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Research Article

GROWTH AND YIELD RESPONSES OF HYBRID AND OPEN-POLLINATED MAIZE TO PLANTING DENSITIES IN A TRANSITIONAL AGRO-ECOLOGICAL ZONE OF NIGERIA

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Abstract

Sub-optimal plant density is a significant factor limiting the profitability of maize (Zea mays L.) production in Nigeria. Despite this, the maize planting density recommendation has remained constant at 53,333 plants per hectare across various maize genotypes and agroecologies. Increasing plant density has the potential to enhance resource utilization and improve maize productivity.

In this study, two open-pollinated maize varieties (DMRLSR-W and SUWAN-1) and two hybrids (OBASUPER-1 and OBASUPER-2) were grown under two plant densities: 80,000 and 53,333 plants per hectare. The experiment was conducted at the Institute of Agricultural Research and Training, Ibadan, during the 2017 and 2018 growing seasons. The treatments were arranged in split-plots using a Randomized Complete Block Design (RCBD) with three replications. Data were collected on maize growth parameters, yield components, and grain yield (GY), and the data were subjected to analysis of variance (ANOVA) at a 95% confidence level.

Results showed that the 80,000 plants per hectare density significantly ($P < 0.05$) increased grain yield (GY), with 3.29 t/ha compared to 2.83 t/ha at 53,333 plants/ha. There were no significant differences in grain yield between the maize varieties at $P < 0.05$. Among the varieties, OBASUPER-1 (189.21 cm) and SUWAN-1 (191.85 cm) exhibited higher plant heights compared to OBASUPER-2 (175.04 cm) and DMRLSR-W (176.57 cm). Additionally, OBASUPER-1 (30.38 g) had the highest 100-seed weight, followed by OBASUPER-2 (27.58 g), DMRLSR-W (27.08 g), and SUWAN-1 (27.42 g).

The study concludes that increasing plant density to 80,000 plants per hectare significantly enhanced maize yield compared to the standard 53,333 plants per hectare. The findings suggest that further exploration of these and other maize varieties under higher plant densities across different agroecologies would be beneficial for optimal resource utilization and increased output.

Keywords: Crop growth rate, Grain moisture content, Leaf area, Plant height, Grain yield

Introduction

Maize (Zea mays. L) is an important cereal crop, valuable for human consumption and livestock feed formulation in Nigeria and other sub-Saharan African countries (Adebayo et al., 2018). Presently, there is an unprecedented demand for maize as competition between human and livestock consumption continues unabated.

However, a wide gap still exists between actual maize production and demand in the sub-region. Despite the increase in land area dedicated to maize cultivation in Nigeria, production and yield remains very low compared to other parts of the world, including some countries in Africa (FAO, 2018 and IITA,2018). Some of the major constraints of maize production in Nigeria include drought, pests and diseases, low soil fertility and poor managerial practices. Among the important managerial practices that affect maize yield in Nigeria is nonadherence to improved agronomic practices with respect to variety, appropriate planting dates and planting at suboptimal plant density (Shaibu et al., 2016). Of all the agronomic grass species, maize is most sensitive to differences in plant density and must be optimally sown to maximize the use of growth resources to obtain optimum grain yield (Sangoi, 2002).

Increasing planting densities is an effective agronomic practice which enhances canopy establishment, leaf area expansion, leaf area index, increases photosynthetically active radiation capture, soil water absorption potentials, the efficiency of resource use and increases crop yield (Hammer et al., 2009; Yang et al., 2010; Testa et al., 2016, Farhad et al., 2020; Du et al., 2021). It is worth noting that maize genotypes' productivities and resource utilization efficiencies respond differently across planting densities, seasons and environments (Balkcom et al., 2011; Tokatlidis, 2013). As planting at increased plant density increases interception of photosynthetically active radiation, there is also an increase in competition among plants for resources such as light, water and nutrients among plants (Clampitti & Vyn, 2011; Rossini et al., 2011). Intense competition for resources results in abiotic stress evidenced by reduced; leaf area, leaf chlorophyll content and grain yield (Osakabe et al., 2014). There is a significant reduction in grain yield of plants under abiotic stress due to a decline in partitioning and allocation of dry matter to the reproductive organs (Anjorin et al., 2021; Du et al., 2021; Zhang et al., 2021). Similarly, under intense plant density, there is a significant reduction in the plant's photosynthetically active radiation interception and photoassimilate production. This is because the light intensity within the maize canopy decreases with increasing density as the ability of light to penetrate the lower canopy is greatly reduced (Liu et al., 2014; Gou et al., 2017).

In Nigeria, over the years, maize plant density has remained at 53,333 per hectare or 5.3 plants per m^2 (most Nigerian's small-scale farmers plant even less than 50% of this recommended density). This sowing recommendation is about half the sowing density adopted in countries with the highest maize grain yields per unit of land (NAERLS and FDAE, 2017). In Brazil, a plant density of 80,000 plants/ha is considered the optimum plant population (Beruski et al., 2020). In Maryland (located along the eastern shoreline, of the South Atlantic region, in the United States), an increase in maize grain yield with plant density from 56,000 to 88,000 plants/ha was reported by Li et al. (2015) and Djaman et al. (2022). The 5.3 plants per m^2 is the general or blanket sowing plant density for all maize genotypes in Nigeria irrespective of the planting dates and the ecological suitability (Adnan et al., 2020) unlike the United States, where there are different optimum planting window recommendations for maize cultivation across the country depending on the location even within the same State (Abendroth et al., 2017; Long et al., 2017; Baum et al., 2019).

This low plant density may be responsible for the low tonnage per hectare in maize productivity in Nigeria. Therefore, there is a need to explore the potentials of most of the common maize genotypes (Hybrids and openpollinated maize) over different planting densities, to determine appropriate optimum planting densities for maximum resource utilization and productivity. Most especially, the hybrids are known for high yield potentials due to high leaf angles, higher assimilatory surfaces that could facilitate diffusion of light into the lower portion of the canopies (Aderibigbe et al., 2017).

Hence, this study attempts to evaluate the implications of increased plant density on the growth and yield performances of two open-pollinated and two hybrid maize varieties in the Rainforest- Savanna-Transition Agroecology of Nigeria.

Materials and Methods

The study was conducted during the growing seasons of 2017 and 2018 under rainfed conditions at the Institute of Agricultural Research and Training (IAR&T) in Ibadan, Oyo State, in the Rainforest- Savanna-Transition Agroecology of Nigeria. The experimental area is located at 7° 23' and North; 3° 51' East.

The experiment was laid out in a Randomised Complete Block Design with split plots arrangement and replicated three times. The experiment consisted of two plant densities (D1= 80,000 plants/ha and D2= 53,333 plants/ha) as the main plots while the four maize varieties (DMR LSR-W, Suwan-1, Oba Super-1 and Oba Super-2) constituted the subplot. The desired plant densities were achieved with intra and interrow spacing of 25 cm x 50 cm (80,000 plants/ha) and 25 cm x 75 cm (53,333 plants/ha), respectively forming a net plot size of 3 m x 3 m.

After ploughing and subsequent harrowing of the experimental land, two seeds of maize were sown per hole while the emerged seedlings were later thinned down to one plant per hill. Pre-emergence herbicide was sprayed a day after planting and later complemented with manual weeding at three and 6 weeks after sowing to avert weed build up. For optimum plant growth fertiliser 60 kg N $ha^{-1}$was applied using NPK 20:10:10) within 14 days (2 weeks) while Urea (40 kg N ha^{-1}) was applied six weeks after planting for 53,333 plants/ha and 90 kg ha^{-1} NPK 20:10:10 at six weeks after planting and followed up with 60 kgN ha^{-1} of Urea for the second application at six weeks after planting.

Data were collected on the following parameters from five randomly selected plants from each plot:

- Leaf area: This was obtained by measuring the length of a fully expanded tagged leaf and the breadth, fortnightly. The product of the length and the width was multiplied by 0.75 which is the calibration factor for maize leaf (Francis et al., 1969) Leaf area index: This was determined using the formula, fortnightly.
  - Leaf Area Index (LAI)=Leaf Area per plant (m^2) / Land Area covered by plant (m^2)

- Crop growth rate = NAR × LAI (g m^{-2} day^{-1}), fortnightly.

NAR= Net Assimilate Rate

- Plant height (cm): Five plants were selected randomly from each plot. The height was measured from the soil surface to the tip of the flag leaf with the help of a meter rod at every two weeks and average height was calculated.
- Number of rows and the number of kernels per cob: Five cobs were selected randomly from each plot. The number of rows and number of kernels per row was counted and the average was calculated.
- Grain yield (t/ha) = (FWT (kg)/Plot size (m^2) x [(100 – moisture content) x 10,000 x SP]/86 x 1000

Biomass Yield = Field weights of the complete plant **Data**

Analysis

The collected data were pooled across the two years of the experimental trials and subjected to analysis of variance for split plot in RCBD using Statistical Tool for Agricultural Research (STAR, 2014), significant means were separated using Fisher's Least Significant Difference (LSD) at 5% probability level.

Results

Figure 1 presents the pooled mean of plant heights over 12 weeks after planting. The maize population in D1 shows higher plant height than D2 plant heights at 6 and 8 weeks, while across weeks 4, 10 and 12, no significant difference was observed ($P<0.05$). Plant heights of the varieties over 12 weeks of plant development were presented in Figure 3. From the results, maize variety OBASUPER-1 (16.75 cm) and SUWAN-1(16.60 cm) showed similar but higher plant heights at four weeks after planting than DMRLSR-W and OBASUPER-2 which showed no significant difference. In the sixth week, SUWAN-1 still maintained the highest plant height of 65.31 cm followed by OBASUPER-1(56.02 cm), DMRLSR-W (50.65) while OBASUPER-2 had the least height of 48.33 cm. Across 8, 10 and 12 weeks of growth, SUWAN-1 was consistently superior in heights, followed by OBASUPER-1, while OBASUPER-2 was the lowest.

Interactive means of varieties and plant population densities are presented in Table 1. From the result, the interactions between plant densities and maize varieties for plant height were not significant across the weeks except for OBASUPER-2 at the 8th and 10th week which showed the lowest plant heights of 112.65 cm and 144.68 cm in plant population density 2, respectively. Figure 2a also presents the crop growth rate (CGR) between the two maize populations, growth rate was higher in D1 than D2. From the result, a sharp increase in CGR was observed in the 8th week followed by a progressive decline in CGR. Plant height was significantly higher in D1 than D2 ($P<0.05$) (Fig. 2b)

Leaf area and leaf area indices were presented in Figures 2c & 2d. Maize plants in D1 had a broader leaf area than maize plants in D2, this progresses close to the 8th week where there was an overlap and it seems no significant differences were observed between leaf areas of maize plants in the two maize populations. The leaf area indices as represented in figure 2d showed clear distinct differences in the leaf area indices of maize plants in the two maize plant populations as D1 was significantly higher than D2 (P<0.05).

Plant density and variety interaction means on leaf area showed no significant differences in this study. Similarly, in Table 2, no significant difference was also observed across the various planting distance-variety interaction levels of leaf area index and crop growth rates.

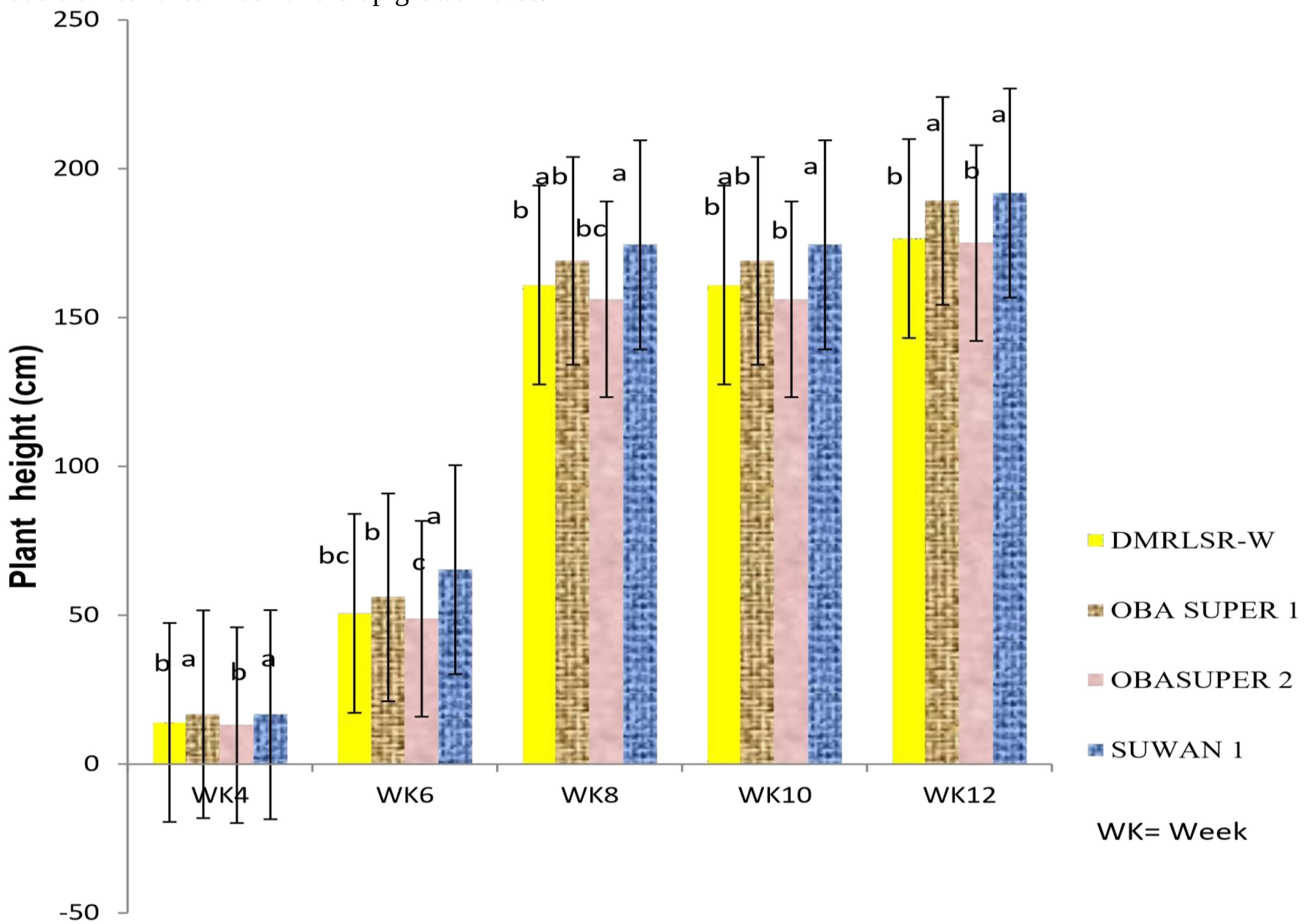
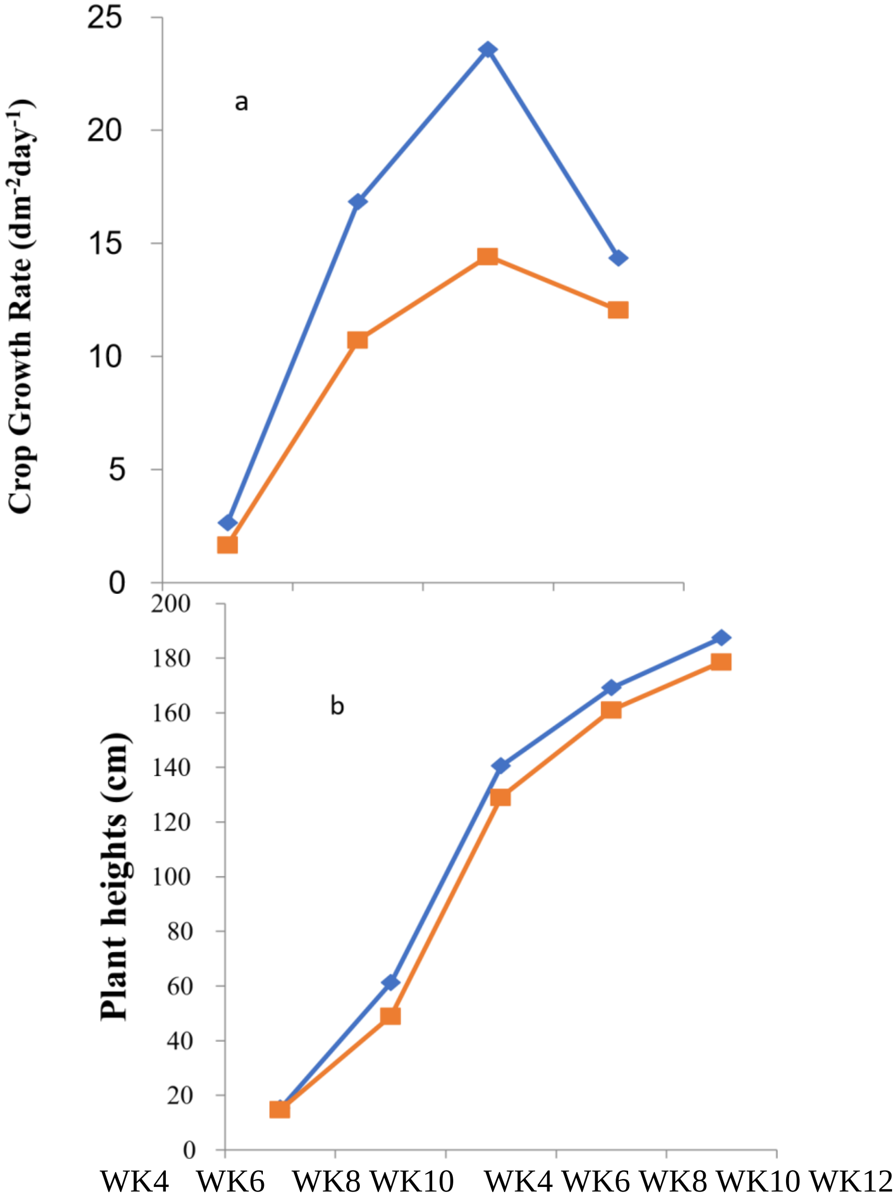


Figure 1: Maize varietal plant height responses to varying planting distances


a
b
Crop Growth Rate (dm-2day-1)
Plant heights (cm)
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180
200
WK4 WK6 WK8 WK10 WK4 WK6 WK8 WK10 WK12

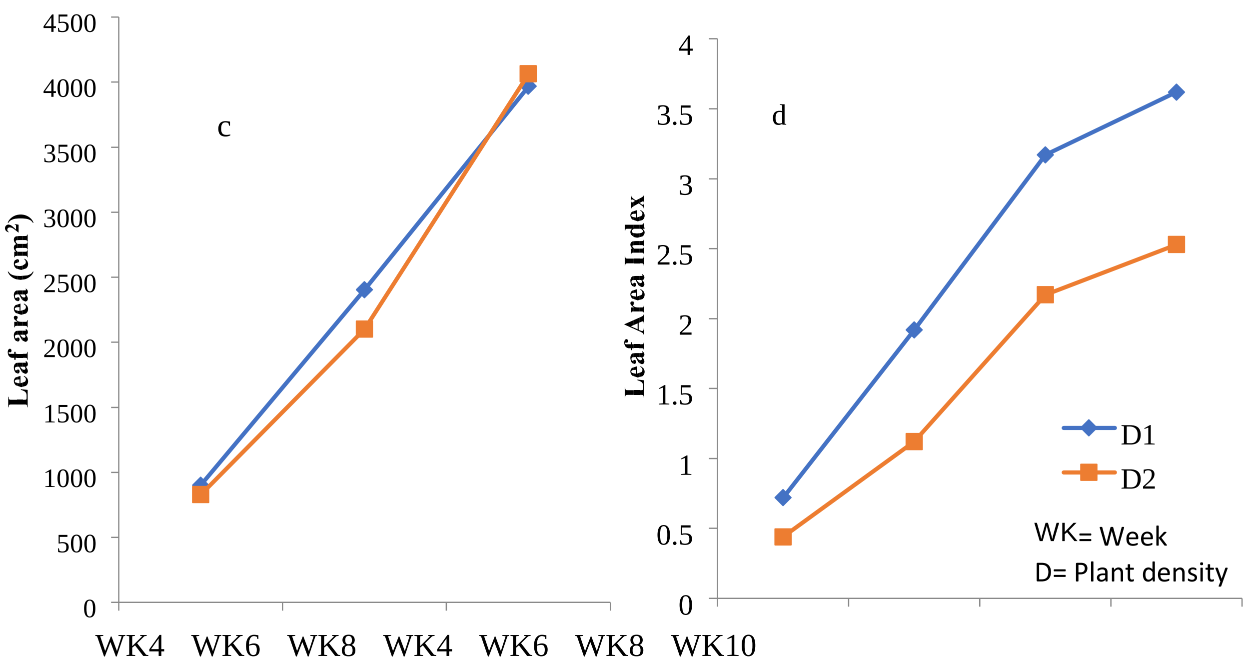


Figure 2: Effects of Plant density (D1=80,000; D2=53,333 plants per hectare) on weekly performances of plant heights, crop growth, leaf area and leaf area indices of four maize varieties grown in Ibadan

Table 1: Interactive Means of Varieties and Plant Density of Growth Traits of Four Maize Varieties Grown under Two Plant Densities in Ibadan

	Plant Height (cm)					Leaf Area (cm^2)		
Plant density and Maize variety interaction	**4 WAP**	**6 WAP**	**8 WAP**	**10 WAP**	**12 WAP**	**4 WAP**	**6 WAP**	**8 WAP**
D1*DMRLSR-W	13.99a	57.65a	138.81a	164.74a	182.10a	971.06a	2825.97a	4073.02a
D1*OBASUPER 1	16.82a	61.78a	136.38a	170.64a	190.44a	922.71a	2415.24a	4080.09a

D1*OBASUPER 2	14.04a	53.46a	143.35a	167.63a	185.79a	747.66a	1727.62a	3562.88a
D1* SUWAN 1	16.58a	72.39a	144.13a	173.78a	191.91a	967.71a	2650.44a	4156.81a
D2*DMRLSR-W	13.99a	43.64a	129.14a	157.20a	171.04a	777.60a	2023.42a	4100.68a
D2*OBASUPER 1	16.69a	50.27a	130.32a	167.49a	187.97a	836.03a	2119.91a	4487.45a
D2*OBASUPER 2	12.15a	44.19a	112.65b	144.68b	164.28a	820.00a	2030.95a	4053.11a
D2*SUWAN1	16.62a	58.23a	145.13a	175.11a	191.80a	885.38a	2235.15a	3614.57a
Means	15.11	55.20	134.99	165.16	183.17	866.02	2253.59	4016.07
SE	0.44	1.66	2.31	14.32	15.18	26.01	99.50	113.53

Interaction, WAP = Weeks After Planting. Mean designated with same alphabets are not significantly different at P<0.05 according to least significant difference. PHT=Plant height, LA= Leaf Area, D1=80,000 plant stands per hectare, D2=53,333 plant stands per hectare

Table 2: Interactive Means of Varieties and Plant Density of Growth Traits of Four Maize Varieties grown under Two Plant Densities in Ibadan

	Leaf Area Index			Crop Growth Rate (gm-^{2}day^{1})			
	4WAP	6WAP	8WAP	1WAP	2WAP	3WAP	4WAP
D*Variety							
D1*DMRLSR-W	0.78	2.26	3.26	2.66	14.69	23.51	16.03
D1*OBASUPER-1	0.74	1.93	3.26	3.05	17.76	26.63	10.46
D1*OBASUPER-2	0.60	1.38	2.85	2.27	18.93	20.68	16.98
D1*SUWAN-1	0.77	2.12	3.33	2.59	16.05	23.49	13.92
D2*DMRLSR-W	0.41	1.08	2.19	1.63	10.44	14.60	10.35
D2*OBASUPER-1	0.45	1.13	2.39	1.69	13.12	12.21	10.94
D2*OBASUPER-2	0.44	1.08	2.16	1.68	9.46	15.22	14.51
D2*SUWAN-1	0.47	1.19	1.93	1.64	9.95	15.72	12.39
Means	0.58	1.52	2.67	2.15	13.8	19.01	13.20

D*V=Density and Variety interaction, LAI=Leaf Area Index, CGR= Crop Growth Rate, WAP=Weeks After Planting

Table 3: Means of Plant density, Variety and interactions on the Yield Traits of Four Maize Varieties grown under 80,000 and 53,333 Plants per Hectare in Ibadan

	E/P	GMC (%)	100 GWT	K/R	R/C (cm)	CBT	GY (t/ha)
Density (D)							
D1	1.05a	27.06a	28.06a	32.54a	13.32a	16.11a	3.29a
D2	1.04a	28.04a	27.96a	31.99a	13.34a	15.43a	2.83b
Variety (V)							
DMRLSR-W	1.01a	27.39a	27.08b	33.75a	13.23a	15.83ab	3.14a
OBASUPER-1	1.07a	27.31a	30.38a	32.25a	13.16a	16.24a	3.07a
OBASUPER-2	1.08a	28.52a	27.38b	31.38a	13.50a	15.06b	3.01a
SUWAN-1	1.03a	26.98a	27.42b	31.72a	13.44a	15.95a	3.23a
D*V							
D1*DMRLSR-W	1.01a	26.59a	27.25a	35.23a	13.58a	16.26a	3.23a
D1*OBASUPER-1	1.08a	27.02a	30.08a	32.13a	12.82a	16.38a	3.19a
D1*OBASUPER-2	1.08a	27.99a	27.75a	31.08a	13.63a	15.42a	3.25a
D1*SUWAN-1	1.04a	26.63a	27.17a	31.68a	13.26a	16.37a	3.51a
D2*DMRLSR-W	1.01a	28.18a	26.92a	32.27a	12.88a	15.41a	3.05a
D2*OBASUPER-1	1.05a	27.60a	30.67a	32.36a	13.50a	16.10a	2.95a
D2*OBASUPER-2	1.08a	29.04a	27.00a	31.68a	13.37a	14.71a	2.77a
D2*SUWAN-1	1.02a	27.33a	27.67a	31.70a	13.61a	15.52a	2.96a
CV (a)%	4.22	4.15	11.24	3.82	6.67	5.55	9.31
CV (b)%	8.99	8.66	9.55	8.10	7.04	6.33	19.16
Mean	1.05	27.55	28.06	32.27	13.33	15.77	3.11
SE	0.01	0.35	0.14	0.37	0.13	0.16	0.09

†Means designated with same alphabets are not significantly different according to LSD at P<0.05.*Interaction, SE= Standard Error, E/P=Number of ears per plant, MC=Moisture content, BY=Biomass yield, K/R=Number of kernels per row, R/C=Number of rows per cob,100-GWT= 100-Grain weight, CBT=Cob length, GY=Grain yield, CV=Coefficient of variations.

Discussion

A blanket plant population recommendation for the cultivation of all maize varieties is one of the major reasons for low maize productivity in Nigeria. However, growing maize under increase and optimal plant population has been described as an effective agronomic practice that has the potential to enhance maize growth and maximize crop productivity. To validate this assertion, four maize varieties were grown under two plant densities, DI (80,000 plants/ha) and D2 (53, 3333 plants /ha) in Ibadan. From the results, planting at 80,000 plants per hectare significantly produced more grain yield than planting at 53,333 plants per hectare (the recommended plant population in Nigeria). In variance with the earlier reports of Abuzar et al. (2011) and Li et al. (2015) which attributed significant increase in yield components to increase in plant density. In this study the number of ears per plant, rows per cob, kernels per row and weight of 100-grains were not significantly influenced by the increase in plant density. Rather than the yield components, significant variations and higher leaf area indices and crop growth rates might have contributed significantly to the higher grain yield observed in 80,000 plants/ha in this trial. Du et al. (2021) had earlier reported the association of an increased plant population with an increase in leaf area index, improved utilisation of solar radiation and total dry matter accumulation. Similarly, the exponential increase in leaf area index observed between the kneel stage and early reproductive stage of 80,000 maize population in this study indicates a significantly higher rate of photosynthetically active radiation interception, assimilate accumulation and partitioning to the sinks (Kayad et al., 2022). This assertion agrees with the reports of Djaman et al. (2022) and Du et al. (2021) Berdjour et al. (2020) which established a close association between an increase in leaf area index, broader leaf canopy closure with an effective interception of photosynthetic active radiation and an enhanced capacity for resource uptake and utilisation. Furthermore, significant variation observed in plant heights and weights of 100 grains among the four maize varieties evaluated in this study was in accordance with the report of Oloyede and Olaniyan (2020). Contrary to the previous reports of Griesh & Yakout (2001) and Zhang et al. (2006) which affirms improvement in heights of maize with an increase in plant density (up to 10 plants m-2). In this study, plant heights were not affected by the increased plant density (80,000 plants/ha) as expected. Planting at 80,000 plants/ ha may not be enough to impose intense competition for environmental resources (light, water and soil nutrients) that would have brought about plant pressure and apical dominance leading to expected plant heights increase (Ahmad et al., 2020). It is also worth noting that much difference was not observed in the general performances of the openpollinated maize varieties compared with the two hybrids in this study. Although, high tolerance to increased plant densities by hybrid maize varieties had been reported by previous research studies, there is every possibility that the two maize varieties used in this study were not grown at optimum plant densities. There is the possibility that they could still perform better at planting density higher than 80,000 maize plants per hectare. This study therefore suggests further exploration of these maize varieties, especially the hybrids across different higher planting densities and agroecologies higher than 80,000 for optimum resource utilisation and productivity.

Conclusion and Recommendation

Maize growth and yield attributes were higher at 80,000 plants/ha in this study, while plant heights and weights of 100 grains among the four maize varieties responded differently to the different plant densities. The growth and yield performances of the two open-pollinated maize varieties (SUWAN-1 and DMRLSR-W in this study were very similar to the two maize hybrids (OBASUPER-1 and OBASUPER-2). There is a need for appropriate review and evaluation of the most common maize varieties for optimal plant population recommendation across agroecologies of the country. The need becomes highly inevitable in view of the prevailing climatic change and increasing demand for maize to cater for the Nigeria exponential population growth. The general recommendation of 53,333 maize stands per hectare for all maize varieties in Nigeria irrespective of the maize genetic make-up and the agroecological variabilities is grossly unprofessional. The National Variety Release Council should consider details of optimal plant population of the nominated maize variety based on agroecologies as prerequisites for maize varietal certification and release. I hereby suggest that the maize varieties used in this study should be further evaluated under higher plant density above 80,000 plants/ ha for appropriate optimum plant density recommendation.

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