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Enhancing the Productivity and Sustainability of Bambara Groundnut (*Vigna subterranea* (L.) Verdc.) Production Using Inorganic Phosphorus Fertilizer

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Abstract

Phosphorus (P) is a vital element required for nodulation, stomatal regulation and photosynthesis in legume crops. P-deficiency in tropical soils limits the growth and productivity of Bambara groundnuts. The current study focused on determining the potential suitability of underutilized crops for food security using phosphorus fertilizer as soil amendment practice. A field trial was carried out at the Council for Scientific and Industrial Research—Crops Research Institute (CSIR-CRI), over two growing seasons to determine the optimum P rate for Bambara production. This trial was laid out in a split plot in a randomized block design with three replications. Bambara genotypes represented the main plots while four P fertilizer rates (0, 30, 45 and 60 kg P_2O_5 ha^{-1}) were the sub-plots. The appropriate application rate of 60 kg P_2O_5 ha^{-1} showed excellent performance based on growth and yield analysis, and the results indicate a positive significant interaction between landraces and phosphorus fertilizer rates. The biological suitability of 60 kg P_2O_5 ha^{-1} increased the number of nodules per plant for Tiga Necuru, Kenya Capstone and Nav Red by 42.8%, 51.3% and 42.1% respectively, over control plots. The same for pod yield is 12%, 28% and 52% significantly higher than when P was applied at 45, 30 and 0 kg P_2O_5 ha^{-1} respectively. The results further revealed that on days to flowering and maturity, the plant height, the number of branches and dry matter increased significantly at each level of P fertilizer rate applied. Bambara production at 0 kg P fertilizer rate might not be sufficient to enhance Bambara productivity significantly. The outcome of this study reveals the suitability of phosphorus fertilizer application in enhancing the sustainability of Bambara groundnut productivity and the potential of Bambara in diversifying crop production to ensure food security.

Keywords

Bambara Groundnut, Phosphorus, Genotypes, Pod Yield

1. Introduction

Increasing crop production to meet global food demand requires an increase in fertilizer usage in environments that are highly depleted of soil nutrients across Sub-Saharan Africa. Contrary, the production of legumes, however, rarely receives any form of mineral phosphorus (P) fertilizer and relies solely on naturally available soil phosphorus and other nutrients for nitrogen fixation and growth. There is evidence that legume yields significantly decrease due to deficiency in soil P which contributes to low N-fixation [1].

Phosphorus (P), along with nitrogen (N) is the most important growth hampering mineral nutrient for plant growth in the world [2]. Soil P, unlike other nutrient sources such as nitrogen, cannot be fixed from the atmosphere through symbiotic association. Because most soils are deficient in P, a high-yielding and nutrient mining crop's P requirement must be met regularly through the use of exogenous applications of different fertilizers.

In studies of balanced nutrition, phosphorus is an important nutrient element for enhancing N-nutrition and biological nitrogen fixation to the soil by legumes. The basic physiological function of any crop that is associated with biomass production and grain yield is affected by P-availability, uptake and translocation and directly influences root development, root nodulation and increases grain yield in legumes [3]. Largely in Ghana, Bambara groundnut production usually occurs on marginal soils, which are mostly deficient in several nutrients including P and N [4]. The continuous soil nutrient loss in sub-Saharan Africa continues to deteriorate due to rising fertilizer costs among rural smallholder farmers in developing countries with a declining human capacity for soil and natural resource research [5]. However, closing the huge yield gap existing between sub-Saharan Africa and other developed world requires the adoption of improved soil nutrient management and accompanying good agronomic practices and the use of improved crop varieties [6].

Better management of soil fertility is imperative for crop production and [3] reinforce the positive influence of P fertilizer on crop growth and yield on highly leached soils. According to [6], a maximum application rate of 75 kg P ha^{-1} of single super phosphate fertilizer increased leaf dry weight, stem and root dry weight, number of nodules per plant, number of fresh pod per plant, fresh pod weight and soil total nitrogen on a degraded Ultisol soil in Southeast Nigeria. Based on the positive response to P fertilizers, [7] and [8] recommended a routine application of phosphorus fertilizer if the pod yield of legume is to be improved substantially. The use of phosphorus fertilizer represents a means to overcome the dilemma of low legume productivity by offering high yields through proper utilization of nutrient under circumstances where the crop seldom receives any form of mineral phosphorus fertilizer but rely entirely on naturally available soil phosphorus and other nutrients for growth and yield.

There are various reports on Bambara groundnut nutrition that shows that climate, site conditions, genotypes and cultural practices greatly influence the response of Bambara to P application [9]. Even when optimal fertilizer rates have been determined, interactions between phosphorus fertilizer and genotypes on yield and yield parameters of Bambara groundnut need to be considered. As a result, new technologies, current cultural methods and more productive cultivars are required to ensure food security in Ghana. Phosphorus application could be used as a cost-effective and efficiently proven ability to improve Bambara groundnut yield and soil qualities. Due to its variable performance in diverse soil and climatic conditions, the response of Bambara to P is not well documented. To better understand the effect of phosphorus in increasing Bambara growth and yield and P availability from different levels on limiting P soils in Ghana, this study was conducted.

2. Materials and Methods

2.1. Study Site

The experiment was conducted in the 2017 and 2018 growing season at the Council for Scientific and Industrial Research—Crops Research Institute (CSIR-CRI) experimental field at Fumesua (6˚45 00.58'N; 1˚31 51.28'W) in the semi-deciduous forest zone of Ghana. The soil type is Ferric Acrisol with low fertility and moisture retention capacity. This study site is characterized by a major cropping season between March and mid-August, followed by a minor cropping season with moderate rains from September to November. The average long-term maximum and minimum temperatures ranged from 20˚C to 32˚C.

2.2. Plant Material

Three genotypes of Bambara groundnut, *Nav Red* (Red), *Kenya Capstone* (Black) and *Tiga Necuru* (Cream) were used in this study. *Tiga Necuru* and *Kenya Capstone* were sourced from Mali and Kenya respectively. The local cultivar (*Nav Red*) was sourced from the CSIR-Crops Research Institute. The selection of the three landraces was based on seed coat color (Kenya Capstone = black; Tiga = Cream and Nav Red = Red), with the three landraces exhibiting similar growth patterns and maturity groups. All three landraces used were medium maturing (90 - 110 days) landraces with erect growth architecture.

2.3. Crop Management

The land was ploughed and harrowed to obtain the desirable tilth. The whole experimental land was divided into unit plots following the design of the experiment. A total land area measuring 288 m^2 were used for the experiment. The land was divided into three blocks, and each was sub-divided into twelve plots making a total of thirty-six plots. Plots measuring 3 m × 2 m (6 m^2) were separated by 1 m × 1 m pathway between and in between plots. The Bambara seeds were planted at 10 cm depth using 0.20 m × 0.50 m planting distance at one seed per hole giving a plant population of 100,000 plants $hectare^{-1}$.

Phosphorus fertilizer was applied according to experimental treatment. A single source fertilizer in the form of triple super phosphate (TSP) was used and applied at sowing. The seeds of Bambara groundnut were sown in rows made by hand plough. Two weedings were done during the study period. Irrigation was given at the early stage of the crop because of the absence of sufficient moisture in the field.

2.4. Experimental Treatments and Design

The treatments consisted of three (3) Bambara groundnut genotypes (Nav Red, Kenya Capstone and Tiga Necuru) and 4 rates of phosphorus fertilizer (0, 30, 45 and 60 kg P_2O_5 ha^{-1}). The experiment was laid out in a split plot in randomized block design in a split-plot arrangement with three replicates. The main plot treatments were the three Bambara groundnut genotypes; *Nav Red*, *Kenya Capstone* and *Tiga Necuru*. The sub-plot treatments consisted of the four levels of triple super-phosphate (TSP) phosphorus fertilizer; 0, 30, 45 and 60 kg P_2O_5 ha^{-1}.

2.5. Sampling and Measurement

Before the phosphorus fertilizers were applied, a mixed soil sample was collected using an auger at 0 - 15 cm depth from randomly selected positions to provide baseline soil data. Each soil sample was air-dried, ground, passed through a 2 mm sieve to remove stones and analyzed for soil organic matter, pH, available P, available N and available K content (**Table 1**). Using routine analytical methods [10], soil pH was measured in a soil-to-water suspension ratio of 1:1, available N (AN) was determined by Alkali N proliferation method, available P (AP) and available K (AK) were determined by the molybdate blue and flame photometry methods, respectively. Hydrometer method was used to determine the texture of the soils.

Table 1. Attributes of selected genotypes.

	Genotype	Traits Of Interest	Seed Colour	Source
1	Kenya Capstone	Dual purpose; drought tolerance	Mottled Black	Kenya
2	Nav red	High yielding; dual purpose	Red	Ghana
3	Tiga Necuru	High yielding	Cream	Mali

Samples of nodules for nodule count were collected from six plants at 50% flowering growth stage by cutting the stem at about 5 cm above ground level. The roots were carefully dug to a depth of 30 cm using a hand shovel. The roots together with detached nodules collected from the soil were placed in transparent polyethylene bags and labeled accordingly. The roots were then washed thoroughly on a 1 mm sieve mesh under running tap water to remove the adhered soil. The nodules were removed, blotted dry using a paper napkin and counted.

Ten randomly selected plants were marked in each plot and harvested separately to measure the height, number of branches and dry matter accumulated. Dry weights were obtained after oven-drying at 80˚C for 72 hours. At maturity, plants were harvested from the central row of an area of 3.4 m^2 in each treatment (sub-plot) for yield component evaluation. Grain yield was reported at 10% moisture content by weight. Non-destructive observations included dates of mid-flowering and maturity of each plant. Daily counts of open flowers per plant were carried out on six plants per treatment per replicate from the onset of flowering to the onset of podding of these plants.

2.6. Statistical Analyses

The data were analyzed as a Factorial Repeated Measure (RM) Analysis of Variance using GenStat version 11.1. Where R is the response variable [the growth and the yield traits of Bambara groundnut] measured for 2017 and 2018 and two factors; genotype and P fertilizer rate having 3 and 4 levels respectively in three replicates.

Suppose R_{kji} = observation on unit k in the j^{th} group at time i, where $k = 1,\cdots,a_j$, where a_j represents the number of units in group *j*. $j = 1,2$; i = 2017 and 2018. The model for R_{kji} is given by:

$$R_{kji} = \alpha + \beta_j + \rho_i + (\beta\rho)_{ji} + c_{kj} + \epsilon_{kji} \quad (1)$$

where $\propto$ is the "overall mean", β_j is the deviation from the overall mean associated with being in group *j*; ρ_i is the deviation associated with time *i*; $(\beta\rho)_{ji}$ is an additional deviation associated with group *j* and time *i*; $(\beta\rho)_{ji}$ is the interaction effect for group *j* and time *i*. Also, c_{kj} is the random deviation as a result of among-unit causes, ϵ_{kji} is the random error as a result of within-unit variation [11]. A Greenhouse-Geisser epsilon correction factor was applied to the degree of freedoms for the various response variables. The LSD (5%) was used for the separation of means.

3. Results and Discussions

3.1. Local Rainfall at the Experiment Site

Daily rainfall throughout the experiment was approximately 493 and 562 mm over the 90 days with near 35 and 31 days rainless (**Figure 1**).

An aggregate rainfall recorded during the planting period of this study was

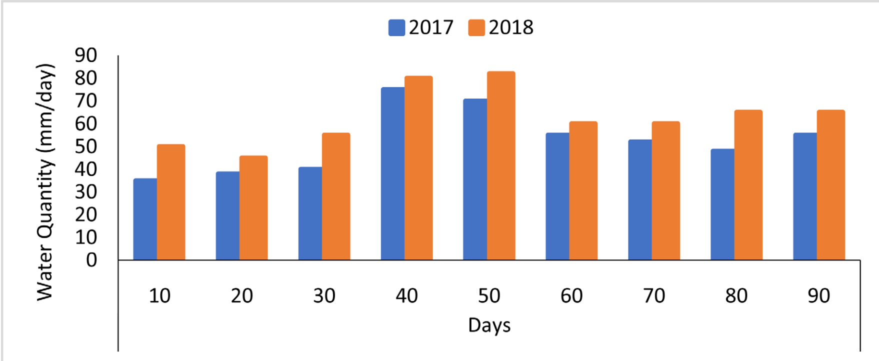

Figure 1. Rainfall distribution at Fumesua between September and December.

493 and 562 mm for 2017 and 2018 respectively (**Figure 1**). The average rainfall requirement for Bambara groundnut production has been estimated to range from 900 to 1000 evenly distributed over the growing season [12]. The recorded aggregate rainfall for this current study falls below the minimum rainfall requirement for the growth and development of Bambara groundnut. However, excessive rainfall conditions, especially during harvest, result in drastic yield losses.

3.2. Soil Properties

Results of the soil analysis showed low levels of N and available P as well as exchangeable calcium and magnesium (**Table 2**) based on the soil testing interpretation manual by [13]. However, variability in the N content of the soil among the two depths remained relatively low. The soil of the experimental site was sandy loam having a slightly acidic pH (5.7). According to [14], the soil P levels at the trial sites were far below the critical values recommended for Bambara groundnut. Available potassium and organic carbon levels were below the critical values required for the proper growth and development of legumes [15]. This could be attributed to the fact that the site was used for continuous maize cultivation, characterized by regular tillage practices and excessive use of inorganic fertilizers which contribute substantially to soil degradation through rapid organic matter depletion [16].

The potential of such soils is limited in supporting the growth and development of Bambara groundnut. For soils with low soil nutrient contents, the inclusion of P in soil management is irreplaceable because of the inability to replace it with any other element [17] indicating the need for improvement in Bambara groundnut productivity.

3.3. Effects of Phosphorus Fertilizer Rate, Variety and Year on the Growth Parameters

It was verified for the phenological parameters, days to flowering and days to maturity as well as plant height showed significant differences among Bambara genotypes, P fertilizer levels. However, there was no difference between the interactions

Table 2. Physical and chemical properties of soils of the experimental site.

	Soil Depth-2017	Soil Depth-2018
Soil Properties	**0 - 15 cm**	**0 - 15 cm**
pH (1:2.5)	5.69	5.5
Organic carbon (%)	1.21	1.25
Total Nitrogen (%)	0.11	0.12
Available P (ppm)	14.6	18.5
Organic Matter (%)	2.09	2.1
Exchangeable cation (cmol/kg^{-1})		
Calcium	4.26	4.28
Magnesium	2.13	2.2
Potassium	0.35	0.3
Sodium	0.16	0.15
T.E.B	6.9	6.8
Ex. Acidity	0.6	0.65
ECEC (cmolc·kg^{-1})	7.5	7.4
% Base Saturation	92	91.5
% Sand	86	86
% Silt	8	8
% Clay	6	6
Texture	Loamy sand	Loamy sand

among season by genotypes by P fertilizer levels for the days to flowering, days to maturity and plant height.

3.4. Effect of Varying Rates of P Fertilizer on Days to 50% Flowering of Bambara Groundnut Genotypes

Regarding the phenology attributes referring to the days to flowering of the genotypes, there was a significant difference between the effect of P fertilizer (**Figure 2(a)**); and the interaction of season × genotype (**Figure 2(b)**) on the number of days to flowering of Bambara groundnut was significant at the 5% significance level (**Table 3**). Genotype × phosphorus interaction was not significant for days to flowering.

The positive response of Bambara groundnut (BG) genotypes to phosphorus nutrition could be attributed to the stimulatory effect of phosphorus on growth hormones and its ability to induce early flowering in Bambara groundnut. These differences in the observed reduction in flowering days as influenced by phosphorus fertilization could confirm the influence of environmental conditions on the growth and development of Bambara groundnut [18]. The results agree with

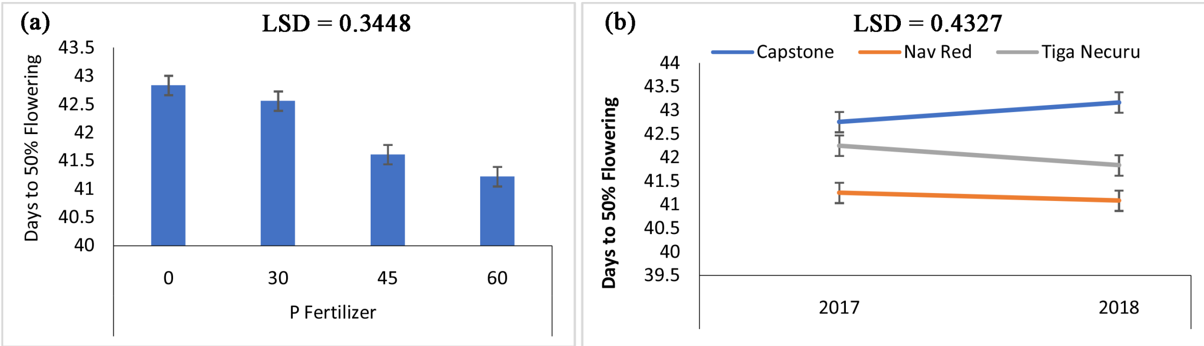

Figure 2. Effect of (a) Soil P fertilizer (b) interaction of Season × Genotype on days to 50% flowering.

Table 3. Summary of variance ratio from analysis of variance for Yield Parameters of Bambara groundnut.

Sources	Df	Emergence	Days to Flowering	Days to Maturity	Plant Height (cm)	No. of Branches
Genotype (G)	2	132.94***	77.45***	2321.72***	259.00***	32.82***
Soil P level (SP)	3	0.74	42.14***	81.70***	62.04***	10.97***
Genotype * Soil P	6	0.44	1.21	6.38***	0.43	0.69
Season (S)	1	6.23**	0.18	60.24***	175.56***	62.86***
Season * Genotype	2	0.69	3.59**	25.82***	1.00	1.93
Season * Soil P	3	0.28	2.97	5.80***	5.06***	12.25***
Season * Genotype * Soil P	6	0.59	0.92	1.27	1.00	1.07

the findings of [18] who reported that phosphorus application reduced the number of days to 50% flowering compared to the untreated plots.

3.5. Effect of Varying Levels of P Fertilizer on Days to Maturity of Bambara Groundnut Genotypes

The interactions of season × P fertilizer; season × genotype and genotype × P fertilizer on days to maturity were significant at the 5% significance level (**Table 3**). In each phosphorus fertilizer rate, Nav Red had significantly the least maturity days; followed by Tiga Necuru, which also had significantly lower maturity days than Capstone (**Figure 3(a)**).

The role of phosphorus in plant photosynthesis, biological nitrogen fixation of legumes and crop maturation investigated by [19] confirmed that the application of phosphorus decreases maturity days. Cultivation of various genotypes of Bambara groundnut has become one of the strategies to escape drought and enhance food security. Because of the relatively prolonged maturity days, the application of phosphorus to Bambara groundnut is partially, a significant means of reducing maturity days. The decrease in days to maturity with increasing levels

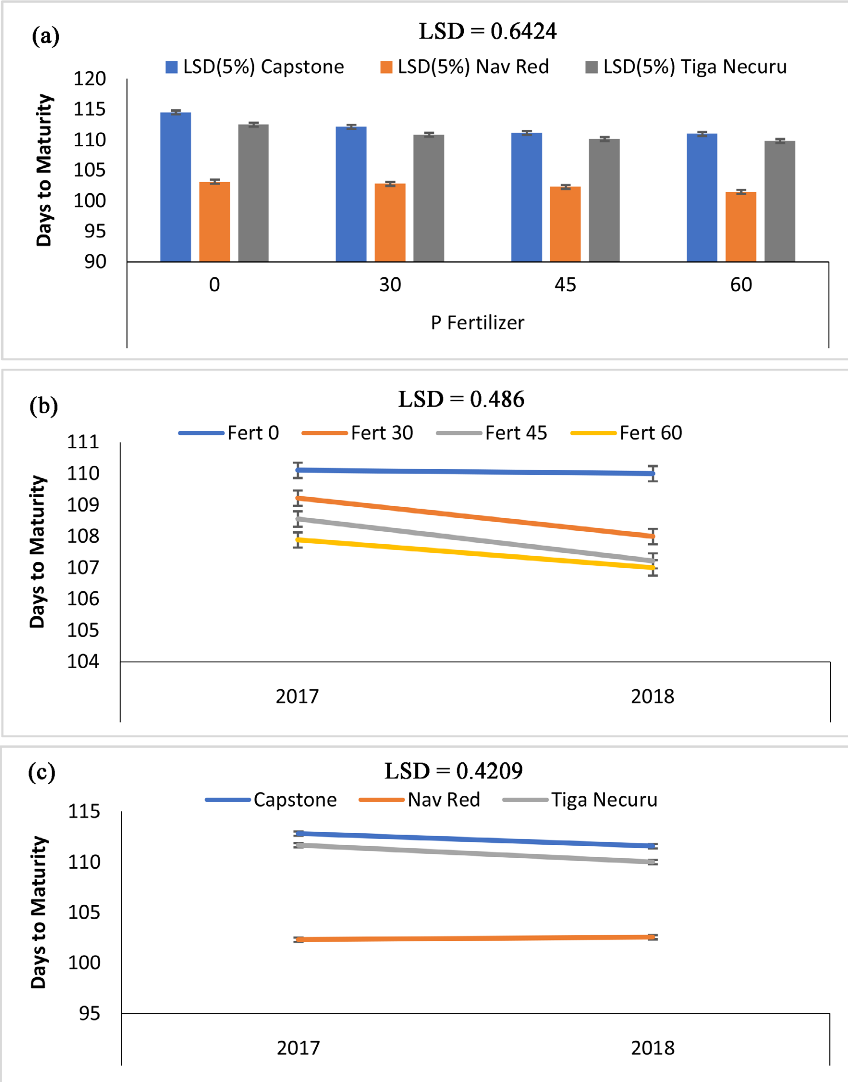

Figure 3. Effect of (a) interaction of Genotype × P fertilizer (b) interaction of Season × P fertilizer (c) interaction of Season × Genotype on days to Maturity.

of phosphorus dwells much on the fundamental role played by phosphorus in the reproductive phases of the crops which enhances their growth.

3.6. Effect of Varying Rates of P Fertilizer on Plant Height of Different Bambara Groundnut Genotypes

The effects of genotype and the interaction of season and P fertilizer rate on plant height (cm) were significant at the 5% significant level (Table 3). Nav Red had the lowest height, followed by Tiga Necuru, which was also significantly lower than Capstone (Figure 4(a)). The plant height measured was significantly increased by phosphorus fertilizer application, with all the levels of applied P (30, 45 and 60 kg P_2O_5 ha^{-1}) recorded as the highest plant height. The mean highest plant height (23 cm) was recorded in the application of 60 kg P_2O_5 ha^{-1} and was significantly different from other P levels. However, significant differences

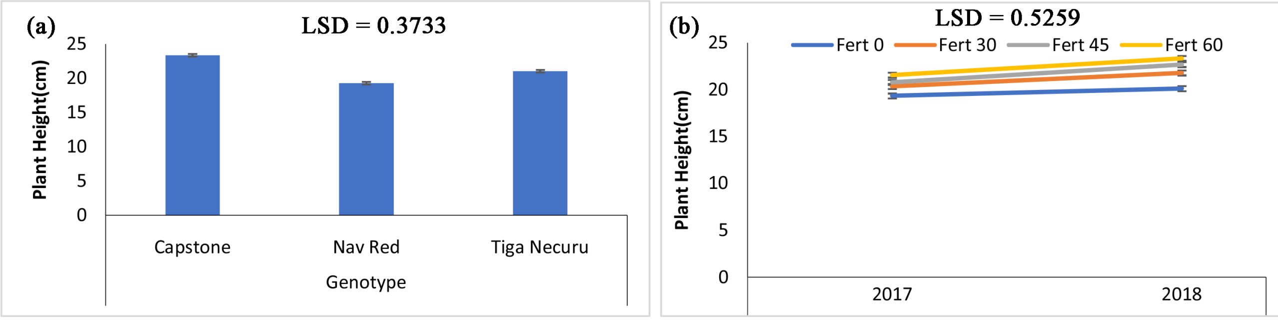

Figure 4. Effect of (a) Genotype (b) interaction of season × P fertilizer on Plant Height (cm).

were recorded between 45 kg P_2O_5 ha^{-1} and 60 kg P_2O_5 ha^{-1} treatments in both years.

Plant height was observed to have increased linearly with increasing application of phosphorus fertilizer relative to the control treatment (Figure 4(b)). Previous studies have reported similar relations between plant height and increasing phosphorus application for different leguminous species including soybean [20] and cowpea [21]. In this study, the increased plant height associated with increasing P levels might have resulted from phosphorus fertilizer's ability to regulate enzymatic reactions leading to the enhancement of plant metabolism and formation of new cells and consequently increasing stem length [22]. The control plants produced the shortest plants as they had to rely on the native soil fertility which from the result of the chemical analysis was deficient in nutrients.

Effects of Phosphorus fertilizer rate, variety and year on the Yield Parameters of Groundnuts

3.7. Effect of Varying Rates of P Fertilizer on Nodule Count of Different Bambara Groundnut Genotypes

Variations attributable to the interactions between phosphorus rate and genotype were significant for the number of active nodules per plant (Table 4). Bambara genotypes responded differently to different rates of phosphorus application in terms of nodule count. Similarly, genotypes that received 60 kg P_2O_5 ha^{-1} had a significantly higher number of nodules per plant compared to 0 kg P_2O_5 ha^{-1}. These results showed that for Tiga Necuru, Kenya Capstone and Nav Red, the number of nodules per plant increased by 42.8%, 51.3% and 42.1% respectively when compared with their corresponding genotypes plots that did not receive SSP fertilizers in the two seasons (Figure 5(a)).

[8] reported that phosphorus had no significant effect on nodule count on Bambara groundnut. Our somewhat different results suggest that the response of Bambara to phosphorus fertilizer may differ depending on the environment and cultural practices [7]. In this study, the soils had low levels of P (12 - 18 ppm) resulting in a strong nodule response to P. In addition, phosphorus fertilizer is required for plant growth and development as it helps in root development and also serves as an energy source, which in turn may lead to increased nodule

Table 4. Summary of variance ratio from analysis of variance for Yield Parameters of Bambara groundnut.

Sources	df	No. of Pods per Plant	Pod Yield (kg/ha)	Dry Matter (kg/ha)	100 Seed Weight (g)	Nodule Count at 60
Variety	2	28.46***	137.19***	394.34***	172.73***	17.95***
P Fert	3	81.69***	1075.44***	217.99***	293.43***	182.16***
Genotype * P Fert	6	0.49	6.01***	5.90***	5.27***	2.75**
Season	1	764.02***	14.88***	242.68***	806.36***	222.15***
Season * Genotype	2	116.42***	1.98	1.84	23.59***	0.73
Season * P Fert	3	0.61	25.07***	39.66***	34.68***	2.13
Season * Genotype * P Fert	6	0.73	1.80	6.00***	1.80	2.44

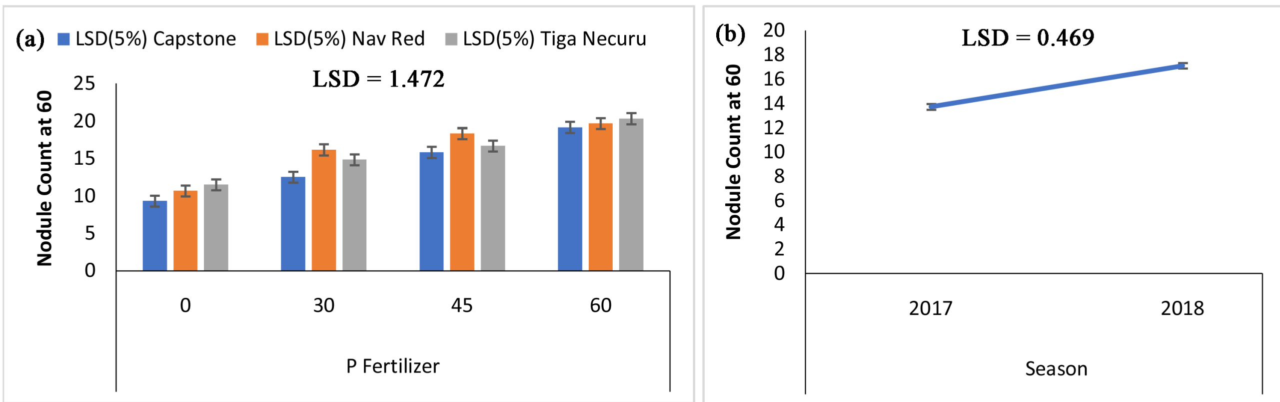

Figure 5. Effect of (a) interaction of Genotype and P fertilizer (b) Season on Nodule Count at 60.

formation thereby enhancing N_2 fixation. The results obtained agree with the work by [23] who reported that the nodule number per plant increased when P was applied.

3.8. Effect of Varying Rates of P Fertilizer on Pod Load of Different Bambara Groundnut Genotypes

The effects of phosphorus fertilizer rate and the interaction of season × Genotype on a number of pods per plant were significant at the 5% significant level (Table 4). The three genotypes of Bambara groundnut responded differently to the application of phosphorus at different rates. The genotype plots fertilized with 60 kg P_2O_5 ha^{-1} produced the highest number of pods per plant (35) of Bambara groundnut and this was significantly higher than when P was applied at 45 kg P_2O_5 ha^{-1}, 30 kg P_2O_5 ha^{-1} and 0 kg P_2O_5 ha^{-1} by 11.4%, 25.7% and 34.3% respectively for the two cropping seasons (Figure 6(b)).

The increase in the number of pods per plant recorded in this study is due to the increased supply of phosphorus [24] that, the application of P fertilizer stimulates node and pod formation in legumes so the P applied may have caused this increase through increased podding [24]. The observation by [7] [23] that a significant increase in pod number per plant in various legume plants was due to

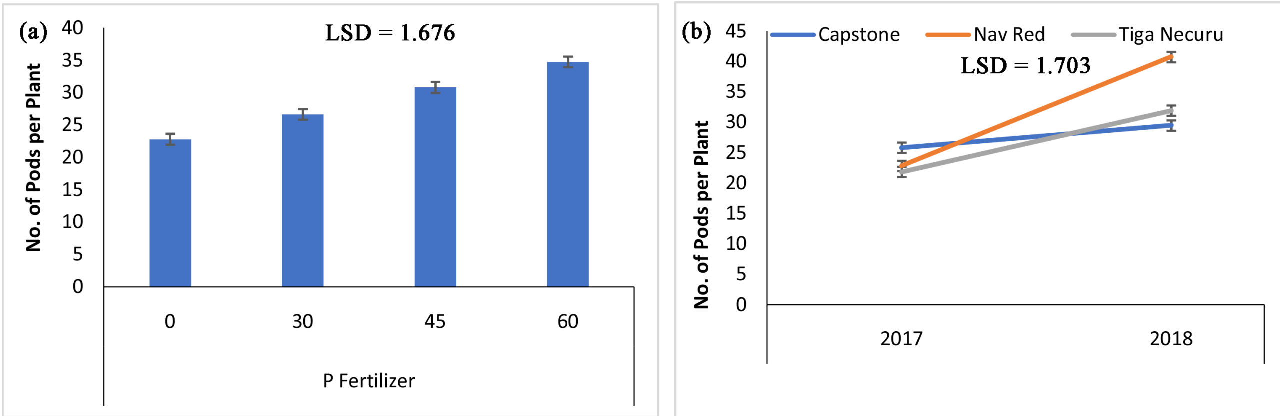

Figure 6. Effect of (a) P fertilizer (b) interaction of season × genotype on number of pods per plant.

increased P application confirms the results obtained in this current study. In considering the above yield parameters, it is obvious that the wider genetic variation in pod production is by far influenced by climatic and edaphic conditions, of which phosphorus application is immeasurable.

3.9. Effect of Varying Rates of P Fertilizer on 100 Seed Weight of Different Bambara Groundnut Genotypes

The effect of the interactions between genotype and fertilizer rate; season and genotype; season and fertilizer rate on Hundred Seed Weight were significant at the 5% significance level. The 100 seed weight increased significantly with an increasing rate of single super phosphate fertilizer added to the soil in the order of influence of 45 kg P_2O_5 ha^{-1} < 55 kg P_2O_5 ha^{-1} < 61 kg P_2O_5 ha^{-1} < 62 kg P_2O_5 ha^{-1} for Kenya Capstone genotypes fertilized with 0 kg P_2O_5 ha^{-1} < 30 kg P_2O_5 ha^{-1} < 45 kg P_2O_5 ha^{-1} < 60 kg P_2O_5 ha^{-1} respectively (Figure 7(a)).

Similarly, for Nav Red genotype, 100 seed weight increased with an increasing rate of single super phosphate fertilizer addition to the soil in the order of influence of 58 kg P_2O_5 ha^{-1} < 62 kg P_2O_5 ha^{-1} < 66 kg P_2O_5 ha^{-1} < 70 kg P_2O_5 ha^{-1} when fertilized with 0 kg P_2O_5 ha^{-1} < 30 kg P_2O_5 ha^{-1} < 45 kg P_2O_5 ha^{-1} < 60 kg P_2O_5 ha^{-1} respectively. Hundred seed weight was higher in Nav red than Tiga and Necuru and Kenya Capstone genotypes. This finding is in agreement with [25]. He reported that increasing phosphorus levels increased 100-seeds weight.

3.10. Effect of Varying Rates of P Fertilizer on Dry Matter of Different Bambara Groundnut Genotypes

Dry matter yield in this study showed that the interaction of season, genotype and P fertilizer rate was significant at the 5% significance level over the two seasons of study (Table 4). A Similarly study by [26] on Bambara dry matter yield also showed a significant interactive difference between the genotypes and phosphorus studied. In that study of Bambara, dry matter yield was slightly higher than in our study, something that might be attributed to the genotypic variations in materials used.

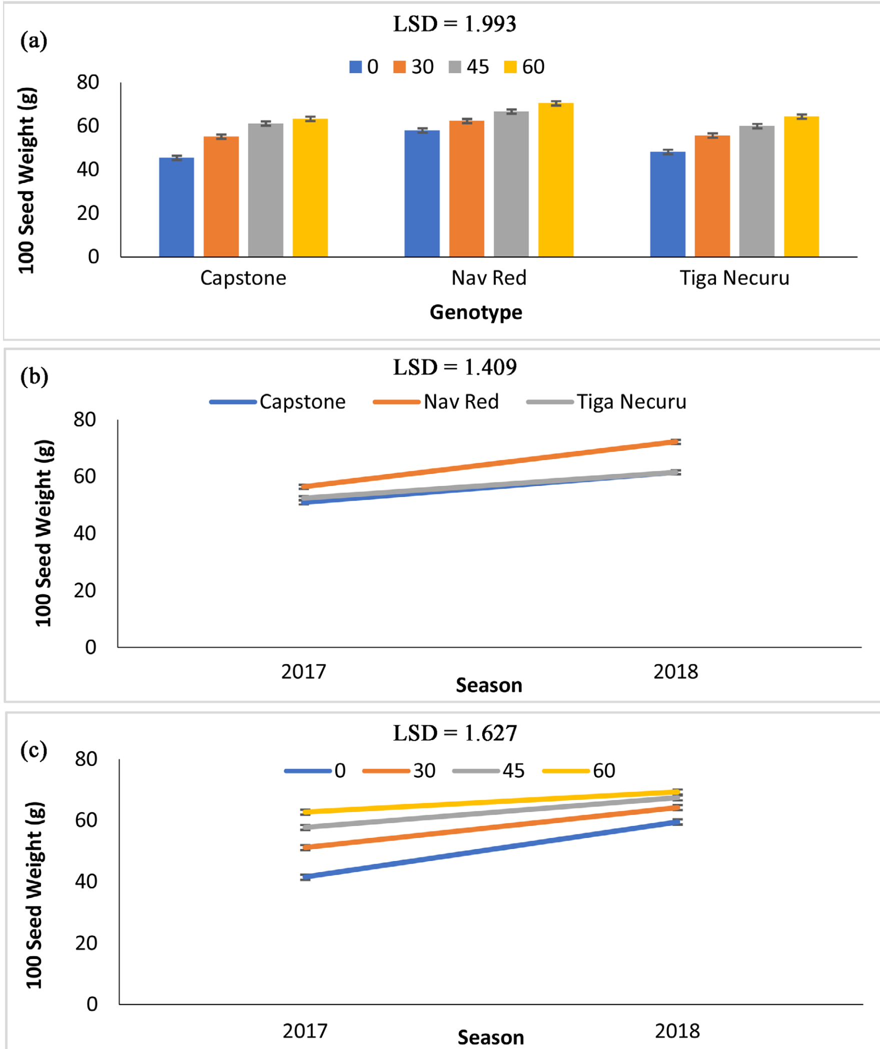

Figure 7. Effect of the (a) interaction of Genotype and P fertilizer rate (b) interaction of Season and Genotype (c) interaction of Season and P fertilizer rate on 100 Seed Weight.

For above-ground dry matter, a positive significant genotype × P fertilizer rate was also evident in the combination of Kenya Capstone with 60 kg P_2O_5 ha^{-1} which gave the highest dry matter (3200 kg/ha); this was 43.7%, 37.5% and 31.2% higher than Tiga Necuru, Nav Red and Kenya Capstone alone respectively. However, the rate of application on dry matter varied considerably as dry matter increased with an increasing application of phosphorus fertilizer (**Figure 8**). From this current study, it is clear that more branches with a higher level of phosphorus application may be due to maximum vegetative growth.

Vegetative growth increased with an increasing level of P at all stages of growth. The result obtained is in agreement with [7] who reported that phosphorus fertilizer application usually enhances nitrogen uptake which enhances vegetative growth and contributes to the increases in dry matter production of legumes. The reason for the increased dry matter accumulation was due to accelerated cell division and system development resulting from the application of phosphorus fertilizer [27]. More so, [28] reported that dry matter production increased with increasing phosphorus application. The absence of soil nutrients is likely to be the reason for the reduction in plant resource allocation for growth and biomass accumulation in the control treatment plots.

3.11. Effect of Varying Rates of P Fertilizer on Pod Yield of Different Bambara Groundnut Genotypes

The genotype × phosphorus interaction was significant for pod yield ($P < 0.05$) (**Figure 9**). The result showed that the interaction between Nav Red and 60 kg P_2O_5 ha^{-1} recorded the highest average pod yield (2600 kg/ha) whereas Tiga Necuru at control gave the least pod yield (1100 kg/ha). In this study, with 60 kg P_2O_5 ha^{-1}, the increasing rate of phosphorus fertilizer resulted in a significant increase in pod yield, which was 12%, 28% and 52% significantly higher than when P was applied at 45, 30 and 0 kg P_2O_5 ha^{-1} respectively. The phosphorus (P) effect on performances of the 3 Bambara genotypes showed that soil fertility amendments had a significant influence on the growth and development of the crop. Our results also confirmed the study of [29] which has shown that season (S) had a significant effect on days to flowering performance of Bambara genotypes.

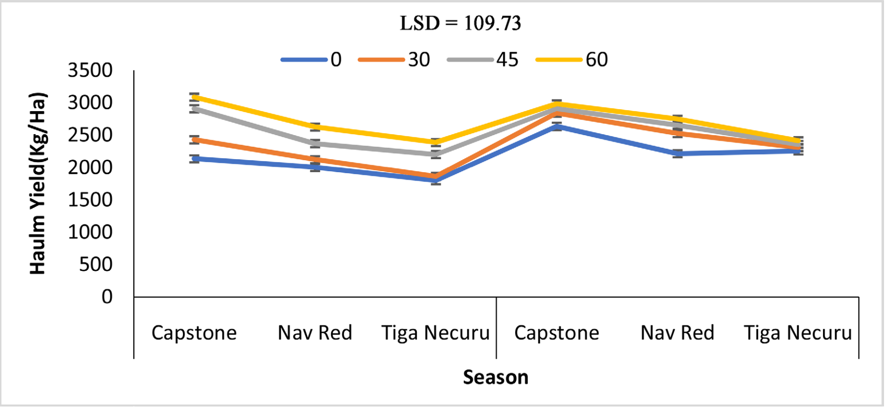

Figure 8. Effect of the interaction of Season, Genotype and P fertilizer on Dry matter

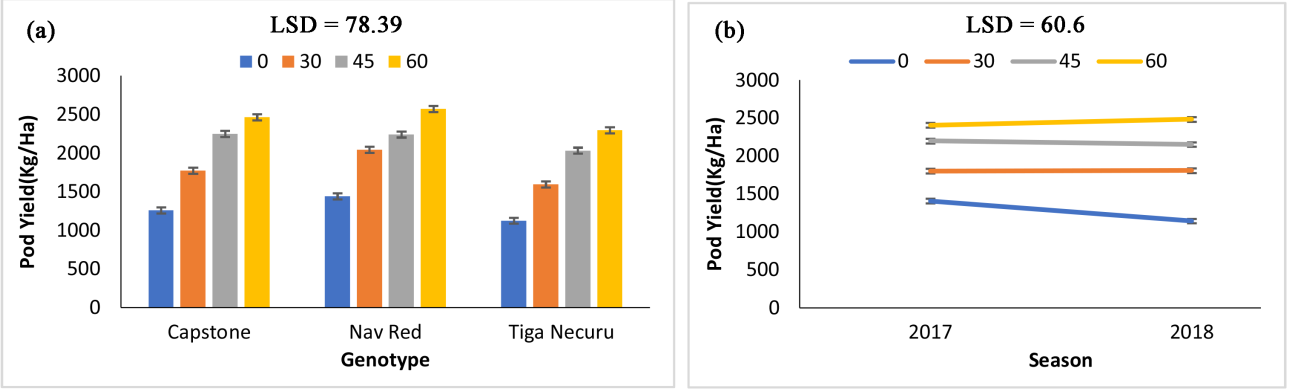

Figure 9. Effect of (a) interaction of Genotype and P fertilizer (b) interaction of Season and P fertilizer rate on pod yield.

In this study, the genotype (G) effect showed to have influenced the means of all agronomic traits among the three genotypes showed high significant differences. Similarly, a significant difference was attributed to P fertilizer effect being higher than the effect of the season (S). A high G x P interaction in all traits except the number of pods per plant was observed in this study, a higher interaction was also observed by [30] when evaluating several cultivars of cowpea under different P fertilizer rates and in contrast [31] found out that the interaction accounted for a lesser percentage in difference in yield traits.

In groundnut, the highest pod yield was obtained at 60 kg P_2O_5 ha^{-1}, according to [28]. The maximum treatment rate of 60 kg P_2O_5 ha^{-1} resulted in the highest pod yield of Bambara groundnut, as established in previous a previous study [28]. As a result, higher phosphorus rates enhanced nodule formation and pod development regardless of the Bambara groundnut genotype studied, implying that the rate of P application has a significant influence on Bambara growth and development. This indicates that phosphorus-deficient soils restrict growth, the process of photosynthesis, translocation of sugars and other such functions which directly or indirectly influence nitrogen fixation [9].

3.12. Pearson Correlation among the Quantitative Traits

There is a significant positive correlation between pod yield and 100 seed weight($r = 0.93$); pod yield and days to maturity ($r = 0.68$); days to flowering and days to maturity ($r = 0.68$); pod yield and chlorophyll content ($r = 0.92$); pod yield and number of branches ($r = 0.74$). The other high positive correlation was observed between pod yield and leaf area ($r = 0.91$); pod yield and number of nodules ($r = 0.85$); pod yield and number of pods per plant ($r = 0.84$). Moreover, we found pod yield to have a high to a moderate positive relationship with dry matter ($r = 0.76$) and the number of branches ($r = 0.74$) (**Table 5**). However, the correlation between pods yield and days to maturity ($r = -0.42$) and pod yield and days to flowering ($r = -0.62$) were negatively correlated, though not significant (**Table 5**). Another study [12] has shown that the most relevant traits of Bambara groundnut were related to pod yield. Previous studies have also studied correlations between yield and yield-related parameters on Bambara [24] and on other legume crops like soybean [32] and cowpea [3] [21].

4. Conclusion

There is variability between Bambara groundnut genotypes and phosphorus fertilizer rates in terms of phenological and yield attributes. Correlation analysis in our study showed that to improve the pod yield of Bambara groundnut it is important to first improve the yield-related traits like the number of pod per plant, 100 seed weight and dry matter yield. The Nav Red genotype showed to perform better with respect to pod yield, the number of pods per plant and hundred seed yield when applied with 60 kg P_2O_5 ha^{-1}, therefore, can be studied further before being released to farmers. Phosphorus availability at 60 kg P_2O_5 ha^{-1} rate was

Table 5. Pearson correlation coefficients between the quantitative traits studied

	DF	DMT	PHT	CC	NB	LA	NC	NPP	HSW	PY	DM
DF	1										
DMT	0.68*	1									
PHT	0.32*	0.69**	1								
CC	−0.61	−0.42	0.22	1							
NB	−0.23	0.04	0.66**	0.75**	1						
LA	−0.64	−0.50	0.12	0.90**	0.62**	1					
NC	−0.61	−0.27	0.24	0.84**	0.50*	0.89**	1				
NPP	−0.4	−0.03	0.57*	0.85**	0.89**	0.76**	0.76**	1			
HSW	−0.7	−0.43	0.44*	0.91*	0.63*	0.87*	0.81**	0.79**	1		
PY	−0.62	−0.42	0.25	0.92**	0.74*	0.91*	0.85**	0.84**	0.93**	1	
DM	−0.28	0.01	0.64**	0.72**	0.94**	0.63*	0.55*	0.83**	0.61*	0.76**	1

*Significant at 0.05; **Significant at 0.01: DF = days to 50% flowering, DMT = days to maturity, PHT = plant height, NPP = number of pods per plant, HSW = 100 seed weight, PY = pod yield, DM = dry matter, CC = chlorophyll content, LA = leaf area, NC = nodule count.

found to have increased plant height, the number of nodules and contributed to an increase in the number of pods per plant, pod yield and dry matter production. 60 kg P_2O_5 ha^{-1} is considered the optimum P rate for Bambara production in this study. Phosphorus fertilizer application could be beneficial for the development of underutilized legume crops such as Bambara groundnut which are mostly cultivated by farmers across Africa on largely degraded soils.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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