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RESPONSE OF BAMBARA GROUNDNUT (VIGNA SUBTERRANEA [L.] VERDC.) TO A SINGLE SUPER PHOSPHATE APPLICATION IN THE NORTHERN GUINEA SAVANNA OF NIGERIA

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ABSTRACT: *The trial was conducted in the Institute of Agricultural Research (IAR) farm, located at Samaru, Nigeria, in two-year field trial (2019-2020) to identify the reaction and performance of Bambara groundnut landraces to single super phosphate (SSP) fertilization under Northern Guinea Savannah conditions. The experiment was tested on three landraces (Burkina, Nav-4, and Black) and three SSP rates (0, 45, and 90 kg* P_2O_5 *ha⁻¹) in a three-replication Randomized Complete Block Design. The findings demonstrated that 90 kg* P_2O_5 *ha⁻¹ had a significant positive effect in terms of nodulation, biomass production, pod yield, seed yield, shelling percentage and hundred-seed weight. Nav-4 landrace was confirmed as superior vegetative performance (plant height, canopy spread, leaf area index, and growth rate) with a maximum seed yield, shelling percentage, and biomass weight. The black landrace produced the largest number of pods and seeds. Correlation analysis showed that there was a strong positive correlation between seed yield and pod weight (r = 0.96), shelling percentage (r = 0.50-0.56), and biomass weight (r = 0.72). Path analysis found a pod weight as the key yield determinant, which explained 78-86% of the seed production variation. It was economically shown that the most profitable rates of net returns in 2020 were 90 kg* P_2O_5 *ha⁻¹: N315,468 (Burkina), N327,834 (Nav-4), N334,037 (Black). The study concludes that the use of SSP at 90 kg* P_2O_5 *ha⁻¹ in combination with Nav-4 landrace is the best option to achieve maximum Bambara groundnut production in Northern Guinea savannah of Nigeria.*

KEYWORDS: *Northern Guinea Savanna, Bambara groundnut, Single super phosphate, Landraces, and Response.*

Introduction

Bambara groundnut (Vigna subterranea [L]) Bambara groundnut ranks as the third most significant pulse crop in Africa, after groundnut (Arachis hypogaea L.) and cowpea (Vigna unguiculata) (Shiyam *et al*., 2016). The nutritional value of the crop is high, with a protein content of 9.6-40% (Nwidi *et al*., 2020), which makes the crop a significant source of protein to the people who cannot afford animal protein. Bambara groundnut grains are rich in carbohydrates (55.5–70.0%), proteins (17–24%), lipids (4–12%), fibre (3–12%), and ash (3–5%), and provide 362–414 kcal/100 g of metabolizable energy, contributing to their value as a complete food (Halimi *et al.,* 2019). Through symbiosis with nitrogen-fixing rhizobia, Bambara groundnut (BGN) can contribute approximately 4–200 kg N ha^{-1} to the soil (Puozaa *et al*., 2017).

Although these are the advantages, the production of Bambara groundnuts is still at low levels of production with low yields. The most prominent world producer is Nigeria with over 100,000 tonnes in 2017 (FAOSTAT, 2017) but agricultural production in the field of small holder farmers is far less than the genetic potential of the crop (Hillocks *et al*., 2021). Despite its nutritional and agronomic importance, Bambara groundnut generally produces low yields ranging from 300 to 850 kg ha^{-1}, largely due to phosphorus (P) deficiency, particularly in acidic soils (Mayes *et al*., 2019; Temegne *et al.*, 2019). This low productivity is attributed to the crop's high sensitivity to P deficiency, as phosphorus plays a critical role in nodulation and biological nitrogen fixation (Nziguheba *et al*., 2016).

Single Super Phosphate (SSP) is a compound of 16 percent P^{-3}-$_2O^{-4}$-$_5$ ha^{-1}, which has a formula, Ca (H2PO4)2H2O, and includes sulfur and calcium (Prakash, 2023). It has been reported that P fertilization promotes crop growth through solubilization and P uptake in Bambara groundnut (Nweke and Emeh, 2013; Temegne *et al*., 2018).

The planting materials used mostly are local landraces that have different seed morphology (Mohammed *et al*., 2016), thus are genetically different. Very little research has been done on the interaction between phosphorus fertilization and landrace selection in Nigeria. This study, therefore aimed to:

1. Evaluate the growth and yield potential of Bambara groundnut landraces in response to a single super phosphate application.
2. Determine the optimum level of single super phosphate for good growth and yield of Bambara groundnut landraces.

Materials and Method

These tests were done in the 2019 and 2020 wet seasons at the Institute of Agricultural Research Farm, (IAR), Ahmadu Bello University (ABU), Samaru -Zaria (Latitude 110 111N and Longitude 70 381E) located in the Northern Guinea Savannah of the agro- ecological zone of Nigeria. The treatments included three Bambara groundnut landraces (Burkina, Nav-4 and Black) and three levels of phosphorus using single super phosphate (0, 45 and 90 kg P_2O_5 ha^{-1}). The experiments had been planned in a three replication, Randomized Complete Block Design. The plot size was 11.25 m2 (2.5 m x 4.50 m) and had 6 ridges, with the net plot of 2 ridges (3.75m 2).

Glyphosate was sprayed at 4 litres ha^{-1} before undertaking land preparation. The soil was plowed and plowed using harrows with 75cm spacing and plots and replications were made based on experiment design. On 28 June 2019 and 26 June 2020, inter- and intra-row spacing of 75 and 30 cm was used to plant respectively. At 3 WAS two seeds were put in each hole and thinned to one plant per stand. Side placement was used with SSP at 5 cm against plants at sowing depending on treatments (0, 45 and 90 kg P_2O_5 ha^{-1}) and paraquat and metolachlor were applied at sowing (4 litres ha^{-1} each) and three additional hoe weedings at 3, 6 and 9 WAS. Aphid control was done by the application of Profenofos 40% + cypermethrin 4% EC twice at 500 ml ha^{-1} at 6 and 8 WAS. They were harvested when physiological maturity occurred where the leaves were yellowish brown and pods brown. Stand count, plant height (cm), canopy spread (cm), number of branches, biomass weight, number of nodules at 30 and 60 days, leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR), number of pods per plant, weight of the pod per plant, pod yield (kg ha^{-1}), seed yield (kg ha^{-1}), haulm yield (kg ha^{-1}), harvest index, shelling percentage, and hundred-seed weight (g) data were taken.

Data collected was analyzed and compared in terms of ANOVA using the General Linear Model (GLM) procedure in (statistical analysis software) SAS software (version 9.4). Treatments means were separated using DMRT at 5% probability level (Duncan, 1955) to determine significant effects of the treatment. Correlation analysis (Little and Hills, 1978), and path analysis (Singh & Chaudhary, 2019), were done. Farm net income: FNI = TR - TC was used to undertake economic analysis.

Results and discussion

Soil Properties

Both years had the soil that was sandy loam. The soil pH was moderately acidic (4.98 in 2019 and 5. 03 in 2020). The level of phosphorus was low, 9.65 mg kg 1 less than 12.15 mg kg^{-1}. The organic

carbon (12.05-13.60 g kg^{-1}) and the total nitrogen (1.48-1.65 g kg^{-1}) were also low, which proved the low soil fertility (Chude *et al.,* 2011).

Table 1: Physical and chemical properties of soils of experimental fields at Samaru during the 2019 and 2020 wet seasons

Years	2019	2020
Soil depth (cm)	0-30	0-30
Soil characteristics		
Physical composition (g kg^{-1})		
Sand	620	580
Silt	220	240
Clay	160	180
Textural class	Sandy Loam	Sandy Loam
Chemical composition		
P^H in H_2O (1:2.5)	5.85	6.01
P^H in 0.01m $CaCl_2$ (1:2.5)	4.89	5.03
Organic carbon (g kg^{-1})	12.05	13.60
Available phosphorus (mg kg^{-1})	9.65	12.15
Total nitrogen (g kg^{-1})	1.49	1.65
Exchangeable bases (cmolkg^{-1})		
Ca	2.98	3.05
Mg	0.49	0.56
K	0.15	0.16
Na	0.21	0.24
CEC	3.83	4.01

Soil samples as analyzed in the Agronomy Department, Ahmadu Bello University, Samaru, Zaria.

Effect of SSP on Growth Parameters

In 2019, the power of SSP in 45 kg P_2O_5 ha^{-1} generated taller (18.29 cm) plants at 3 WAS than the control (14.64 cm) (Table 2). In 2019, SSP at 45 kg P_2O_5 ha^{-1} at 9 and 12 WAS resulted in plants with a height of 22.00 cm and 27.44 cm at 9 and 12 WAS, respectively. In 2019, SSP of 90 kg P_2O_5 ha^{-1} was least (26.21 cm) at 3 WAS, and SSP of 45 kg P_2O_5 ha^{-1} was widest (38.48 cm) at 6 WAS than the control (30.96 cm) (Table 2). At 6 WAS, 90 kg P_2O_5 ha^{-1}generated SSP at 90 kg P_2O_5 ha^{-1} created wider canopy (32.33 cm) compared to the control (28.67 cm). In 2019, the mean of branches was higher at 45 and 90 kg P_2O_5 ha^{-1} than at the control (11.77) at 6 WAS (Table 2). The splendid outcome of SSP at 90 kg P_2O_5 ha^{-1} was that fresh and dry haulm weight was the most prolific at the majority of all sampling periods in 2019.

Table 2: Effect of SSP levels and landrace on crop vigour, canopy spread, number of branches and plant height of Bambara groundnut at Samaru during 2019 and 2020 wet seasons

Treatment	Rate	Canopy Spread (cm)		Number of Branches		Plant Height (cm)	
	kg P_2O_5 ha^{-1}	2019	2020	2019	2020	2019	2020
		6WAS	6WAS	9WAS	9WAS	12WAS	12WAS
				Landrace (L)			
Burkina		31.83b	29.33	11.86b	12.13b	15.25	26.46b
Nav-4		37.56a	31.00	13.40a	13.60a	16.84	29.06a
Black		34.77ab	30.73	12.93ab	13.40a	16.77	28.26a
SE±		1.135	0.765	0.425	0.452	0.763	0.502
				Phosphorus (P)			
Control	0	30.96c	28.67b	11.77b	12.11b	14.64b	26.78b
SSP	45	38.48a	29.89ab	13.56a	13.89ab	18.29a	27.44ab
SSP	90	32.99bc	32.33a	12.22ab	13.78ab	18.27a	28.11ab
SE±		1.466	0.988	0.549	0.584	0.985	0.648
				Interaction			
L x P		NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are statistically similar at 5% level using DMRT. WAS = Weeks After Sowing, NS = Not significant.

The highest LAI was 1.22 at 6 WAS in 2020, which was obtained at SSP at 90 kg P_2O_5 ha^{-1} (Table 3). In 2019, there were many more nodules at 60 days produced by SSP at 90 kg P_2O_5 ha^{-1} than the control (9.33 and 7.78, respectively) (Table 3). When SSP was applied at 90 kg P_2O_5 ha^{-1} (5196 kg ha^{-1}) yielded a higher biomass weight in 2019 (3024.9 kg ha^{-1}) and 2020 (2923.4 kg ha^{-1}) than the control (1990.7 and 2261.7 kg ha^{-1}), respectively (Table 3).

Table 3: Effect of SSP levels and landrace on leaf area index, number of nodules and biomass weight of Bambara groundnut at Samaru during 2019 and 2020 wet seasons

Treatment	Rate	Leaf Area Index		Number of Nodules		Biomass Weight (kgha^{-1})	
	KgP_2O_5 ha^{-1}	2019	2020	2019	2020	2019	2020
		3 WAS	6 WAS	60 days	60 days		
				Landrace (L)			
Burkina		0.65b	0.92	7.93b	17.67	2635.0b	2660.6
Nav-4		0.99a	0.93	9.26a	13.67	3493.4a	2785.1
Black		0.83ab	1.06	8.67ab	14.60	2838.9b	2740.8
SE±		0.116	0.062	0.418	1.763	184.6	117.6
				Phosphorus (P)			
Control	0	0.84	0.83b	7.78b	14.22	1990.7c	2261.7c
SSP	45	0.81	0.93b	7.89b	15.00	2300.9c	2563.0b
SSP	90	0.69	1.22a	9.33ab	14.89	3024.9b	2923.4ab
SE±		0.150	0.080	0.506	2.276	238.7	151.9
				Interaction			
L X P		NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are statistically similar at 5% level using DMRT. WAS = Weeks After Sowing, NS = Not significant.

Impact of SSP on Yield Components

The mean pods per plant (27.89 in 2019 and 29.89 in 2020) and the fresh and dry pod weight (30.89 g in 2019 and 26.33 g in 2020) were the highest in SSP at 90 kg P_2O_5 ha^{-1} in 2019 and 2020, respectively, as compared to the control (Table 4). There was a high yield of pods when SSP was applied. In 2020, the control yielded 0.78 tonnes ha^{-1}, SSP at 45kg P_2O_5 ha^{-1} yielded 1.00 tonnes ha^{-1}, and SSP at 90kg P_2O_5 ha^{-1} yielded 1.11 tonnes ha (Table 4).

SSP with 90 kg P_2O_5 ha^{-1} resulted in the greatest number of seeds per plant (37.89 in 2019 and 41.11 in 2020) and yield of seeds (1.00 tonnes ha 5 in 2019 and 1.11 tonnes ha 5 in 2020) than the control (0.33 tonnes ha 5 in both years). In 2019 and 2020, SSP at 90 kg P_2O_5 ha^{-1} had greater shelling percentage (88.00 and 86.89, respectively) and hundred seed weight (62.33 g and 62.67 g, respectively) than the control (Table 4).

Effect of Landrace

The plants of Nav-4 and Black grew taller and broadened their canopy spread as compared to Burkina in most of the sampling times (Table 4). At 3 WAS in 2019 (0.99), and 9 and 12 WAS in 2020 (2.15), Nav-4 has significantly higher LAI than Burkina (Table 4). In 2019, Nav-4 had more biomass weight (3493.4 kg ha^{-1}) compared to Burkina (2635.0 kg ha^{-1}) and Black (2838.9 kg ha^{-1}) (Table 4). In 2020, the number of pods (25.60) and seeds per plant (31.87) were the highest in the black landrace (Table 4). In 2019, Nav-4 gave more seed yield (1.07 tonnes ha), shelling percentage (86.46%), and hundred seed weight (68.96 g) than other landraces (Table 4).

Table 4: Effect of SSP levels and landrace on pod yield, seed yield, shelling percentage and 100-seed weight of Bambara groundnut at Samaru during 2019 and 2020 wet seasons

Treatment	Rate	Number of Pods Plant^{-1}		Pod Yield (t ha^{-1})		Seed Yield (t ha^{-1})		Shelling %		100-Seed Weight (g)	
	kg P_2O_5 ha^{-1}	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
					Landrace (L)						
Burkina		24.86	24.80ab	1.27a	1.27	0.93ab	1.07	80.60b	82.60	59.38b	60.53
Nav-4		23.20	22.53b	1.20ab	1.20	1.07a	1.07	86.46a	82.27	68.96a	66.67
Black		24.60	25.60a	0.93b	1.13	0.73b	0.93	80.60b	84.20	65.18ab	66.53
SE±		1.258	0.965	0.102	0.067	0.086		1.818	2.426	2.464	2.442
					Phosphorus (P)						
Control	0	14.33c	12.00e	0.67c	0.78c	0.33c	0.33c	70.00b	76.11b	52.33c	50.89c
SSP	45	17.11c	18.44d	0.89bc	1.00b	0.89b	1.00b	84.56ab	83.78ab	64.56b	63.22b
SSP	90	27.89b	29.89b	1.00bc	1.11b	1.00ab	1.11b	88.00a	86.89a	62.33b	62.67ab
SE±		1.625	1.246	0.131	0.083	0.111	0.111	2.348	3.132	3.181	3.153
					Interaction						
L x P		*	NS	NS	NS	NS	NS	NS	NS	NS	*

Means followed by the same letter(s) within a treatment group are statistically similar at 5% level using DMRT. * = significant at 5%, NS = Not significant.

Correlation

Correlation analysis in 2019 (Table 5) revealed that pod weight, canopy spread, and biomass weight were strongly and positively correlated with seed yield under SSP application. This indicates that phosphorus from SSP enhanced reproductive growth, particularly pod development. Conversely, dry haulm showed a negative correlation with seed yield, suggesting that excessive vegetative growth did not translate into higher productivity. These findings are consistent with Yaroson *et al*. (2019), who reported that SSP significantly improved pod weight and seed yield in Bambara groundnut, while excessive haulm growth reduced harvest efficiency.

Table 5: Pearson correlation coefficient between the growth and yield parameters of bambara groundnut landraces at Samaru, 2019

	1	2	3	4	5	6	7	8	9	10	11
1	1										
2	0.960**	1									
3	0.503**	0.476**	1								
4	0.071	0.007	0.120	1							
5	0.091	0.017	0.112	0.118	1						
6	0.044	-0.059	0.241	0.006	0.317*	1					
7	-0.011	0.002	0.316*	0.317*	0.230	0.121	1				
8	0.367*	0.369*	-0.090	0.066	0.079	0.211	0.071	1			
9	0.403**	0.396**	0.347*	0.041	0.218	0.066	0.377**	0.023	1		
10	0.255	0.242	0.158	0.211**	0.028	0.524**	0.033	0.023	0.057	1	
11	0.211	0.193	0.398**	0.151	0.378**	0.070	0.191	0.019	0.319*	0.213	1

DF = (n-2) = 44, r = 0.291 (5%) and 0.376 (1%) * = significance at 0.05 and ** = significance at 0.01 level of probability. 1 = seed weight per hectare, 2 = pod weight per hectare, 3 = shelling percentage, 4 = biomass weight per hectare, 5 = hundred seed weight, 6 = leaf area index, 7 = dry haulm, 8 = relative growth rate, 9 = number of branches, 10 = canopy spread and 11 = Plant height.

In 2020 (Table 6), correlation analysis again showed that pod weight was the dominant trait positively associated with seed yield under SSP. Canopy spread and number of branches also correlated positively but contributed indirectly. Negative correlation with dry haulm persisted, reinforcing the idea that reproductive growth is more important than vegetative expansion for yield. These results align with Whitehead *et al*. (2004), who emphasized phosphorus as a limiting nutrient for pod development in legumes, including Bambara groundnut.

Table 6: Pearson correlation coefficient between the growth and yield parameters of Bambara groundnut landraces at Samaru, 2020

	1	2	3	4	5	6	7	8	9	10	11
1	1										
2	0.962**	1									
3	0.561**	0.521**	1								
4	0.723 **	0.770**	0. 314	1							
5	0. 736**	0.753**	0. 359 *	0.775**	1						
6	0.140	0.084	0. 147	0.189	0.206	1					
7	-0.085	-0.035	0. 090	0.055	0.297	0.189	1				
8	0.105	0.094	0.127	0.096	0.156	0.100	-0.165	1			
9	0.425**	0.443**	0.450**	0.271	0.468**	0.140	0.043	0.228	1		
10	0.388**	0.411**	0.275	0.412**	0.582**	0.227	-0.079	0.188	0.396**	1	
11	0.037	0.026	0.349*	0.003	0.104	0.054	0.272	0.351*	0.164	0.375*	1

DF = (n-2) = 44, r = 0.291 (5%) and 0.376 (1%) * = significance at 0.05 and ** = significance at 0.01 level of probability. 1 = seed weight per hectare, 2 = pod weight per hectare, 3 = shelling percentage, 4 = biomass weight per hectare, 5 = hundred seed weight, 6 = leaf area index, 7 = dry haulm, 8 = relative growth rate, 9 = number of branches, 10 = canopy spread and 11 = Plant height.

Path Analysis

Path analysis in Table 7 confirmed that pod weight had the highest direct effect on seed yield, while canopy spread and branch number contributed indirectly through pod weight. This highlights pod weight as the most critical yield determinant under SSP fertilization. Similar conclusions were drawn by Ibrahim *et al*. (2019), who found pod weight to be the strongest direct contributor to Bambara groundnut yield under phosphorus fertilization.

Table 7: 2019 Direct and indirect contribution

Pod weight	**0.928328**	**0.027317**	**0.001311**	**0.002361**	**0.005951**	**-0.00527**	**0.96**
Number of seeds plant^{-1}	0.441884	0.057389	0.008638	0.002069	0.003886	-0.01087	0.503
Seed weight ha^{-1}	0.015782	0.006428	0.077122	0.0013	0.000689	-0.01032	0.091
Number of branches	0.367618	0.019914	0.016813	0.005963	0.001402	-0.00871	0.403
Canopy spread	0.224655	0.009067	0.002159	0.00034	0.024593	-0.00582	0.255
Plant height	0.179167	0.022841	0.029152	0.001902	0.005238	**-0.0273**	0.211

Path analysis in 2020 (Table 8) demonstrated that pod weight exerted the strongest direct contribution to yield, while canopy spread and branch number acted indirectly. This confirms the consistency of

SSP's effect across seasons. The findings agree with Vanlauwe *et al*. (2002), who reported that phosphorus fertilization enhances pod filling and seed weight in African legumes.

Table 8: 2020 Direct and indirect contribution

Pod weight	**0.885509**	**0.053641**	**0.045997**	**-0.01377**	**-0.00899**	**-0.00039**	**0.962**
Number of Seeds plant^{-1}	0.46135	0.102958	0.02193	-0.01398	-0.00602	-0.00524	0.561
Seed weight ha^{-1}	0.666788	0.036962	0.061085	-0.01454	-0.01273	-0.00156	0.736
Number of branches	0.39228	0.046331	0.028588	-0.03108	-0.00866	-0.00246	0.425
Canopy spread	0.363944	0.028313	0.035552	-0.01231	-0.02188	-0.00563	0.388
Plant height	0.023023	0.035932	0.006353	-0.0051	-0.0082	-0.01501	0.037

Conclusion and Recommendations

Based on the results of the current research, it can be concluded that using SSP at a rate of 90 kg P_2O_5 ha^{-1} has a significant positive impact on the growth and yield of Bambara groundnut, achieving the highest pod yield (1.00-1.11 tonnes ha^{-1}), seed yield (1.00-1.11 tonnes ha^{-1}), number of pods (27.89-29.89), shelling percentage (86.89-88.00%), and the Nav-4 landrace showed better performance. It is suitable for most of the Northern Guinea Savanna. Based on the findings of the study, the following recommendations were made:

1. In the case of farmers in the Northern Guinea Savanna of Nigeria, Nav-4 landrace and the use of SSP at 90 kg P_2O_5 ha^{-1} production are suggested as the combination that would bring farmers the most seed and profitability of Bambara groundnut production.
2. In the case of resource-constrained farmers, application of a minimum of 45 kg P_2O_5 ha^{-1} should be used to gain reasonable yield increments.
3. Extension services need to change the level of educating farmers about the necessity of phosphorus fertilization and the importance of selecting the landraces, so that demonstration plots should be created to reveal the economic advantage.

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