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OPTIMIZING PLANT POPULATION FOR DROUGHT-TOLERANT MAIZE CULTIVAR IN A RAINFOREST ENVIRONMENT

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ABSTRACT

Drought tolerant (DT) maize cultivars are increasingly adopted to cope with unpredictable drought conditions in sub-Saharan Africa. Occurrence of incessant dry spells during cropping season, with the concomitant reduction in yield, is becoming a frequent phenomenon in particularly the rainforest of Nigeria. The objective of this research was to identify the ideal plant population of DT maize as climate smart cultivars under drought episodes in a rainforest region of Nigeria. Field trials were carried out in the early growing seasons of 2017 and 2018, in Benin City, with nine DT maize cultivars (DMRLSR-W, DT STR-W SYN2, DT STR-Y SYN2, DT SYN11-W, DT SYN11-Y, IWD C3 SYN F2, TZL COMP3 C3 DT, TZL COMP4 C3 DT and WHITE DT STR SYN) and three plant populations (53,333, 66,666 and 88,888 plants ha^{-1}). The experiment was laid out in a randomized complete block design with a split-plot arrangement having three replications. Results showed that 66,666 and 88,888 plants ha^{-1} plant populations led to taller plants, accumulated greater dry matter content and produced higher grain yield than the standard plant population of 53,333 plants ha^{-1}. Cultivars had an average yield of 3.0 t ha^{-1}. Higher grain yield correlated on higher plant height, higher number of ears, higher dry matter, higher 1000-seed weight and higher harvest index. Grain yield indicates that the cultivars can be grown in the agro-ecology. Absence of plant population × maize cultivar interaction for all traits suggests that plant population may not have reached the maximum necessary for growing these cultivars in the zone.

Key words: drought tolerant maize, harvest index, plant population, rainforest agro-ecology, yield

INTRODUCTION

Maize (*Zea mays* L.) is considered to be one of the most important cereal crops in Sub-Saharan Africa (SSA), with over 300 million Africans relying on it as their primary source of nutrition (IITA, 2022). Maize is grown by over 85% of the rural populace in West and Central Africa (WCA) because it fits into various farming systems and has a high potential for yield increase with improved management practices compared to other cereal crops (Badu-Apraku *et al*., 2013). Being an essential cereal, it is one of Nigeria's most important food crops (Kamara *et al*., 2020). However, maize yields are typically low in Nigeria due to various factors including but not limited to abiotic and biotic restraints (Shiferaw *et al*., 2011; Tesfaye *et al*., 2018).

Drought is an important abiotic factor hindering maize cultivation and productivity in SSA, reducing grain yield by 44% to 58% in WCA (Badu-Apraku *et al*., 2010; Meseka *et al*., 2018). Recurrent droughts and heat waves due to climate changes adversely affect the production of maize in Nigeria (Tofa *et al*., 2021). Many parts of Nigeria now experience regular droughts, often coinciding with the flowering phase of maize crops, resulting in low grain yield or crop failure (Adebayo and Menkir, 2014). In rainforest of Nigeria, early cropping season (rainy season) and late cropping season (dry season) are periods for growing maize because they can support good yield. Both seasons are rain-fed but the late cropping season relies on residual rains and soil moisture to complete the maize production cycle. In recent years however, intermittent dry spells are becoming frequent in the early cropping season. In addition, end-of-season drought now comes earlier than before in the late cropping season with the resultant negative influence on maize grain yield.

Fortunately, stress-tolerant maize cultivars that can assist smallholder farmers in managing environmental stress such as drought have been developed in recent years (Simtowe *et al*., 2019). Cultivation of drought-tolerant (DT) maize is one promising technology that can help smallholder farmers adapt to drought hazards (Katengeza *et al*., 2018). Tofa *et al*. (2021) indicate that the usage of DT maize cultivars has been shown to mitigate losses in maize production due to climate change. In extreme drought conditions, it is anticipated that DT maize cultivars can provide a yield gain of up to 40 percent over other maize cultivars (Tesfaye *et al*., 2016).

Despite the potential of newly developed DT maize cultivars for higher yield, yields may not improve if appropriate plant populations are not developed for them in the environments they are grown. Plant density is an important component that influences the overall plant yield, as well as individual plant yield (Adubasim *et al.,* 2017; Obalum *et al*., 2017; Oloniruha *et al*., 2021; Obi *et al*., 2024). Crop

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production at below the optimum plant population results in low yields (Oloyede-Kamiyo and Olaniyan, 2020). Bruns and Abbas (2005) state that an ideal plant population for optimum yield exists for each crop species and varies depending on cultivars and environmental conditions. Kareem *et al*. (2020) note that maize cultivars respond differently to populations and are influenced by soil and climatic conditions. Plant spacing has been reported to influence soil pH and available P (Umeugokwe *et al.,* 2021), which is a critical nutrient element in maize production (Ndzeshala *et al.,* 2023). These concerns suggest that, even with the release of many DT maize cultivars for cultivation in Nigeria, the expected yield increases may not be attained without appropriate plant population.

In Nigeria, maize is mostly grown at a recommended plant density of 53,333 plants ha^{-1}. This plant density may not support full utilization of available resources for maximum yield of DT maize in a rainforest environment. To address climate change impacts on maize production in the rainforest zone, it's essential to adopt drought-tolerant maize cultivars and determine the best planting densities for the cultivars. It is believed that DT maize cultivars will perform optimally at higher plant population (overcrowding stress) since they are tolerant to moisture stress and more so in an environment with more rainfall and moisture. Therefore, it is essential to identify drought-tolerant maize cultivars that perform well with increased overcrowding stress. Valuable insights into their performance under different plant populations could aid in bridging the climate-induced yield gap in maize production. Consequently, this study aims to evaluate how drought-tolerant maize cultivars respond to different plant populations in a rainforest environment.

MATERIALS AND METHODS

Experimental Site

Trials were conducted during the early growing seasons of April to July in both 2017 and 2018 at the Training & Research Farm of the Faculty of Agriculture, University of Benin, Benin City (6° 20' 50" N, 5° 37' 23" E; 78 m asl) located in Nigeria's rainforest. The region is classified by a tropical climate, exhibiting a mean annual rainfall of 1,900 mm, a diurnal temperature range oscillating between 23 °C and 37 °C, and a circadian relative humidity fluctuation from 89% at 10:00 a.m. to 75% at 4:00 p.m., as evidenced by an 18-year meteorological dataset (NIFOR, 2013). The rainfall pattern is bimodal, with peaks in July and September; however, there is a brief period in mid-August featuring occasional thunderstorms. The dry season commences in early November and ends in March, while the wet season spans the remainder of the year. The soil composition includes recent coastal plain sands known as the Benin formation, which consists of unconsolidated sands and sandy clay, as well as alluvial deposits (Umweni *et al*., 2014). Prior to the commencement of the field study, soil samples were collected randomly at a depth of 0-15 cm with a soil auger, and analyzed for soil texture, organic carbon, N, P, K, exchangeable cations and pH in accordance with the procedures of IITA (1982).

Cultivars Utilized

The study focused on the evaluation of the following drought-tolerant open-pollinated maize varieties (OPVs); DMR LSR-W, DT STR-W SYN2, DT STR-Y SYN2, IWD C3 SYNF2, TZLCOMP3 C3 DT, TZLCOMP4 C3 DT, and WHITE DT STR SYN. These cultivars were developed and produced by the International Institute of Tropical Agriculture (IITA).

Treatments and Experimental Design

The experiment was structured using a randomized complete block design (RCBD) with a split-plot layout, and encompassed three replications. The main plot had the plant populations; specifically, 53,333 plants ha^{-1} (standard plant population, STP), 66,666 plants ha^{-1}, and 88,888 plants ha^{-1}. Drought-tolerant (DT) maize open-pollinated varieties (OPVs) were allocated to the subplots. Each treatment plot occupied an area of 15 m^2 (3 m × 5 m). Adjacent treatment plots were delineated by a separation distance of 0.75 m, with an identical spacing employed between consecutive replications.

Cultural Practices

At the commencement of the field study, existing vegetation on the experimental field was eradicated using a pre-plant and systemic herbicide, glyphosate (formulated by Candel Company Limited, Lagos, Nigeria) at a concentration of 200 ml/ 16 liters of water, applied with a knapsack sprayer. Seeds were planted on April 6 and April 5 for the years 2017 and 2018, respectively, with a density of two seeds per planting hole. Plant populations of 53,333, 66,666, and 88,888 plants ha^{-1} were established by spacing of 75 cm × 25 cm, 75 cm × 20 cm, and 75 cm × 15 cm, respectively. Seedlings were selectively thinned to a single plant per stand at two weeks post-sowing to attain the intended plant populations. Maize seeds were treated prior to sowing using seed plus 30 WS (10% 1 ml dacloprid, 10% metalaxyl, and 10% carbendazim, formulated by Jiangsu Flag Industry Company Limited, China) at a dosage of 10 g per 4 kg of seeds. Basal fertilization was done by applying NPK 15:15:15 at rates of 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 60 kg K_2O ha^{-1} at one-week post-sowing. At four weeks after sowing, urea was applied to supply additional 60 kg N ha^{-1}. At sowing, a herbicidal mixture of paraquat (24% w/w 1,1-dimethyl-4,4-bipyridinium dichloride) and atrazine (80% w/w WP), manufactured by Jinan Glyline Chemical Company Limited, Shandong, China and Jubaili Agrotec Limited, Nigeria, respectively, were applied at concentrations of 200 ml and 300 g per 16 liters of water for effective weed control using a knapsack sprayer. Subsequent manual weeding was performed at seven weeks post-sowing, with a hoe.

Measurements

Data were obtained from the central two rows within each treatment plot (net plot). Days to Anthesis was documented as the time period (in days) from sowing until 50% of the plants in the net plot shown pollen shedding on their tassels. Days to Silking was similarly recorded as the duration from sowing to the point at which 50% of the plants in the net plot established silk extrusion. The Anthesis-Silking Interval (ASI) was calculated as the difference between the Days to Anthesis and Days to Silking. At the stage of full tasseling, plant height was determined on randomly selected five plants within the net plot. Measurements were taken from ground level to the last leaf – often referred to as the flag leaf – prior to the appearance of the tassel, using a calibrated measuring rule in centimeters (cm). Upon reaching physiological maturity, all plants within the net plot were harvested for evaluation of number of ears, dry matter content, seed weight, and grain yield. Plant components were segregated into leaves, stems, husks, cobs, and grains. Ears were enumerated and noted as number of ears per m^2. Leaves, stems and husks were sundried to constant weight. Cobs were air-dried for one week, weighed and threshed. A thousand seed was counted and weighed (1000-seed weight) for each treatment plot in grams (g). Grain mass was weighed and expressed as kilograms per hectare (kg ha^{-1}). Total dry matter per m^2 was computed using leaf, stem, husk, cob, and grain weight. Harvest Index was determined as the ratio of grain weight to the total dry matter.

Statistical Analysis

Statistical analysis of the data was conducted using SAS for Windows Version 9.2 (SAS Institute Inc., 2011). Analysis of Variance (ANOVA) was done using the mixed model procedure within SAS. In the model, replication was classified as a random effect, while both plant population and cultivar were categorized as fixed effects. These classifications were used to compute expected mean squares and to conduct corresponding F-tests within the framework of ANOVA. Subsequent to the ANOVA, pairwise comparisons of treatment means were conducted using Student's t-test, based on the Least Significant Difference (LSD) criterion at a 5% significance level ($\alpha = 0.05$). Proc Corr procedure of SAS was used to compute Pearson's correlation coefficients. This analysis was carried out to establish the relationship between grain yield and other agronomic traits, separately for each level of plant population.

RESULTS

Growing Conditions

The experimental site has a soil texture characterized by a sand, silt and clay contents of 790, 60 and 150 g kg^{-1}, respectively The soil's nutrient profile was enriched with organic carbon at 1.04 g kg^{-1}, nitrogen (N) at 0. g kg^{-1}, phosphorus (P) at 2.13 mg kg^{-1}, and potassium (K) at 0.12 cmol kg^{-1}. The pH of the soil was 4.2. The 2018 rainfall was much higher than that of 2017 over the cultivation months, and the temperature hovered between a consistent average minimum of 23 °C and a mean daily maximum of 33 °C. Number of rainy days and amount of rainfall in a month during the experimental period did not differ from a 14-year average (Table 1).

Variance Analysis

Table 2 shows the probability of F values, highlighting the responses of drought-tolerant maize cultivars under varying plant populations. Results show that year influenced days to anthesis and days to silking, plant height, and number of ears m^{-2}, total dry matter m^{-2}, 1000-seed weight, harvest index, and grain yield. Anthesis-silking interval was however, not influenced by year. Of these traits, plant population influenced plant height, number of ears, total dry matter, and grain yield. Remarkably, only the number of ears showcased a significant interaction between year and plant population. Differences among cultivars occurred for days to anthesis, days to silking, plant height, number of ears, total dry matter, harvest index, and grain yield. Year × cultivar interaction was significant for days to anthesis, days to silking, plant height and number of ears, total dry matter, 1000-seed weight, and grain yield. There was no significant interaction between plant population and cultivar for any of the studied traits. Additionally, except for the number of ears, the three-way interaction (year × plant population × cultivar) remained non-significant for all traits.

Table 1: Number of rainy days during April-July of the trial at Benin City, Rainforest zone of Nigeria

Months	2017		2018		14-year mean	
	No. of days	Mean Rain-fall	No. of days	Mean Rain-fall	No. of days	Mean Rain-fall
April	21	209.5	17	157.13	17	168.3
May	22	171.5	20	230.2	18	220.8
June	15	164.6	26	451.46	18	303.9
July	19	557.5	27	652.2	19	370.2

Source: Benin City weather data (*http://worldweatheronline.com*)

Table 2: Statistical significance (F-values) of agronomic traits in drought-tolerant maize cultivars across plant populations

Effect	Days to 50 % anthesis	Days to 50 % silking	Anthesis-silking interval	Plant height (cm)	Number of ears (no. m^{-2})	Dry matter (g m^{-2})	1000-seed weight (g)	Harvest index (g g^{-1})	Grain yield (kg ha^{-1})
Year (Y)	0.0004	0.0052	0.5432	<.0001	<.0001	<.0001	0.0219	0.0287	<.0001
Plant Population (P)	0.6291	0.4707	0.4312	0.001	<.0001	0.0037	0.3135	0.3859	0.0017
Y × P	0.7627	0.7213	0.8715	0.6009	<.0001	0.3287	0.7868	0.4127	0.1006
Variety (V)	0.0166	0.0026	0.071	0.0135	<.0001	0.0074	0.1794	0.0139	0.0011
Y × V	0.0435	0.0328	0.0876	<.0001	0.0254	0.0193	0.0034	0.3823	0.0072
P × V	0.5621	0.5316	0.43	0.4571	0.1538	0.5536	0.0984	0.6852	0.686
Y × P × V	0.8824	0.8612	0.8963	0.422	0.0184	0.3013	0.7533	0.1976	0.5126

Plant Population Influence on Agronomic Performance of Drought Tolerant Maize

The performance of maize as affected by plant population is summarized in Table 3. Among the different plant populations, days to anthesis was observed to be between 62 and 63 days, while for days to silking, between 64 and 65 days was recorded. The anthesis-silking interval was between 1.9 and 2.3, without significant differences. Plant height for plant population of 53,333 plants ha^{-1} was lower than for 66,666 plants ha^{-1} (p = 0.0066) and for 88,888 plant ha^{-1} (p = 0.0004). From the standard plant population (STP) through 66,666 plants ha^{-1} to 88,888 plants ha^{-1}, plants grew higher by 4.5% and 6.0%, respectively. Compared with STP, number of ears was comparable for 66, 666 plants ha^{-1} (p = 0.9729) but higher for 88, 888 plants ha^{-1} (p < 0.0001); similarly, it was higher for 88,888 plants ha^{-1} compared with 66,666 plants ha^{-1} (p < 0.0001). Percent increase from either the STP or 66,666 plants ha^{-1} was 17.1%. Dry matter was lower for the STP compared with the performance at either 66,666 (p = 0.0174) or 88,888 plants ha^{-1} (p = 0.0012). Between 66,666 and 88,888 plants ha^{-1}, there was lack of significant difference (p = 0.3656) for dry matter. Seed weight ranged from 216.1-224.3 g with no significant differences among the plant populations. Similarly, harvest index ranged from 47-49% though with no significant differences among the treatments. However, as plant population increased, there was a corresponding rise in grain yield. It differed between the STP and 66,666 plants ha^{-1} (p = 0.0062) and 88,888 plants ha^{-1} (p = 0.0007); it did not differ between the non-standard treatments (p = 0.4966). Grain yield increased by 17.5% for 66,666 plants ha^{-1} and 21.8% for 88,888 plants ha^{-1} when compared to the STP.

Mean Agronomic Performance of Drought Tolerant Maize Cultivars

Performance of maize as affected by cultivar is summarized in Table 4. It took between 61 and 64 days for cultivars to reach 50% anthesis with a mean of 62 days. TZL COMP 4 C3 DT had higher number of days to reach anthesis whereas DT SYN 11-Y was the earliest to reach anthesis. Four cultivars (DMR LSR-W, DT SYN 11-W, TZL COMP 3 C3 DT and TZL COMP 4 C3 DT) had above average performance in days to anthesis. Two cultivars (DT STR-W SYN 2 and DT SYN 11-Y) performed below average. Days to silking varied between 62 and 67 days, averaging at 64 days. TZL COMP 4 C3 DT took more days to reach silking, while DT SYN 11-Y took fewer days to reach silking. Three cultivars (DMR LSR-W, DT SYN 11-W and TZL COMP 4 C3 DT) reached silking at above average number of days to silking. Two cultivars (DT STR-W SYN 2 and DT SYN 11-Y) performed below average. Anthesis-silking interval ranged from 1.4 days for TZL COMP 3 C3 DT to 2.7 days for TZL COMP 4 C3 DT, though these were comparable statistically. Four cultivars (DMR LSR-W, DTSYN 11-W, IWD C3SYN F2 and TZL COMP 3 C3 DT) grew above average plant height (122 cm). The remainder five cultivars (DT STR-W SYN2, DT STR-Y SYN2, DT SYN 11-Y, TZL COMP 4 C3 DT and WHITE DTSTR SYN) had plant heights that were below average. However, DT SYN 11-W had the tallest plants with WHITE DT STR SYN having the shortest plants. Plants had 3-5 number of ears per m^2 with a mean of 4 ears. All cultivars with the exception of TZL COMP 4 C3 DT had comparable and higher number of ears. Dry matter per m^2 ranged from 421 to 556 g with a mean of 500 g. Four cultivars (DMR LSR-W, DT STR-W SYN 2, DT SYN 11-W and TZL COMP 3 C3 DT) accumulated higher dry matter than the average. The other cultivars had dry matter that was lower than the average. Dry matter was highest for TZL COMP3 C3 DT and lowest for TZL COMP 4 C3 DT. Seed weight was comparable among the cultivars and ranged from 205 g for DT STR-Y SYN2 to 227 g for TZL COMP3 C3 DT. Harvest index measured between 0.43 and 0.52 g g^{-1} with a mean of 0.48 g g^{-1}, with DMR LSR-W, DT STR-Y SYN2, DT SYN 11-Y and WHITE DT STR SYN having harvest index that were above average while another four cultivars (DT STR-W SYN 2, DT SYN 11-W, TZL COMP 4 C3 DT and IWD C3 SYN F2) had harvest index that was below average. Of these, harvest index was highest for DMR LSR-W and DT SYN 11-Y and lowest for TZL COMP 4 C3 DT. Grain yield increased from 2366 - 3210 kg ha^{-1} with an average of 2944 kg ha^{-1}. Five cultivars (DMR LSR-W, DT STR-W SYN 2, DT STR-Y SYN 2, DT SYN 11-Y and TZL COMP3 C3 DT) had grain yield that was above the average yield. The remainder cultivars (DTSYN 11-W, IWDC3 SYN, TZL COMP 4 C3DT and WHITE DT STR SYN) had a below average yield. Grain yield was highest for TZL COMP3 C3 DT and lowest for TZL COMP 4 C3 DT.

Table 3: Plant population influence on drought-tolerant maize at Benin City in the rainforest agroecology of Nigeria

Plant Population (P)	Days to 50% anthesis	Days to 50% silking	Anthesis-silking interval	Plant height (cm)	Number of ears (no. m^{-2})	Dry matter (g m^{-2})	1000-seed weight (g)	Harvest index (g g^{-1})	Grain yield (kg ha^{-1})
53333 (Standard)	62	64	1.9	117.8	4.1	464.8	216.1	0.47	2718.7
66,666	62	64	2.3	123.1	4.1	509.6	217	0.49	3020.3
88,888	63	65	2.2	124.9	4.8	526.5	224.3	0.49	3094
SED P	ns	ns	ns	1.92	0.15	18.56	ns	Ns	108.01

Table 4: Mean performance of drought-tolerant maize varieties at Benin City in the rainforest agroecology of Nigeria

Variety (V)	Days to 50% anthesis	Days to 50% silking	Anthesis-Silking interval	Plant height (cm)	Number of ears (no. m^{-2})	Dry matter (g m^{-2})	1000-seed weight (g)	Harvest index (g g^{-1})	Grain yield (kg ha^{-1})
DMR LSR-W	63	65	2.4	122.6	4.6	510.0	226.1	0.52	3166.1
DT STR-W SYN 2	61	63	1.9	121.2	4.5	532.7	220.0	0.47	3024.5
DT STR-Y SYN 2	62	64	2.1	117.9	4.7	489.5	205.0	0.49	2965.0
DT SYN 11-W	63	66	2.3	128.5	4.7	523.4	218.0	0.46	2936.7
DT SYN 11-Y	60	62	1.7	121.6	4.3	499.9	214.9	0.52	3089.5
IWD C3 SYN F2	62	64	2.4	123.3	4.2	483.5	219.8	0.47	2825.4
TZL COMP 3 C3 DT	63	64	1.4	126.2	4.4	555.8	227.4	0.48	3209.9
TZL COMP 4 C3 DT	64	67	2.7	119.2	3.4	421.4	221.3	0.43	2366.4
WHITE DT STR SYN	62	64	2.2	116.9	4.2	486.6	219.8	0.49	2915.3
Mean	62	64	2.1	121.9	4.3	500.3	219.1	0.48	2944.3
SED V	1.06	1.12	ns	3.3.2	0.25	17.15	ns	0.025	187.08

Table 5: Correlation coefficients of grain yield with other traits of drought-tolerant maize at each plant population

Traits	Plant population (P, plants ha^{-1})		
	53,333	66,666	88,888
Days to anthesis	–0.211	–0.086	–0.126
Days to silking	–0.237	–0.112	–0.164
Anthesis-silking interval	–0.146	–0.116	–0.112
Plant height	0.660***	0.541***	0.552***
Number of ears	0.422**	0.759***	0.694***
Dry matter	0.880***	0.950***	0.875***
1000-seed weight	0.296*	0.586***	0.284*
Harvest index	0.474***	0.559***	0.603***

Relationship of Grain Yield with Other Attributes

The relationship of grain yield with other attributes at each plant population is summarized in Table 5. At each plant population (53,333, 66,666 and 88,888 plants ha^{-1}), grain yield correlated positively and significantly with plant height, numbers of ears, dry matter, 1000-seed weight and harvest index. However, grain yield had a negative insignificant correlation with days to anthesis and days to silking, and anthesis-silking interval at each plant population.

DISCUSSION

The growing conditions present at the experimental site were conducive for maize production. However, nutrient analysis of the soil provided the cause to add N, P and K minerals as required. The lack of differences among plant populations for days to anthesis and days to silking, and anthesis-silking interval (ASI) suggests that given the available environmental resources and management, plant population could be increased beyond the upper limit recorded in this study; the plant population that could evoke a crowding effect that could cause differences in ASI has not been reached. ASI stands as a significant auxiliary trait used for selecting drought tolerance in maize, as evidenced by numerous studies including those by Bolaños and Edmeades (1993, 1996), Edmeades *et al.* (1993), Byrne *et al.* (1995), Ribaut *et al.* (1997), Bänzinger *et al.* (2000), and Ziyomo and Bernardo (2012). This is because ASI plays an important role as drought tolerance index (TI) (Hyo *et al.*, 2017).

Plant population influenced plant height, number of ears, dry matter and, grain yield. Increases in these traits were recorded at high compared to low plant population. For plant height, increases at 66,666 and 88,888 plants ha^{-1} may be due to the higher number of plants per given area possibly due to competition for sunlight and concomitant quicker canopy closure. This results in greater light interception for upward expansion. Also, at higher plant populations, maize plants tend to grow taller in competition for more light when nutrients and moisture conditions have been satisfied. Greater soil cover and plant height would result in greater photosynthetic apparatus for higher assimilate production. This is because early canopy closure is achieved and greater light intercepted for growth and dry matter accumulation at higher than lower plant populations (Ewansiha *et al.*, 2015). The highest number of ears obtained per m^2 at 88, 888 plants ha^{-1} could be ascribed to the increased number of ears from higher plant stands per m^2 compared to lower plant stands. This is evidenced by the stronger correlation at higher than at lower plant populations. Thus, number of ears per plant is reduced at higher plant population due to intra-specific competition but increased per unit area. Zamir *et al.* (2011) noted that an increase in plant density within a given area led to a decrease in the number of ears per plant, attributable to interplant competition. For dry matter, the higher quantities recorded at 66, 666 and 88, 888 plants ha^{-1} may be due to the higher assimilate production at these plant populations. The increases in dry matter accumulation resulted in the corresponding higher yields. This may be so because dry matter had strong relationship with grain yield. This observation aligns with the increases in grain yield with increasing plant density reported by Sharifai *et al.* (2012). These researchers linked the increases to enhanced light utilization by plants in closer proximity, leading to greater dry matter accumulation for grain filling. Also, Kareem *et al.* (2020) emphasized that plant density serves as an effective strategy to optimize grain yield by enhancing the absorption of solar radiation within the plant canopy. The reduced yield observed at the Standard plant population suggests that the population may not have reached its optimum for DT maize.

Maize cultivar had influence on days to anthesis, days to silking, plant height, number of ears, dry matter, harvest index and grain yield. Days to anthesis and days to silking were close such that anthesis-silking interval (ASI) was narrow and insignificant for all the cultivars. This may mean that there were sufficient environmental resources to prevent stress. All cultivars performed well in terms of grain yield. Seven cultivars had an average yield of 3.0 and two had an average yield of 2.6 t ha^{-1}, an indication that the cultivars did well in the environment when compared to the average maize yield in Nigeria (1.6 t ha^{-1}) and 2.1 t ha^{-1} for Africa (FAOSTAT, 2022). With an 87.5% increase in yield above the national average, the cultivars are good for use in the Rainforest agro-ecology. Grain yield depended on plant height, number of ears, dry matter, and seed weight and harvest index. Higher performance in these traits permitted higher performance in grain yield. The best two yielding cultivars (TZL COMP 3 C3 DT and DMR LSR-W) grew taller than the mean plant height for cultivars, had above mean number of ears, accumulated dry matter that was above the mean as well as above mean harvest index. Tallness was advantageous, making the cultivars intercept more light for greater assimilate production for high yielding. The poorest two cultivars (IWD C3 SYN F2 and TZL COMP 4 C3 DT) had below mean performance for these traits. In fact, taller plants, consequent on increasing plant population and or because of varietal traits, intercept greater light and this may translate to corresponding higher dry matter production, higher harvest index and higher grain yield. This was evidenced in the strong and positive relationship between plant height and grain yield.

Performance of maize cultivars evaluated in the present study, primarily bred for droughty environments, but grown in rainforest agro-ecology has some implications. One, farmers can overcome the intermittent dry spells that occur in some years during the early growing season in this zone. This is so because the occurrence of intermittent dry spells during the rainy season is becoming more frequent in recent times. Two, these drought tolerant cultivars can be effectively grown in the late cropping season. Late cropping season sowing will guarantee that maize is safely and profitably grown in this dry season of the year. In this way, the cultivars will become climate change resilient maize for the zone. Thus, it may be worthwhile evaluating these cultivars in a late cropping season environment for confirmation.

The absence of a notable interaction between plant population and maize cultivars across all the examined traits suggests that maize cultivars responded similarly to plant population in these traits. The recorded absence of significant interaction between plant population and maize cultivars for all traits may be ascribed to very mild or no stress imposed by plant population on the maize cultivars. Grain yield was not negatively impacted by an increase in plant population. Instead, it showed an upward trend as plant population increased. Other possible causes of stress were adequately satisfied-adequate moisture, adequate nutrient level and good weed and pest management. ASI, which is an important indicator of stress in maize was very narrow having an average of 2 days. Therefore, the crop environment was free from stress. Again, this may imply that plant population has not yet reached its maximum for growing these maize cultivars in the agro-ecology.

CONCLUSION

Maize performance was influenced by plant population and cultivar. Plants grew taller, accumulated higher dry matter and produced higher grain yield when grown at plant populations of 66, 666 and 88, 888 plants ha^{-1} compared to the standard plant population of 53, 333 plants ha^{-1}. Number of ears was highest at plant population of 88, 888 plants ha^{-1} compared to other plant populations. Differences did not occur among plant populations for days to anthesis, days to silking, ASI, 1000-seed weight and harvest index. Seven cultivars (DMR LSR-W, DT STR-W SYN 2, DT STR-Y SYN 2, DT SYN 11-W, DT SYN 11-Y, TZL COMP3 C3 DT and WHITE DT STR SYN) had an average yield of 3.0 t ha^{-1} and two others (IWD C3 SYN F2 and TZL COMP4 C3 DT) had an average yield of 2.6 t ha^{-1}. Grain yield depended on plant height, number of ears, dry matter, 1000-seed weight and harvest index. Higher performance in these traits resulted in higher grain yield. Grain yield performance indicates that the tested drought tolerant maize cultivars could be advantageously cultivated in the agro-ecology and so would serve to mitigate climate change effects when adopted by farmers in the zone, which now frequently experience intermittent dry spells. But the absence of plant population × maize cultivar interaction for grain yield and other traits suggests that plant population may not have reached the maximum necessary for growing these cultivars in the zone.

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REFERENCES

Adebayo M.A. and Menkir A. (2014). Assessment of hybrids of drought tolerant maize (*Zea mays* L.) inbred lines for grain yield and other traits under stress managed conditions. *Niger. J. Genet.,* **28,** 19-23. https://doi.org/10.1016/j.nigjg.2015.06.004

Adubasim C.V., Law-Ogbomo K.E. and Obalum S.E. (2017). Sweet potato (*Ipomoea batatas*) growth and tuber yield as influenced by plant spacing on sandy loam in humid tropical environment. *Agro-Science*, **16 (3),** 46-50. https://dx.doi.org/10.4314/as.v16i3.7

Badu-Apraku B., Menkir A., Ajala S.O., Akinwale R.O., Oyekunle M. and Obeng-Antwi K. (2010). Performance of tropical early-maturing maize cultivars in multiple stress environments. *Can. J. Plant Sci.*, **90,** 831-852. http://dx.doi.org/10.4141/cjps10059

Badu-Apraku B., Oyekunle M., Menkir A., *et al.,* (2013). Comparative performance of early-maturing maize cultivars developed in three eras under drought stress and well-watered environments in West Africa. *Crop Sci.,* **53,** 1298-1311. https://doi.org/10.2135/cropsci2012.11.0640

Bänzinger M., Edmeades G.O., Beck D.L. and Bellon M. (2000). *Breeding for Drought and Nitrogen Stress Tolerance in Maize: From Theory to Practice*, pp. 1-64, Mexico, DF, CIMMYT. http://hdl.handle.net/10883/765

Bolaños J. and Edmeades G.O. (1996). The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. *Field Crops Res.*, **48 (1),** 65-80

Bolaños J. and Edmeades G.O. (1993). Eight cycle of selection for drought tolerance in lowland tropical maize. II. Responses in reproductive behavior. *Field Crops Res.*, **31,** 269-289. https://doi.org/10.1016/0378-4290(93)90064-T

Bruns H.A. and Abbas H.K. (2005). Ultra-High plant populations and nitrogen fertility effects on corn in the Mississippi Valley. *J. Agron.,* **97 (4),** 1136. https://doi.org/10.2134/agronj2005.0143

Byrne P.F., Bolaños J., Edmeades G.O. and Eaton D.L. (1995). Gains from selection under drought versus multilocation 212 testing in related tropical maize populations. *Crop Sci.*, **35,** 63-69. https://doi.org/10.2135/cropsci1995.0011183X003500010011x

Edmeades G.O., Bolaños J., Hernandez M. and Bello S. (1993). Causes for silk delay in a lowland tropical maize population. *Crop Sci.,* **33 (5),** 1029-1035. http://dx.doi.org/10.2135/cropsci1993.0011183X003300050031x

Ewansiha S.U., Kamara A.Y., Chiezey U.F. and Onyibe J.E. (2015). Performance of cowpea grown as an intercrop with maize of different populations. *Afr. Crop Sci. J.,* **23 (2),** 113-122

FAOSTAT (2022). FAOSTAT Database. Rome: Food and Agriculture Organization of the United Nations. Accessed 05 Sep. 2022 from http://faostat.fao.org

Hyo C.K., Jun-Cheol M., Jae Y.K., Kitae S., Kyung-Hee K. and Byung-Moo L. (2017). Evaluation of drought tolerance using anthesis-silking interval in maize. *Korean J. Crop Sci.,* **62 (1),** 24-31. https://doi.org/10.7740/kjcs.2016.62.1.024

IITA (1982). Automated and semi-automated methods for soil and plant analysis. Manual series no. 7. International Institute of Tropical Agriculture, Ibadan. p. 33

IITA (2022). Maize (*Zea mays*). International Institute of Tropical Agriculture (IITA). Accessed 26 Dec. 2022 from https://www.iita.org/cropsnew/maize/

Kamara A.Y., Kamai N., Omoigui L.O., Togola A., Ekeleme F. and Onyibe J.E. (2020). *Guide to Maize Production in Northern Nigeria*, p. 18, lbadan, Nigeria.

Kareem I., Taiwo O.S., Kareem S.A., *et al.,* (2020). Growth and yield of two maize varieties under the influence of plant density and NPK fertilization. *J. Appl. Sci. Environ. Manage.,* **24 (3),** 531-536. https://dx.doi.org/10.4314/jasem.v24i3.22

Katengeza S.P., Holden S.T. and Lunduka R.W. (2018). Adoption of drought tolerant maize varieties under rainfall stress in Malawi. *J. Agric. Econ.* https://doi.org/10.1111/1477-9552.12283

Meseka S., Menkir A., Bossey B. and Mengesha W. (2018). Performance assessment of drought tolerant maize hybrids under combined drought and heat stress. *Agronomy,* **8,** 274. https://doi.org/10.3390/agronomy8120274

Ndzeshala S.D., Obalum S.E. and Igwe C.A. (2023). Some utilisation options for cattle dung as soil amendment and their effects in coarse-textured Ultisols and maize growth. *Int. J. Recycl. Org. Waste Agric.,* **12 (1),** 123-139. https://doi.org/10.30486/ijrowa.2022.1934239.1284

NIFOR (2013). Weather data (Temperature, Rainfall and Relative Humidity) 1993-2011. Nigeria Institute for Oil Palm Research Main Station, Benin City, Nigeria

Obalum S.E., Edeh I.G., Imoh O.N., *et al.* (2017). Agronomic evaluation of seedbed and mulching alternatives with plant spacing for dry-season fluted pumpkin in coarse-textured tropical soil. *Food Energy Secu.*, **6 (3),** 113-122. https://doi.org/10.1002/fes3.111

Obi J.O., Onah C.J., Nnadi A.L., *et al*. (2024). Sensitivity of rainfed okra (*Abelmoschus esculentus* L. Moench) to mulch material and plant spacing in drought-prone tropical soils. *Agroind. Sci.,* **14 (2),** 97-106. http://doi.org/10.17268/agroind.sci.2024.02.02

Oloniruha J.A., Ogundare S.K. and Olajide K. (2021). Growth and yield of sesame (*Sesamum indicum*) as influenced by plant population density and organo-mineral fertilizer rates. *Agro-Science*, **20 (1),** 15-21. https://dx.doi.org/10.4314/as.v20i1.3

Oloyede-Kamiyo Q.O. and Olaniyan A.B. (2020). Varietal response to double plant population density in maize: Implications for breeding. *J. Agric. Sci. - Sri Lanka,* 15, 387-394. https://doi.org/10.4038/jas.v15i3.9030

Ribaut J.M., Jiang C., Gonzalez-de-Leon D., Edmeades G.O. and Hoisington D.A. (1997). Identification of quantitative trait loci under drought conditions in tropical maize 2: Yield components and marker-assisted selection strategies. *Theor. Appl. Genet.*, **94,** 887-896

SAS Institute (2011). SAS for windows release 9.2 SAS Institute, Cary, NC

Sharifai A.I., Mahmud M., Tanimu B. and Abubakar I.U. (2012). Yield and yield components of extra early maize (*Zea mays* L.) as influenced by intra-row spacing, nitrogen and poultry manure rates. *Bayero J. Pure Appl. Sci.*, **5 (1),** 113-122. https://doi.org/10.4314/bajopas.v5i1.21

Shiferaw B., Prasanna B.M., Hellin J. and Bänziger M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Secur.*, **3,** 307-327. https://doi.org/10.1007/s12571-011-0140-5

Simtowe F., Amondob E., Marenyaa P., Rahutc D., Sonderc K. and Erensteinc O. (2019). Impacts of drought-tolerant maize varieties on productivity, risk, and resource use: Evidence from Uganda. *Land Use Policy*, **88,** 104091 https://doi.org/10.1016/j.landusepol.2019.104091

Tesfaye K., Kruseman G., Cairns J.E., *et al.* (2018). Potential benefits of drought and heat tolerance for adapting maize to climate change in tropical environments. *Clim. Risk Manag.,* **19,** 106-119. https://doi.org/10.1016/J.CRM.2017.10.001

Tesfaye K., Sonder K., Caims J., *et al.* (2016). Targeting drought-tolerant maize varieties in southern Africa: A geospatial crop modeling approach using big data. International Food and Agribusiness Management Review. *Special Issue,* **19 (A),** 75-92. https://hdl.handle.net/20.500.11766/6037

Tofa A.I., Kamara A.Y., Babaji B.A., Akinseye F.M. and Bebeley J.F. (2021). Assessing the use of a drought tolerant variety as adaptation strategy for maize production under climate change in the savannas of Nigeria. *Scientific Reports,* **11,** 898 https://doi.org/10.1038/s41598-021-88277-6

Umeugokwe C.P., Ugwu V.U., Umeugochukwu O.P., Uzoh I.M., Obalum S.E., Ddamulira G., Karwani G.M. and Alenoma G. (2021). Soil fertility indices of tropical loamy sand as influenced by bambara groundnut variety, plant spacing and fertilizer type. *Agro-Science*, **20 (1),** 65-71. https://dx.doi.org/10.4314/as.v20i1.11

Umweni A.S., Uwadiae I. and Okunsebor F.E. (2014). Evaluating the distribution of some selected heavy metals in the soils of a university community farm land in Mid-Western Nigeria. *J. Res. Environ. Earth Sci.*, **1 (3),** 01-16

Zamir M.S.I., Ahmad A.H., Javeed H.M.R. and Latif T. (2011). Growth and yield behavior of two maize hybrids (*Zea mays* L.) towards different plant spacing. *Cercetări Agronomiceîn Moldova,* **44 (2),** 33-40. http://dx.doi.org/10.2478/v10298-012-0030-9

Ziyomo C. and Bernardo R. (2012). Drought tolerance in maize: Indirect selection through secondary traits versus genome wide selection. *Crop Sci.,* **53 (4),** 1269-1275. https://doi.org/10.2135/cropsci2012.11.0651