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Population Effect on Individual Crop Growth, Development, and Yield in Rainfed Maize in Southern Guinea Savanna Ecological Zone of Nigeria

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ABSTRACT

Maize yield is closely related to plant population; more plants mean higher yield. However, there are limitations to increasing plant population in tropical conditions. A 3 x 4 Factorial experiment with four replications was conducted to evaluate four plant populations (53, 333, 106, 666, 159,999, 213,332 plants/ha) on crop growth, development, yield and yield components of three maize varieties (Local variety, Oba Super and Samaz 52). The crops were spaced 25 cm x 75 cm and seeds were sown in line with the expected plant population per hectare: 53, 333, 106, 666, 159,999, 213,332 plants/ha. Six plant stands were randomly selected and tagged from the net plot for height measurement, average numbers of leaves per plant, leaf areas, and stem girth at 3, 5, 7 and 9WAS, as well as for yield and yield components. Significant ($p \leq 0.05$) influence of population was observed on days to 50% tassel, ear weight, ear length, kernel/ear, 100-kernel weight and grain yield per plant. Generally, increasing plant population led to the processive delay in days to 50% heading, reduction in ear weight, ear length, kernel/ear, 100-kernel weight as well as grain yield. There were significant interactions between variety and population on days to 50% tassel, ear weight, ear length,kernel/earr, 100-kernel weight and grain yield per plant. The better response of hybrids to population stress was evident in this trial compared with the local variety where the highest grain yield per plant was recorded in Oba Super II (779.13g and 890.01g, respectively in 2021 and 2022 cropping seasons), while the least grain yield per plant was in the local variety (530.80g and 475.00g, respectively in 2021 and 2022 cropping seasons). Sowing seeds at one seed/hole gave the highest grain yield/plant, 790.27g and 970.00g, respectively in the 2021 and 2022 cropping seasons. The least grain yield/plant, 513.27g and 322.50g, respectively in 2021 and 2022 cropping seasons were observed when four seeds were sown/hole. The highest amount of grain yield/ha was obtained in Oba super II (103,883.74kg and 118,667.70kg), respectively in the 2021 and 2022 cropping seasons, with the local variety giving the lowest grain yield in both seasons. While the lowest grain yield/plant was recorded in P4 (213,332 pop/ha), in the first year, the plot compensated for the yield reduction/plant with an increase in plant population cumulating in significantly greater harvest/ha (109,496.94 kg/ha), with P1(53,333 plant/ha) recording significantly the lowest grain yield/ha in both seasons. However, P4(213,332 pop/ha) did not repeat the same feat attained in the first trial as it trailed behind P3 (160,000 pop/ha) and P2 (106,666 pop/ha) in yield/ha; an indication that the population may not be able to maintain stable yield. The most consist population relative to yield/ha was P3 (160,000 pop/ha).

INTRODUCTION

It has been reported that maize producers in many parts of the world, particularly in developing countries where good-quality data from local trials are not available, rely on published information to make agronomic decisions. Observing that many papers have been published on the effects of plant population on yield, but the results are associated with prevailing local environmental conditions and agronomic practices of each study. Stating that this could lead to confusion among maize producers regarding the most appropriate agronomic management decision for their specific conditions and farming systems. Thus, there is a need to indigenize such studies to identify how plant population affects maize grain yield under local conditions.

It has generally been observed that maize yield in Nigeria is low compared to some other countries in Africa (Oloyede-Kamiyo and Olaniyan, 2020). While the authors observed that the reason adduced to this yield disparity has been low soil nitrogen, the problem of pests and diseases as well as poor access to quality seeds, they stressed that apart from these factors, one other major cause of poor yield of maize in Nigeria is suboptimal plant population. When adequate plant population is not maintained, low yield results, are observed Oloyede-Kamiyo and Olaniyan (2020). They reported that the recommended plant population for maize is 53,333 plants/haa at a spacing of 25cm within a row and 75cm between rows at one plant per hill, while a population density of 80,000 plants/ha was found to be optimal for hybrids (Olaniyan, 2014; Oloyede-Kamiyo and Olaniyan, 2020).

Erenstein et al. (2022) observed that, since its domestication some 9,000 years ago, maize (*Zea mays* L.) has played an increasing and diverse role in global agri-food systems. Stressing that global maize production has surged in the past few decades, propelled by rising demand and a combination of technological advances, yield increases and area expansion (Erenstein et al. 2022). The authors added that maize is already the leading cereal in terms of production volume and is set to become the most widely grown and traded crop in the coming decade.
In 2021, world maize production was 1,210 million thousand tonnes; an increase from 308 million thousand tonnes in 1972 with an average annual rate of 3.18% (Erenstein et al. 2022). Maize (Zea mays L.) plays a critical role in meeting the high food demand and is globally one of the most widely cultivated crops (FAO, 2017). Both the land area used for maize grain production and the amount of maize produced per unit area been increasing in recent years (FAO, 2017). It is one of the highest-yielding and most versatile cereals, adding that the global demand for maize has shown an increasing trend in the past decade (FAO 2009); with maize productivity increasing globally as a result of improved genetics and agronomic practices.

Oyewole et al. (2010) opined that the establishment of adequate plant stands is a prerequisite for successful crop production. In maize production, plant population and row spacing are two key agronomic factors known to have a strong influence on maize grain yield (IPNI Canada (2018), stating that maize yield is closely related to plant population, with more plants meaning higher yield. However, there are limitations to increasing plant population. The most favorable planting densities for high yield in the tropics are probably in the range of 65,000 to 75,000 plants/ha. Stressing that a population of less than 65,000 plants/ha is not advisable because a 10 percent loss of plants is not uncommon under rainfed field conditions (IPNI Canada, 2018). The report further added that having more than 75,000 plants/ha will not increase yield unless growing conditions are very favorable with a yield potential of >13 t/ha. Adding that for drought-prone environments, it is not advisable to have more than 75,000 plants/ha (IPNI Canada, 2018).

The optimum plant population depends on several crucial factors, including soil fertility, soil water-holding capacity, and hybrid maturity group, observed

Sangoi et al. (2002). Modern hybrids possess the ability to withstand greater stress attributable to high population densities than older hybrids, which in turn enables producers to establish higher plant populations, leading to higher yields per unit area (Russell, 1984; Duvick, 1997).

The number of plants per unit area is influenced by the distance between rows, the distance between plants in a row, and the number of plants in a hill. Farmers have been advised to, select an optimal plant spacing that allows for ease of field operations, such as fertilizer application or weeding, minimizes competition among plants for light, water, and nutrients, and creates a favorable micro-climate in the canopy to reduce the risk for pests and diseases (IPNI Canada, 2018). Narrow row widths of about 50 to 70 cm are recommended to ensure that sunlight falls on the plants and not on bare soil.

The agronomic practices implemented in a production system should allow the selected germplasm to react positively to the increased plant populations when favorable environmental conditions occur (Haegele et al. 2014) while also being tolerant to increased plant-to-plant competition under suboptimal growing conditions (Tokatlidis and Koutroubas, 2004). Changes in agronomic practices such as fertilization, effective weed control, and tillage practices can further alter the relationship between population density and maize grain yield. Thus, it is important to adjust the plant population accordingly to achieve optimal grain yields. Interactions between plant genotype and plant population can also affect maize grain yield, with a recent study conducted by DeBruin et al. (2017) finding a positive relationship between maize grain yields and plant population in modern hybrids, but a contrasting response in older hybrids. Previous reports observed that during the past six decades, much work has been done to evaluate the effects of plant population on maize grain yield in a wide variety of environments and regions (Duncan, 1958; Pretorius and Human, 1987; Ciampitti and Vyn, 2012; Hörbe et al. 2013; Assefa et al. 2016; Qin et al. 2016); with the observation that rainfall is a major determinant of differences in agronomic practices used between regions.

The authors reported that in arid and semiarid regions, rainfall is scarce and variable, and soil water is often the most limiting factor for grain production. Climatic conditions affect soil water content throughout the growing season, influencing the number of plants per unit area the soil can maintain throughout this period and, therefore, the optimal plant population. Both plant population and row spacing affect leaf canopy architecture (Sharratt and McWilliams, 2005) and, in turn, affect crop uptake of water and nutrients, as well as light interception. They pointed out that to justify the establishment of low plant populations, rapid canopy closure is needed for efficient resource use. Hammer et al. (2009) found that at high plant populations, root architecture was more important than canopy architecture and light interception for increasing grain yield.

As the human population is increasing with the total land area remaining fixed, the problem of scarcity of land for agricultural purposes is becoming pronounced. To feed this increasing population, the productivity of available land must be increased. As agricultural land becomes limiting, with the increasing human population, planting more seeds/hole maybe a justifiable means of addressing food scarcity. The study was to determine the effect of increasing the number of seeds/holes on plant growth, development, yield components and yield of maize under rainfed condition.

MATERIALS AND METHODS

A 3 x 4 Factorial experiment with three replications was conducted to evaluate four plant population (53, 333, 106, 666, 159,999, 213,332 plants/ha) on growth, development, yield and yield components of three maize varieties (Local variety, Oba Super and Samaz 52). Variety was a main treatment factor with population as sub treatment factor. The experiment was conducted in the rainy seasons of 2021 and 2022 in Kogi State University Anyigba Students' Research and Demonstration Farm (Latitude 70 301 and Longitude 70 091 E). The land was ploughed, harrowed and ridged. The crops were spaced 25 cm x 75 cm in subplots measuring 4m by 5m and seeds sown in line with the expected plant population per hectare. To achieve the experimental population, seeds were sown at either 1, 2, 3 or 4 seeds / hole, to give, respectively 53, 333, 106, 666, 159,999, 213,332 plants/ha. Nitrogen fertilizer (NPK 20:10:10) was applied in 2 split doses, starter doze at 2 weeks (60kg N/ha, 30kg P2O5/ha and 30 kg K2O/ha) after planting while crops were top dressed with Urea (46 % N) just before tasseling. Weed management was manually done with hoe at 2 and 6 weeks after sowing. However, after tasseling, emerging weeds were handpulled. For the control of insect pests such as grasshoppers, stem borers and Fall Army Worms (FAW), Emamectin Benzoate was sprayed at the rate of 30ml/16litres of water using a knapsack sprayer.

Data Collection

Six stands of crops were tagged in each net plot (3.5m by 4.5m) for data collection throughout the period of the experiment. Growth and development data were collected at 2, 4, 6, 8 and 10WAS, while data on yield components and yield were determined at the termination of the trial. Data were collected on plant height, being a measure of plant height from ground level to the pick of the longest leaf (before tassel) or the tassel (after tassel); Number of leaves per plant, numerical counting of all fully unfolded leaves. Other parameters collected were leaf area, and stem girth in accordance with Oyewole et al. (2015 a & b). While data on yield and yield components, such as cob yield, cob weight and grain yield were also obtained over a Metler weighing scale to two decimal places.

Growth Parameters

• Plant height (cm): The heights of each of the tagged plants were measured using a meter rule; from the soil surface to the apex and recorded an average of the total plants measured.
• Number of leaves per plant: This parameter was obtained by a simple count of the total functional leaves produced by tagged plants and recorded as average numbers of leaves/plant.
• Leaf area per plant (cm2): This was determined by measuring the lamina length and maximum width, multiple by a constant of 0.75 as described by Oyewole (2011).
• Stem girth (cm): This was determined with the aid of veneer calipers and recorded as an average of six tagged stands. Measurements were taken just above the ground level.

Yield Parameters

• Number of ears/plant: The number of ears from tagged plants in each net plot was averaged over the number of tagged plants to obtain a mean number of ears for the plant.
• Ear length (cm): Lengths of harvested ears were measured with the aid of measuring tape and averaged over the number of harvests.
• Ear weight (g): Harvested ears were weighed and averaged over total harvests per net plot.
• Threshing percentage: The harvested cobs were weighed, threshed and the grains were weighed. The result was expressed as ratios of grain weight over total cob or ear weight expressed in percentage.
• Number of kernels/ear: Kernels on the harvested ears were manually striped counted and averaged over the total number of sampled cobs/plot.
• 100-grain weight: Samples of three batches of hundred kernels per plot were drawn and weighed and recorded as mean of three batches.
• Grain yield: Cobs in the net plots were separately harvested, threshed, winnowed and weighed to give grain yield per plot (tons/ha).

Analysis of Data

Data collected were subjected to Analysis of Variance (ANOVA) as described for Factorial Experiment (Statistical Analysis System (SAS), 1998) and means found to be statistically significant at 5% probability were separated using LSD.

RESULTS AND DISCUSSION

Effect of increasing maize population per stand on height (cm) of three varieties of maize

Plant height at maturity (cm) is an important component which helps in the determination of the growth attained during the growing period (Abuzar et al. 2011), however height is dependent on many variables, among which are variety used, nutrient available, as well as plant population among other factors. Generally, it has been observed that agronomic practices implemented in a production system should allow the selected varieties to react positively to increased plant populations when favorable environmental conditions occur (Haegele et al. 2014) while also being tolerant to increased plant-to-plant competition under suboptimal growing conditions (Tokatlidis and Koutroubas, 2004). While stressing that changes in agronomic practices such as fertilization, effective weed control, and tillage practices can further alter the relationship between population density and maize grain yield. Thus, it is important to adjust the plant population accordingly to achieve optimal grain yields. Analysis of data in this trial showed that variety investigated significantly ($p \leq 0.05$) influenced crop heights at 4, 8 and 10WAS in the 2021 cropping season (Table 1) and at 4, 6, 8 and 10WAS in the 2022 cropping season. At the end of the trial, Sammaz 52 recorded the tallest crops in both seasons (385.71 cm and 340.83 cm, respectively in the 2021 and 2022 seasons), while the local variety recorded the tallest crops (363.11 cm) in the 2021 trial, while coming behind the other two varieties in 2022 trials. It should be expected that taller plants will lodge easily and are likely to break as a result of the wind effect (Oyewole et al. 2015a & 2015b). This will be more pronounced where an increase in plant height is not complemented by thicker plant stems / girths and where cobs are also borne high up the stems, which put more weight towards the top of the crop; such weight may make the plant tilt over under the influence of wind.

Table 1: Effect of increasing maize population per stand on height (cm) of three varieties of maize (*Zea mays*) in 2021 and 2022 cropping seasons

Treatment	**2021 Cropping Season**				**2022 Cropping Season**			
	Height (cm)							
	4WAS	**6WAS**	**8WAS**	**10WAS**	**4WAS**	**6WAS**	**8WAS**	**10WAS**
Variety								
V1: Sammaz 52	78.95^{a}	139.99	304.91^{b}	385.71^{a}	77.79^{a}	140.83^{a}	303.00^{a}	340.83^{a}
V2: Oba super-II	63.56^{b}	138.78	290.02^{c}	356.25^{c}	65.95^{b}	143.08^{a}	301.06^{a}	338.83^{a}
V3: Local Variety	64.53^{b}	140.49	318.04^{a}	363.11^{b}	63.61^{b}	121.42^{b}	275.39^{b}	297.92^{b}
LSD (0.05)	3.671*	NS	12.754*	7.891*	6.885*	13.895*	17.987*	12.761*
Population								
P1: 53,333 pop/ha	62.05^{d}	125.54^{d}	281.70^{b}	337.48^{c}	60.56^{b}	112.67^{d}	228.39^{d}	253.67^{c}
P2: 106,666 pop/ha	64.95^{cd}	137.36^{c}	293.41^{b}	356.29^{b}	65.67^{b}	134.78^{c}	303.21^{c}	336.44^{b}
P3: 160,000 pop/ha	67.33^{bc}	141.94^{b}	293.73^{b}	367.50^{b}	73.59^{a}	140.22^{b}	309.70^{b}	344.44^{b}
P4: 213,332 pop/ha	72.74^{a}	155.18^{a}	348.44^{a}	412.15^{a}	77.74^{a}	152.77^{a}	331.27^{a}	368.89^{a}
LSD (0.05)	2.781*	4.721*	15.932*	13.732*	6.223*	4.881	3.612	9.657*
Interaction								
V1P1	67.59^{bc}	125.22^{f}	271.02^{f}	351.99	72.40	118.00	288.40	318.00
V1P2	69.27^{b}	141.21^{cd}	297. 10d^{e}	377.21	72.80	144.33	304.23	344.33
V1P3	70.17^{b}	141.55^{cd}	300. 45^{cd}	388.41	81.30	144.66	313.23	344.66
V1P4	81.76^{a}	151.99^{b}	351. 05^{b}	425.22	84.66	156.33	306.13	356.33
V2P1	58.85^{e}	128.17^{f}	282. 31^{e}	338.77	59.66	130.00	289.44	318.00
V2P2	61.58^{cde}	134.64^{e}	287. 01^{e}	344.66	62.26	135.00	300.21	330.00
V2P3	65.95^{bc}	142.87^{c}	282. 54^{e}	342.77	70.23	147.00	304.23	347.00
V2P4	67.93^{bc}	149.44^{b}	308. 23^{c}	398.78	71.63	160.33	310.34	360.33
V3P1	59.70^{de}	123.22^{f}	291. 77d^{e}	321.67	49.63	90.00	107.34	125.00
V3P2	64.00^{bcde}	136.23^{d}	296. 12^{d}	346.99	62.66	125.00	305.20	335.00
V3P3	65.87^{bcd}	141.41^{cd}	298. 22^{d}	371.33	69.23	129.00	311.67	341.66
V3P4	68.53^{b}	161.11a	386. 04^{a}	412.45	72.93	141.66	377.34	390.00
LSD (0.05)	6.781*	5.329*	8.712*	4.672*	3.526*	8.782*	3.884*	9.563*
CV%	14.45	8.83	13.35	21.72	16.56	11.56	18.67	17.77

Means with the same letter(s) are not significantly different at 5% level of probability

Table 2: Effect of increasing maize population per stand on number of leaves of three varieties of maize (Zea mays) in 2021 and 2022 cropping seasons

Treatment	2021 Cropping Season				2022 Cropping Season			
	Leaf Number							
	4WAS	6WAS	8WAS	10WAS	4WAS	6WAS	8WAS	10WAS
Variety								
V1: Sammaz 52	8	10	12	12	8	10	12	12
V2: Oba super-II	7	10	11	12	7	10	11	13
V3: Local Variety	7	10	11	13	7	10	11	13
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Population								
P1: 53,333 pop/ha	8	10	11	13	8	10	12	13
P2: 106,666 pop/ha	8	10	11	13	8	10	11	13
P3: 160,000 pop/ha	7	9	11	12	7	9	11	12
P4: 213,332 pop/ha	7	10	11	12	7	10	11	12
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interactions								
V1P1	8	10	12	12	7	10	12	12
V1P2	8	11	11	13	8	11	13	13
V1P3	8	9	12	12	7	10	12	13
V1P4	8	9	11	12	8	9	11	12
V2P1	7	9	12	12	8	10	12	11
V2P2	7	10	11	12	6	10	10	12
V2P3	7	10	10	13	6	10	11	13
V2P4	7	10	11	13	8	9	9	12
V3P1	8	9	11	13	8	9	11	12
V3P2	7	10	11	13	5	9	11	12
V3P3	7	9	11	13	7	9	11	12
V3P4	7	10	11	13	8	9	10	12
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV%	11.37	7.99	8.04	5.17	17.24	4.73	7.29	15.02

Means with the same letter(s) are not significantly different at 5% level of probability

There was a significant (p≤0.05) influence of population investigated on crop heights at 4, 6, 8, and 10WAS in both seasons, with early signs of leaf etiolation observed due to competition for solar radiation (Hay and Walker, 1989) as seeding rates increase (Oyewole, 2011). Seeding at four seeds per hole consistently gave the tallest crops, followed by seeding three seeds per hole, with one seed per hole giving the shortest crops at 4, 6, 8 and 10WAS in both seasons; definitely because this experienced the least competition for solar radiation, compared with other treatment. Understandably, as crops are clustered together, they compete for solar radiation (Hay and Walker, 1989), and this competition leads to leaf elongation (Oyewole, 2011; Hay and Walker, 1989). It is expected that the higher the population per unit area, the stiffer the competition for solar radiation (Oyewole, 2011; Hay and Walker, 1989), thus producing taller crops as observed in this trial. The observation is in line with the outcomes of trials conducted by Oyewole et al. (2015a and 2015b). In a similar experiment conducted by Abuzar et al. (2011) data showed that plant height was significantly affected by plant population densities, which they observed was due to crowding effect of the plant and higher intra-specific competition for resources. Sangakkara et al. (2004) explained that as the number of plants increased in a given area the competition among the plants for nutrients uptake and sunlight interception also increased, with competition for sunlight leading to increase in plant heights. It is, however not uncommon to find stunted plants with increasing plant population, particularly in an environment where major crop nutrients are critically limiting. Planting at one seed / hole gave the shortest average crop height at the end of the trial (337.48 cm in 2021 and 253.67 cm in 2022 cropping seasons), while the tallest average plant height at the end of the trial were observed when four seeds were sown per hole (412.15 cm 368.89 cm, respectively in 2021 and 2022 cropping seasons).

Table 3: Effect of increasing maize population per stand on leaf area (cm^2) of three varieties of maize (*Zea mays*) in 2021 and 2022 cropping seasons

Treatment	2021 Cropping Season				2022 Cropping Season			
	Leaf Area (cm^2)							
	4WAS	6WAS	8WAS	10WAS	4WAS	6WAS	8WAS	10WAS
Variety								
V1: Sammaz 52	149.94	405.07	414.79	340.34	149.94	405.17	415.59	341.34
V2: Oba super-II	126.50	388.09	414.17	355.67	128.25	388.09	414.43	355.67
V3: Local Variety	123.72	353.22	407.07	349.60	124.22	350.04	406.51	349.60
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Population								
P1: 53,333 pop/ha	150.77	420.18	464.67^a	416.85^a	150.77	420.32	465.74^a	417.33^a
P2: 106,666 pop/ha	138.06	397.31	426.74^{ab}	359.06^{ab}	138.06	398.02	427.09^{ab}	359.39^b
P3: 160,000 pop/ha	126.01	357.11	381.28^b	317.92^b	128.13	356.45	381.59^b	318.10^b
P4: 213,332 pop/ha	117.44	353.91	375.35^b	300.31^b	119.59	349.62	374.30^b	300.65^c
LSD (0.05)	NS	NS	57.960*	66.580*	NS	NS	58.160*	55.370*
Interactions								
V1P1	146.79	413.19	435.51	383.23	171.65	517.34	497.96	436.45
V1P2	165.53	473.79	475.24	347.41	182.62	497.26	447.96	378.98
V1P3	151.39	377.64	379.16	333.08	180.92	438.80	413.33	376.57
V1P4	136.02	355.66	369.23	297.61	150.08	359.99	379.34	288.42
V2P1	123.70	399.41	375.17	350.34	150.09	435.27	363.66	396.40
V2P2	123.70	438.22	469.71	379.63	84.47	403.81	437.70	297.56
V2P3	109.96	361.34	399.89	326.71	154.33	443.69	459.23	361.20
V2P4	141.50	353.36	411.92	399.33	106.30	302.91	358.68	367.50
V3P1	145.20	380.65	449.05	467.99	88.12	302.68	324.95	425.95
V3P2	106.33	347.19	432.79	350.12	80.60	364.64	444.87	331.60
V3P3	107.54	332.35	364.78	303.67	120.48	398.63	420.09	293.70
V3P4	135.74	352.69	381.65	276.59	123.62	338.86	307.10	135.77
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV%	26.63	18.10	16.73	21.57	12.64	11.56	19.91	22.19

Means with the same letter(s) are not significantly different at 5% level of probability

Table 4: Effect of increasing maize population per stand on stem girth (cm) of three varieties of maize (Zea mays) in 2021 and 2022 cropping seasons

Treatment	2021 Cropping Season				2022 Cropping Season			
	Stem girth (cm)							
	4WAS	6WAS	8WAS	10WAS	4WAS	6WAS	8WAS	10WAS
Variety								
V1: Sammaz 52	3.52	4.84	5.51	5.69	3.49	5.11	5.75	6.00
V2: Oba super-II	3.23	5.37	5.49	5.80	3.23	5.55	5.69	5.77
V3: Local Variety	3.24	5.17	5.54	5.70	3.24	4.81	5.42	5.81
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Population								
P1: 53,333 pop/ha	3.44	5.61[a]	5.87[a]	6.22[a]	3.58	5.84[a]	6.29[a]	6.43[a]
P2: 106,666 pop/ha	3.53	5.52[a]	5.67[a]	5.91[ab]	3.41	5.79[ab]	5.64[a]	5.93[ab]
P3: 160,000 pop/ha	3.09	4.84[b]	5.45[ab]	5.55[bc]	3.58	5.29[b]	5.69[a]	6.03[bc]
P4: 213,332 pop/ha	3.24	4.52[b]	4.93[b]	5.23[c]	3.11	4.55[c]	4.85[b]	5.05[c]
LSD (0.05)	NS	0.496*	0.521*	0.603*	NS	0.543*	0.642*	0.592*
Interactions								
V1P1	3.53	5.02	5.35	5.76	4.26	5.83	6.70	6.70
V1P2	4.14	5. 21	5.92	6.07	4.20	5.23	5.96	6.43
V1P3	3.27	4.66	5.72	5.72	3.53	4.40	5.13	5.60
V1P4	3.14	4.45	4.97	5.19	3.40	4.96	5.20	5.26
V2P1	3.31	5.83	6.13	6.26	3.67	6.63	6.50	6.60
V2P2	3.35	5.76	5.76	6.30	2.80	5.20	5.53	5.60
V2P3	3.04	5.10	5.46	5.50	3.86	5.56	6.16	6.23
V2P4	3.20	4.77	4.82	5.13	2.86	4.80	4.56	4.63
V3P1	3.49	5.97	6.13	6.65	2.83	5.06	5.66	6.00
V3P2	3.11	5.58	5.32	5.35	3.23	5.43	5.43	5.76
V3P3	2.97	4.76	5.18	5.43	3.36	4.83	5.78	6.23
V3P4	3.39	4.35	4.99	5.37	3.06	3.90	4.80	5.26
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV%	16.59	10.19	9.95	10.76	6.61	12.87	8.54	12.48

Means with the same letter(s) are not significantly different at 5% level of probability

There were statistically significant interactions between variety and plant population on plant height at 4, 6, 8 and 10WAS in both seasons; an indication that the variety investigated were significantly influenced by variation in population per unit area. The observed interaction is not unexpected, as it has been observed that agronomic practices implemented in a production system should allow selected varieties to react to plant population manipulations when favorable environmental conditions occur (Haegele et al. 2014).

Effect of increasing maize population per stand on number of leaves, leaf area and stem girth of three varieties of maize

Plant leaves play crucial role in crop photosynthesis, any effect of imposed treatment on either leaf number or leaf area which may impact on photosynthesis should probably be expected to affect crop yield. Worthy of note, however is the fact that the process of yield formation involves complex interplays of various yield determining factors (Jamileh and Moghadam, 2015), besides leaf number and leaf area (Hay and Walker, 1989) with usually unpredictable outcomes. Such varying factors which may affact sink-source relation may moderate expectations away from basic principles. However, in this trial analysis of data indicated that variety as well as population investigated did not significantly ($p \geq 0.05$) influence number of leaves at 4, 6, 8 and 10WAS in 2021 and 2022 cropping seasons (Table 2). There were also no observed interaction effects between variety and population on leaf number in both seasons (Table 2). Oyewole et al. (2015b) observed that where leaf formation is gene dependent, leaf number may not respond to agronomic practices; such as population manipulation; this may be particularly so in determinate crops such as maize. While it could be deduced that the non-significant effect of the treatment imposed on leaf numbers, could be an indication of a possible non-significant effect on yield outcomes, seeing that leaves are vital in crop photosynthesis; with Valadabadi and Farahani (2010) reporting that photosynthesis increases by development of leaf area. However, reports have shown that soil water is often the most limiting factor for grain production in arid and semiarid regions (Sharratt and McWilliams, 2005), while Hammer et al. (2009) found that at high plant populations, root architecture was more important than canopy architecture and light interception for increasing grain yield.

Leaf area is an important parameter of maize. Data analysis indicated that variety did not significantly ($p \geq 0.05$) influence leaf area at 4, 6, 8 and 10WAS in 2021 and 2022 cropping seasons (Table 3). Generally, leaf area increased among the variety though not significantly at 4WAS to 8WAS then dropped at 10 WAS. Plant population significantly ($p \leq 0.05$) influenced leaf area at 8 and 10WAP in both seasons, but not at 4 and 6WAS in 2021 and 2022 cropping seasons. Leaf area was observed to diminish as plant population per stand was increased from one to four plants / stand. Thus, the highest leaf areas were observed in one plant / stand. Just as observed in outcome of variety above, leaf area increased among studied population through 4WAS to 8WAS then dropped at 10WAS. The drop in leaf areas could be attributed to leaf senescence. There were no observed interaction effects between variety and population on leaf area in both seasons throughout the period of data collection (Table 3). The significant effect of population on leaf area conformed to the report of Valadabadi and Farahani (2010) who reported that leaf area, among other things, is influenced by plant population. Observing that the highest physiological growth indices are achieved under high plant density, because photosynthesis increases by development of leaf area. Previous research findings also indicated that in high maize density, leaf area index and crop growth rate increased than low maize density throughout crop growth season (Saberali, 2007).

Data analysis showed that variety investigated did not significantly ($p \geq 0.05$) influence stem girth at 4, 6, 8 and 10WAS in 2021 and 2022 cropping seasons (Table 4), while population had significant effect on stem girth at 6, 8 and 10WAS. At the termination of the trial, the widest stem girth was recorded in the single maize stand in 2021 and 2022 cropping seasons (6.22 and 6.43 cm, respectively), while the least stem girth was among four plants / stand (5.23 and 5.05 cm). Stem girth was found to reduce with increasing plant population per stand; a phenomenon that may encourage easy lodging or stem breakage.

Effect of increasing maize population per stand on yield component and yield of three varieties of maize

Analysis of data showed that variety investigated significantly ($p \leq 0.05$) influenced days to first tassel, days to 50% tassel, as well as grain yield per plant (Table 5), but no significant effect ($p \geq 0.05$) of variety was not observed on ear weight, ear length, kernels per ear as well as 100-kernel weight. Significant ($p \leq 0.05$) influence of population was observed on days to 50% tassel, ear weight, ear length, kernel/ear, 100-kernal weight and grain yield per plant (Table 5). Generally increasing plant population led to processive delay in days to 50% heading, reduction in ear weight, ear length, kernel/ear, 100-kernal weight as well as grain yield per plant. There were significant interactions between variety and population on days to 50% tassel, ear weight, ear length, kernel / ear, 100-kernal weight and grain yield per plant (Table 5).

Previous researchers have observed that interactions between plant genotype and plant population can affect maize parameters, especially grain yield, with DeBruin et al. (2017) finding a positive relationship between maize grain yields and plant population in modern hybrids.

Though explaining that modern hybrids possess the ability to withstand greater stress attributable to high population densities than older hybrids, which in turn enables producers to establish higher plant populations, leading to higher yields per unit area (Russell, 1984; Duvick, 1997).

The observation in this trial quite agreed with those previous reports of positive response of yield components and yield to varietal and population influence (Russell, 1984; Duvick, 1997; DeBruin et al. 2017). Similarly, in line with the experimental outcome, Abuzar et al (2011) reported that biomass yield was significantly affected by different plant population densities in a maize plot. They reported that treatments having a population of 60000 and 80000 plants/ ha produced the maximum biomass yield of 16890 kg/ha each, while the lowest biomass yield (13330 kg/ha) was recorded with a population of 140,000 plants/ha. Several studies show that biomass yield decreases progressively as the number of plants increases in a given area because the production of the individual plant is reduced (Hamidia et al. 2010).

Similarly, they also observed that grain yield was significantly affected by plant population densities. Emam (2001) verified that kernels/ear and kernels/ear row are the most important yield adjustment components in response to plant population density in maize; an observation which was quite in line with this experimental outcome. The better response of hybrids to population stress was evident in this trial where the highest grain yield per plant was recorded in Oba Super II (779.13g and 890.01g, respectively in 2021 and 2022 cropping seasons) while the least grain yield per plant was in the local variety (530.80g and 475.00g, respectively in 2021 and 2022 cropping seasons). Sowing seeds at one seed/hole gave the highest grain yield/plant, 790.27g and 970.00g, respectively in 2021 and 2022 cropping seasons. The least grain yield/plant, 513.27g and 322.50g, respectively in 2021 and 2022 cropping seasons were observed when four seeds were sown/hole.

The highest amount of grain yield/ha was obtained in Oba super II (103,883.74kg and 118,667.70kg), respectively in 2021 and 2022 cropping seasons, with the local variety giving the lowest grain yield in both seasons. While the lowest grain yield/plant was recorded in P4 (213,332 pop/ha), in the first year, the plot compensated for the yield reduction/plant with increase in plant population cumulating in significantly greater harvest/ha (109,496.94 kg/ha), with P1(53,333 plant/ha) recording significantly the lowest grain yield/ha in both seasons. However, P4(213,332 pop/ha) did not repeat the same feat attained in the first trial as it trailed behind P3 (160,000 pop/ha) and P2 (106,666 pop/ha) in yield/ha (Table 6); an indication that the population may not be able to maintain stable yield. The most consist population relative to yield/ha was P3 (160,000 pop/ha), thus recommended for the experimental area, thus maintaining a mean population of 133, 333 plants/ha is predicted to give better performance for the varieties. While Oba super II is recommended for the experimental area.

CONCLUSION

It has been observed that stand density affects plant architecture, alters growth and developmental patterns and influences carbohydrate production. High population increases interplant competition for light, water and nutrients, which may be detrimental to final yield because it stimulates apical dominance, induces barrenness, and ultimately decreases the number of ears produced per plant and kernels set per ear, observed Sangoi (2000). Keeping this in view, the present study was formulated to optimize the planting density of maize under the Southern Guinea savannah agro-ecological zone in Nigeria.

The better response of hybrids to population stress was evident in this trial where the highest grain yield per plant was recorded in Oba Super II (779.13g and 890.01g, respectively in 2021 and 2022 cropping seasons) while the least grain yield per plant was in the local variety (530.80g and 475.00g, respectively in 2021 and 2022 cropping seasons). Sowing seeds at one seed/hole gave the highest grain yield/plant, 790.27g and 970.00g, respectively in the 2021 and 2022 cropping seasons. The least grain yield/plant, 513.27g and 322.50g, respectively in 2021 and 2022 cropping seasons were observed when four seeds were sown/hole. The highest amount of grain yield/ha was obtained in Oba super II (103,883.74kg and 118,667.70kg), respectively in the 2021 and 2022 cropping seasons, with the local variety giving the lowest grain yield in both seasons. While the lowest grain yield/plant was recorded in P4 (213,332 pop/ha), in the first year, the plot compensated for the yield reduction/plant with an increase in plant population cumulating in significantly greater harvest/ha (109,496.94 kg/ha), with P1 (53,333 plant/ha) recording significantly the lowest grain yield/ha in both seasons.

Table 5: Effect of increasing maize population per stand on yield component and yield of three varieties of maize (Zea mays) in 2021 and 2022 cropping seasons

Treatment	Days to first tassel		Days to 50% tassel		Ear weight (g)		Ear length (cm)		Kernel / ear		100-kernel weight (g)		GY / Plant (g)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Variety														
V1: Sammaz 52	56^{b}	55^{c}	62^{b}	61^{b}	99.23	124.00	12.52	13.52	249.93	301.58	26.17	27.98	621.03^{ab}	782.50^{b}
V2: Oba super-II	57^{a}	58^{b}	64^{a}	64^{a}	124.45	137.50	14.12	14.43	310.43	345.38	25.83	26.38	779.13^{a}	890.01^{a}
V3: Local Variety	57^{a}	60^{a}	65^{a}	65^{a}	103.34	83.03	13.50	12.93	287.78	244.40	23.67	22.97	530.80^{b}	475.00^{c}
LSD (0.05)	0.3	0.2	1.1	1.4	NS	NS	NS	NS	NS	NS	NS	NS	197.65	85.98
Population														
P1: 53,333 pop/ha	57	57	64^{a}	63^{b}	145.30^{a}	146.22^{a}	14.87^{a}	15.14^{a}	337.66^{a}	336.13^{a}	28.67^{a}	30.59^{a}	790.27^{a}	970.00^{a}
P2: 106,666 pop/ha	56	58	62^{b}	63^{b}	120.20^{a}	155.33^{a}	14.19^{a}	14.72^{a}	313.92^{a}	342.47^{a}	25.56^{ab}	24.63^{b}	753.30^{b}	840.00^{b}
P3: 160,000 pop/ha	57	57	65^{a}	63^{b}	87.83^{b}	106.33^{b}	12.57^{b}	13.09^{b}	253.26^{b}	298.21^{b}	24.22^{b}	25.88^{b}	517.77^{c}	623.34^{c}
P4: 213,332 pop/ha	56	58	65^{a}	65^{a}	82.73^{b}	72.33^{c}	11.88^{b}	11.44^{c}	226.01^{b}	211.67^{c}	22.44^{b}	22.00^{c}	513.27^{c}	322.50^{d}
LSD (0.05)	NS	NS	1.4	1.7	30.310*	29.810*	1.480*	0.861*	41.810*	38.270*	3.300*	2.170*	27.250*	56.860*
Interactions														
V1P1	57	54	62	60	123.30	185.00	13.61	15.84	295.50	373.60	28.00	34.00	777.60	1190.00
V1P2	55	55	59	60	122.30	130.00	14.04	14.39	283.20	337.80	27.30	24.00	766.60	850.00
V1P3	54	54	62	59	86.30	100.00	11.83	12.56	242.80	273.60	26.00	30.00	533.30	620.00
V1P4	56	56	63	63	65.00	81.00	10.59	11.31	178.30	221.30	23.30	23.90	406.60	470.01
V2P1	57	57	65	63	166.30	201.00	15.90	17.26	356.30	394.60	28.60	28.00	1046.60	1260.00
V2P2	54	60	60	63	137.30	144.00	14.83	14.77	331.30	353.90	26.60	27.90	863.30	930.00
V2P3	60	57	66	63	97.60	124.00	12.58	13.22	269.50	343.40	24.60	27.65	600.00	790.02
V2P4	56	59	64	66	96.60	91.00	13.14	12.46	284.50	289.60	23.30	22.00	606.60	580.00
V3P1	57	60	64	66	146.30	80.00	15.10	12.31	361.06	240.20	29.30	29.78	546.60	460.01
V3P2	59	60	66	66	101.00	112.10	13.68	15.36	327.40	335.70	22.60	22.00	630.00	740.00
V3P3	58	59	66	66	79.60	95.00	12.47	13.48	232.41	277.63	20.60	20.00	420.00	460.00
V3P4	55	59	62	66	86.60	45.00	12.73	10.56	230.16	124.10	22.00	20.10	526.60	240.00
LSD (0.05)	NS	NS	NS	NS	29.581*	19.610*	3.348*	2.091*	24.891*	33.457*	2.127*	4.671*	245.341*	123.119*
CV%	2.87	2.97	2.33	2.97	5.68	22.31	11.39	11.27	21.66	21.53	13.97	14.20	12.47	12.22

Means with the same letter(s) are not significantly different at 5% level of probability

Table 6: Effect of increasing maize population per stand on yield of three varieties of maize

Treatment	2021 cropping season		2022 cropping season	
	Grain yield/ Plant (g)	Grain yield /ha Kg/ha	Grain yield/ Plant (g)	Grain yield /ha Kg/ha
Variety				
V1: Sammaz 52	621.03	82,803.64	782.50	104,333.07
V2: Oba super-II	779.13	103,883.74	890.01	118,667.70
V3: Local Variety	530.80	70,773.16	475.00	63,333.18
Population				
P1: 53,333 pop/ha	790.27	42,147.47	970.00	51,733.01
P2: 106,666 pop/ha	753.30	80,351.50	840.00	89,599.44
P3: 160,000 pop/ha	517.77	82,843.20	623.34	99,734.40
P4: 213,332 pop/ha	513.27	109,496.92	322.50	68,799.57

However, P4 (213,332 pop/ha) did not repeat the same feat attained in the first trial as it trailed behind P3 (160,000 pop/ha) and P2 (106,666 pop/ha) in yield/ha; an indication that the population may not be able to maintain stable yield. The most consist population relative to yield/ha was P3 (160,000 pop/ha), thus recommended for the experimental area. Maintaining mean population of 133, 333 plants/ha is predicted to give better performance for the varieties. While Oba super II is recommended for the experimental area; as it performed better than the other varieties investigated.

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