GROWTH AND YIELD OF OKRA (*Abelmoschus esculentus* L) IN RESPONSE TO PLANT DENSITY AND NPK APPLICATION IN TROPICAL HUMID ENVIRONMENT

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Abstract
Effects of plant density and NPK application on the performance of okra were studied in 2011 and 2012 at the Teaching and Research Farm of Benson Idahosa University, Benin City, Nigeria to determine the appropriate plant density and NPK application rate for optimum okra production. This study involved two plant densities (55555 and 33333 pph) and three levels of NPK (0, 200 and 300 kg ha-1) on the growth and yield of okra was determined. The trial was a 2 x 3 factorial arrangement fitted into randomized complete block design and replicated three times. From the results, the plant density and fertilizer application rate increased plant height, stem girth, pod yield, number of leaves per area, leaf area index and total dry weight. The growth under higher plant density and fertilizer application achieved this efficiency through higher degree of foliation than plants grown under lower plant density and fertilizer rate. The higher leaf area index associated with higher plant density and fertilizer rate elicited corresponding effects on higher yield in terms of total dry matter and pod yield. Weed biomass was significantly reduced by plant density and increased by NPK application. Untreated plants had an average of 4.26 t ha-1, while NPK gave an average pod yield of 6.87 and 8.47 at 200 and 300 kg ha-1, respectively. A combination of 55555 plants per hectare and 300 kg NPK was the most economical as it had the highest benefit-cost ratio (4.77).

Keyword: Growth, NPK, plant density and yield
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Introduction

Okra productivity in Nigeria is low when compared to other major producer countries like India (10.6 t ha-1). According to FAOSTAT (2012), total cultivated area in Nigeria for the production of okra was 455,100 hectares and the production quantity was 955,600 tonnes giving an average of 2.10 t ha-1 which is below African average of 2.78 t ha^{-1}. The yield of okra is known to be mostly limited by soil fertility and cultural management (lack of proper weed control, insect attack, improper use of fertilizer, lack of improved varieties of seeds, sub-optimal plant density, and inappropriate planting dates). In most cases, the crop is intercropped with other field crops at population higher than the 10,000 plants per hectare recommended for Okra intercrop (Udoh *et al*. 2005).

The use of inorganic fertilizer and optimum plant density can increase Okra productivity in the humid forest of Nigeria. Therefore, there is need to develop a sustainable cropping system through appropriate plant density and supply of sufficient nutrients through inorganic fertilizer application for optimum Okra growth and development. This study was conducted to evaluate the effects of planting density and NPK application on growth and yield of okra in a bid to identify an optimum plant population per hectare and NPK regime that would optimize yield and productivity.

Materials and methods

The experiment was conducted in the Teaching and Research farm of Benson Idahosa University, Benin City, Nigeria in April to June, 2011 and 2012. Benin City is located on 5^0 45′ N and longitude 5^0 04′ E characterized by a humid tropical climate. The area has a mean annual rainfall of 1762 mm and daily temperature of 26.4 ^{0}C. It lies within rainforest agro-ecological zone of Mid-western region of Nigeria, which had degraded to secondary forest as a result of shifting cultivation. Okra cultivar "OCRA" and NPK 15:15:15 fertilizer were obtained from Edo State Agricultural Development Programme, Benin City.

The trial involved two plant densities (55555 and 83333 plant per hectare (pph)) and three NPK rates (0, 200 and 300 kg ha^{-1}) factorial arrangement fitted into randomized complete block design with three replication. NPK fertilizer was applied two weeks after sowing. Each plot size was 3.60 x 3.00 m^2.

Composite soil sample was collected from top soil (0-15 cm depth) before the application of fertilizer. Standard laboratory procedures were followed in analyzing the soil sample. Accordingly, determination of soil particles size distribution was carried out using the hydrometer method. Soil pH was measured potentiometrically using digital pH meter in 1:2.5 soil to solution ratio with water and IM KCl solution. Exchangeable bases were extracted with 1.0 M ammonium acetate at pH 7.0 Ca and Mg in the extract was measured by atomic adsorption spectrometer while K was determined using flame photometer. Organic carbon was determined following wet digestion method as described by Walkey and Black (1934). Total nitrogen in soils was determined by the Kjeldahl procedure as described by Jackson (1963). Available P in soils was determined by the Olsen (Olsen *et al*.1954) and Bray ll (Bray and Kurtz, 1945) methods.

The land was cleared of the existing vegetable and beds constructed using hoes. Three seeds of okra were sowed on the prepared beds at spacing of 60 x 30 cm and 40 x 30 cm giving plant densities of 55555and 83333 pph respectively. Before sowing, seeds were soaked in water over night. Supplies were made to missing stands at one week after sowing (WAS). Thinning to one per stand was done at two weeks after sowing (WAS). NPK 15:15:15 was applied at 0, 200 and 300 kg ha^{-1} by band placement.

Weeding commenced at two WAS and subsequently weeding was carried out as at when due. Chemical spraying with Cypermetrin was carried out to control some insect pests. Three plants were randomly collected from each plot for determination of growth and yield parameters. Successive harvesting was done thrice as pods reached market table size.

Vegetative parameters assessed include days to emergence, % germination, plant height, stem girth, leaf area index (LAI), total dry weight (TDW) and weed biomass at two and four weeks after sowing (WAS). At flowering, days to 50 % flowering in addition to earlier parameters assessed at two and four WAS. At two, WAS, four WAS and 50% flowering, two okra plants were uprooted from each plot, chopped and packed into brown envelope and oven dried at 60^0C for 2-3 days to a constant weight for TDW determination.

Data collected were statistically analyzed with GENSTAT Programme, version 8.1 (GENSTAT, 2005) using analysis of variance. The least significant difference (LSD) was applied to defect the significant difference among treatment combination means.

To Determine the optimum fresh fruit yield in the trial, the gross margin (GM), return per naira invested, the net returns (NR) and the benefit: cost ratio (BCR) were used (Erhabor, 2005). All the expenses and revenue were estimated per hectare. GM is the difference between total revenue (TR) and total variable cost (TVC) and was determined using:

GM = TR - TVC

Net Return (NR) represents the total profit which was determined using:

NR = TR - TC

Where TC= Total Cost

$$\text{Return Per naira invested} = \frac{Gross\ margin}{Total\ Cost}$$

$$\text{BCR} = \frac{Total\ Revenue}{Total\ Cost}$$

Results

Some physical and chemical properties of the soil on which the trial was sited are presented in Table 1. The particle size analysis revealed that the soil is sandy loam, neutral with a pH of 7.4 while the percentage organic carbon content was 5.54 %. The nutrient status of the soil only showed deficiency in total nitrogen (0.07 %). However, since Ca/Mg ratio is less than 3, it is an indication of Ca and Mg deficiency.

Table 1: Routine properties of the experimental site prior to cropping

Soil properties	Value
pH (H_2O)	7.40
Organic carbon (g kg^{-1})	55.40
Total nitrogen (g kg^{-1})	0.70
Available phosphorus (mg kg^{-1})	81.00
Exchangeable cations (cmol kg^{-1})	
K	0.64
Ca	0.92
Mg	0.45
Particle size analysis	
Clay (g kg-`)	250.00
Silt (g kg-`)	170.00
Sand (g kg-`)	580.00
Textural class	Sandy loam

The effect of plant density and NPK application on growth of okra is presented in Table 2. Generally, all measured growth characters increased with age up to 50 % days to flowering. Plant density had a significant (p>0.05) effect on plant height at 4 WAS and days to 50 % flowering with plant population of 55,555 per hectare producing the tallest plants at 4 WAS (24.67 cm) and days to 50 % flowering (28.44 cm). NPK application had significant effect on plant height at 4 WAS and days to 50 % flowering. At 4 WAS, 200 kg ha^{-1} NPK and untreated control were not significantly different from each other but statistically inferior to 300 kg ha^{-1} NPK. At days to 50 % flowering, both NPK application rates were significantly different from untreated control.

Similarly, significant stem girth was noted at 4 WAS and flowering for 55,555 pph. The thickest plant was observed with 55,555 pph. For NPK application, 300 kg ha^{-1} NPK was superior to 200 kg ha^{-1} NPK and untreated control in that order. Number of leaves per plant increased progressively throughout the sampling periods. The number of leaves per plant was significantly higher with 55,555 pph at 4 WAS and days to 50 % flowering than with 83,333 pph. Increasing plant density resulted in decreased number of leaves per plant but increased per unit area (m^2). NPK application had significant effect on number of leaves at all sampling periods except 2 WAS. At 4 WAS and days to 50 % flowering, number of leaves increased with increasing NPK application rate reaching peak at 300 kg ha^{-1} NPK had the highest number of leaves in both sampling periods.

Plant density had no significant effect on LAI at all sampling periods ($P > 0.05$). However, application of NPK led to signification enhancement at LAI over control at 4 WAS and flowering. At 4 WAS, the highest LAI was obtained with both 200 kg ha^{-1} (2.32) and 300 kg ha^{-1} NPK (2.32). At days to 50 % flowering, 300 kg ha^{-1} NPK had significantly the higher LAI (4.29) than 200 kg ha^{-1} NPK (3.28) and untreated control (1.08) in that order.

The TDW increased with higher plant density only at 4 WAS. Application of 200 and 300 kg ha^{-1} NPK resulted in significantly increased over the control in TDW at 4 WAS and days to 50 % flowering. In both sampling periods, the highest TDW was obtained at 300 kg NPK ha^{-1}. The TDW obtained under control was the least. The total dry matter and LAI were positively correlated ($r = 0.70$ and 0.72 at four WAS and days to 50 % flowering, respectively). Interactive effect of plant density and NPK application was significant ($p>0.05$) for plant height, stem girth, number of leaves and TDW at 4 WAS and days to 50 % flowering. However, it was only significant for LAI at 4 WAS.

The effect of plant density and NPK application on days to 50 % flowering and weed biomass are shown in Table 3. Weed biomass increased as fertilizer application rate increased and decreased in plots without fertilizer treatment and increasing plant density. Weed biomass was lowest in all plots without fertilizer treatment and at higher plant density.

Pod yield and yield components of okra as influenced by plant density and NPK application are planted in Table 4. Plant density had negative effect on number of pod and weight of pod per plant. Number of pod per plant decreased as plant density increased. This observation was also mirrored with weight of pod per plant.

Table 2: Effects of plant density and NPK application on the growth of okra

Plant density (pph)	Plant height (cm) Weeks after sowing			Stem girth (cm) Weeks after sowing			Number of leaves Weeks after sowing			Leaf area index Weeks after sowing			Total dry weight (t ha^{-1}) Weeks after sowing		
	2	4	DTF	2	4	DTF	2	4	DTF	2	4	DTF	2	4	DTF
55,555	3.94	24.67	28.44	1.27	4.09	4.34	5.33	10.33	11.67	0.50	1.94	3.00	0.21	1.24	1.35
83,333	4.00	17.33	24.06	1.22	2.74	3.62	5.44	8.67	9.00	0.84	2.22	2.78	0.18	1.41	1.29
LSD $_{0.05}$	ns	3.271	1.862	ns	0.417	0.382	ns	1.498	0.920	ns	ns	ns	ns	0.114	ns
NPK (kg ha^{-1})	**Plant height (cm) Weeks after sowing**			**Stem girth (cm) Weeks after sowing**			**Number of leaves Weeks after sowing**			**Leaf area index Weeks after sowing**			**Total dry weight (t ha^{-1}) Weeks after sowing**		
	2	4	DTF	2	4	DTF	2	4	DTF	2	4	DTF	2	4	DTF
0	4.00	17.33	20.17	1.25	2.62	2.95	5.33	7.83	7.67	0.60	0.93	1.08	0.20	1.04	0.78
200	4.08	20.67	26.92	1.25	3.68	4.17	5.33	9.67	10.83	0.62	2.32	3.28	0.20	1.33	1.46
300	3.83	25.00	31.67	1.23	3.95	4.83	5.50	11.00	12.50	0.79	2.32	4.29	0.20	1.60	1.72
LSD $_{0.05}$	ns	4.007	2.28	ns	0.511	0.426	ns	1.834	1.126	ns	0.853	0.414	ns	0.139	0.137
LSD $_{0.05}$ PD x NPK	ns	5.666	3.225	ns	0.722	0.603	ns	2.594	1.591	ns	1.206	ns	ns	0.197	0.194

PD - plant density; DTF - Days to 50 % flowering; pph - plant per hectare; TDW - Total dry weight; ns - not significant

Table 3: Effects of plant density and NPK application on days to 50 % flowering and weed biomass

Plant Density (pph)	Days to 50 % flowering	Weed biomass ($t\ ha^{-1}$)
55,555	35.00	1.22
83,333	38.11	0.73
$LSD_{0.05}$	0.43	0.131
NPK ($kg\ ha^{-1}$)	Days to 50 % flowering	Weed biomass ($t\ ha^{-1}$)
0	41.33	0.27
200	34.17	1.10
300	33.67	1.57
$LSD_{0.05}$	0.524	0.160
$LSD_{0.05}$ plant density x NPK	0.740	0.227

There were significant effects ($p>0.05$) of increasing fertilizer application rate on number of pod per plant and weight of pod per plant). Both number of pods per plant increased with fertilizer application rate between 200 and 300kg NPK. Average pod weight per plant and fertilizer application rate were significantly correlated ($p>0.05$, $r = 0.72$). Contrary to number of pod and weight of pod, pod yield per hectare and dry pod yield per hectare increased with higher plant density. The highest fresh and dry pod yields were recorded with a plant population of 83,333 pph. NPK application had significant effect on fresh and dry pod yield per hectare.

Table 4: Effects of plant density and NPK application on pod yield and yield components of okra

Plant density (pph)	Nos of pod ($g\ plant^{-1}$)	Weight of pod ($g\ plant^{-1}$)	Pod yield ($t\ ha^{-1}$)	Dry pod yield ($t\ ha^{-1}$)
55,555	17.56	110.00	6.10	0.47
83,333	9.56	83.90	6.97	0.56
$LSD_{0.05}$	1.079	6.520	0.507	0.048
NPK ($kg\ ha^{-1}$)	Nos of pod ($g\ plant^{-1}$)	Weight of pod ($g\ plant^{-1}$)	Pod yield ($t\ ha^{-1}$)	Dry pod yield ($t\ ha^{-1}$)
0	7.17	63.70	4.26	0.33
200	9.67	102.20	6.87	0.52
300	17.83	125.00	8.47	0.69
$LSD_{0.05}$	1.322	7.990	0.620	0.059
$LSD_{0.05}$ PD x NPK	1.869	11.30	0.877	0.083

PD - plant density

Interactive effect of plant density and NPK application was significant for number of pod per stand, weight of pod per plant, fresh and dry pod yield per hectare at $P < 0.05$ (Table 5). The population of 55555 pph with 300 kg NPK ha^{-1} had greatest pod weight per plant and highest number of pods per plants with values of 138.30g and 20.33 pods, respectively. The population of 83333 pph with 300 kg NPK ha^{-1} had the highest pod yield and dry pod yield per hectare with values of 9.27 and 0.74, respectively.

Table 5: Interactive effects of plant density and NPK application on pod yield and yield components of okra

Plant density (pph)	NPK (kg ha^{-1})	Nos of pod (g plant^{-1})	Weight of pod (g plant^{-1})	Pod yield (t ha^{-1})	Dry pod yield (t ha^{-1})
55,555	0	8.67	74.00	4.08	0.31
	200	11.67	117.70	6.53	0.46
	300	20.33	138.300	7.68	0.64
83,333	0	5.67	53.30	4.44	0.36
	200	7.67	86.70	7.22	0.56
	300	15.33	111.70	9.27	0.74
LSD $_{0.05}$ plant density x NPK		1.869	11.300	0.877	0.083

The gross margin, net return and benefit: cost ratio were highly influenced by plant density and fertilizer application. The total cost of production increased as both fertilizer application rate and planting density increased and ranged from ₦13, 125.75 to ₦ 36,344.55, which is an indication of 177 % difference between 55555 pph without fertilizer treatment and 83333 pph treated with 300 kg NPK ha^{-1} (Table 6). The accrued revenue ranged from ₦ 40,800.00 to ₦ 92,700.00, which is an indication of 127 % differences between 55555 pph without fertilizer treatment and 83333 pph treated with 300 kg NPK ha^{-1} (Table 6). In general, revenue increased as plant density and fertilizer application rate increased up to a population of 83333 plants treated with 300 kg NPK ha^{-1}. The gross margin and net return followed the same trend as the production cost and revenue. The population of 83333 pph with 300kg NPK ha^{-1} had the highest gross margin and net profit of ₦ 73,674.85 and ₦ 66,355.45, respectively (Table 6). However, the population of 55555 pph with 300kg NPK had the highest benefit: cost ratio of 4.77.

Table 6: Economic analysis of the effect of plant density and NPK application on the performance of okra

Item (N)	55555 pph NPK (kg ha^{-1})			83333 pph NPK (kg ha^{-1})		
	0	200	300	0	200	300
Output (t ha-1)	4.08	6.53	7.68	4.44	7.22	9.27
Revenue (N 0.10)	40800.00	65300.00	76800.00	44400.00	72200.00	92700.00
Total variable cost	9886.80	11088.60	12287.55	21524.25	25274.70	29025.15
Total fixed cost	3238.95	3527.70	3814.80	4684.35	6319.50	7319.40
Total cost	13125.75	14616.30	16102.35	26208.60	31594.20	36344.55
Gross margin	30913.20	54211.40	64512.45	26875.75	46925.30	73674.85
Net margin	27674.25	50644.70	60697.65	22191.60	40605.80	66355.45
Benefit: cost ratio	3.11	4.47	4.77	1.69	2.29	2.55

Discussion

Okra productivity in Nigeria is low (2.10 t ha^{-1}) (FAOSTAT, 2012). According to FAOSTAT (2012), the low okra productivity is attributed to low native fertility of the soil, very low plant density and complex intercropping practices. In most cases, the crop is intercropped with other field crops at population higher than 10,000 pph recommended for okra intercrop (Udoh *et al*. 2005). In this trial, pod yield was increased through higher plant density and NPK application. These cultural practices had increased the productivity of the crop in this trial above the African average of 2.78 ha^{-1} (FAOSTAT, 2012).

The reduction in the yield of okra plant observed in treatments without fertilizer may be related to insufficient nutrient uptake as the plants had to rely on the native fertility of the soil which has been shown to be deficient in total N, exchangeable Ca and exchangeable Mg. The significant pod yield increase obtained by the application of fertilizer clearly demonstrated the benefit of the application of NPK to okra plants. Increasing plant density increased yield ha^{-}

[1] and this effect was more effective and noticeable when it was combined with fertilizer application as observed in the trial.

Observation from the resent study has shown that plant height decreased with increasing plant density and increased with fertilizer application. The decrease in the plant height resulting from increased plant density was attributed to intra-plant competition for space, light, moisture and nutrients. The results observed show that plant height is sensitive to adequate nutrient supply (Sharma, 1997) and light interception. The plant height is an important growth character directly linked with the productive potential of a plant in terms of yield. An optimum plant height is claimed to be positively correlated with productivity of the plant (Saeed *et al*., 2001).

The decrease in plant height associated with plant increasing density was with significant changes in stem girth. The significant increase in plant height associated with increased fertilizer application could be attributed to the improvement in the soil fertility due to application of NPK fertilizer which replenished the soil with nutrients especially with nitrogen which was below the critical level (Ibedu et al., 1988). The added nitrogen enriched the soil and resulted in the elongation of the internode leading to increase in plant height.

Changes in stem girth were significant as fertilizer application level and plant density increased. This observation is supported by work of Aliyu and Olanrewaju (1996) on *Capsicum annum*, where they observed that the beneficial effects of N, P and K could be seen in the increase of stem girth and thus interpreted as accumulative growth. Lower plant density led to increase in stem girth. This was due probably to differences in improved light interception and utilization capacity of plants (Robert and Andrew, 1997).

Increasing plant density resulted in the increase of number of leaves per unit area and was more pronounced when NPK was applied. The increase in number of leaves per unit area was due to additional number of stands per unit area leading to additional number of leaves being produced from the extra stands. Changes in the number of leaves are bound to affect the general plant growth and vigour, as they are the major organs of photosynthesis of the plant. Increasing plant density resulted in plants producing smaller leaves, but the increase in fertilizer application level led to the production of wider leaves. Increasing plant density and fertilizer application level caused the production of larger sizes of leaves in tomatoes (Law-Ogbomo and Egharevba, 2008).

Numbers of leaves and size increased as plant density and NPK application rate increased leading to increase in LAI. The LAI of any plant is a measure of the capacity of the photosynthetic system and translocation. The increased LAI resulting from NPK application led to higher dry matter production and pod yield, resulting from better utilization of solar radiation which favoured photosynthetic capacity (Law-Ogbomo and Egharevba, 2008).

Higher plant density suppressed weed biomass as observed in the present trial. This arisen from the fact that at higher plant density, less space is available for weed in the farm to thrive hence, the cultivated plants has competitive advantage over weeds and less income will be spent on weed removal.

The significantly increased pod yield through increasing plant density and fertilizer application would enable okra production and farmer's income. Benefit-cost ratio is an indication of the return per naira invested and was greater than 1.00 at all plant density and fertilizer rate combinations. The population of 5555 pph with 300 kg NPK ha^{-1} had the highest benefit cost ratio of 4.77. This implies that maximum yield does not indicate maximum profit per amount of money invested (Doll and Osarem 1957). These findings also imply that profitable crop production depends on adequate essential nutrients and plant density but not excessive plant stands.

Conclusion and Recommendation

This study has revealed that okra pod yield can be increased to ensure food sustainability through plant density and NPK application to the optimum level. In the present study, optimum pod yields (7.68 to ha^{-1}) with the highest benefit-cost ratio (4.77) were produced with 55555 pph and 300 kg NPK ha^{-1} for the forest zone of Edo State was found to be a combination of 55555 pph and 300 kg NPK ha^{-1} Plant density and NPK have a profound effect on the overall performance of *A. esculentus* in Benin City, Nigeria, a humid forest zone..

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