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Response of Groundnut to Plant Density and Phosphorous Application in the Sudan Savanna Zone of Nigeria

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Abstract

Despite the recent release of several improved varieties of groundnut in Nigeria the productivities have not increase significantly due to lack of commensurate recommendation in agronomic practices. Two groundnut varieties were evaluated for their response to different plant density and phosphorus application in two locations in the Sudan Savanna zone of Nigeria in 2012 and 2013. The groundnut were planted at density of 44444, 66667, and 133333 hills ha^{-1} with average of two plants per hill. Phosphorus was applied at rate of 0 or 20 kg P ha^{-1}. P fertilizer application increased pod and haulm yields by 26% and 16% respectively in Minjibir. It increased pod and haulm yields by 62% and 27% respectively in Wudil. Pod and haulm yields, harvest index, revenue, profit and cost benefit ratio increased with increasing plant density. Samnut-24 produced pod yields that were significantly higher than Samnut-22 across treatments. Pod yields at density of 133,333 hills ha^{-1} was 31% higher than at 66667 and 40% than at 44,444 hills ha^{-1}. Application of fertilizer increased profit by 22% and 49% in Minjibir and Wudil respectively. Planting at density of 133,333 hill ha^{-1} increased profit by 19% and 27% over 66,667 and 444444 hill ha^{-1} respectively in Minjibir, while it increase profit by 9% in Wudil. Cultivation of Samnut-24 at high density with phosphorus application will make groundnut production a more profitable venture in Sudan Savanna zone of Nigeria.

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Introduction

Groundnut (*Arachis hypogea* L.) is a leguminous crop of economic importance around the world, with about 94% of the world production coming from the rain-fed crop grown largely by resource-poor farmers (Dwivedi *et al.,* 2002). Nigeria is the largest groundnut producing country in West Africa accounting for 40% production of the region. In Northern Nigeria, Groundnut contributes 23% of household cash revenue (Ndjeunga *et al.*, 2010) and was grown on 2.4 million hectares in 2012 producing 3.07 million tons with an average pod yield of 1.268 tons/ha (FAOSTAT, 2015).

The average yields of groundnut in Nigeria and most parts of West Africa are lower (903 kg ha-1) than those in South Africa (2000 kg ha-1), Asia (1798 kg ha-1), or the rest of the world (1447 kg ha-1) (FAOSTAT, 2015). The main constraints limiting groundnut production in the Nigerian savannas are diseases (early and late leaf spot and rosette), drought, low soil fertility and poor agronomic practices (Ndjeunga and Ajeigbe, 2012). Naab *et al.* (2005) noted that the lower yields in West Africa are largely due to leaf spot disease as well as low soil fertility and water limitation (drought). Drought is an important constraint in the dry savannas and it can come early, mid or late season drought. While early maturing varieties may escape early or end of season drought, varieties with drought resistant or tolerance are required to produce economic yields when mid-season drought occurs.

Recently released varieties (Samnut 24, Samnut 25, and Samnut 26) in Nigeria (NACGRAB 2014,) are resistant/tolerant to most of the important diseases and are early maturing to escape drought. These varieties are being promoted in the dry savannas of Nigeria through several initiatives (Monyo and Gowda, 2014). However poor agronomic practices, especially the practice of wide spacing and limited or lack of fertilizer application particularly phosphorus limits on-farm yield (Ajeigbe and Singh, 2006) and profitability of groundnut production. Crop production in sub-Saharan Africa, especially in the semiarid and sub-humid Savannas, is often limited by biophysical constraints, including poor soil fertility (Manu *et al.*, 1991; Giller *et al.*, 2011;). Groundnut is a leguminous plant and it can fix its own nitrogen from the atmosphere, however, it needs other macro and micronutrient in the soil. Phosphorus deficiency is the most frequent nutrient stress for growth and development of grain legumes including groundnut (Kwari 2005; Kamara *et al.*, 2008; Kamara *et al.*, 2011). Phosphorus is essential for many processes that occur in the growing plants such as biological nitrogen fixation, photosynthesis, respiration, energy storage and cell division. Sharma and Yadov (1997) reported that phosphorus plays a beneficial role in legume growth and promotes extensive root development and thereby ensuring good yield. Kamara *et al.* (2011b), reported response of soybean to P fertilizer in the savannas of northern Nigeria, while Kamara *et al.* (2011a) reported linear increase in pod yields of groundnut with increase in P rates from 0 to 40 kgP/ha. Addition of phosphorus fertilizer enhances root development which improves the supply of other nutrients and water to the growing parts of the plants, resulting in an increased photosynthetic area and therefore, more dry matter accumulation (Maity *et al.,* 2003; Atayese, 2007).

Farmers in Nigeria and many other West Africa countries plant grain crops in rows spaced 75 cm because most tractor and animal drawn ridgers available are fixed at width of 75 cm leaving the farmers with no option in reducing row spacing. This long established practice has been in line with the recommended groundnut spacing (75 cm x 20cm) corresponding to plant density of 66,667/ha using about 50 to 60 kg of seed (Ousmane and Ajeigbe, 2009). This density though higher than the initial recommendation of 44,000/ha (NAERLS, 1977), it may not be optimal for maximising groundnut yield. In India for example, between row spacing varies from 20 - 100 cm and within row spacing from 7.5 cm to 15 cm (Nigam *et al.*, 2006) ensuring hill density of 100 to over 200,000 hill/ha. Kamara *et al.* (2014) reported soybean yield increased by 62-100% when density increased from 266,666 to 666,700 ha^{-1} in the

Guinea savanna of Nigeria. They noted that appropriate plant density enhances productivity through efficient use of soil moisture and nutrient as well as adequate photosynthetic light capture. Nigam *et al*. (2006) suggested that optimum plant stand remains the key to higher yields in groundnut. Most of the newly released groundnut varieties are erect types of early duration with much smaller foliage compared to the older varieties which are spreading medium to late maturing. While the plant characteristics of most of the modern varieties have changed, the recommended seeding rate of 50-60 kg seed ha-1 and planting densities have remained unchanged. Combining adapted early maturing groundnut varieties with phosphorous application and optimal plant density may increase groundnut productivity and make groundnut cultivation a more profitable enterprise for smallholder farmers. On this basis, field trials were established in two locations in the Sudan Savanna ecology of Nigeria to evaluate the response of two contrasting groundnut varieties to P application and increased plant density.

Materials and methods

Experimental site

The experiments were carried out in 2012 and 2013 cropping seasons at Wasai (latitude 8.67^{o}E and longitude 12.15^{o}N), Minjibir local government authority (LGA) and Wudil (latitude 8.78^{o}E and longitude 11.82^{o}N), Wudil LGA of Kano State. Soil samples were taken from the two locations, air dry in the shade and analysed in the soil analytical laboratory of ICRISAT Niamey. The results of soil analysis for both locations are presented in Table 1. The soils were slight acidic with very low organic matter, N and P. most of the other nutrients are limiting.

Rainfall (Table 2) in both locations had mono-modal distribution which starts in June and end in September with most of the rains falling in July and August. Rainfall in Minjibir was 994 mm in 2012 and 1054 mm in 2013 with raining days of 32 and 36 in 2012 and 2013 respectively; Wudil had 945.8 mm rainfall in 2012 and 907.4 mm in 2013 with raining days of 43 and 38 in 2012 and 2013 respectively.

Cultural practices

The fields were harrowed and ridged at 75cm between ridges using tractor drawn implements before plot layout and sowing. Groundnut seeds were sown at the rate of 2 seeds per hole at depth of 3-5 cm. Weeds were controlled manually using hand hoe at 3, 6 and 9 weeks after sowing (WAS).

Experimental design and treatments

The experimental design was a split-split-plot with 4 replications. The groundnut varieties; SAMNUT 22 (a medium maturing Virginia type variety released in 2001) and SAMNUT 24 (an early maturing Spanish type variety released in 2011) were the main plots. The fertilizer application; 20 kg P ha^{-1} applied at sowing and a control with no fertilizer were the sub-plots.

The 20 kgP ha^{-1} was applied as SSP by drawing a furrow on the ridge. The required SSP was spread evenly in the furrow and covered with soil. One blank row was left in between the sub-plots. The sub-sub-plots were the density treatments of 44,444, 66,667 and 133,333 hills ha^{-1} obtained using a spacing of 75 x 30, 75 x 20 and 75 x 10cm respectively. The sub-sub-plots sizes were 12 m^{2} (4 rows 4 m long).

Data collection

The two middle rows per plot were used for data collection. Data were collected on % soil cover at 3 and 6 weeks after sowing (WAS) which was the proportion of the plated area covered by the groundnut at 3 and 6 weeks respectively after sowing. Days to 50% flowering (number of days from sowing to when at least 50% of the plants in the net plot had at least one flower), days to physiological maturity (days to when at least 90% of the plants in the net plots have attained physiological maturity). Plant height (cm) at maturity (mean height from base to highest point of five plants), number of branches per plant, pod and haulm yields (Pod and haulm weights were obtained after sun-drying all the plants harvested from the two middle rows per plot to constant weight and then converted to kg ha-1).

Economic analysis

Partial budgeting was used to estimate revenue, and total profit per hectare for each groundnut variety at different fertilizer and density treatments using the method suggested by Ajeigbe and Singh (2006). The variable cost consisted of the cost of seed, fertilizer and fertilizer application. Labour cost for planting and harvest were assumed constant across seeding rate. Profit margin was estimated by deducting the cost of the seed, fertilizer and fertilizer application from the income derived from grain and haulm produced. Farm gate price were determined each year by taking average price across locations two months after harvest.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using the GENSTAT statistical programme (GENSTAT, Statistical software 16th edition). Least significance difference between means was used to compare treatments (LSD) using a significance level of α = 0.05. Pearson's correlation coefficients were calculated between the variable and yields.

Results

Variety (V), Phosphorus fertilizer application (F) and plant density (P) significantly influenced groundnut performance in both locations. Table 3A shows the mean squares from the Analysis of Variance for the measured parameters in Minjibir. Year of planting significantly affected all the agronomic parameters except pod yield. Phosphorus fertilizer application significantly influenced pod and haulm yields as well as harvest index (HI). Plant density significantly affected pod and haulm yields. Differences between the two varieties were significant for all parameters except for haulm yield.

Table 1. Soil analysis for Minjibir and Wudil experimental plots, 2012 and 2013 Cropping Seasons.

	Minjibir		**Gambawa**	
	2012	2013	2012	2013
Organic Carbon (%)	0.221	0.198	0.162	0.156
N-total (mg/kg)	230.0	202.1	167	152
Zn (mg/kg)	,,	,,	Trace	,,
Available P (mg/kg)	3.1	3.6	2.6	2.9
pH/H2O	5.10	5	5.4	5.7
Exchangeable K (Cmol/kg)	0.5	0.5	0.4	0.3
Ca2 (Cmol/kg)	0.44	0.53	1.21	0.8
Pb	0.012	,,	,,	,,
Sand (%)	91.7	89.8	88.9	92.8
Silt (%)	4.0	4.2	4.6	4.6
Clay (%)	4.2	6.0	6.5	2.5

Table 2. Monthly rainfall (mm) in the experimental sites in 2012 and 2013.

	Minjibir				Wudil			
	2012		2013		2012		2013	
	mm	days	mm	days	mm	days	mm	days
January	0	0	0	0				
February	0	0	0	0				
March	0	0	0	0				
April	0	0	0	2			11	1
May	21.5	1	21.5	1	62	4	45	2
June	156.2	6	84.2	6	250	11	178	5
July	293.7	11	262.4	9	206	10	257	11
August	424.8	11	522.9	13	285	11	160	9
September	98	4	159.3	4	136	6	247	9
October	0	0	4	1	7	1	9	1
November	0	0	0	0				
December	0	0	0	0				
Total	994	32	1054.3	36	945.8	43	907.4	38

Year ×Variety (Y×V) interaction was significant for plant height at harvest, number of branches per plant, haulm yields and harvest index. No significant value was observed for Y × F interaction. The responses of number of branches to P fertilization was dependent on groundnut variety. V×P interaction significantly affected pod yield and harvest index. The three way interactions among V, F and P was not significant for most parameters.

Table 3. Combined mean squares from the analysis of variance for days to 50% flowering, plant height, number of branches per plant and pod weight of groundnut 3A. Minjibir, 2012 and 2013.

Source of variation	d.f	50% flowering	Plant height (cm)	Number of branches/plant	Pod yield (kg/ha)	Haulm yield (kg/ha)	Harvest Index
Replication	3	0.1771	190.97	6.134	70570	100955	15.29
Year (Y)	1	3.7604*	374.82**	57.196**	219938^{ns}	4586753**	975.38**
Variety (V)	1	2390.0104**	6491.33**	79.753**	19846200**	306230^{ns}	32340.04**
Fertilizer (F)	1	0.0938^{ns}	71.99^{ns}	0.230^{ns}	1780243**	1917045**	630.38**
Hill Density (P)	2	1.1563^{ns}	31.99^{ns}	1.089^{ns}	2741981**	1127381**	174.59^{ns}
Y.V	1	23.0104**	359.56**	155.296**	34694^{ns}	3393024**	1584.38**
Y.F	1	0.0938^{ns}	57.77^{ns}	6.050^{ns}	6518^{ns}	61611^{ns}	40.04^{ns}
V.F	1	0.0104^{ns}	83.24^{ns}	13.425*	8381^{ns}	551^{ns}	0.04^{ns}
Y.P	2	0.6979^{ns}	22.58^{ns}	9.040^{ns}	48348^{ns}	185065^{ns}	88.16^{ns}
V.P	2	0.8229^{ns}	28.44^{ns}	5.981^{ns}	433357**	156101^{ns}	299.89*
F.P	2	0.4063^{ns}	2.69^{ns}	0.869^{ns}	117552^{ns}	372367^{ns}	267.97^{ns}
Y.V.F	1	0.2604^{ns}	0.09^{ns}	0.555^{ns}	85264^{ns}	169680^{ns}	63.37^{ns}
Y.V.P	2	0.3229^{ns}	28.11^{ns}	3.790^{ns}	5462^{ns}	60857^{ns}	0.28^{ns}
Y.F.P	2	1.7813^{ns}	34.17^{ns}	2.826^{ns}	32605^{ns}	422342^{ns}	443.57*
V.F.P	2	1.0729^{ns}	13.98^{ns}	16.846**	149041^{ns}	341336^{ns}	80.39^{ns}
Y.V.F.P	2	1.0729^{ns}	3.26^{ns}	3.181^{ns}	50641^{ns}	17170^{ns}	61.91^{ns}
Residual	69	0.9959	35.13	3.023	78589	191376	98.63
Total	95						

WAS = Weeks after sowing.

3B. Wudil, 2012 and 2013.

Source of variation	d.f	50% flowering	Plant height (cm)	Number of branches/plant	Pod yield(kg/ha)	Haulm yield (kg/ha)	Harvest index
Replication	3	1.288	79.22	3.956	64792	250731	404.0
Year (Y)	1	297.510**	137.31*	49.121**	67257^{ns}	1068715**	9440.7**
Variety (V)	1	90.094**	2274.39**	147.684**	4945422**	2674339**	11926.0**
Fertilizer (F)	1	5.510*	229.19**	6.136*	5310534**	2637083**	4240.0**
Hill Density (P)	2	2.542^{ns}	36.52^{Ns}	2.424^{Ns}	427201**	270668^{Ns}	218.0^{ns}
Y.V	1	1.260^{ns}	1467.42**	9.047*	14875^{ns}	4803018**	2242.7**
Y.F	1	0.094^{ns}	44.65^{ns}	2.242^{ns}	2071231**	661178*	770.7*
V.F	1	1.260^{ns}	0.00^{ns}	6.136*	1160061**	857871*	0.0^{ns}
Y.P	2	0.667^{ns}	57.88^{ns}	0.432^{ns}	2681901**	2309461**	148.0^{ns}
V.P	2	0.125^{ns}	39.01^{ns}	2.683^{ns}	106311^{ns}	16356^{ns}	70.6^{ns}
F.P	2	0.542^{ns}	9.74^{ns}	0.090^{ns}	15009^{ns}	33741^{ns}	61.3^{ns}
Y.V.F	1	0.010^{ns}	8.90^{ns}	2.004^{ns}	20621^{ns}	92566^{ns}	42.7^{ns}
Y.V.P	2	0.667^{ns}	5.27^{ns}	0.168^{ns}	240700*	100620^{ns}	159.8^{ns}
Y.F.P	2	1.500^{ns}	3.02^{ns}	0.350^{ns}	53423^{ns}	148161^{ns}	392.4^{ns}
V.F.P	2	0.542^{ns}	29.61^{ns}	1.872^{ns}	101458^{ns}	191350^{ns}	46.9^{ns}
Y.V.F.P	2	0.667^{ns}	13.68^{ns}	1.746^{ns}	22829^{ns}	292683^{ns}	72.4^{ns}
Residual	69	79.385	35.93	1.552	64578	160993	177.3
Total	95						

WAS = Weeks after sowing

Table 3B shows the mean squares from the Analysis of Variance for the measured parameters in Wudil. Year of planting significantly affected all the agronomic parameters except pod yield. Significant differences were observed between the varieties for all the agronomic parameters. P fertilizer application significantly influenced plant height, number of branches per plant, pod and haulm yields as well as HI. Plant density significantly affected pod yield. Y×V interaction was significant for plant height at harvest, number of branches per plant, haulm yields and harvest index. Y × F interaction was significant for pod and haulm yields as well as HI. V×F interaction was significant for number of branches per plant pod and haulm yields. Y×P interaction was significant for pod and haulm yields. V×P and F×P interactions were not significant for any of the attributes. The three way interactions among V, F and P was not significant for any parameter.

Table 4. Effect of fertilizer, groundnut variety and hill density on plant cover, days 50% flowering, plant height, and number of branches of groundnut in Minjibir.

	Minjibir			Wudil		
Treatments	50% flowering	Plant height (cm)	Number of branches/plant	50% flowering	Plant height	Branches per plant
Year						
2012	25.60	43.13	7.84	32.33	34.30	6.84
2013	25.21	39.18	9.38	28.81	36.69	8.27
P of F	0.056	0.002	<.001	<.001	0.055	<.001
LSD	0.406	1.414	0.708	0.437	2.441	0.507
Variety						
Samnut 22	30.40	32.93	9.52	31.54	30.63	8.80
Samnut 24	20.42	49.38	7.70	29.60	40.36	6.32
P of F	<.001	<.001	<.001	<.001	<.001	<.001
LSD	0.406	1.414	0.708	0.437	2.441	0.507
Fertilizer						
Control	25.38	40.29	8.56	30.81	33.95	7.81
20 kg P/ha	25.44	42.02	8.66	30.33	37.04	7.30
P of F	0.760	0.157	0.783	0.032	0.014	0.51
LSD	0.406	1.414	0.708	0.437	2.441	0.507
Hill density						
133333	25.50	42.28	8.45	30.28	36.52	7.24
66667	25.19	40.38	8.57	30.59	35.58	7.70
44444	25.53	40.81	8.81	30.84	34.39	7.73
P of F	0.319	0.407	0.699	0.118	0.367	0.217
LSD	0.498	2.956	0.867	0.535	2.990	0.621
Mean	25.41	41.16	8.61	30.57	35.49	7.56
CV	3.9	14.4	20.2	3.5	16.9	16.5

Effect of fertilizer, groundnut variety and hill density on growth parameters

Table 4 shows the effect of year, groundnut varieties, phosphorus fertilizer application and plant density on days to 50% flowering, plant height and number of branches per groundnut plant in Minjibir and Wudil. The plants were significantly taller in 2012 than 2013 but produced more branches in 2013 than 2012. Samnut 24 flowered and matured significantly earlier than Samnut 22.

Table 5. Interaction effect of variety and Hill density on pod weight (kgha^{-1}) of groundnut at Minjibir and Wudil.

Hill density/ha	Minjibir				Wudil			
Variety	133333	66667	44444	Mean	133333	66667	44444	Mean
Samnut 22	954	626	647	742	831	745	720	765
Samnut 24	2111	1502	1342	1652	1414	1163	1082	1220
Mean	1533	1064	995		1123	954	901	
LSD Variety (V)	114.2				103.5			
LSD Density (P)	139.8				126.7			
LSD V x P	197.7				179.2			

It was also observed that Samnut 24 grew significantly taller than Samnut 22 but had significantly less branches per plant than Samnut 22. Application of Phosphorus fertilizer had no significant effect on growth parameters (days to 50% flowering, plant height and number of branches per plant). Plant density had no significant effect on the growth parameter. In Wudil, number of days to flowering were lower in 2013 than in 2012. The number of branches per plant were significantly higher in 2012 than in 2013. Samnut 24 was significantly taller than Samnut 22 but had significantly lower number of branches per plant. Application of phosphorus fertilizer significantly increased plant height.

Table 6. Interaction effect of variety and P fertilizer application on haulm yield (kgha^{-1}) of groundnut at Minjibir and Wudil.

	Minjibir			Wudil		
Variety	0 kg P/ha	20 kgP/ha	Mean	0 kg P/ha	20 kgP/ha	Mean
Samnut 22	1839	2126	1922	1131	1273	1202
Samnut 24	1730	2008	1869	1226	1796	1536
Mean	1785	2067		1203	1535	
LSD Variety (V)	178.1			163.4		
LSD Fertilizer (F)	218.2			163.4		
LSD V x F	308.6			283.0		

Effect of variety and Hill density on groundnut yield

Table 5 shows the interaction of groundnut varieties and plant density on groundnut pod yields in the Sudan savannah zone of Nigeria. Pod yields generally increased with increasing plant density for the two varieties in both locations. In Minjibir mean pod yield was 44% higher at plant density of 133,333 plants ha^{-1} than that at density of 66,666 plants ha^{-1} and 54% higher than that at density of 44444 plants ha^{-1}. In Wudil, pod yield was 17% higher at plant density of 133,333 plants ha^{-1} than that at density of 66,666 plants ha^{-1} and 25% higher than that at density of 44444 plants ha^{-1}. In both locations, the early maturing variety SAMNUT 24 produced higher pod yields than SAMNUT 22 at all plant density. The mean pod yield of SAMNUT 24 were higher than SAMNUT 22 by 122% in Minjibir and by 59% in Wudil. While pod yields of SAMNUT 24 were higher than SAMNUT 22 by 121% 140 and 107% at density of 133333, 66667 and 444444 hills ha^{-1} respectively in Minjibir, it was higher by 70, 56 and 50% respectively in Wudil.

Table 7. Pearson`s correlation coefficient of agronomic traits with pod yield at each location.

	Variables	Minjibir	Wudil
1	cover3wks	0.609***	0.2433*
2	cover6wks	0.6819***	0.258**
3	%50Flw	-0.7061***	-0.3225***
4	Maturity	-0.7357***	-0.4328***
5	Plt_Ht	0.6999***	0.4279***
6	brch_plt	-0.2281*	-0.3292***
7	Hindex	0.794***	0.6063***
8	HlmYld	0.2528*	0.6137***

Table 6 shows the interaction of groundnut varieties and P fertilizer on groundnut haulm yields in the Sudan savannah zone of Nigeria. While there was no significant difference between the groundnut varieties for mean haulm yields in Minjibir, Samnut 24 produced significantly higher mean halum yield (1536 kg/ha) than Samnut 22 (1202 kg/ha) in Wudil. There was also significant variety x P fertilizer interaction.

However, there was no significant difference between the two varieties for haulm yields in the unfertilized plot, Samnut 24 produced haulm yields (1796 kg/ha) that was significantly higher than Samnut 22 (1273 kg/ha) in the P fertilized plot. In both location P fertilizer applications produced mean haulm yields that were significantly higher than control (16% and 28% in Minjibir and Wudil respectively).

The Pearson`s correlation coefficient of agronomic traits with pod yield at each location is presented in Table 7. All the traits were significantly correlated with pod yields in both locations. Days to flowering and maturity and number of branches per plant were negatively correlated with pod yield

Effect of groundnut varieties, P fertilizer and plant density on revenue, profit and cost benefit ratio

Table 8 shows the effect of groundnut varieties, P fertilizer and plant density on mean total revenue, total profit and cost benefit ratio of groundnut.

Mean total revenue and profit were significantly higher for Samnut 24 than for Samnut 22, while cost-benefit ratio was significantly higher for Samnut 22 than for Samnut 24. In addition, P fertilizer application produced higher mean total revenue and profit than the control in both locations. Total revenue was higher at higher plant density of 133,333 plants ha^{-1} than at the lower plant density of 66,667 and 44,444 plants ha^{-1}. There were no significant difference in the mean total profit between plant density of 66667 and 444444 plants ha^{-1} in both locations. Similar results were obtained for total profit and cost-benefit ratio in both locations.

Table 8. Combined means of treatments for total revenue, total profit and cost benefit in the Sudan Savanna zone of Nigeria.

Treatments	Total Revenue (US$ha^{-1})		Total profit (US$ha^{-1}		Cost benefit	
	Minjibir	Wudil	Minjibir	Wudil	Minjibir	Wudil
Variety						
Samnut 22	1949	1431	1739	1221	1.14	1.23
Samnut 24	2601	2029	2391	1819	1.09	1.14
P of F	<.001	<.001	<.001	<.001	<.001	<.001
SED	92.0	81.1	92.0	81.1	0.008	0.025
LSD	183.6	161.8	183.6	161.8	0.017	0.049
Fertilizer						
Control	2069	1431	1859	1221	1.13	1.23
20 kgP/ha	2481	2029	2271	1819	1.10	1.15
P of F	<.001	<.001	<.001	<.001	0.001	0.003
SED	92.0	81.1	92.0	81.1	0.008	0.025
LSD	183.6	161.8	183.6	161.8	0.017	0.049
Plant density						
133333	2663	1913	2358	1607	1.15	1.27
66667	2188	1678	1984	1474	1.12	1.17
44444	1975	1600	1853	1478	1.07	1.12
P of F	<.001	0.007	<.001	0.318	<.001	<.001
SED	112.7	99.3	112.7	99.3	0.010	0.030
LSD	224.8	198.1	224.8	198.1	0.020	0.060
Mean	2275	1730	2065	1520	1.11	1.19
CV	19.8	23.0	21.8	26.1	3.6	10.2

Discussion

The results obtained from the study revealed that year, variety, P fertilizer application and plant density have significant effect on several growth attributes as well as income derived from groundnut cultivation.

The groundnut varieties responded to P application with maximum yield obtained at 20 kg P ha^{-1}. Kamara *et al.* (2011a) reported increases in pod and halum yield of groundnut in northeast Nigeria by 49.3% when applied at 20kg P/ha and 57.8% when applied at 40 kg p/ha. This suggests that groundnut responds to application of P even in smaller quantities. Kamara *et al.* (2011b) also reported significant response of soybean to P application in the savannas of northern Nigeria. They however, reported that there were no responses to nitrogen applications. Soil analysis of the trial sites revealed that the soils were low in P. This is in agreement with Ekeleme *et al.*, 2014, who reported that the P levels in the sites of this study are very low. Our findings suggest that, groundnut farmers should apply phosphorus fertilizer to groundnut in order to achieve higher yield. Increasing plant density increased soil cover. This would result into high leaf area index (LAI) and the fraction of intercepted photosynthetic active radiation and high pod yield. Purcell *et al.*, (2002) and (Ball *et al.*, 2000) reported that increasing plant density increased LAI and light inception of soybean in the USA. Greater light interception often increases yield (Alessi *et al.*, 1977). Grain and haulm yield of both varieties increased with increasing plant density. Planting groundnut at density of 133,333 hills ha^{-1} increased pod yield by 54 and 25% over density of 44444 plants ha^{-1} in Minjibir and Wudil respectively and by 44 and 18 % over density of 66667 plants ha^{-1} in Minjibir and Wudil respectively. Similarly increasing the plant density from 44444 to 66667 plants ha^{-1} increased haulm yield by 13 and 3% in Minjibir and Wudil respectively. Increasing plant density to 133,333 hills/ha^{-1} increased haulm yield by 22 and 14% over 44444 plants ha^{-1} in Minjibir and Wudil respectively and by 7 and 10 % over 66667 plants ha^{-1} in Minjibir and Wudil respectively. The higher yield obtained at the highest density of 133,333 plants ha-^{1} showed that the current low density of 66,666 plants ha^{-1} (Ousmane and Ajeigbe, 2009) is not sufficient for optimal groundnut yield. In most Asian countries, the row spacing varies between 30 cm and 45 cm while within the row spacing varies between 10 and 15 cm (Nigam *et al.*, 2006). This high density of 148000 to over 300000 ensures mean yield of about 1.8 t ha^{-1} to tons ha^{-1}. It is interesting to note that higher significant yields were obtained at higher density than the recommended and probably the density at which the varieties were developed. This signifies the need for legume breeders to work more closely with agronomist in the variety development and dissemination to obtain the true potentials of varieties developed. Several other studies has shown that the current recommended plant density for grain legumes for the Nigerian savannas are not optimal. Kamara *et al.* (2014), reported that optimum plant density for soybean in the Nigerian savannas ranged from 533,300 to 666,700 plants ha-1 compared to 266,666 plants ha^{-1}.

Samnut 24, produced higher mean pod yields and haulm yields than Samnut 22. It also responded better to increase plant density in both locations. Samnut 24, is an early maturing Spanish bunch type drought-tolerant variety (Monyo and Gowda, 2014). It is early maturing which allows it to escape late season drought and also withstand mid-season drought. This attribute and the bunch growth habit allow it to respond more to higher plant density as well as produce higher yields in the Sudan ecology. It can thus be recommended to the farmers in Sudan savanna, which experiences short rainy seasons.

Groundnut variety plays a significant role in productivity of groundnut production. Samnut 24 produced 33 and 42% higher total revenue than Samnut 22 in Minjibir and Wudil respectively. It also produced 37 and 49% higher profit than Samnut 22 in Minjibir and Wudil respectively, implying the profitability of the new improved early maturing variety over the older variety. Similarly, P fertilizer application produced 20 and 42% higher total revenue and 22 and 49% profit control in Minjibir and Wudil respectively. These results agree with the findings of Semalulu *et al.* (2012), who reported that phosphorus application increased groundnuts yield and income. It is important to note that revenue and profit were higher in Minjibir than Wudil because the soils in Wudil were relatively less fertile than in Minjibir. The yield advantages and differences noticed among the plant density treatments were reflected in the income and profit. Groundnut production was also more profitably in the relatively more fertile soil in Minjibir compared to Wudil, since total revenue and income were higher in Minjibir than Wudil in both years, under the two varieties, fertilizer applications and plant density.

Conclusion

Results obtained in these experiments, showed that there is a need to adjust the density recommended for the cultivation of groundnut in the Sudan Savanna of Nigeria. Both medium and early maturing varieties responded positively to increased plant density. Pod and haulm yields of over 2.4 t ha^{-1} are possible under higher plant density with appropriate P fertilizer application. P fertilizer application was also found to be necessary for increased grain yield and profitable groundnut cultivation and should be recommended along with a minimum plant density of 133,333 hill ha^{-1} (75 x 10cm). The highest density used in this experiment (133333 at 75 x 10cm) may not be the ceiling density for increased groundnut production. It is therefore necessary to further evaluate the productivities of the groundnut varieties at density higher than 133333 hills ha^{-1} in the Sudan savanna zone of West Africa. Legume breeders and breeding projects in West Africa should collaborate more closely with the agronomist in varietal development and dissemination to ensure that appropriate agronomic needs are identified anddisseminated.

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