivity was significantly affected by P fertilization. The PFP was much higher when lower rates of phosphorus were applied and decreased as the rate of nutrient application increased. The highest value of PFP (42 kg ha^{-1}) was recorded in treatment with 15 kg P^{-1} and declined as the rate increased to 60 kg P ha^{-1}. Shilpa *et al.* (2021) found that PFP was notably higher, ranging from 24.28 kg kg^{-1} in the case of finger millet mono-cropping to 110.50 kg kg^{-1} in finger millet-groundnut rotation. Beyond a certain point, further phosphorus application became non-beneficial and uneconomical, as the plants absorbed smaller proportion of the applied phosphorus, with the rest becoming fixed in the soil (Chandrakala, 2014).

Table 3. Effect of phosphorus fertilization on nutrient use efficiency

Treatments	**Agronomic efficiency (kg grain kg P^{-1})**	**Partial factor productivity (kg grain kg P^{-1})**
15 kg P ha^{-1}	9a	42a
30 kg P ha^{-1}	3b	21b
45 kg P ha^{-1}	7ab	19b
60 kg P ha^{-1}	3b	12b
SE±	1.4	3.3

Means within column followed by the same letter are not significantly different at $P < 0.05$

CONCLUSION AND RECOMMENDATIONS

The findings of the study indicate that P was more efficiently used by soybean at lower rate compared to a higher rate as indicated by the AE and PFP.Fertilizer recommendation for the area can be modified to include P application at rate of 15 kg ha^{-1} to enhance the economic and profitable yields of soybean and for efficient use of P to minimize environmental pollution by P.

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