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EFFECTS OF PLANT DENSITY AND NPK APPLICATION ON THE GROWTH AND YIELD OF WHITE GUINEA YAM (*Dioscorea rotundata* Poir) IN A FOREST ZONE OF NIGERIA

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ABSTRACT

Studies were conducted at Evboneka, Edo State, Nigeria in a forest zone to examine the effect of increasing plant population and NPK application on the growth and tuber yield of *Dioscorea rotundata* (Poir) cv "Obiaoturugo". This study involved three trials. The first was conducted in 2010 involving five plant densities (10000, 13333, 17778, 20000 and 266667 plants per hectare (pph)) laid in a randomized complete block design (RCBD) and replicated four times. The second trial was conducted in 2010 involving five NPK application rate (0, 100, 200, 300 and 400 kg NPK 15:15:15 ha^{-1}) using RCBD and replicated three times. In the third trial, the best three plant densities (10000, 13333 and 17778 pph) from the first trial were re-evaluated with the best two NPK application rates (200 and 300 kg NPK ha^{-1}) and control (0 kg ha^{-1}) from the second trial using a 3 x 3 factorial arrangement fitted into RCBD with three replicates. Results from the plant density trial revealed that increasing plant density significantly resulted in increased fresh tuber yield and decreased in number of tuber per stand, tuber size, % unmarketable tuber and multiplication ratio (MR). Based on MR, the best tuber yield was produced from 10000 pph, followed by 13333 and 17778, which were statistically comparable. Results from the fertilizer trial showed that the application of 300 kg ha^{-1} had the highest tuber yield (19.16 t ha^{-1}) statistically similar to 200 kg ha^{-1} (19.12 t ha^{-1}). There was no significant interaction effect on agronomic traits assessed as both factors acted independently on yam plants. Increasing plant density and NPK application rate resulted in increased degree of foliation and leaf area index (LAI). These parameters imparted higher photosynthetic capacity and translocation leading to higher total dry matter production and tuber yield. A plant density of 10000 pph and 300 kg ha^{-1} could be most profitable and also bring about a considerable increase in growth and tuber yield of yam.

Key words: Growth, multiplication ratio, yield, yam

INTRODUCTION

Edible yams (*Dioscorea rotundata* Poir) are one of the major principal tuber crops grown and consumed in Nigeria and other tropical countries [1]. Apart from being the major source of carbohydrate, it has other diverse uses in pharmaceutical, confectionary and livestock industries. Nigeria is the world largest producer of edible yams, accounting for 70-76 % of the total world production [2]. Nigeria produced about 18.3 million tonnes of yams from 1.5 million hectares in 2004[3] giving an average tuber yield of 12.20 t ha^{-1} [3]. This yield is low in terms of cost and benefit of producing yams. The low tuber yield per hectare is attributed to obsolete cultural practices, which include inappropriate plant population and relying on bush fallow practices for the recovering of soil fertility.

Two cultural practices which greatly influence fresh tuber yield are spacing and fertilizer application [4]. One of the ways of increasing the economic yield of most crops is by increasing plant density [5]. However, it has been reported that higher planting population up to 20000 plants per hectare (pph) is associated with higher yield, reduced tuber size and better tuber shape but low net yield due to larger weight of planting materials used [6]. The other cultural practice is fertilizer application in terms of type and rates. Adequate fertilizer application in terms of types and rates are known to influence growth and high yield [7].

In view of inconsistent and inadequate results concerning the combination of these two cultural practices in literature, field trials were conducted to determine the optimum planting density and NPK fertilizer application rate on the growth and yield of *D. rotundata* in forest zone.

MATERIALS AND METHODS

The study was conducted at Evboneka, Edo State, Nigeria during the 2010 and 2011 planting seasons. The total annual precipitations of the area were 1928.80 mm and 1595.00 mm for 2010 and 2011, respectively. This study involves three trials.

Trial 1

This trial was conducted during the 2010 planting season at Evboneka, Nigeria. A composite sample of top soil (0-30 cm depth) was taken and analysed for its physical and chemical properties before planting using standard laboratory procedure as described by Mylavarapu and Kennelley [8] and presented in Table 1.

The planting commenced April 2010 and harvested in December 2010. One variety of *D. rotundata* cv "Obiaoturugo" was used with five planting densities, P_1, 10000 pph (100 x 100 cm); P_2, 13333 pph (100 x 75 cm); P_3, 17778 pph (75 x 75 cm); P_4, 20000 pph (100 x 50 cm) and P_5, 26667 pph (75 x 50 cm). The trial was a randomized complete block design with four replicates.

The size of planting sett was 250 g and treated with wood ash and Aldrex T before planting to protect it against nematode and fungi, respectively. After planting, each stand was mulched with dry grass to conserve soil moisture. Staking was done for each stand and the plots were weeded when necessary. Basal application of 200 kg of NPK fertilizer ha^{-1} was applied to all plots at 6 weeks after planting (WAP) as recommended by Obigbesan and Agboola [8].

The yams were harvested at 33 WAP. Data were collected on number of tuber per stand, tuber yield per stand and hectare, average tuber size, multiplication ratio and % tuber that were less than 0.70 kg.

Trial 2

The trial was conducted at Evboneka, Nigeria. Composite soil sample was collected before cropping and analysed using Mylavarapu and Kennelley [8] procedure for their physical and chemical properties and presented in Table 1. The trial consisted of five levels of NPK 15:15:15 fertilizer application (0, 100, 200, 300 and 400kg ha^{-1}). The same variety of *D. rotundata* was used for planting and treated in the same way as in experiment 1. Planting of yam setts were done in April, 2010 at a spacing of 100 cm on ridges and 100 cm apart. Application of NPK treatments were made at 6 WAP. The plots were weeded when necessary.

The yams were harvested at 33 WAP. Data were collected on number of tuber per stand, tuber yield per stand and hectare, average tuber size and relative tuber yield.

Trial 3

This trial was carried out as on-farm project at Evboneka, Nigeria. Although the site was cultivated in previous years, there was no record of fertilizer application. The pre-trial physical and chemical characteristics of the soil are presented in Table 1. The 3x3 factorial arrangements were carried out in randomized complete block design with three replicates. The treatments consisted of nine complete factorial combinations of three planting densities (10000, 13333 and 17778 pph) and three levels of NPK 15:15:15 fertilizer (0, 200 and 300 kg ha^{-1}).

The field was cleared of existing vegetation and ridges constructed. *D. rotundata* cv "Obiaoturugo" 250 g setts were planted after receiving similar treatment as in trial 1 and 2 in April 2011 and spaced 100 x 100 cm, 100 x 75 cm and 75 x 75 cm to achieved plant population of 10000, 13333 and 17778 pph, respectively. The plots were weeded when necessary. At six WAP, NPK 15:15:15 fertilizer was applied at the rate of 0, 200 or 300 kg ha^{-1} depending on the treatment combination using basal application method.

Two plants were sampled per plot for morphological characters at 4 and 8 WAP. Data taken included vine length, vine girth, internode length, number of vines, nodes and leaves stand^{-1}. Two whole plants were randomly sampled from each plot for growth analysis at 16 and 24 WAP. The growth parameters were number of leaves, leaf area index (LAI), total dry weight (TDW) and harvest index (HI).

The yams were harvested at maturity (33 WAP), yield and yield components were estimated as in experiment 1. Data collected in all the experiments were analysed with

GENSTAT 8.1 programme and significant differences among treatment means were separated using the least significant difference (LSD).

RESULTS

Effects of plant density on yield and yield components of white guinea yam

Table 2 shows that 10000 pph had the highest number of tuber per stand (1.89) and was significantly different from 17778 and 20000 pph but statistically similar with 13333 and 26667 pph. The number of tuber per stand decreased as plant density increased. There was a positive correlation between plant density and number of tubers per hectare (r = 0.73).

Plant density had no significant effect on tuber yield per stand. The tuber yield per hectare increased with increasing plant density (Table 2). The highest tuber yield was obtained from 27778 pph with 21.93 t ha^{-1} and was significantly difference from 10000 and 13333 pph and statistically comparable to 17778 and 20000 pph. Average tuber size decreased with increasing plant density significantly. The heaviest tubers were obtained from 10000 pph and statistically similar with 13333 and 17778 pph and superior to 20000 and 27778 pph (Table 2). As the plant density increased, the production of unmarketable tubers (tuber less than 0.70 kg) also increased. The 27778 pph produced the highest percentage of unmarketable tubers (33 %) which was statistically comparable to 20000 pph (30 %) and inferior to 10000 (8.25 %), 13333 (10.03 %) and (9.05 %) (Table 2). Multiplication ratio (MR) in Table 2 showed a significant different among plant densities. 10000 pph had the highest (5.46) while 27778 pph had the least (3.29).

Effects of NPK on yield and yield components of yam

The influence of NPK application on tuber yield and its components is presented in Table 3. Fertilizer application had significant effect on number of tuber per stand. The highest number of tubers was observed in plots treated with 300 kg NPK ha^{-1} and the least was observed in plots without fertilizer application which was statistically comparable with plots treated with 400 kg NPK ha^{-1}. There was positive correlation (r = 0.56) between fertilizer application rate and number of tuber per stand. The highest tuber yield per stand was observed in 300 kg ha^{-1} treated plots but was not significantly different from other fertilizer application rates except 400 kg ha^{-1}. The least was control which was statistically the same with 400 kg ha^{-1}.

Generally, there was increase in tuber yield as the level of fertilizer application increased up to 300 kg ha^{-1} and declined sharply at 400 kg ha^{-1}. The highest tuber yield (19.16 t ha^{-1}) was obtained with the application of 300 kg ha^{-1} which was statistically comparable to 200 kg ha^{-1} (19.16 t ha^{-1}) while the lowest was 10.36 t ha^{-1} obtained from control plots which was statistically the same as the yield obtained from 400 kg ha^{-1} (11.55 t ha^{-1}). The average tuber size from fertilizer treatment was greater than that of the control. There was a steady increase up to 300 kg ha^{-1} and then a decline at 400 kg ha^{-1}. Relative tuber yield ranged from 1.00 to 1.85 for control and 300 kg ha^{-1}, respectively. It followed the same trend with tuber size and tuber yield per stand.

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Effects of plant density and NPK application on the growth and yield of yam
Generally, plant density and NPK application rate had no significant effects on vegetative characters at four WAP (Table 4). At eight WAP, fertilizer application rate varied significantly only in the number of leaves per stand. Fertilizer treated plots witnessed greater number of leaves compared to untreated plots. Mean number of leaves ranged from 81.80 to 137.03for control and 300 kg ha^{-1}, respectively.

Number of leaves per m^2, LAI, total dry matter (TDM) and harvest index (HI) witnessed greater mean values as plant density increased at 16 and 24 WAP (Table 5). At 16 WAP, increasing plant density and fertilizer application rate enhanced increase in the number of leaves. However, there was no significant interaction effect between plant density and fertilizer application. At 24 WAP, plant density had no significant effect on number of leaves. 300 kg NPK ha^{-1} significantly had the highest number of leaves per m^2. Plant density and fertilizer application had no significant effect on LAI at 16 WAP. However, there was a significant positive correlation (r = 0.63) between LAI and number of leaves at 16 WAP. At 24 WAP, LAI increased as fertilizer application rate increased. All fertilizer rates were not significantly different from each other (Table 5). At 24 WAP, there was also positive correlation (r = 0.59) between number of leaves and LAI. There was no significant interaction between plant density and NPK application at 16 and 24 WAP.

Increasing plant density and fertilizer application rate had increasing effect on TDM at 16 WAP. However, at 24 WAP, significant increase only occurred with fertilizer application while plant density had no significant effect (Table 5). The TDM was positively correlated with LAI at 16 and 24 WAP with values of r = 0.63 and 0.65, respectively. There was no significant interaction between plant density and fertilizer application at both sampling periods. At 16 WAP, HI varied from 0.16 and 0.22 for 17778 and 10000 pph, respectively. HI decreased significantly as plant density increased and increased as fertilizer application rate increased (Table 5). At 24 WAP, and there was increase in mean values of HI; however, significant increase only occurred with increasing fertilizer application rate while plant density had no significant effect on HI. There was no significant interaction of plant density and fertilizer application on HI at both sampling periods.

Table 6 presents the effects of plant density and fertilizer application on fresh tuber yield and its components. Generally, there was no significant interaction of plant density and NPK application on tuber yield and its components. Both plant density and NPK application had no significant effect on number of tuber per stand. Increasing plant density resulted in reduced average tuber size; however, the reverse was the case with NPK application. Plots treated with 300 kg NPK ha^{-1} had the highest tuber size (0.81 kg). This was comparable statistically to 200 kg ha^{-1} (0.78 kg). For plant density, the heaviest tubers (0.86 kg) were produced from 10000 pph plots. This value was statistically comparable to 13333 pph.

Plant density and fertilizer application had no significant effect on tuber yield per stand. Tuber yield per hectare varied from 16.51 to 19.44 t ha^{-1} for 10000 and 17778 pph, respectively. Fertilizer application had an increasing effect on tuber yield per hectare. The highest tuber yield (21.25 t ha^{-1}) was produced from 300 kg ha^{-1}. This value was about 12 % higher than that 200 kg ha^{-1}. Increasing plant density had a depressing effect on MR. The highest MR was observed in 10000 pph plots. There was a positive enhancing effect of increasing fertilizer application rate on MR. the highest MR was produced from 300 kg ha^{-1}, which was statistically similar to 200 kg ha^{-1}.

DISCUSSION

Plant density exerts a strong influence on tuber yield [9]. This study revealed that increasing plant density increased yield per unit area. Crop yield primarily depends upon the yield per plant and the plant population. As a rule, all crops tend to increase yield per unit area as population increased but to a certain limit. Therefore, at higher plant density, it produces high yield due to higher number of plants per hectare, only if fertilizer was applied as per plant basis.

The yam plant showed the usefulness of fertilizer application in improving its productivity as the tuber yield was reduced where fertilizer was not applied at all. This may be related to insufficient nutrient uptake as the plants have to rely on the on the native fertility of the soil which has been shown to be deficient in primary nutrients (N, P and K). Increasing plant density resulted in the increase in the number of leaves m^2. This was due to additional number of plants in a given area leading to additional of leaves being produced from the extra stands. However, without corresponding increased in fertilizer application, the leaves produced will be of small size. Corresponding increase in fertilizer application rate will lead to the production of leaves of appropriate sizes. 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 [10].

Increase in number of leaves is a precursor 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 increasing plant density and NPK application led to higher dry matter production and tuber yield, due to optimized utilization of growth resources to enhanced photosynthetic efficiency [10]. Increasing plant density without corresponding increased in fertilizer application will have a negative effect on HI. However, increasing NPK application rate enhanced efficiency of translocation of assimilates to tuber and hence positive effect on HI.

Too low a plant density is a common cause of poor fertilizer response [11]. Where soil fertility status is low, farmers tend to have fewer plants per hectare so that each plant gets a better share of the scare nutrients in the soil. However, low plant densities with added nutrients through fertilizer application may not result in a commensurate increase in yield owing to suboptimal utilization of added nutrients by the relative low number of plants. As a result of this, there is need to increase plant density for efficient utilization of added nutrient when fertilizer input is introduced in order to maximize yield. However, at very high plant density with adequate nutrients would induce

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excessive foliage production. Excessive foliage production caused shading of some leaves. Consequently, leaves shading resulted in low yield due to insufficient light interception.

Low MR associated with high plant density could be due to intense competition for light, nutrient and physical space resulting in reduced efficiency of light interception. Low to appropriate density had higher MR emanating from less competition for growth factors. The significant increase in MR as a result of fertilizer application clearly demonstrated the benefit of its usefulness. This arisen from adequate nutrition for vegetative growth prolongation thereby increasing greater production per unit of planting material.

CONCLUSION

This study has revealed that tuber yield can be increased to ensure food sustainability through adequate plant population and fertilizer application. In this study, there was no signification interaction effect between plant density and NPK application indicating that both acted independently. Based on MR, which is the rate of production per unit of planting material, the best plant density was 10000 pph while optimal NPK application rate was 300 kg ha^{-1}.

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Table 1: Soil physical and chemical properties of the experimental sites before cropping with yams in 2010 and 2011

Soil properties	Experimental site		
	Evboneka I	Evboneka II	Evboneka III
pH (H_2O)	6.32	5.70	6.30
Organic carbon (%)	1.90	1.62	1.66
Total nitrogen (%)	1.20	0.18	0.18
Available phosphorus (mg kg^{-1})	6.50	7.30	1.10
Calcium (cmol kg^{-1})	0.45	7.80	5.75
Magnesium (cmol kg^{-1})	0.34	0.60	1.75
Potassium (cmol kg^{-1})	0.14	0.40	0.27
Clay (%)	10.90	11.00	22.60
Silt (%)	8.60	11.00	23.40
Sand (%)	80.50	78.00	54.40
Textural class	Loam sand	Loam sand	Sandy loam

Keys: Evboneka I - Planting density trial site

Evboneka II - NPK fertilizer trial site

Evboneka III - Planting density and NPK fertilizer trial site

Table 2: Effects of planting density on yield and yield components of *D. rotundata* at final harvest

Planting density (pph)	No. of tubers Stand^{-1}	Fresh tuber yield kg stand^{-1}	t ha^{-1}	Tuber size (kg tuber^{-1})	MR	% Tuber < 0.7 kg
10000	1.89	1.04	13.65	0.73	5.46	8.25
13333	1.83	1.00	13.36	0.58	4.01	10.03
17778	1.49	1.09	19.34	0.78	4.35	9.05
20000	1.47	0.92	18.35	0.63	3.67	30.04
26667	1.60	0.82	21.93	0.53	3.29	33.00
Mean	1.66	1.04	17.33	0.64	4.16	18.07
LSD(0.05)	0.299	0.227	3.198	0.154	0.898	3.198

Table 3: Effects of different levels of NPK application on yield and yield components of *D. rotundata*

NPK (kg ha^{-1})	No. of tubers Stand^{-1}	Tuber yield (kg stand^{-1})	(t ha^{-1})	Average tuber size(kg)	Relative tuber Yield
0	1.67	1.04	10.36	0.61	1.00
100	2.11	1.77	17.72	0.86	1.90
200	2.42	1.91	19.12	0.83	2.03
300	2.78	2.18	19.16	0.89	2.42
400	1.89	1.16	11.55	0.61	1.23
Mean	2.17	1.61	15.60	0.76	1.72
LSD(0.05)	0.32	0.60	2.32	0.20	0.86

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Table 4: Effects of plant density and NPK application on early vegetative traits of *Dioscorea rotundata*

Treatment	Four weeks after planting					Eight weeks after planting					
	Nos of vine	Vine girth (cm)	Vine length (cm)	Internode length (cm)	Nos. of nodes	Nos of vine	Vine girth (cm)	Vine length (cm)	Internode length (cm)	Nos. of leaves	Nos. of nodes
Plant density (pph)											
10000	2.50	2.19	80.00	7.67	7.57	2.11	2.25	305	16.78	10.00	24.57
13333	1.95	2.27	102.00	11.39	8.22	2.11	2.58	285	20.00	19.00	27.85
17778	1.78	2.41	93.00	9.51	9.56	2.19	2.47	336	20.22	14.00	33.85
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
NPK (kg ha^{-1})											
0	1.78	2.24	0.92	10.00	9.56	2.22	2.39	2.56	22.30	18.00	22.10
200	1.78	2.35	0.86	9.56	7.44	1.94	2.59	2.98	18.60	16.00	28.00
300	2.22	2.31	0.97	9.01	8.33	2.24	2.31	282	16.20	13.00	34.00
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	1.539	ns
LSD (0.05) PD x NPK	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

PD - Plant density ns - not significant

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Table 5: Effects of plant density and NPK application on the growth of *D. rotundata* at 16 and 24 WAP

Treatment	Nos. of leaves		Leaf area index		Total dry matter (t ha^{-1})		Harvest index	
	WAP		WAP		WAP		WAP	
	16	24	16	24	16	24	16	24
Plant density (pph)								
10000	424.00	681.00	2.34	3.60	1.66	5.93	0.22	0.46
13333	442.07	677.67	2.40	3.50	1.85	6.82	0.16	0.52
17778	517.10	791.33	2.44	3.80	1.96	8.19	0.16	0.53
LSD (0.05)	64.000	ns	ns	ns	0.200	ns	0.010	ns
NPK (kg ha^{-1})								
0	323.00	501.00	1.89	2.63	1.32	3.13	0.10	0.35
200	475.83	748.00	2.44	3.67	1.90	7.58	0.18	0.56
300	564.33	900.48	2.85	4.61	2.36	9.20	0.26	0.60
LSD (0.05)	64.000	105.500	ns	1.620	0.200	0.160	0.010	0.160
LSD (0.05) PD x NPK	ns	ns	ns	ns	ns	ns	ns	ns

PD - Plant density
WAP - weeks after planting

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Table 6: Effects of plant density and NPK application on tuber yield and components of *D. rotundata*

Treatment	Nos. of tuber	Tuber size (kg)	Tuber yield		Multiplication ratio
			kg stand^{-1}	t ha^{-1}	
Plant density (pph)					
10000	1.92	0.86	1.65	16.51	6.61
13333	1.77	0.75	1.37	18.31	4.50
17778	1.70	0.64	1.09	19.44	4.04
LSD (0.05)	ns	0.140	ns	0.190	1.090
NPK (kg ha^{-1})					
0	1.59	0.65	1.06	14.03	4.16
200	1.83	0.78	1.44	18.97	5.2
300	1.97	0.81	1.62	21.25	5.81
LSD (0.05)	ns	0.140	ns	0.190	1.090
LSD (0.05) PD x NPK	ns	ns	ns	ns	

PD - Plant density
ns - not significant

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