Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 February 2020 doi:10.20944/preprints202002.0409.v1

Type of the Paper (Article)

Plant density and nitrogen responses of maize hybrids in diverse agro-ecologies of West and Central Africa

Babatope S. Ajayo[1,2], Baffour Badu-Apraku[1,*], Morakinyo A. B. Fakorede[2], and Richard. O. Akinwale[2].

[1]Maize Improvement Program, International Institute of Tropical Agriculture, P.M.B. 5320, Ibadan, Nigeria.

[2]Department of Crop Production and Protection, Obafemi Awolowo University, Ile-Ife, Nigeria.

* Correspondence: E-mail: b.badu-apraku@cgiar.org (B.B.)

Abstract: Maize (*Zea mays* L.) production in West and Central Africa is constrained by drought, low soil-N and *Striga* infestation. Breeders in the region have developed and commercialized extra-early and early-maturing hybrids (E-EH and EH), which combine high yield potentials with tolerance/resistance to the three stresses. Hybrids of both maturity groups are new to the farmers; thus, the urgent need to recommend appropriate agronomic practices for these hybrids. We investigated the responses of four hybrids belonging to extra-early and early-maturity groups to plant density (PD) and nitrogen (N) application in five agroecologies. The EHs consistently out-yielded the E-EHs in all the five agroecologies. The hybrids showed no response to N-fertilizer application above 90 kg ha^{-1}. All interactions involving N had no significant effect on all traits except in few cases. The E-EHs and EHs had similar response to PD; their grain yield decreased as PD increased. Contrarily, flowering was delayed and expression of some other agronomic traits such as plant and ear aspects became poorer with increased PD. Optimal yield was obtained at approximately 90 kg N ha^{-1} and 66,666 plants ha^{-1}. Most of the measured traits indicated high repeatability estimates (i.e. ≥ 60) across the N levels, PDs and environments. Evidently, the hybrids were intolerant of high PD.

Keywords: Agronomic traits; Hybrid performance; Nitrogen response; Plant density; Variability.

1. Introduction

Maize (*Zea mays* L.), a cereal crop adapted to a wide range of ecological conditions, is cultivated in all agro-ecologies of West and Central Africa (WCA) but primarily produced in the savannas. The savannas of WCA offer the highest productive environment for maize because of relatively high incidence of solar radiation, low night temperature and reduced occurrence of pests and diseases during the cropping season [1]. In 2013, the global maize production was 1.02 billion tonnes, 71 million tonnes came from Africa and 10.4 million tonnes from Nigeria [2]. The area under maize production in the savannas of WCA has continued to intensify at the disadvantage of other traditionally cultivated cereal crops such as sorghum (*Sorghum bicolor* L.) and millet (*Pennisetum glaucum* L.) [3,4]. The acceptability of maize by farmers and its potential to combat food security challenges posed by population increase in WCA have greatly improved due to its high yield potential, wider adaptability to different environments, and relative ease of cultivation, processing, storage, and transportation [3,5]. However, maize production in most agro-ecological zones of WCA is constrained by three stresses: drought, low soil nitrogen (low N), and *Striga* infestation. Presently, the extra-early (85 – 90 days to maturity) and early (90 – 95 days to maturity) maize hybrids, that combined high yield potentials with resistance/tolerance to the three stresses are available in sub-Saharan Africa (SSA) [4]. These maize hybrids have been adopted by the farmers in the region, although, grain yield in farmers' fields has averaged only 1 to 2 t/ha in contrast to the potential yields of about 5 to 7 t/ha reported for experiment stations [6]. Clearly, the heterotic advantage of the hybrids were not fully exploited. This may possibly because the hybrids are new to the farmers, and the existing agronomic conditions may not be appropriate for the full expression of the yield potential of the hybrids.

Maize grain yield is largely influenced by the interaction between the genetic and management factors. Successful maize production depends on the adequate use of production inputs that will sustain the environment as well as agricultural production [7]. An adequate amount of N, phosphorus, and potassium must be supplied to maize crop for good development, growth and high yield. [8]. Nitrogen performs an important role in crop life and is one of the most essential nutrients needed by maize plants in large quantities. Kamara et al. reported severe yield losses in maize in Nigerian savannas when no mineral fertilizer was applied [9]. Soils of SSA are characterized by low fertility due to continuous cultivation and heavy rainfall associated with the region. Fertilizer use in the region accounts for only 3 % of global fertilizer use, an amount which has not improved over two decades [10]. Maize has potential for high yield and considerably respond to N fertilizer application. Torbert et al. found that N-fertilizer application increased grain yield and yield components of maize [11]. In many areas of Africa, farmers grow improved maize cultivars without fertilizer. Even in areas where fertilizer is being used, the rate is often inadequate [12]. Zero or low rate of N-fertilizer application may be one of the reasons for lower grain yield frequently obtained by the farmers in SSA. Correct application of N fertilizer and optimal use of plant density can maximally exploit the full grain yield potential of modern maize hybrids.

For improved maize production, optimal rate of plant density is an important factor. About four decades ago, IITA reported that a plant density range of 40,000 to 100,000 plants ha^{-1} was optimal for well managed improved maize varieties, depending on the maturity group [13]. More recently, a study conducted in the northern Nigeria showed that in addition to good land preparation, plant density range of 106,666 – 266,666 plants ha^{-1} varied the performance of maize variety considerably, but concluded that 106,666 plants ha^{-1} was suitable for maize variety production in the agroecology [14]. Low plant density results in reduced grain yield, while high density leads to stress on the plants. Plant density is dependent on both row width and intra- row spacing. In WCA, the intra-row spacing used by local farmers for open-pollinated maize varieties has been the same used for extra-early and early maturing maize hybrids [15,16]. This also, could be associated with the low grain yield of the improved maize hybrids on the farmers' field. Furthermore, the use of high density under drought condition may heighten plant stress and reduce grain yield severely specifically if the drought coincides with the flowering and grain filling period [17] Therefore, drought stress especially when combined with high plant density can cause complete loss of grain production, if stress occurs during the tasselling and silking stage of production [18,19]. The use of hybrids that combine tolerance to drought and high density may be a promising production practice for the improvement of grain yield, particularly in drought-prone environments. The International Institute of Tropical Agriculture

(IITA) and collaborators have developed and released extra-early and early-maturing maize hybrids that combine high yield potentials with tolerance/resistance to low soil-N and drought at flowering and grain filling periods, and are being adopted by the farmers in the sub-region. However, the responses of these hybrids to plant density and N application has not been investigated. It is desirable to investigate and document grain yield response to plant density and N application of these hybrids released for the different agro-ecologies in WCA. Such information can guide future breeding of new cultivars and cropping technique innovation. This study was conducted to: (i) investigate the response of grain yield and other agronomic traits to plant density and N rates of recently released four extra-early and early-maturing drought tolerant (DT) maize hybrids and the performance of each maturity group in different agro-ecologies of Nigeria, and (ii) partition the total variation in grain yield to its various components.

2. Materials and Methods

2.1 Experimental sites

This study was conducted during the growing season of 2015 at five locations, one location in each of five agro-climatic zones in Nigeria; Ile-Ife (Marginal Rainforest – MRF: 07°28′N, 04°34′E), Ikenne (Rainforest – RF: 06°53′N, 03°42′E), Mokwa (Southern Guinea Savanna – SGS: 09°18′N, 05°40′E), Zaria (Northern Guinea Savanna –NGS: 12°00′N, 08°22′E) and Kadawa (Sudan Savanna –SS: 12°01′N, 08°19′E). The soil physical and chemical characteristics at the experimental sites are described in Supplementary Table 1.

2.2 Germplasm and experimental design

Four DT maize hybrids (belonging to extra-early and early maturity groups) recently released in Nigeria, Mali, and Ghana were evaluated. For each maturity group, one single-cross (SC) and one top-cross (TC) hybrids were evaluated in the study. The hybrids are tolerance to low soil-N, drought and resistant to *Striga* with high yield potentials [20]. The detailed descriptions of the hybrids are presented in Supplementary Table 2. Each experiment in each location was grown in a randomized complete block with a split-split-plot arrangement and three replications. The main plots were the N fertilizer rates (90, 120 and 150 kg N ha^{-1}), plant densities (66,666; 88,888 and 133,333 plants ha^{-1}) were subplots, and the four hybrids were sub-subplots. The inter-row spacing of 0.75 m and three intra-row spacings of 0.4 m, 0.3 m and 0.2 m were used to obtain the three plant density levels. Each sub-subplot comprised four rows, 5 m long each. Three seeds were planted per hill and thinned to two plants/stand two weeks after emergence. Urea was the source of N.

2.3 Data collection

Observations were made on the two central rows within each sub-subplot. Data obtained included anthesis (ANTH) and silking (DYSLK) which, respectively were the number of days from planting to the date when 50% of the plants in a sub-subplot had shed pollen and emerged silks. Anthesis-silking interval (ASI) was computed as the difference between DYSLK and ANTH. Plant height (PLHT) and ear height (EHT) were measured as the distance from the base of the plant to the height of the first-tassel branch and to the node bearing the upper ear, respectively. Root lodging (RL) was determined

Table 1: Description of soil of each trial location and broad sense heritability (H^2) estimates for grain yield.

	Location				
Parameter	Ikenne	Ife	Mokwa	Zaria	Kadawa
Physical characteristics					
Sand (%)	77	81	85	79	73
Silt (%)	14	11	7	8	10
Clay (%)	9	8	8	13	17
Texture	Sandy Loam	Loamy Sand	Loamy Sand	Sandy Loam	Sandy Loam
Chemical characteristics					
Soil pH (water)	5.58	5.23	5.13	5.27	6.18
Organic Carbon (%)	0.45	0.68	0.42	0.85	1.33
Total N (%)	0.36	0.14	0.15	1.16	0.63
Available Phosphorous (ppm)	17.13	49	44.95	27.88	15
Exch. Acidity (cmol/kg)	0.61	0.6	0.68	1.34	0.99
K^+ (cmol/kg)	0.03	0.04	0.04	0.26	0.32
Na^+ (cmol/kg)	0.02	0.02	0.02	0.2	0.2
Mg^{2+} (cmol/kg)	0.04	0.05	0.05	0.51	1.13
Ca^{2+} (cmol/kg)	0.2	0.21	0.2	1.25	2.14
ECEC (cmol/kg)	0.9	0.91	0.98	3.57	4.78
H^2	0.66	0.67	0.81	0.48	0.57

ECEC = Effective cation exchange capacity

Table 1: Description of the hybrids used for this study

Release Name	Pedigree	Year of Release	Country of Release	Owner	Hybrid Type	Maturity Range	Traits
Ifehybrid 5	TZEEI 29 x TZEEI 21	2013	Nigeria	IAR&T/IITA	SC	Extra-early	High grain yield, LNT, DT, STR
Sosani	TZEE-Y Pop DT SRT C5 x TZEEI 58	2014	Mali	IER/IITA	TC	Extra-early	High grain yield, DT, STR
Sammaz 41	TZEI 124 x TZEI 25	2014	Nigeria	IAR/IITA	SC	Early	High grain yield, LNT, DT, STR
Suhudoo	TZE-W Pop DT STR C4 x TZEI 7	2015	Ghana	SARI/CRI/IITA	TC	Early	High grain yield, LNT, DT, STR

Source: Maize Improvement Program (MIP), IITA, Ibadan, Nigeria.

LNT = low soil nitrogen tolerant; DT = drought tolerant; STR = *Striga* resistance; SC = Single-cross; TC =Top-cross

as the number of plants leaning about 45º or more from the upright position and stalk lodging (SL) as the number of plant stalks broken below the ear taken a week before harvest. The number of ears per plant (EPP) was determined by dividing the total number of ears per plot by the number of plants harvested. Plant aspect (PASP) was based on the overall plant appeal (visual), considering factors such as relative plant and ear heights, lodging, uniformity, reaction to diseases and insects and was scored on a scale of 1 to 9, where 1 = excellent plant type and 9 = poor plant type. Ear aspect (EASP) was based on freedom from disease and insect damage, ear size, uniformity of ears, and grain filling and was scored on a scale of 1 to 9, where 1 = clean, uniform, large, and well-filled ears and 9 = ears with undesirable features. Husk cover (HC) was scored on a scale of 1 to 5, where 1 = husks tightly arranged and extended beyond the ear tip and 5 = open tip cover (ear tips clearly exposed). Field weight was recorded as the weight in kg of all de-husked ears (cobs) in the sub-subplot. Representative cobs were selected and grains removed from their cobs. Moisture meter was used to measure the moisture of the grains. Grain yield (GYLD) in kg ha^{-1} was calculated based on 80% shelling percentage and adjusted to 15% moisture content as follows:

Grain yield (kg ha^{-1}) = Field weight × (100 – actual grain moisture %) /85 × {10000/plot area (m^2)} × 0.80.

2.4 Statistical analysis

Analysis of variance (ANOVA), combined across trial environments was performed on plot means for the individual traits with PROC GLM in SAS using a RANDOM statement with the TEST option [21]. In the combined ANOVA, location and replication nested within location was considered as random effect for each trait, while N, plant density, and genotype, and their interactions were considered as fixed effects and interactions involving locations were considered as independent effect. Comparison between and within maturity group was achieved by partitioning the genotype sum of squares into orthogonal contrasts. Linear regression was fitted to quantify the grain yield and other traits responses to plant density using Microsoft Excel package. Each trait was considered as dependent variable and plant density as the independent variable. The proportion of total variation in grain yield accounted for by the different sources of variation in the combined ANOVA was manually computed by dividing the individual sum of square of each source of variation by the total sum of square, estimated in percentage. The estimates of broad-sense heritability (H^2) for grain yield were computed for each environment. All the environments included in the present study revealed an H^2 value of ≥ 0.30 (Table S1). The H^2 of grain yield was estimated as follows:

$$H^2 = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_e^2}{r}}$$

where σ_g^2 is the variance attributable to genotypic effects, σ^2_e is experimental error variance; and r = the number of replicates within each environment [22]. Repeatability (R) estimates of grain yield and other agronomic traits [23] across environments were calculated on a hybrid-mean basis as follows:

$$R = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_{ge}^2}{e} + \frac{\sigma^2}{re}}$$

where σ_{ge}^2 is the variance attributable to genotype x environment effects, and e is the number of environments; σ_g^2, σ^2, and r as defined above

3. Results

3.1 Field performance of extra-early and early hybrids and repeatability of traits.

The combined ANOVA showed highly significant genotype (G), environment (E) and G x E interaction mean squares for grain yield and all other measured traits (3a and 3b). The contrast analysis for the two maturity groups (extra-early vs early maturing hybrids) showed highly significant mean squares for all the traits. (Tables 3a and 3b). The between-group comparison (extra-early vs early maturing hybrids) for grain yield accounted for 56% of the variation among genotypes. The early maturing hybrids consistently out-yielded the extra- early maturing hybrids in all the agroclimatic zones with an average of 428 kg ha^{-1} (16%) across environments (Table 4). Furthermore, mean squares of the orthogonal comparison of SC extra-early versus TC extra-early and SC early versus TC early (comparison within each maturity group) were highly significant for grain yield and most traits (Tables 3a and 3b). For each maturity group, the SC hybrid consistently out-yielded the TC hybrid in all the agro-climatic zones. Across agro-climatic zones, the SC out-yielded TC by 420, 343 and 381 kg ha^{-1} for the extra-early, early maturing groups and across the maturity groups respectively.

For plant and ear heights, the extra-early hybrids were consistently taller and had higher ear placement than the early maturing hybrids in all the agroclimatic zones except in the MRF zone where the early hybrids were taller. The TC extra-early hybrid (TZEE-Y Pop DT SRT C5 x TZEEI 58) was consistently taller and had higher ear placement than the SC extra-early hybrid (TZEEI 29 x TZEEI 21) in all the agro-climatic zones except in the MRF zone where SC had taller plants and higher ear placement (Table 4). Conversely, the SC early hybrid (TZEI 124 x TZEI 25) consistently had taller plants with lower ear placement when compared with the TC early hybrid (TZE-W Pop DT STR C4 x TZEI 7) in all the agro-climatic zones (Table 4). Also, root and stalk lodging were higher for the extra-early than for the early maturing hybrids, although; both lodgings were more pronounced at the forest than the savanna locations (Table 4). In each maturity group, root and stalk lodgings were higher for TC than for SC hybrids (Table 4). It is striking to note that both maturity groups received good scores (in the range of 3 and 5) for PASP in all the agro-climatic zones except for extra-early hybrids that received a poor score (6) in the MRF zone. For EASP, both maturity groups received poor scores (6) at the two forest locations and good scores (4 and 5) at the savanna locations (Table 4).

The repeatability estimate of grain yield was 0.83. The repeatability estimates of other agronomic traits varied from 0.40 for EASP to 0.90 for DYSK (Table 4). Most of the measured traits of the hybrids indicated high repeatability estimates (i.e. ≥ 60) across the three N levels, three PDs and five environments (Table 4).

Table 3a: Mean squares from the combined analysis of variance and repeatability estimates of grain yield, EPP, PASP, EASP, ASI and DYSK of extra-early and early maturing hybrids under varying plant densities and fertility levels at five locations in 2015.

SOURCE OF VARIATION	DF	GYLD	EPP	PASP	EASP	ASI	DYSK
Environment (E)	4	13501563.85**	0.324**	137.49**	39.98**	65.53**	733.74**
Rep(Environment)	10	1510848.11**	0.003	0.77	1.88**	1.19	3.75
Nitrogen (N)	2	280416.3	0.001	1.61	1.72*	1.10	2.70
Environment x Nitrogen	8	438288.5	0.018	0.61	0.41	0.24	1.91
Error a	20	280108.21	0.01	0.81	0.42	0.90	2.61
Plant Density (PD)	2	1543455.86**	1.239**	76.08**	63.58**	8.05**	15.43**
E x PD	8	573188.88**	0.075**	7.05**	0.85	1.00	3.04
N x PD	4	124712.16	0.009	0.76	0.12	1.49	2.53
E x N x PD	16	88637.08	0.008	0.42	0.27	0.59	0.41
Error b	60	182528.40	0.01	0.44	0.46	0.61	1.52
Genotype (G)	3	14851949.75**	0.119**	11.18**	7.63**	37.35**	204.10**
Extra-early vs Early Hybrids	*1*	*24725078.86***	*0.09***	*16.02***	*1.78**	*39.47***	*578.67***
SC extra-early vs TC extra-early	*1*	*11883076.97***	*0.26***	*7.50***	*20.28***	*14.70***	*4.28*
SC early vs TC early	*1*	*7947693.43***	*0.01*	*10.01***	*0.83*	*57.87***	*29.34***
G x E	12	1223804.12**	0.011	1.37**	3.37**	3.51**	7.05**
G x N	6	79424.77	0.008	0.53	0.81	0.47	0.27
G x PD	6	261305.19	0.018*	1.12	1.78**	1.37	1.91
G x E x N	24	204975.68	0.004	0.5	0.49	0.81	2.86*
G x E x PD	24	135430.29	0.007	0.87*	0.38	0.97	1.18
G x N x PD	12	110498.68	0.004	0.28	0.25	0.39	1.29
G x E x N x PD	48	91815.05	0.007	0.41	0.36	0.69	1.06
Error c	270	203948.9	0.01	0.53	0.39	0.69	1.75
R^2		0.760	0.785	0.866	0.817	0.767	0.900
CV		16.78	9.2	16.73	12.00	65.38	2.49
Repeatability Estimate		0.83	0.54	0.64	0.40	0.79	0.90

***, ** Significantly different at 0.05 and 0.01 level of probability respectively; DF = Degree of Freedom; GYLD = Grain yield (kg ha^{-1}); EPP = Ears per plant; PASP = Plant aspect; EASP = Ear aspect; ASI = Anthesis-silking interval; DYSLK = Days to silk formation; SC = Single-cross; TC =Top-cross.**

Table 3b: Mean squares from the combined analysis of variance and repeatability estimates of ANTH and other agronomic traits of extra-early and early maturing hybrids under varying plant densities and fertility levels at five locations in 2015.

Source of variation	DF	ANTH	HC	PLHT	EHT	RL	SL
Environment (E)	4	457.31**	29.63**	25389.99**	13200.35**	14464.34**	3457.13**
Rep(Environment)	10	2.98	0.25	279.87*	235.51**	138.65**	39.16
Nitrogen (N)	2	1.99	0.15	173.47	31.91	51.97	8.31
Environment x Nitrogen	8	2.14	0.45	143.89	115.5	28.83	16.61
Error a	20	1.28	0.45	89.56	58.21	46.06	51.06
Plant Density (PD)	2	1.47	4.14**	63.81	209.73	3665.27**	1656.99**
E x PD	8	1.97	2.26**	214.2	104.06	1344.23**	254.50**
N x PD	4	1.46	0.16	161.68	34.94	4.91	66.07**
E x N x PD	16	0.6	0.13	97.94	39.23	28.3	24.69
Error b	60	1.29	0.21	112.47	70.34	25.44	16.65
Genotype (G)	3	113.60**	6.30**	4999.35**	1553.40**	7336.84**	3417.50**
Extra-early vs Early Hybrids	*1*	*260.42***	*7.37***	*6734.54***	*1703.11***	*3634.82***	*2530.67***
SC extra-early vs TC extra-early	*1*	*77.87***	*2.31***	*4526.41***	*580.80***	*18335.65***	*7637.39***
SC early vs TC early	*1*	*2.50*	*9.22***	*3737.11***	*2376.30***	*40.05*	*84.45*
G x E	12	6.64**	2.28**	791.13**	321.52**	2238.21**	546.19**
G x N	6	0.56	0.16	177.26	180.51*	108.87*	19.15
G x PD	6	1.17	0.71**	92.02	46.58	316.51**	28.611
G x E x N	24	1.27	0.25	12.5	57.79	74.97*	19.41
G x E x PD	24	0.93	0.72**	57.89	77.15	81.63**	46.59
G x N x PD	12	0.97	0.11	103.26	78.47	41.02	21.55
G x E x N x PD	48	1.15	0.19	86.86	62.24	29.8	33.53
Error c	270	1.35	0.24	133.35	76.09	40.83	30.23
R^2		0.880	0.800	0.811	0.800	0.926	0.840
CV		2.25	24.87	6.18	9.51	72.17	77.35
Repeatability Estimate		0.86	0.49	0.69	0.57	0.67	0.78

***, ** Significantly different at 0.05 and 0.01 level of probability respectively; DF = Degree of Freedom; ANTH = Days to pollen shed; HC = Husk cover; PLHT = Plant height (cm); EHT = Ear height (cm); RL = Root lodging; SL = Stem lodging; SC = Single-cross; TC =Top-cross.**

Table 4: Mean performance of grain yield and other agronomic traits of extra-early and early hybrids evaluated at five locations of five agro-climatic zones of Nigeria in 2015.

Zone/Location	Genotype	GYLD	PASP	EASP	PLHT	EHT	RL	SL
Rainforest Zone: IKENNE								
	Extra-early hybrids							
	TZEEI 29 X TZEEI 21	2446.9	5	5	193.1	94.4	5	14
	TZEE-Y Pop STR C5 X TZEEI 58	2082.0	5	6	206.3	98.2	24	26
	Mean	**2264.5**	**5**	**6**	**199.7**	**96.3**	**29**	**20**
	Early hybrids							
	TZE-W Pop DY STR C4 X TZEI 7	2491.3	5	5	184.2	92.4	8	14
	TZEI 124 X TZEI 25	2656.4	5	6	192.7	83.5	7	10
	Mean	**2573.8**	**5**	**6**	**188.5**	**88.0**	**8**	**12**
Marginal Rainforest Zone: IFE								
	Extra-early hybrids							
	TZEEI 29 X TZEEI 21	2654.9	5	5	208.9	104.1	10	3
	TZEE-Y Pop STR C5 X TZEEI 58	2072.2	6	6	205.0	98.9	61	9
	Mean	**2363.6**	**6**	**6**	**207.0**	**101.5**	**36**	**6**
	Early hybrids							
	TZE-W Pop DY STR C4 X TZEI 7	2653.9	5	6	206.5	105.1	22	7
	TZEI 124 X TZEI 25	2758.9	5	6	218.0	97.9	20	8
	Mean	**2706.4**	**5**	**6**	**212.3**	**101.5**	**21**	**8**
Southern Guinea Savanna Zone: MOKWA								
	Extra-early hybrids							
	TZEEI 29 X TZEEI 21	2808.6	5	5	180.5	77.6	1	2
	TZEE-Y Pop STR C5 X TZEEI 58	2403.9	5	6	190.7	85.0	7	12
	Mean	**2606.3**	**5**	**6**	**185.6**	**81.3**	**4**	**8**
	Early hybrids							
	TZE-W Pop DY STR C4 X TZEI 7	3362.6	5	5	172.7	83.7	2	3
	TZEI 124 X TZEI 25	3791.2	5	5	181.0	74.8	1	2
	Mean	**3576.9**	**5**	**5**	**176.9**	**79.3**	**2**	**3**
Northern Guinea Savanna Zone: ZARIA								
	Extra-early hybrids							
	TZEEI 29 X TZEEI 21	3213.3	3	4	178.6	81.9	0	0
	TZEE-Y Pop STR C5 X TZEEI 58	2573.4	4	4	192.2	86.8	6	2
	Mean	**2893.4**	**4**	**4**	**185.4**	**84.4**	**3**	**1**
	Early hybrids							
	TZE-W Pop DY STR C4 X TZEI 7	2947.9	3	4	169.6	80.8	1	0
	TZEI 124 X TZEI 25	3472.2	3	4	172.4	74.3	1	0
	Mean	**3210.1**	**3**	**4**	**171.0**	**77.6**	**1**	**0**
Sudan Savanna Zone: KADAWA								
	Extra-early hybrids							
	TZEEI 29 X TZEEI 21	2310.2	3	5	169.8	102.2	0	1
	TZEE-Y Pop STR C5 X TZEEI 58	2204.5	3	5	177.6	105.9	0	24
	Mean	**2257.4**	**3**	**5**	**173.7**	**104.1**	**0**	**13**
	Early hybrids							
	TZE-W Pop DY STR C4 X TZEI 7	2211.2	3	5	164.4	102.6	0	3
	TZEI 124 X TZEI 25	2704.0	2	4	170.6	104.4	0	1
	Mean	**2457.6**	**3**	**5**	**167.5**	**103.5**	**0**	**2**

GYLD = Grain yield (Kg ha^{-1}); PASP = Plant aspect; EASP = Ear aspect; PLHT = Plant height (cm); EHT = Ear height (cm); RL = Root lodging; SL = Stem lodging.

3.2 Response of grain yield and agronomic traits to plant density

Plant density (PD) mean squares were highly significant for all traits except for ANTH, PLHT, and EHT. The E x PD interaction had a highly significant effect on GYLD, EPP, PASP, HC, RL, and SL. However, PD x G interaction and other interactions involving PD had no significant effect on grain yield and most traits (Tables 3a and 3b). Across locations, grain yield decreased significantly as PD increased although; the decrease was only about 6% from the lowest (66,666 plants ha^{-1}) to the highest (133,333 plants ha^{-1}) density (Table 5). The trend in PD response across genotypes and N rates was different within locations for grain yield. For each of the two forest locations, grain yields at 66,666 and 88,888 plants ha^{-1} were not significantly different but were significantly higher than grain yield at 133,333 plants ha^{-1}. In contrast, grain yields at the three densities were about the same in each of the three savanna locations (Table 5 and 6), suggesting that yield reductions associated with increased PD were lower in the savannas than in the forest locations. On average across densities, however, the savanna locations were 357 kg ha^{-1} (about 14.4%) higher yielding than the forest locations. The overall grain yield of the hybrids of each maturity group showed a negative linear response to plant density and the predicted maximum grain yield from the negative linear response to PD was obtained at approximately 66,666 plants ha^{-1} for the range of plant densities used in this study (Figure 1). Extra-early and early hybrids had similar linear trends for PD, although, the regression parameters were higher for the early than extra-early hybrids (Figure 1). Rates of decrease in grain yield related to increased PD were roughly the same for all hybrids except the SC extra-early hybrid, TZEEI 29 x TZEEI 21, which had a lower rate relative to others (Table 6). The R^2 value (0.0616) for the linear response of TZEEI 29 x TZEEI 21 to PD was far lower than those obtained from the linear responses of other hybrids (Table 6). The response of EPP to PD was similar to that of grain yield; that is, it decreased with increased PD (Table 5). On average across PD, the number of EPP produced in the savanna locations were about 9% higher than those produced in the two forest locations. The trait (EPP) exhibited a negative linear response to PD (Table 6). In contrast, the mean values of PASP, HC, RL, and SL increased significantly with increased density, although the mean values were much lower in the savanna than forest locations (Table 5). The respective linear trends in the PD response (averaged across the four hybrids, three N rates, and five locations) for PASP, EASP, HC, ASI, RL, and SL were all positive (Table 6). The coefficients of determination, R^2 of the traits ranged from 89.29% for PASP and EASP to 100% for RL and SL (Table 6), indicating high reliability of the linear regression models for the traits. Interestingly, EASP and PASP had the same R^2 value (89.29%) and the rate of increase in score value (2E-05) associated with increased PD, but the intercepts were quite different about 3.8 and 2.8 for EASP and PASP, respectively (Table 6).

3.3 Response of grain yield and agronomic traits to N rates

The combined ANOVA showed no significant N mean squares for grain yield and all other measured traits (Tables 3a and 3b). The effect of the three N rates for grain yield across the three plant densities and five environments was the same for all the genotypes (Tables 3a and 3b). Although, the highest grain (2734.34 kg ha^{-1}) across the four genotypes, three plant densities and five environments was obtained at 120 kg N ha^{-1}, but was not different statistically with grain yield (2681.43 kg ha^{-1}) obtained at 90 kg N ha^{-1}. Thus, the hybrids showed no response to N-fertilizer application rates above 90 kg N ha^{-1}. N x PD interaction, as well as all other interactions involving N, had no significant effect on

Table 5: Means of grain yield and some agronomic traits of extra-early and early hybrids evaluated under varying plant densities in five agro-climatic zones of Nigeria in 2015.

Agro-climatic zone	Plant Density	GYLD	EPP	PASP	HC	RL	SL
Rainforest Zone: IKENNE							
	66,666 Plants ha^{-1}	2477.43	0.96	5	1.36	5	9
	88,888 Plants ha^{-1}	2594.30	0.88	5	1.46	11	15
	133,333 Plants ha^{-1}	2185.67	0.72	6	1.46	17	24
	LSD at 5%	**138.13**	**0.04**	**0.25**	**0.06**	**2.99**	**3.66**
Marginal Rainforest Zone: IFE							
	66,666 Plants ha^{-1}	2733.80	0.93	4	1.44	16	4
	88,888 Plants ha^{-1}	2594.64	0.85	5	1.44	23	6
	133,333 Plants ha^{-1}	2276.57	0.70	7	1.76	44	10
	LSD at 5%	**176.04**	**0.03**	**0.25**	**0.13**	**5.77**	**2.02**
Southern Guinea Savanna Zone: MOKWA							
	66,666 Plants ha^{-1}	3162.20	0.96	4	1.93	2	3
	88,888 Plants ha^{-1}	3097.80	0.92	5	2.01	3	4
	133,333 Plants ha^{-1}	3014.80	0.84	6	1.95	4	7
	LSD at 5%	**235.67**	**0.05**	**0.35**	**0.17**	**1.16**	**1.57**
Northern Guinea Savanna Zone: ZARIA							
	66,666 Plants ha^{-1}	3031.60	0.96	3	2.3	1	0
	88,888 Plants ha^{-1}	3028.90	0.91	3	2.2	2	0
	133,333 Plants ha^{-1}	3094.60	0.77	3	2.2	4	1
	LSD at 5%	**310.56**	**0.05**	**0.43**	**0.11**	**1.43**	**0.49**
Sudan Savanna Zone: KADAWA							
	66,666 Plants ha^{-1}	2381.10	0.99	3	2.2	0	6
	88,888 Plants ha^{-1}	2337.10	0.96	3	2.7	0.1	7
	133,333 Plants ha^{-1}	2354.20	0.96	3	3.3	0	10
	LSD at 5%	**160.18**	**0.03**	**0.41**	**0.45**	**0.09**	**3.69**
Plant Density Combined							
	66,666 Plants ha^{-1}	2757.23	0.96	4	1.85	5	4
	88,888 Plants ha^{-1}	2730.55	0.90	4	1.96	8	6
	133,333 Plants ha^{-1}	2585.17	0.80	5	2.13	14	10
LSD at 5%		**104.00**	**0.08**	**0.16**	**0.11**	**1.23**	**0.99**

GYLD = Grain yield (Kg ha^{-1}); EPP = Ears per plant; PASP = Plant aspect; HC = Husk cover; RL = Root lodging; SL = Stem lodging

Table 6: Contrast analysis of plant density effect on combined grain yield of four hybrids in and across five agro-climatic zones, and regression parameters showing the effect of plant density on the grain yield and agronomic traits of extra-early and early maturing maize hybrids evaluated in five environments.

Agro-climatic zone	**DF**	**P1 vs P3**	**P1 vs P2**
Hybrid combined (Grain Yield)			
Rainforest	1	1532188.0520**	245875.5520
Marginal Rainforest	1	3762960.4050**	348578.6640
Southern Guinea Savanna	1	391148.7354	74569.6669
Northern Guinea Savanna	1	71511.3910	132.4894
Sudan Savanna	1	13023.5032	36113.8697
Across agroecologies	1	2664170.4330**	64027.7780
Regression parameters for effect of plant density on grain yield and agronomic traits			
	Intercept (a-value)	**b-value ± S.E.**	**R^2**
For each hybrid (Grain Yield)			
TZEEI 29 x TZEEI 21	2734.5	-0.0005 ± 0.0019	0.0616
TZEE-Y Pop DT SRT C5 x TZEEI 58	2759.1	-0.005 ± 0.0001	0.9996
TZE-W Pop DT SRT C4 x TZEI 7	2920.3	-0.002 ± 0.0006	0.9191
TZEI 124 x TZEI 25	3382.0	-0.003 ± 0.0008	0.9409
Agronomic traits			
EPP	1.1157	-2.4E-06 ± 1.11E-07	0.9978
PASP	2.7857	1.61E-05 ± 5.57E-06	0.8929
EASP	3.7857	1.61E-06 ± 5.57E-06	0.8929
ASI	0.6822	6.14E-06 ± 1.61E-06	0.9353
HC	I.5807	4.15E-06 ± 2.78E-07	0.9955
RL	-3.9998	1.35E-04 ± 7.52E-10	1.0000
SL	-1.9999	9.00E-05 ± 5.01E-10	1.0000

P1 = 66,666 plants ha^{-1} P2 = 88,888 plants ha^{-1} & P3 = 133,333 plants ha^{-1}

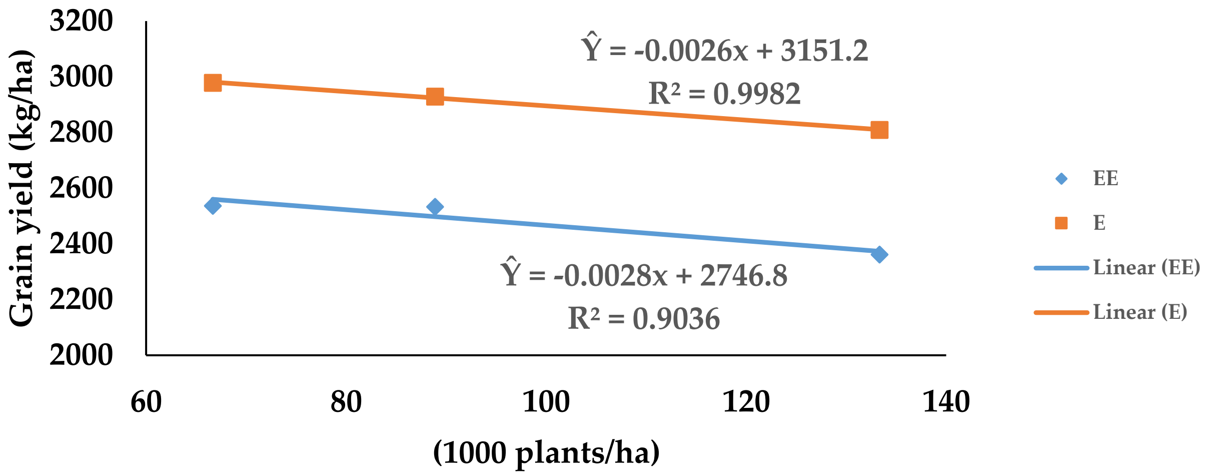

Figure 1: Grain yield response of extra-early and early maturing hybrids to plant density. Plotted points are observed yields average across hybrids within each group, N rates, and locations.

all the studied traits except in a few cases such as SL (Tables 3a and 3b).

3.4 Partitioning of the total variation in grain yield into its various components

The E, G, and G x E interaction mean squares in that order, were the most important contributors determining grain yield. Environment, the largest contributor, accounted for 23.5%. The variance accounted for by the G and G x E interaction sum of squares were 19.4% and 6.4 %, respectively (Table 7). Partitioning of the variance contribution of the genotype sum of square revealed that orthogonal contrast between maturity groups (extra-early vs early hybrids) accounted for 55.5 % and within each maturity group accounted for 26.7 % (SC vs TC extra-early hybrids) and 17.8 % (SC vs TC early hybrids). The N and PD sum of squares accounted for 0.2 and 1.3 %, respectively (Table 7). Thus, the PD sum of square contribution to the total variance in grain yield was more important relative to that of N. The variance magnitude accounted for by the remaining components ranged from 0.2 % for N x PD and G x N interaction sum of squares to 6.6 % for Rep(Environment) sum of square. The summation of the variance accounted for by the three Error terms (i.e. Error a + Error b + Error c) and replications gave approximately 38%. This proportion of the total Error variance was arbitrarily high, particularly, the magnitude of the residual, Error c (24%) (Table 7).

4. Discussion

In an effort to combat the major stresses (drought, low soil N, and *Striga* infestation) constraining maize production in WCA, breeders have developed and commercialized extra-early and early-maturing maize hybrids that combine high yield potentials with tolerance/resistance to the stresses and are being adopted by the farmers in the sub-region. Hybrids of both maturity groups are new to the farmers; therefore, there is a rather urgent need to recommend appropriate agronomic practices for such hybrids in the whole of WCA. In this study, the lowest density level used (66,666 plant ha^{-1}) and N fertilizer rate applied (90 kg N ha^{-1}) were those presently recommended for the two maturity groups. The recommendations were based on open-pollinated varieties (OPVs) in the two maturity groups developed and evaluated in the NGS zones many years ago. It was desirable to increase the rates for hybrids of these maturity groups to take advantage of the heterosis to increase production. The results showed that the hybrids were intolerant of high plant densities and could not take advantage of higher N rates to increase production.

The results of this rather preliminary study partly confirm and refute existing knowledge, and partly open up new areas for further research on the agronomy of early and extra-early maize in the different agro-climatic zones of WCA. Our study confirmed the presence of significant differences in the performance of the hybrids both between and within maturity groups for grain yield and most other traits as earlier reported by several researchers who worked in some of the agro-ecologies used in the present study [24,25] inter alia. In another study, Oluwaranti et al. found no significant differences among varieties within maturity groups for grain yield, vegetative and flowering traits [26]. That study, which involved only OPVs, was conducted in the two seasons of the MRF agro-ecology used in the present study. The inconsistency of their findings with those obtained in the present study could be attributed to the difference in genetic materials and experimental design or methodology employ. Further studies are needed to resolve this conflicting situation.

Table 7: Proportion of total variation (%) in grain yield accounted for by the different sources of variation in a study involving three N rates, three plant densities and four maize hybrids evaluated in five agro-climatic zones of Nigeria.

Source of variation	DF	Sum of squares	Proportion of Variation (%)
Environment (E)	4	54006255.39	23.5
Rep(Environment)	10	15108481.10	6.6
Nitrogen (N)	2	560832.60	0.2
Environment x Nitrogen	8	3506308.02	1.5
Error a	20	5602164.28	2.4
Plant Density (PD)	2	3086911.72	1.3
E x PD	8	4585511.00	2.0
N x PD	4	498848.64	0.2
E x N x PD	16	1418193.29	0.6
Error b	60	10951703.71	4.8
Genotype (G)	3	44555849.25	19.4
Extra-early vs Early Hybrids	*1*	*24725078.86*	*55.5*
SC extra-early vs TC extra-early	*1*	*11883076.97*	*26.7*
SC early vs TC early	*1*	*7947693.43*	*17.8*
G x E	12	14685649.47	6.4
G x N	6	476548.62	0.2
G x PD	6	1567831.15	0.7
G x E x N	24	4919416.22	2.1
G x E x PD	24	3250327.01	1.4
G x N x PD	12	1325984.19	0.6
G x E x N x PD	48	4407122.31	1.9
Error c	270	55066211.70	24.0
Total	539	229580149.70	100

The significant G x E interaction effect observed for grain yield and other agronomic traits is another confirmation of existing common global knowledge of maize evaluation trials. In this study, the significant G x E interaction mean squares for grain yield was magnitudinal rather than directional; that is, the differential grain yield performance of the genotypes in all the studied environments was only in magnitude (differences in the grain yield means) and not in ranking. The early hybrids were consistently higher yielding than the extra-early hybrids in all of the agro-climatic zones, even in the Sudan savanna location, a terminal drought-prone environment. This result was rather surprising because it was expected that the extra-early hybrids would be higher yielding than the early hybrids which are later maturing and could have been a victim of the terminal drought in this location. Partitioning the existing G x E interaction into its components is desirable when efforts are directed to releasing varieties into the ecologies of their best adaptation. Results of this study clearly indicated that extra-early hybrids are not better adapted to the Sudan savanna agro-ecology and should not be preferred to early hybrids in that ecology. In general, early hybrids are only higher yielding in all agro-ecologies, including those which have longer rainy seasons, they are not necessarily better adapted to the ecologies than the extra-early hybrids. Early maturing hybrids take a longer period to complete necessary physiological processes and grain filling before physiological maturity than extra-early maturing hybrids. The results of this study confirmed the existing knowledge of the environmental physiology of maize that extra-early varieties, including hybrids, are not necessarily more suitable than the early varieties for the Sudan savanna and, by inference, other short rainy season, terminal drought-prone environments such as the late season in the marginal forest agro-ecology of WCA, unless terminal drought really occurs.

Furthermore, the results of this study also, revealed that the yield performance of SC hybrids was superior to that of TC hybrids irrespective of the maturity group. The grain yield advantage of SC hybrids over the TC hybrids may be related to the variation in their genetic background and perhaps in the level of expression of heterosis. This is because SC hybrids give the maximum degree of heterosis. The higher grain yield performance of the SC hybrids may also be related to the consistent lower ear placement and reduced root and stalk lodging reported in this study. Many researchers have reported that higher ear position could increase the susceptibility to both root and stalk lodging, particularly in the extra-early, and consequently, a significant reduction in grain yield [27,28]. Therefore, the relatively lower grain yield of the TC hybrids in the present study may be linked with the higher ear placement, as well as higher root and stalk lodging consistently obtained for these hybrids in all the studied environments. Differential performance of the two maturity groups of hybrids also contributed to the significant G x E that occurred in the present study. Whereas SC hybrids were about 21% higher yielding than the TC hybrids at Zaria in the NGS, they were about 17% higher yielding in the MRF and only about 13-14% better in all other agro-ecologies.

Enhanced adaptation to high PD is key to maize grain yield improvement [29]. Optimization of plant density and fertilizer levels result in increased grain yield per unit land area. Investigating the PD and N fertilizer response of commercial hybrids offers invaluable information that can guide breeders in breeding new cultivars and or in modelling innovative cropping techniques for grain yield improvement. In the present study, grain yield and other studied traits showed no significant response to N application. This result is at variance with the findings of other researchers such as Fakorede and Mock, who reported significant differences among four N rates (0, 90, 180 and 270 kg N ha^{-1}) [30]. Al-Naggar et al., (2015), also obtained significant differences among the three N rates (0, 285 and 570 kg N ha^{-1}) [31]; and in another study by Qian et al., significant differences were similarly obtained among four N rates (0, 150, 300 and 450 kg N ha^{-1}) [32]. It was particularly striking that early and extra-early hybrids evaluated in our study did not respond to N fertilizer above 90 kg ha^{-1} whereas those evaluated in earlier studies, especially the more recent studies, responded to 150 kg ha^{-1} and higher rates. Because farmers in SSA, on average, apply less than 10 kg N ha^{-1} to maize, IITA and International Maize and Wheat Improvement Centre (CIMMYT) researchers, along with their national programs collaborators are now developing low-N (about 30 kg N) tolerant maize germplasm. Studies by Badu-Apraku et al., showed that, in addition to being low-N tolerant, the resulting germplasm had the value addition of being high yielding at a high level of N, usually 90 kg ha^{-1} [4,33]. The present study was the first attempt at evaluating such material at N rates higher than 90 kg ha^{-1}. Perhaps the N response in the present study would have been different if low N rates such as 0, 30 and 60 kg ha^{-1} had been included in the study. Seemingly, the greater challenge to maize breeders in SSA now is to develop hybrids that would respond to high N rates for increased grain yield in commercial farms that can afford high input levels. By implication, this challenge also extends to density response, along with the non-significant N x PD interaction mean square for grain yield both of which made it impossible to determine the response surface combinations of N and PD in our study.

Lack of significant G x PD interaction effect in this study indicated that the hybrids had similar response of reduced performance in grain yield and other traits as PD increased, a confirmation of results of earlier studies on the subject-matter [7,30,32,34]. Generally, the extra-early and early maturing hybrids were intolerant of high density. Therefore, selection and development of hybrids or lines under high plant population density may be a promising strategy to improve the tolerance and adaptation of hybrid maize to higher PD. In contrast to the hybrids, PD response within locations for grain yield, yield components, and few other agronomic traits varied significantly and this was indicated by highly significant PD x E mean squares for the traits, a valid justification for extensive evaluation of density response in multiple environments in order to draw conclusion and before recommendation could be made.

Across PD, grain yield performance in the savanna locations was about 14.4% higher than in the forest locations, thereby supporting Badu-Apraku et al., (2006) that the savanna agroecologies are the most favorable environments for maize production in WCA. PASP and EASP score values increased with increased PD. This suggests that the general plant and ear phenotypic appeal becomes poorer with increased PD, implying that the overall plant and ear traits such as uniformity of stand, uniformity of plant and ear heights, lodging, resistance or reaction to diseases and pest, general growth and development of plant and ear, uniformity of ears, and flowering were all influenced by PD. This appears to be a general response by the plant during the growth and reproductive stages due to a reduction in photosynthate formed during these stages resulting from intense interplant competition for growth resources. Similarly, ASI value increased significantly with increased PD. Results from other researchers have consistently shown that increased ASI is associated with increased PD due to the increased number of days to silking after anthesis [30,35,36]. The increased ASI values associated with increased PD may be related to the stress imposed on the maize plant due to intense interplant competition for light, water, and nutrients resulting from increased plant population. Fakorede and Mock reported that increased ASI is a useful indicator of density stress in maize [30] and that, by implication, could be an effective trait to use for selecting density-tolerant varieties.

The savanna locations produced a higher number of ears per plant (EPP) than the forest locations, indicating that barrenness was more pronounced in the forest than in the savanna locations. This is probably one reason; higher grain yield was obtained in the savanna than forest locations in this study. Fakorede et al. (1989), in yield trials conducted for four years, found that the yield advantage of the savanna over forest locations was due primarily to ear number. In the present study, EPP reduced and, by implication, barrenness increased with increased PD. Conversely, root lodging and stalk lodging increased with increased PD. The increased root and stalk lodgings obtained as PD increased may be attributed to stress resulting from interspecific competition for growth resources imposed by the increased plant population density. However, the magnitude of both root and stalk lodgings were larger in the forest locations than in the savanna locations implying that lodging is also largely dependent on the environment. The high repeatability estimates obtained for grain yield and most agronomic traits across the agro-climatic zones implied that the expression of the traits would be consistent under the levels of N fertilizer and plant densities.

Partitioning the total variance of multi-environment trial data into its various components among experimental factors and their interaction effects offers researchers the convenience to separate and compare the relative importance of the different variance components. In this study, E had the largest share of the total variance in grain yield but was only about 4% higher variation than the G. This is not surprising because the genotypes evaluated were improved cultivars and by implication optimization of the growing condition of the hybrids may result in a significant improvement of their grain yield. Also, the variance estimate of G was 13% higher than that of the G x E interaction. This trend of components of total variance; E > G > G x E has been consistently observed in earlier studies in WCA. The closeness of G to E in this study is encouraging, an indication that proper management of the E as done in this study will reduce its masking effect on the performance of the genotypes. However, the unexpectedly large estimate of the total error variance obtained in this study suggested that more attention is still needed to minimize unexplainable sources of error in agronomic trials conducted in WCA. It is a common and routine practice of agronomists and breeders to conduct yield trials in multi-environments (locations and years) in order to identify high yielding and stable genotypes. It is, however, challenging that the effects of various management (M) practices on cultivar adaptation have not been given keen attention. Improved M practice is essential for improving grain yield particularly when the crop is managed under high plant population density. High PD generally results in increased inter-plant competition for growth resources. Such condition can be improved with best M that involves effective control of pests, diseases, and weeds, uniformity of plant stands, and consequently, effective utilization of solar radiation and soil water, and nutrients by the maize crop. Breeding and agronomic decisions have primarily been based on G x E interaction but maize scientists seem to have neglected the significance of G x E x M.

5. Conclusions

In summary, the DT extra-early and early-maturing maize hybrids were genetically distinct, with the early maturing hybrids producing higher grain yield than extra-early hybrids in all the studied environments. Irrespective of the maturity group, the single-cross hybrids expressed greater yield performance relative to the top-cross hybrids primarily due to the variability in their genetic background, as well as the lower ear placement and reduced root and stalk lodging associated with single-cross hybrids. Grain yield advantage of the savanna locations relative to the forest locations was attributed to the number of ears per plant. The E, G, and G x E were the most important factors determining variation in grain yield. No significant difference was found for grain yield and other traits among N rates of 90 to 150 kg N ha^{-1}. Plant density, however, was found to affect grain yield and most of the studied agronomic traits significantly; grain yield and EPP exhibited negative linear responses, whereas ASI, PASP, EASP, RL, and SL showed positive linear responses to plant density. The results of our investigation indicated that the genotypes were intolerant of high plant density. We suggested that breeding programs for the improvement of early and extra-early maize germplasm for high plant density tolerance should be initiated in the sub-region. The results of this study, however, showed that 90 kg N/ha and 66,666 plants/ha were optimal for the production of extra-early and early-maturing maize hybrids across the agro-climatic zones of Nigeria.

Author Contributions: Project design, management and execution, data collection, statistical analysis and interpretation of data, and drafting of manuscript, B.S.; funding acquisition and provision of the genetic materials, project administration, supervision, and manuscript revision, B.B.; supervision and manuscript revision, M.A.B.; project planning, data collection and co-supervision, R.O. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by Bill and Melinda Gates Foundation (OPP1134248).

Acknowledgments: The authors are grateful for the financial support of the Drought Tolerant Maize for Africa (DTMA) project and IITA for this research. We are also grateful to the staff of the Maize Improvement Program of IITA for technical assistance.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] B. Badu-Apraku, A. Menkir, M.A.B. Fakorede, A. Fontem Lum, K. Obeng-Antwi, Multivariate analyses of the genetic diversity of forty-seven Striga resistant tropical early maturing maize inbred lines, Maydica. 51 (2006) 551–559.

[2] FAOSTAT, Food and Agriculture Organization of the United Nations Statistics. Food and Agricultural commodities production., (2015). www.faostat3.fao.org.

[3] D. Byerlee, &, C. Eicher, Africa's emerging maize revolution., Boulder, Colorado, Lynee Rienner, 1971.

[4] B. Badu-Apraku, M. Oyekunle, R.O. Akinwale, Breakthroughs in maize breeding, IITA. (2013). http://www.iita.org.

[5] B. Badu-Apraku, R.O. Akinwale, M.A.B. Fakorede, Selection of early maturing maize inbred lines for hybrid production using multiple traits under striga-infested and striga-free environments, Maydica. 55 (2010) 261–274. doi:10.1007/978-3-319-27478-2_17.

[6] A.Y. Kamara, Best practices for maize production in the West African savannas. R4D review, Ibadan, Nigeria, 2013. http://www.iita.org.

[7] L. Sangoi, Understanding plant density effects on maize growth and development: an important issue to maximize grain yield., (2000) 159–168.

[8] J.E. Iken, N.A. Amusa, Maize research and production in Nigeria., African J. Biotechnol. 3 (2004) 302–307. http://www.academicjournals.org/AJB.

[9] A.Y. Kamara, F. Ekeleme, L. Omoigui, A. Menkir, D. Chikoye, I.Y. Dugje, P. Amaza, Influence of nitrogen fertilization on the performance of early and late maturing maize varieties under natural infestation with Striga hermonthica (Del.) Benth., Arch. Agron. Soil Sci. 55 (2009) 125–145.

[10] Z. Druilhe, J. Barreiro-hurlé, Fertilizer subsidies in sub-Saharan Africa, in: ESA Work. Pap. No. 12-04, Agric. Dev. Econ. Div. Food Agric. Organ. United Nations, Rome, Italy., 2012. www.fao.org/economic/esa.

[11] H.A. Torbert, K.N. Potter, J.E. Morrison, Tillage system, fertilizer nitrogen rate, and timing effect on corn yields in the Texas Blackland Prairie., Agron. J. 93 (2001) 1119-1124.

[12] M. Smale, D. Byerlee, T. Jayne, Maize Revolutions in Sub-Saharan Africa BT - An African Green Revolution: Finding Ways to Boost Productivity on Small Farms, in: K. Otsuka, D.F. Larson (Eds.), An African Green Revolut., Springer Netherlands, Dordrecht, 2013: pp. 165–195. doi:10.1007/978-94-007-5760-8_8.

[13] IITA, Maize Production Manual Volume I Chapter 1-9, International Institute of Tropical Agriculture (IITA), Oyo Road, PMB5320, 1982.

[14] K.N. Futuless, Y.M. Kwaga, S.A. Aberakwa, Effect of Spacing on the Performance of Extra Early Yellow Maize (Zea mays L.) Variety TZESR - Y in Mubi, Adamawa State Nigeria, J. Am. Sci. 6 (2010) 708–712.

[15] B.A. Babaji, Y.B. Ibrahim, M.A. Mahadi, M.M. Jaliya, R.A. Yahaya, A.I. Sharifai, A.A. Mukhtar, B.M. Sani, A. Ibrahim, A.A. Muhammad, Response of extra-early maize (Zea mays L.) to varying intra-row spacing and hill density., Glob. J. Biosci. Biotechnol. 1 (2012) 110 – 115.

[16] A. Sharifai, M. Mahmud, B. Tanimu, I. Abubakar, Yield and Yield Componemts of Extra Early Maize (Zea Mays L.) as Influenced by Intra-Row Spacing, Nitrogen and Poultry Manure Rates, Bayero J. Pure Appl. Sci. 5 (2012) 113–122. doi:10.4314/bajopas.v5i1.21.

[17] M.E. Westgate, Seed formation in maize during drought., in: Physiology and Determination of Crop Yield, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 677 S, Segoe, Rd., Madison, WI 53711, USA., 1994: pp. 361–364. doi:10.2134/1994.physiologyanddetermination.c24.

[18] M.P. Herrero, R.R. Johnson, Drought stress and its effects on maize reproductive systems., Crop Sci. 21 (1981) 105-110.

[19] G.O. Edmeades, J. Bolaños, M. Hernandez, S. Bello, Causes for silk delay in a lowland tropical maize population., Crop Sci. 33 (1993) 1029–1035.

[20] MIP - Maize Improvement Program, Drought tolerant maize varieties released under DTMA in Nigeria, Mali and Ghana from 2007 – 2016. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria., (2017). http://www.iita.org.

[21] SAS Institute, Statistical Analysis System Institute. SAS User's Guide. Version 9.0 Cary, NC: SAS Institute Inc., (2002).

[22] W.R. Fehr, Principles of cultivar development—theory and technique, vol 1., Iowa State Univ. (1991).

[23] D.S. Falconer, T.F.C. Mackay, Introduction to quantitative genetics., 4th ed., Longman, New York., 1996.

[24] A. Oluwaranti, M.A.B. Fakorede, B. Badu-Apraku, Grain yield of maize varieties of different maturity groups under marginal rainfall conditions., J. Agric. Sci. 53 (2008) 183 – 191.

[25] O.B. Bello, S.Y. Abdulmaliq, S.A. Ige, J. Mahamood, F. Oluleye, M.A. Azeez, &, M.S. Afolabi,

Evaluation of early and late/intermediate maize varieties for grain yield potential and adaptation to a southern Guinea savanna agroecology of Nigeria., Sch. J. Agric. Sci. 2 (2012) 42 – 51.

[26] A. Oluwaranti, M.A.B. Fakorede, F.A. Adeboye, Maturity groups and phenology of maize in a rainforest location., Int. J. Agric. Innov. Res. 4 (2015) 124 – 127.

[27] H.A. Esechie, V. Rodriguez, H. Al-Asmi, Comparison of local and exotic maize varieties for stalk lodging components in a desert climate, Eur. J. Agron. 21 (2004) 21-30.

[28] A.E. Salami, S.A.O. Adegoke, O.A. Adegbite, Genetic variability among maize cultivars grown in Ekiti-State, Nigeria., Middle-East J. Sci. Res. 2 (2007) 9-13.

[29] J.W. Edwards, Genotype ´ Environment Interaction for Plant Density Response in Maize (Zea mays L .), 1505 (2016) 1493–1505. doi:10.2135/cropsci2015.07.0408.

[30] M.A.B. Fakorede, J.J. Mock, Correlated responses to recurrent selection for grain yield in maize [Zea mays, genotypes]., Res. Bull. Agric. Home Econ. Exp. Stn. (USA). (1982).

[31] A. Al-Naggar, R. Shabana, M. Atta, T. Al-Khalil, Matching the Optimum Plant Density and Adequate N-rate with High-density Tolerant Genotype for Maxmizing Maize (Zea mays L.) Crop Yield, J. Agric. Ecol. Res. Int. 2 (2015) 237–253. doi:10.9734/jaeri/2015/14260.

[32] C. Qian, Y. Yu, X. Gong, Y. Jiang, Y. Zhao, Z. Yang, L. Zea, ScienceDirect Response of grain yield to plant density and nitrogen rate in spring maize hybrids released from 1970 to 2010 in Northeast China, CJ. 4 (2016) 459–467. doi:10.1016/j.cj.2016.04.004.

[33] B. Badu-Apraku, M.A.B. Fakorede, M. Gedil, B. Annor, A.O. Talabi, I.C. Akaogu, M. Oyekunle, R.O. Akinwale, T.Y. Fasanmade, Heterotic patterns of IITA and CIMMYT early-maturing yellow maize inbreds under contrasting environments, Agron. J. 108 (2016) 1321–1336. doi:10.2134/agronj2015.0425.

[34] M. Tollenaar, J. Wu, Yield improvement in temperate maize is attributable to greater stress tolerance., Crop Sci. 39 (1999) 1597-1604.

[35] J.H. Lemcoff, R.S. Loomis, Nitrogen influences on yield determination in maize., Crop Sci. 26 (1986) 1017-1022.

[36] J. Shrestha, Effect of nitrogen and plant population on flowering and grain yield of winter maize, 2 (2013) 64–68.

[37] M.A.B. Fakorede, S.. Kim, J.. Mareck, J.E. Iken, Breeding Strategies and Potentials of available varieties in relation to attaining self-sufficiency in maize production in Nigeria., in: Present. Natl. Symp. “Towards Attain. Self-Sufficiency Maize Prod. Niger., I.A.R. & T., Ibadan., 1989.