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Effects of Plant Population and NPK 20:10:10 Fertilizer Rates on the Growth and Grain Yield of Maize (*Zea mays* L.) in Benin City, Edo State, Nigeria

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Abstract
Maize productivity is low in Nigeria due to declining soil fertility among other factors. This can be improved through balanced soil fertilization with the adoption optimum stand density. Trials were conducted in 2021 and 2022 to evaluate the effects of plant population and NPK 20:10:10 fertilizer on the growth and grain yield of maize in Benin City, Edo State, Nigeria at the Experimental Farm of the Faculty of Agriculture, University of Benin, Benin City, Nigeria. This experiments involved three NPK 20:10:10 rates (0, 600, and 800 kg ha^{-1}) and three number of plants per stand (1, 2, and 3 plants) were laid out in 3 x 3 factorial arrangements fitted into a randomized complete block design (RCBD) and replicated three times. Data were collected on vegetative characters and grain yield components The results showed that increased NPK 20:10:10 fertilizer application rates increased vegetative characters and and grain yield of maize, higher number of plants per stand increased plant growth, LAI, grain yield, and reduced the stem girths

Keywords: *Fertilizer rates. Grain yield, Growth, Maize, NPK 20:10:10, Vegetative characters*

Introduction

Maize (*Zea mays* L.) is one of the major cereals in the world and the most important food crop in Nigeria (Kamara *et al*., 2020). It ranked second after cassava as the most cultivated crop in terms of harvested area (5.8 million hectares) in Nigeria (FAOSTAT, 2014). Nigeria is among the top ten (10) maize producers in Africa and is ranked second after South Africa with an estimated quantity of 10.8 million tonnes produced in 2014 and 11 million tonnes in 2019 (FAOSTAT, 2014; USDA, 2019). The demand for maize was approximately three billion metric tonnes worldwide in 2019 (Kamara *et al*., 2020). Many people classified it as the number one grain crop in the world because of its extensive use as the primary source of calories in feed formulation for farm animals (FAO, 2019). Maize is widely cultivated in many regions of Nigeria, ranging from the coastal swamps of the South to the dry savanna lands of the North. The production of maize crop is very popular in Nigeria among farmers because of its high socio-economic value and importance in tackling food insecurity (Bamire *et al*., 2010). Remison (2005) grouped the uses of maize as staple human food, feed for livestock and industrial raw materials.

Despite the importance of maize and the number of farmers involved in cultivating it in Nigeria, its productivity is low and unable to meet its high demand due mainly among other things to low nutrient status of most soils and inappropriate stand density (Akande, 1994). Nigeria soils are declining in fertility due to soil erosion and low organic matter content, (FAO, 2001). Increasing the nutrient status of a soil may be achieved through fertilizer application but most Nigerian farmers still apply fertilizers without knowing the soil nutrients status and the appropriate fertilizers to use.

Crop yield is directly influenced by the population of plants in the field. If the number of plants per stand is too high or above the recommended number, there will be intra-plant competition among the crops for space, sunlight, available soil water and nutrients. This may result in the alterations of normal growth and development of individual plant, such that the thickness of leaves and stem may be reduced due to increased number of plants per stand. This will eventually result in low yield of individual plant due to a reduction in the number and size of ear in case of maize crops (Nazer *et al.*, 2016). Consequently, number of plant(s) per stand should be maintained at an optimum to ensure maximum crop yield.

Cereal producers in most parts of the developing countries are unaware of the recommended number of plants per stand of cereal crops, and good quality data from local trials are not available to them. My observations from our localities have shown that many researches on the effects of plant population on yield were published, those findings are not readily accessible to farmers and even those that are aware of these results usually do not practice it on the field. There is need to disseminate these global findings to identify how plant population affects grain yields (Haarhoff and Swanepoel, 2018). This study aimed to evaluate the effects of plant population and NPK 20:10:10 fertilizer rates on the growth and grain yield of maize in Benin City, Edo State, Nigeria

Materials and Methods

Description of experimental site

Field experiments were conducted in 2021 and 2022 at the Experimental Farm of the Faculty of Agriculture, University of Benin, Benin City, Edo State, Nigeria. Benin City is in the tropical rainforest zone of Nigeria and it is located between latitude 6^o 30' and 6^o 58' North of the Equator and longitude 5^o 30' and 6^o 10' East of Greenwich Meridian. The city is situated on an average elevation of 77.8 m above sea level where the annual rainfall ranges from 1500 - 2500 mm and minimum and maximum temperatures averages are 25 and 28 ^{o}C, respectively. Relative humidity is about 83 % and rainy season in Benin City begins in March/April and ends in October/November. The dominant soil type of the study area is sandy loam with pH range of 4.7-5.7 (strongly to moderately acidic) (Floyd *et al.,* 2016; Soil Science Division Staff, 2017).

Experimental design and Treatments

The experimental site measuring 23 m x 21.5 m (494.5 m^2) was cleared, ploughed and harrowed manually, Tape, pegs, mallet and ropes were used to demarcate the area into 3 blocks and 54 plots. The experiment involved NPK 20:10:10 fertilizer rates (0, 600, and 800 kg ha^{-1}), and three number of plants per stand (1, 2, and 3 plants per stand), laid out in 3 x 3 factorial arrangements, fitted into a randomized complete block design (RCBD) and replicated three times.

Each plot measured 2 m x 3 m (6 m^2) with a spacing of 0.5 m between plots and 1 m between blocks.

Soil samples and sowing

Soil samples were randomly collected from the experimental site at a depth of 0-15 cm with an auger and bulked together to constitute a composite sample before cropping with maize. The composite sample was air dried under shade in the laboratory and sieved through a 2 mm mesh for physical and chemical properties. Maize seeds were sowed and spaced 75 x 25 cm. At 2 WAS, seedlings were thinned down to one, two and three plants per stand, giving (32, 64, and 96 plants per plot (53,333, 106, 666, and 159, 999 plants per hectare), respectively. Manual weeding of the plots was carried out first at 4 WAS and subsequently as required.

Data collection

Data were collected on vegetative characters (plant height, stem girth, number of leaves, leaf area index), yield and yield components (ear/husk weight, ear/husk length, ear weight, ear length, ear girth, number of kernel rows per ear, number of kernels per row, 1000- grain weight, and grain weight).

Data analysis

All data collected were analyzed using the analysis of variance (ANOVA) with the GENSTAT programme. Least significant difference (LSD) test was used to detect significant differences among the means at 5 % level of significance.

Results

Physical and chemical properties of the soils prior to cropping with maize

The physical and chemical properties of the soils prior to cropping with maize are presented in Table 1. The soils particle sizes were textually sandy loam. The soils of the two experimental sites were strongly acidic. The organic carbon and total nitrogen contents were low but higher in 2021 cropping season. Available P were below the critical level but higher in 2022 cropping season. Exchangeable Ca and Mg were adequate but low in 2022 cropping season where Mg was below critical level. Exchangeable Na contents of the soils were below the tolerant level but higher in the soil of the 2022 cropping season. In the same vain, exchangeable H^+ and Al^{3+} were below the tolerant limits. Both were lower and higher in 2021 and 2022 cropping seasons, respectively. The contents of micronutrients were below the critical level in all the experiments except zinc.

Table 1: Physical and chemical properties of soils prior to cropping with maize

Variable	2021	2022
Particle size (g kg^{-1})		
Sand	864.00	877.00
Silt	65.00	63.00
Clay	71.00	60.00
Bulk density (g cm^{-3})	1.30	1.20
Porosity (%)	50.00	54.00
pH (H_2O)	5.53	5.46
Total organic carbon (g kg^{-1})	9.04	8.25
Total nitrogen (g kg^{-1})	0.72	0.70
Available phosphorus (mg kg^{-1})	6.22	6.45
Exchangeable cation (cmol kg^{-1})		
Calcium	0.76	0.64
Magnesium	0.20	0.15
Potassium	0.23	0.18
Sodium	0.14	0.16
Exchangeable acidity (cmol kg^{-1})		
Hydrogen	0.21	0.26
Aluminium	0.12	0.15
Micronutrients (mg kg^{-1})		
Iron	76.40	75.80
Zinc	24.50	25.00
Manganese	15.30	14.90

Growth of maize

Effects of NPK 20:10:10 and number of plants per stand on the growth of maize are presented in Tables 2a and b. NPK 20:10:10 application rates significantly increased the plant height of maize at all the sampling periods in both cropping seasons and in the combined analysis. At 4 WAS, in 2021, 2022 cropping seasons and in the combined analysis, increase rate of fertilizer application led to increase in plant height and plots treated with 800 kg ha^{-1} NPK 20:10:10 produced the tallest plants. At 50 % tasselling in both cropping seasons and in the combined analysis, tallest plants were produced in plots treated with 800 kg ha^{-1} NPK 20:10:10 while the untreated plants had the shortest plants.

Number of plant per stand significantly influenced the plant height at all sampling periods in both cropping seasons and in the combined analysis. Tallest plants were observed on plots cropped with three plant per stand and the shortest plants were in plots with one plants per stand. Plants were taller in the 2022 than in the 2021 cropping season at 4 WAS and 50 % tasselling. There was significant interaction between NPK 20:10:10 and number of plants per stand on plant height in both cropping seasons and the combined analysis at 50 % tasselling (Table 3). In both cropping seasons and in the combined analysis, plots cropped at one plant per stand fertilized with 800 kg ha^{-1} NPK 20:10:10 had the tallest plants.

Fertilizer application rates significantly influenced stem girth of the maize plants in all sampling periods. 800 kg ha^{-1} NPK 20:10:10 treated plants produced the thickest stems followed by 600 kg ha^{-1} NPK in the 2021 cropping season and in the combined analysis at 4 WAS. However, in 2022 cropping season, all fertilized plants had comparable stem girths but significantly thicker than unfertilized plants. At 50 % tasselling, in both cropping seasons and when both cropping seasons were combined together. Plants which received 800 kg ha^{-1} NPK 20:10:10 had the thickest stems. The number of plant per stand influenced the stem girth of plants in both sampling periods and in the combined analysis. Thickest plants were produced on plots with one plant per stand and the thinnest plants were on plots with three plants per stand in both cropping seasons and in the combined analysis. A plant per stand treated with 800 kg ha^{-1} NPK 20:10:10 had the thickest stems in both cropping seasons and in the combined analysis.

NPK 20:10:10 fertilizer application rates had significant influence on number of leaves throughout the sampling periods in both cropping seasons and in the combined analysis (Table 2b). Unfertilized plants had the fewest number of leaves throughout the sampling periods. At 4 WAS, 800 kg ha^{-1} NPK 20:10:10 fertilizer produced the plants with the highest number of leaves in both cropping seasons and in the combined analysis but not significantly higher than plants treated with 600 kg ha^{-1}. At 50 % tasselling, the highest number of leaves were observed on 600 kg ha^{-1} NPK 20:10:10 in 2021 cropping season but not significantly higher than those plants treated with 800 kg ha^{-1}. In 2022 cropping season, 800 kg ha^{-1} NPK 20:10:10 treated plants had the highest number of leaves. However, when both cropping seasons were combined together, 600 and 800 kg ha^{-1} NPK 20:10:10 had similar number of leaves but significantly higher than control plants.

Leaf area index (LAI) was significantly influenced by NPK 20:10:10 fertilizer application in both cropping seasons and in the combined analysis. Plants on plots treated with 800 kg ha^{-1} NPK 20:10:10 produced the highest LAI throughout the sampling periods in both cropping seasons and in the combined analysis except at 4 WAS in 2022 cropping season where 600 and 800 kg ha^{-1} NPK 20:10:10 had similar LAI. The lowest LAI was observed from plants without NPK 20:10:10 treatment.

Increased in the number of plants per stand brought about increase in LAI throughout the sampling periods in both cropping seasons and in the combined analysis. Plots cropped with one plant per stand produced the least LAI at 4 WAS and 50 % tasselling in both cropping seasons and in the combined analysis. Throughout the sampling periods in both cropping seasons and in the combined analysis, the plots with three plants per stand produced the largest LAI but only significantly larger than two plants per stand except in the 2022 cropping season at 4 WAS and 50 % tasselling day and when the two cropping seasons were combined. The significant interaction effect of NPK 20:10:10 and number of plant per stand on leaf area index was observed at 4 WAS in 2022 cropping season, and in both cropping seasons and in the combined analysis at 50 % tasselling day.

Table 2a: Effects of NPK 20:10:10 and number of plants per stand on growth of maize

Treatment	Plants height (cm)						Stem girth (cm)					
	Four weeks after sowing			50 % flowering day			Four weeks after sowing			50 % flowering day		
	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined
NPK rate (kg ha^{-1})												
0	21.84	23.16	22.50	60.60	70.50	65.56	2.12	2.42	2.27	3.03	3.16	3.10
600	24.27	26.72	25.50	101.20	112.30	106.71	2.50	2.56	2.53	4.04	4.56	4.30
800	25.71	28.61	27.16	108.80	134.50	121.64	2.64	2.58	2.61	4.28	4.99	4.63
$LSD_{(0.05)}$	1.365	0.747	0.743	5.200	6.340	4.070	0.100	0.038	0.055	0.143	0.121	0.130
Number of plants per stand (NPPS)												
1	21.44	24.41	22.93	71.50	93.50	82.50	2.67	2.72	2.69	4.43	4.67	4.55
2	24.03	25.88	24.96	86.30	103.50	94.89	2.44	2.50	2.47	3.75	4.21	3.98
3	26.35	28.20	27.27	112.80	120.20	116.52	2.16	2.53	2.25	3.16	3.84	3.50
$LSD_{(0.05)}$	1.305	0.747	0.743	5.200	6.340	4.070	0.100	0.038	0.053	0.143	0.121	0.130
Mean	23.94	26.16	25.05	90.20	105.70	97.97	2.42	2.52	2.47	3.78	4.24	4.01
$LSD_{(0.05)}$ year			0.607			3.320			0.045			0.102
Interaction												
NPK x NPPS	ns	ns	ns	*	*	*	ns	ns	ns	*	*	*

*- significant at 5 % level of probability, not significant at 0.05 level of probability

Table 2b: Effects of NPK 20:10:10 and number of plants per stand on growth of maize

Treatment	Number of leaves per plant						Leaf area index					
	Four weeks after sowing			50 % flowering day			Four weeks after sowing			50 % flowering day		
	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined
NPK rate (kg ha^{-1})												
0	10.29	10.03	10.16	22.94	22.59	22.76	0.20	0.24	0.22	1.19	1.46	1.33
600	11.79	11.47	11.63	24.57	24.46	24.51	0.31	0.62	0.47	2.89	5.23	4.06
800	11.91	11.80	11.86	24.50	25.23	24.86	0.40	0.62	0.51	3.25	5.98	4.62
$LSD_{(0.05)}$	0.727	0.419	0.401	0.924	0.517	0.527	0.039	0.014	0.030	0.228	0.174	0.141
Number of plants per stand (PPS)												
1	6.46	6.92	6.69	13.73	13.28	13.50	0.27	0.35	0.29	2.07	2.47	2.27
2	11.64	11.10	11.37	24.39	24.64	24.51	0.33	0.50	0.42	2.73	4.34	3.54
3	15.89	15.29	15.59	33.89	34.36	34.76	0.34	0.63	0.40	2.54	5.87	3.38
$LSD_{(0.05)}$	0.727	0.419	0.401	0.924	0.517	0.527	0.039	0.014	0.030	0.228	0.174	0.141
Mean	11.33	11.10	11.22	24.60	24.09	24.05	0.30	0.49	0.40	2.45	4.22	3.34
$LSD_{(0.05)}$ year			ns			ns			ns			0.115
Interaction												
NPK x NPPS	ns	ns	ns	ns	ns	ns	ns	*	ns	*	*	*

*- significant at 5 % level of probability, ns - not significant at 0.05 level of probability.

Table 3: Interaction of NPK 20:10:10 and number of plants per stand on maize plant height (cm) at 50 % tasselling

NPK 20:10:10 (Kg ha^{-1})	No. of plant per stand	2021	2022	Combined
0	1	72.00	76.80	74.41
	2	60.00	69.90	64.92
	3	49.90	64.80	57.35
600	1	126.10	132.60	129.36
	2	98.40	109.40	103.90
	3	79.00	94.70	86.86
800	1	140.40	152.30	145.80
	2	100.50	131.10	115.84
	3	85.50	121.00	103.28
$LSD_{(0.05)}$		9.010	10.980	7.042

Table 4: Interaction of NPK 20:10:10 and number of plants per stand on stem girth (cm) of maize at 50 % tasselling

NPK 20:10:10 (kg ha^{-1})	No. of plants per stand	2021	2022	Combined
0	1	3.27	3.99	3.34
	2	3.02	3.15	3.08
	3	2.79	2.94	2.87
600	1	4.82	5.14	4.98
	2	3.98	4.57	4.27
	3	3.31	3.98	3.87
800	1	5.20	5.48	5.34
	2	4.26	4.90	4.58
	3	3.38	4.59	3.98
$LSD_{(0.05)}$		0.247	0.209	0.217

Grain yield components of maize

Effects of NPK 20:10:10 and number of plants per stand on grain yield components are presented in Table 5. In both cropping seasons and in the combined analysis, NPK fertilized plants produced similar number of kernel rows per ear but significantly higher than those produced by non-NPK 20:10:10 treated plants. The number of plants per stand decreased with increase in the number of kernel rows per ear. There was significant interaction between NPK 20:10:10 and number of plants per stand in the 2022 second cropping season and in the combined analysis (Table 6). In the 2022 cropping season and in the combined analysis, plots sowed with a plant per stand treated with NPK applied at 800 kg ha^{-1} had the highest number of kernel rows per ear while in the combined analysis, plots cropped with a plant per stand treated with NPK 20:10:10 applied at 600 kg ha^{-1} had the highest number of kernel rows per ear.

NPK 20:10:10 application increased the number of kernels per row. Plants fertilized with 800 kg ha^{-1} NPK 20:10:10 had the highest kernels per row in 2021 cropping season and in the combined analysis. However, in the 2022 cropping season, all fertilizer treated plants produced similar number of kernels per row but significantly higher than plants without NPK 20:10:10 treatments. Increased number of plants per stand decreased the number of kernels per row in both cropping seasons except in the combined analysis.

NPK 20:10:10 application increased 1000- grain weight in both cropping seasons and in the combined analysis. Plants treated with NPK 20:10:10 at 800 kg ha^{-1} had the heaviest 1000- grain weight. Increasing number of plants per stand, decreased 1000- grain weight. One plant per stand produced grains with the heaviest 1000- grain weight. All NPK fertilized plants produced similar grain yields in the 2021 cropping season and in the combined analysis but significantly higher than those produced the control plants. In the 2022 cropping season, increased NPK 20:10:10 application rate brought about increase in grain yields. Plants fertilized with 800 kg ha^{-1} NPK 20:10:10 had highest grain yield per hectare. Increasing the number of plants per stand brought about increase in grain yield. Plots sowed with three plants per stand had the heavier grain yield in both cropping seasons and in the combined analysis.

Table 5: Effects of NPK 20:10:10 and number of plants per stand on grain yield components

Treatment	No. of kernel rows per ear			No. of kernels per row			1000-grain weight (g)			Grain yield (t ha^{-1})		
	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined
NPK 20:10:10 rate (kg ha^{-1})												
0	11.88	11.88	11.77	22.56	20.06	21.31	199.21	194.59	196.90	2.25	2.14	2.20
600	12.77	12.77	12.33	24.70	21.34	23.02	211.10	218.23	214.66	4.26	3.67	3.97
800	12.78	12.78	12.50	25.66	21.39	23.52	216.47	227.19	221.83	4.17	3.96	4.07
$LSD_{(0.05)}$	0.337	0.229	0.230	0.884	0.454	0.493	0.884	3.416	2.617	0.323	0.090	0.164
Number of plants per stand (PPS)												
1	13.73	13.39	13.56	26.99	22.95	24.97	252.98	245.47	259.22	2.95	2.65	2.80
2	12.24	11.94	12.09	23.65	20.68	22.17	220.63	216.43	218.53	3.34	3.05	3.19
3	11.47	11.93	11.36	22.27	19.16	20.71	153.17	178.10	212.09	4.40	4.08	4.24
$LSD_{(0.05)}$	0.337	0.229	0.230	0.884	0.454	0.493	3.933	3.416	2.617	0.323	0.090	0.164
Mean	12.48	12.20		24.30	20.93		208.93	213.33		3.57	3.26	
$LSD_{(0.05)}$ year			0.188			0.402			2.136			0.134
Interaction												
NPK x NPPS	ns	*	*	ns	ns	ns	*	*	*	*	*	*

*- significant at 5 % level of probability, ns - not significant at 0.05 level of probability.

Table 6: Interaction of NPK 20:10:10 and number of plants per stand on number of kernel row per ear

NPK 20:10:10 (kg ha^{-1})	Number of plants per stand	2022	Combined
0	1	12.64	12.73
	2	11.58	11.63
	3	11.09	11.11
600	1	13.69	14.02
	2	12.07	12.24
	3	11.22	11.38
800	1	13.84	13.92
	2	12.18	12.39
	3	11.47	11.60
$LSD_{(0.05)}$		0.397	0.398

DISCUSSION

The soils of the experimental sites were sandy loam and of low fertility status evidenced through the exhibition of deficiencies of some essential nutrients like primary macro (NPK) and micronutrients. The soil type was a typical ultisol with low pH values. The total organic carbon contents were low, below critical levels as reported by Gideon and Akinola (1985) and Reddy *et al*. (2017). This also agreed with the findings of FAO (2001) who reported that south-western Nigeria soils were of low fertility and lacking some essential nutrients as they do not adequately replenished plant nutrients, and Akanbi and Togun (2002) reported that most of agricultural soils of southern and northern Nigeria are of low fertility status owing to weathering, leaching and intensive cultivation of crops. The low soil fertility status has resulted in low yield per hectare for maize plants without fertilizer treatments in the study area. An assessment by Stewart *et al.* (2005) found that 40 – 60 % of crop yields were attributed to fertilizer use. This increase in crop yield could be attributed to the supplementation of nutrients in the soil by nutrient content of the applied fertilizers.

In this study, NPK20:10:10 application showed a promising result in improving maize crop productivity. This fertilizer promoted vegetative characters and yields through the enhancement of plant height, stem girth, number of leaves, leaf area index and total yield per hectare. The high values of the plant vegetative characters and other yield components with NPK20:10:10 could be as a result of the nutrients supplied by the fertilizer which acted as the store house of plant nutrients. This coincided with the findings of Adekayode and Ogunkoya (2010) who reported a high significant difference in maize plant height and yield in plots treated with fertilizers compared with no fertilizer application. Leaf is an organ of photosynthesis, any increase in the number of leaves will increase the plant photosynthetic ability and thus enhanced plant growth and vigour. Higher LAI signify greater leaf production rate and this implies efficient production of assimilates (photosynthate) leading to higher dry matter and yield production (Law-Ogbomo *et al.*, 2012).

Increasing the number of plants from one to three plants per stand resulted in plants that were taller with thinner stems but higher number of leaves, larger LAI and higher yield per unit area (per hectare). The taller and thinner stems exhibited by plants grown at higher number than one per stand could be as a result of intra-plant competition. Higher plant densities led to intra-plant competition for plant growth resources (light, water, physical space and nutrients). This negatively influenced the vegetative growth of the maize plants (Antonietta *et al.*, 2014). Higher number of plants per stand produced higher number of leaves and LAI per unit area due to higher number of plants per unit area. This is an indication of higher interception of light and nutrient for photosynthesis which eventually enhanced grain yield per unit area. Lashkere *et al.* (2011) reported that number of plants per stand affected plant growth and development while lesser number of plants per stand encouraged luxuriant growth and wastage of physical space leading to reduced grain yield per hectare. Grain yield increased with increasing number of plants per stand and reached the peak at three plants per stand. Al-Naggar *et al.* (2015) reported that yield increased with increasing plant density up to 9.5 plants per m^2 under high nitrogen application.

Conclusion

This study demonstrated that maize grain yield can be improved through adoption of right number of plants per stand and soil fertility management. Higher number of plants per stand with more intense intra-plant competition resulted in taller and thinner plants but higher number of leaves, LAI and increased grain yield per hectare.

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