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Green Strategy for Maize Varietal Selection and Identification of Suitable Sites in Drought-Prone Ecologies in Southern Guinea Savanna of Nigeria

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ABSTRACT

Drought stress is the most important environmental constraint contributing to grain yield instability of maize (*Zea mays* L.). This study extracted multi-environment trial data sets from southern Guinea savanna of Nigeria maize trials using Additive Main Effects and Multiplicative Interaction (AMMI) and Genotype and Genotype-Environment (GGE) biplot models which assessed the performance of drought tolerant (DT) maize genotypes and identified best genotypes for suitable sites. The impact of environmental changes and economic implications of producing DT maize were estimated. The test environments contributed about 75-100% of the total variation in grain yield. The ideal locations for DT maize cultivation were identified. Ilorin/Ballah, Ejiba/Mokwa and Kishi/Badeggi are core test locations for evaluation of early OPVs, intermediate/late OPVs and Hybrids, respectively. The following promising genotypes are recommended for further evaluation in farmer's fields: TZE-Y-DT-Str-C_4 (early OPV), White-DT-STR-SYN (intermediate/late maturing OPV), TZE-W-Pop-DT STR-C_5 (early maturing hybrid) and TZEEI 3 x TZEEI 46(extra early genotype). The potential impact of investing in drought tolerant maize shows an economic return of US$ 571 and US$ 1426 per hectare for cultivating OPVs and hybrids, respectively. The study shows that maize yields increase with more seasonal rainfall and decrease with higher temperatures. However, increased rainfall variability during the growing season reduces yields for maize. Thus, simultaneous considerations of technological improvements and the development of the overall availability and predictability of water resources are likely required to see sustainable improvements in maize production given projected climate trends and variability.

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ACRONYMS

AMMI	Additive Main Effects and Multiplicative Interaction
BNRCC	Building Nigeria's Response to Climate Change
DT	Drought Tolerant
DTMA	Drought Tolerant Maize for Africa
FAO	Food and Agriculture Organisation
FAOSTAT	Statistical Division of the Food and Agriculture Organisation
FGN	Federal Government of Nigeria
GDP	Gross Domestic Product
GEI	Genotype-Environment Interactions
GGE	Genotype, Genotype by Environment
IPCC	Intergovernmental Panel on Climate Change
IITA	International Institute of Tropical Agriculture
MIP	Maize Improvement Programme
N	Nitrogen
NGS	Northern Guinea savanna
SGS	Southern Guinea savanna
SS	Sudan/Sahel savanna
SSA	Sub-Saharan Africa
UNESC	United Nations Economic and Social Council
WA	West Africa
WCA	West and Central Africa

1.0 Introduction

1.1 Background of the study

Maize (*Zea mays* L.) suffers from moisture deficit condition which may cause yield reduction especially if it occurs during the reproductive phase (Cairns *et al*., 2013). Empirical evidence reveals that maize yield is significantly reduced by 15 to 17% in the humid tropics compared to well-watered condition and when it occurs during or shortly before flowering, the estimated yield loss may be in the range of 21 to 50% (Olaoye, 2009).

In Nigeria, reducing poverty is linked to agricultural productivity and level of improved technology usage. Promotion of appropriate technologies that increase farmers' resilience to climate change manifestations such as droughts and dry spells represents an important way to reducing poverty among resource-limited farmers. In order to mitigate the effect of climate change, innovation on coping strategies are being devised in collaboration with relevant stakeholders. One of such innovations is the drought tolerant maize for Africa (DTMA) project, which is currently being executed in four countries in the sub-Saharan Africa (Nigeria, Ghana, Benin Republic and Mali).

The project which commenced in 2007 is undertaken in the Nigeria's savannas comprising of the southern Guinea savanna (SGS), northern Guinea savanna (NGS) and Sudan/Sahel savanna (SS). Each zone is unique with respect to rainfall amount and distribution, soil nutrient status and other stress factors such as low-N and striga infestation. The SGS in particular is characterized by erratic rainfall pattern, low soil nitrogen (N) and inherent porosity. The drought stress which often manifests either in the form of irregular rainfall pattern, mid-season or terminal drought has restricted maize cultivation to the adoption of early or extra-early maturing maize varieties as escape strategy or the use of multiple cropping to circumvent total crop failure. Consequently, the development and deployment of drought tolerant (DT) maize varieties that have farmer-preferred traits through appropriate

technologies, is expected to provide the much needed stability in maize yields in the drought-prone ecologies of the SGS.

1.2 Overview of the Nigerian Climate and Vegetation

The climate of Nigeria varies more than any other country in West Africa due to its great length from the south to the north (1100 km) that results in virtually all of the climatic belts of West Africa being included within Nigeria's borders (BNRCC, 2011). Climate plays a significant role in the distribution of vegetation and agriculture in Nigeria. According to Federal Government of Nigeria report on drought management (FGN, 1999), the Nigeria landmass is divided into seven ecological zones. This classification is based on the resemblance of climatic elements and the nature of vegetation that can be supported. These ecological zones are the mangrove swamp, rainforest, montane forest/grassland, derived savanna, Guinea savanna, Sudan savanna and the Sahel savanna (Sowunmi and Akintola, 2009).

Available evidence shows that climate change is global, the impact on agricultural production will be greatest in the tropics and sub-tropics, with sub-Saharan Africa (SSA) particularly vulnerable due to the range of projected impacts, multiple stresses and low adaptive capacity (Ohajianya and Osuji, 2012). Previous research strongly suggests maize growing regions of SSA will encounter increased growing season temperatures and frequency of droughts (IPCC, 2007). This would result in some agricultural lands becoming unsuitable for cropping, and some tropical grassland becoming increasingly arid. It is projected that yield of many crops including maize in Africa may fall by 10-20% by 2020 due to climate change (Ajetumobi and Abiodun, 2010). This is because SSA agriculture is predominantly rain-fed and weather dependent. Decreased rainfall would impact negatively on the yields, with estimations of up to 50 percent in some SSA countries by 2020.

This means that about two-thirds of arable land in Africa is expected to be lost by 2025. Land degradation currently leads to the loss of an average of more than 3 percent annually of agriculture gross domestic product (GDP) in SSA (UNESC, 2007). Maize production could be discontinued in some areas in the region. The current national production of maize is put at 7.0 million

tonnes on an area of 3.7 million hectares (FAOSTAT, 2010). However, to meet the increasing demands of Nigeria rapidly expanding population, an estimated 50% increase in maize production is required over the coming decades (FAO, 2009), a goal that is made difficult by the declining natural resources occasioned by global climate variability. The influence of climate change on maize production in the country, only adds to an already complex problem. For this reason, an estimation of its likely impact is vital in planning strategies to meet the increased demands for maize in the next century.

1.3 Drought Tolerant Maize for Africa

Recurrent drought is a major constraint to production and productivity of maize in the savannas of West and Central Africa (WCA). The annual maize yield loss from drought is estimated at 15% but localized losses might be much higher in the marginal areas where the annual rainfall is below 500 mm and soils are sandy or shallow (Edmeades *et al*., 1995). Losses in yield can be as high as 90% if the drought stress occurs near the most drought-sensitive stages of crop growth, such as the flowering and grain filling periods (NeSmith and Ritchie 1992). Outbreaks of recurrent drought have persisted in WCA for about 40 years and the situation calls for a more effective improvement of maize yield under drought stress. Global warming and its associated effects in WCA have changed weather patterns, leading to erratic and unreliable amounts and distribution of rainfall, resulting in drought.

The Drought Tolerant Maize for Africa (DTMA) Project has, since 2007, devoted considerable attention and resources to developing new cultivars with a higher yield potential and stability across varying levels of water availability and growing conditions. Early-maturing open-pollinated cultivars and hybrids have been developed, several of which combine tolerance to drought, low soil N and resistance to *Striga hermonthica* (Del) Benth.

The challenge facing the DTMA Project is to test effectively for the drought tolerance of productive open-pollinated cultivars and hybrids under multiple

environments, and then make the DT genotypes available to farmers in the sub-region.

The DTMA Project uses the Regional Drought Tolerant Trials as the means to test, identify, and exchange DT early-maturing varieties and hybrids of maize with broad adaptation to a particular agro-ecological zone among collaborators in West Africa (WA).

Multi-location trials for maize in WA have demonstrated the existence of genotype-environment interactions (GEI) (Badu-Apraku *et al.*, 2008). This implies the need for the extensive testing of cultivars in multiple environments over years before decisions are taken on cultivar recommendations. However, because of the limited resources of the national maize research programs of WA, there is a need to conduct cultivar evaluation in a limited number of environments. It is therefore very important to develop an understanding of the target agro-ecosystems and to determine if these could be subdivided into different mega-environments to facilitate a more meaningful evaluation and recommendation of cultivars.

The present study sought to use genetic materials evaluated in the different agro-ecologies of the SGS of Nigeria with the objective to ascertain their suitability as replacement to the existing cultivars. To this end, data that have been collected from multi-location trials between 2007 and 2014 involving open pollinated varieties (OPVs) and hybrids were analyzed using the Genotype (G) and genotype x environment (GE) model with the following objectives:

1. assess the performance of DT hybrids and open pollinated (OP) maize varieties for their suitability as cultivars in the different locations of the SGS of Nigeria;
2. identify promising candidates for further evaluation in farmer's fields;
3. identify sites that are representative of the unique environment in the zone;
4. determine the effect of climate change on maize grain yield, and
5. estimate the economic benefit of cultivating DT maize in SGS of Nigeria.

2.0 MATERIALS AND METHODS

2.1 Description of Experimental Materials

The genetic materials used comprised of DT maize germplasm (hybrids, early and late/Intermediate maturing varieties) obtained from the Maize Improvement Programme (MIP) of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Table 1 and 2 shows the agronomic characteristics of the selected DT maize genotypes used in the present study.

2.2 Description of Experimental Sites

This study was conducted in the drought prone ecologies of Nigeria's SGS which comprised many farming communities in four states: Kwara, Kogi, Niger and the northern fringes of Oyo state (Fig. 1). The communities included Ilorin, Oke-Oyi and Ballah in Kwara State, Ejiba in Kogi State, Mokwa, Badeggi and Lapai in Niger State and Kishi in Oyo State all in the SGS of Nigeria. The locations and their coordinates are presented in Table 3. Rainfall distribution at each location is bimodal with annual rainfall of 1100-1400mm. However, the distribution is highly unpredictable, with early false start around April, but which often cease abruptly for few weeks and ending not later than mid-October of every year.

2.3 Planting/ Crop Establishment and Maintenance

The experimental materials were evaluated during the 2007-2014 late cropping seasons. Each set planted as separate experiments, but adjacent to each other, was set up at as a randomized complete block design (RCBD) with three or four replications depending on the availability of planting materials in all the locations.

The plot size consisted of four rows, 5m long with inter and intra row spacing of 0.75m x 0.4m for the early maturing varieties and 0.75m x 0.5m for Intermediate/Late maturing and hybrids.

Three seeds were planted/hill but later thinned to 2/hill to give a plant population of approximately 53,333 plans/ha.

Crop management practices included weed control with pre-emergence application of herbicide (Primextra at 2.5kg ai/ha and supplementary hoe weeding). Fertilizer application was carried out as split-dosage at the rate of 80kgN/ha, 60K_2O/ha and 60P_2O_5 at three weeks after planting (3WAP) and at anthesis (7WAP), using compound fertilizer (NPK 20:10:10).

Table 1. Grain yield and other agronomic traits of selected drought tolerant OPVs' maize genotypes

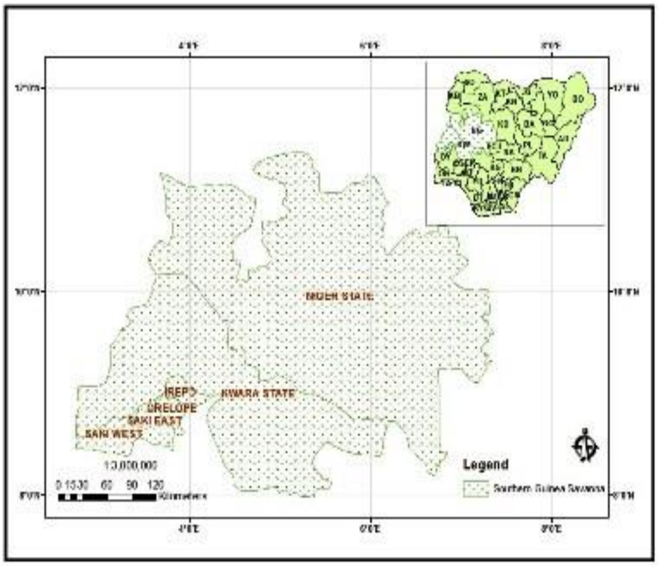
Genotype	Grain yield (kgha^{-1})	Ears per plant	Anthesis-silking interval	Plant height (cm)	Ear height (cm)	Plant aspect	Ear aspect	Husk cover
Early DT OPVs								
TZE Comp 3 DT CO F3	7047.22	1	3	146.5	63.8	2.5	2.5	1.3
TZE- Y DT STR C4	7165.98	1	1	155.5	74.8	2.8	3.0	2.5
TZE Comp 3 DT CO F2	6569.34	1	2	137.5	55.0	2.5	2.8	1.4
EVDT-Y 2000 STR CO	6326.07	1	3	148.5	66.3	3.3	2.6	1.8
TZE Comp 3 DT CO F5	6317.92	1	1	151.6	62.4	2.6	2.5	1.6
TZE-W DT STR C4	5304.06	1	3	200.5	95.8	2.8	2.5	2.0
TZE Comp 3 DT CO F4	5904.38	1	2	149.8	62.5	2.4	2.2	1.2
Intermediate/Late DT OPVs								
DT-SR-W CO F2	5671.58	1	3	136.0	65.0	3.0	3.3	4.0
DT-SYN-1-W	5992.91	1	4	140.7	58.3	1.8	3.3	3.5
SUWAN-1-SR-SYN	4841.56	1	2	156.0	61.7	2.8	3.0	3.8
TZB-SR	4663.24	1	4	168.3	88.3	2.8	3.0	4.0
TZL COMP 1-W- C6 F2	5254.24	1	3	140.7	68.3	3.0	2.8	3.9
TZUTSY-W-STR-SYN	5114.63	1	3	168.7	79.0	2.8	3.3	4.5
White DT STR SYN	5518.14	1	4	162.3	73.7	3.5	3.0	4.0
DT-STR-Y-SYN 2	5029.69	1	2	160.1	55.9	2.5	2.7	4.2
IWD C3 SYN F2	5208.19	1	2	167.3	56.0	2.8	2.5	3.8
TZL COMP3 C3 DT	5422.32	1	3	143.1	54.3	2.6	2.0	4.0
IWD C3 SYN/DT-SYN-1-W	5465.14	1	4	180.8	58.8	3.3	3.0	3.6
(White DT STR SYN/IWD C3 SYN)F2	5467.12	1	5	158.1	59.0	3.1	3.1	4.3
DT-STR-W C2	5468.39	1	4	166.3	56.2	4.0	3.0	4.1
DT-STR-W SYN C2	5517.46	1	3	154.4	64.8	3.6	2.5	4.2
(White DT STR SYN/TZL COMP1-W)F2	5654.69	1	4	154.3	67.3	3.2	2.7	3.8
TZL COMP4 C3 DT	6041.12	1	2	153.0	62.3	2.9	2.5	4.5

Table 2. Grain yield and other agronomic traits of selected drought tolerant maize hybrids

Genotype	Grain yield (kgha^{-1})	Ears per plant	Anthesis-silking interval	Plant height (cm)	Ear height (cm)	Plant aspect	Ear aspect	Husk cover
Early Maturing DT Hybrid								
TZE-Y Pop DT STR C4 x TZEI 11	16984.96	1	3	130.5	47.8	3.8	3.6	3.8
TZEI 24 x TZEI 17	8918.06	1	2	129.8	49.2	2.8	4.0	4.0
TZEI 8 x TZEI 17	8336.88	1	2	126.6	42.9	4.0	3.8	3.9
TZE-W POP DT C4 STR C5	9606.85	1	2	150.7	63.4	3.8	3.1	4.5
DT -W STR Synthetic	9268.36	1	2	153.9	66.5	3.9	3.4	4.0
DTE STR-Y Syn Pop C2	9249.36	1	3	156.2	66.1	3.5	2.7	4.2
2012 TZE-Y DT C4 STR C5	9246.28	1	2	152.9	65.4	2.8	3.5	3.8
DTE STR-W Syn Pop C2	9234.77	1	3	151.0	67.7	2.6	3.0	3.7
Extra Early White DT Hybrid								
TZEE-W Pop STR C5 x TZEEI 14	10484.10	1	2	158.3	68.5	3.3	3.0	3.6
(TZEEI 29 x TZEEI 21) x (TZEEI 14 x TZEEI 37)	9891.24	1	2	155.8	67.0	3.1	3.1	4.3
(TZEEI 21 X TZEEI 14) X TZEEI 29	9809.69	1	2	154.7	59.4	4.0	3.0	4.2
TZEEI 3 x TZEEI 46	9798.16	1	3	141.1	54.1	3.6	2.5	4.2
TZEEI 29 x TZEEI 21	9526.66	1	2	160.3	63.0	3.2	2.7	3.8
(TZEEI 29 x TZEEI 21) x TZEEI 55	9301.26	1	2	170.3	66.4	4.1	3.6	2.9
(TZEEI 29 x TZEEI 37) x TZEEI 13	9270.00	1	2	154.2	63.9	3.8	3.1	4.5
TZEE-W Pop STR C5 x TZEEI 46	9060.39	1	2	157.6	66.8	3.9	3.4	4.0

(TZEEI 4 x TZEEI 14) x (TZEEI 29 X TZEEI 49),	11755.18	1	2	153.0	65.1	3.5	2.7	4.2
(TZEEI W Pop STR C5 x TZEEI 29	9616.21	1	3	164.2	63.8	3.8	3.5	2.8
TZEEI 4 x TZEEI 49) x TZEEI 29	9285.43	1	2	152.8	58.8	2.9	4.0	3.3
TZEEI 29 x TZEEI 21) x (TZEEI 4 x TZEEI 14)	9508.49	1	3	157.2	64.4	3.8	3.6	4.2

A



B

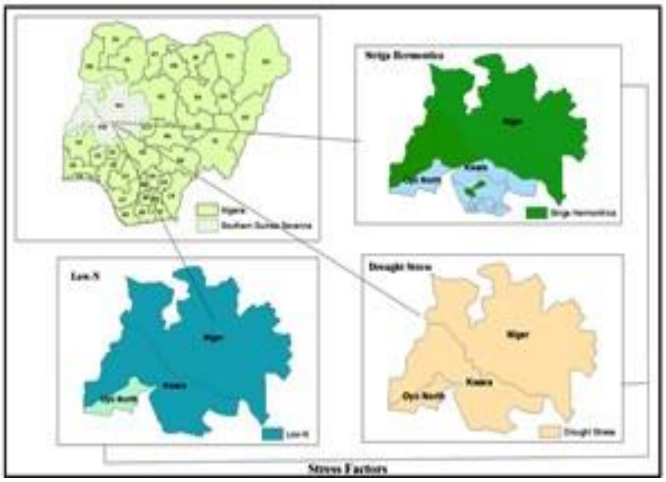


Figure 1. Map of the study area indicating the states within the agro-ecological zone (A) and type of stress factors peculiar to each zone (B).

Table 3. Description of the test locations for the varietal trials of drought tolerant (DT) maize conducted in SGS of Nigeria, 2009-2014.

Location	State[a]	Latitude	Longitude	Altitude (mASL)	Annual Rainfall (mm)	Average Temperature (^{0}C)
Ballah	Kwara	8^026	4^026	341	1234.00	25.12
Badeggi	Niger	9^010	6^002	143	1223.00	24.56
Ejiba	Kogi	8^059	6^056	130	1365.00	24.47
Ilorin	Kwara	8^040	4^036	328	1357.68	26.64
Kishi	Oyo	9^006	3^050	430	1259.00	25.71
Lapai	Niger	9^005	6^055	160	1142.48	25.62
Mokwa	Niger	9^030	5^004	148	1469.56	27.32
Oke-Oyi	Kwara	8^040	4^032	420	1201.00	26.14

[a] = Soil type: Ferruginous Tropical Soils on Crystalline Acid Rocks (JC)

2.4 Data Collection

Data were collected from the two middle rows in a plot for the Early and Late/Intermediate maturing groups and on whole-plot basis for the Hybrids, especially where planting was carried out in two-row plots.

Data collected included crop establishment, agronomic and yield parameters including days to mid-anthesis and silking, plant and ear heights (cm), stand count at harvest, ear aspect, cob weight and moisture at harvest.

Data on establishment count (after thinning), days to mid-anthesis and silking, stand count at harvest, ear aspect and cob weight were obtained on a whole-plot basis from the two inner rows while other parameters were obtained from five randomly selected plants in a plot.

Plant and ear heights were recorded as the distance from the ground level to the flag leaf and the node subtending the uppermost ear, respectively.

For ear aspect, the ears were assessed at harvest on a scale of 1(excellent) to 5 (poor) based on freedom from diseases and insect damage, ear size uniformity and cob filling.

Just before flowering, all plants from the two middle rows in a plot were counted and assessed for occurrence of foliar diseases (rust, blight, curvularia leaf spot and streak).

Only plants with obvious infection signs covering more than 50% of the leaf surfaces were counted and expressed as a percentage of total stand count in a plot. At harvest, plants from the two middle rows were also rated on a scale of 1 (Excellent) to 5 (Very poor) for plant and ear aspects, lodging characteristics (stalk & root) and husk cover.

Anthesis-silking-interval was estimated as the interval (in days) between mid anthesis and silking. Grain yield was estimated from cob weight per plot as FWT * (100-%Moist) * C which depend on the plot size. The formula assumes 80% shelling percentage. Number of ears per plant was estimated as proportion of harvestable ears to final stand count in a plot.

2.5 Data Analyses

Data pooled from DTMA trials collected between 2007 and 2014 on the different maturity groups among OPVs and hybrids. Three traits (grain yield, anthesis-silking interval and ears per plant) were the focus. These three traits have been found to distinguish among genotypes with respect to yielding ability under biotic and abiotic stress conditions.

2.5.1 Combined Analysis of Variance

Genotypes common to specific period were selected and subjected to individual as well as combined analysis of variance of the three-way mixed effects model, where genotype and locations were considered as fixed effect and year effect as random. The form of the analysis of variance and expectations of mean square for the mixed model was computed to ease testing of main and interaction effects and where necessary Sattertwaite approximation was used.

A combined three factor analysis of variance was performed on data collected using the statistical model:

$Y_{ijkl} = \mu + B_i + G_j + E_k + F_l + (GE)_{jk} + (GF)_{jl} + (EF)_{kl} + (GEF)_{jkl} + e_{ijkl}$

Where:

Y_{ijk}= performance of genotype j in the k^{th} environment.

μ = grand mean.

B_i= block effect.

G_j= main effect of the j^{th} genotype.

E_k= main effect of the k^{th} year.

$F_{l=}$ main effect of the l^{th} location.

$(GE)_{jk}$, $(GF)_{jl}$, $(EF)_{kl}$, $(GEF)_{jkl}$ = interaction effects.

e_{ijkl} = random error term

Genotype-Environment (GE) interaction for each trait was determined. Significantly different means were separated using Least Significant Difference while traits for which there were significant GE interactions were further analysed using the GGE Biplot and Additive Main Effects and Multiplicative Interaction (AMMI) methods to identify superior genotypes,

ideal genotypes, specifically adapted genotypes as well as ideal location for future testing of the varieties. The genotype and genotype x environment (GGE) biplot analyses were conducted using GGE biplot software (Version 7.0) to assess grain yield stability and identify superior genotypes (Yan *et al*., 2007).

2.5.2 Regression Analysis

Multiple regression analysis was used to estimate the relationship between the grain yields of superior genotype(s) in an ideal environment(s) with some meteorological variables using a non-linear (quadratic) model:

$Y = f(X_1, X_2)$

$\mathbf{Y_t = \beta + \beta_1 X_{1t} + \beta_2 X_{2t} + \beta_{3t} X^2_{1t} + \beta_4 X^2_{2t} + \beta_5 X_{1t} X_{2t} + \ldots\ldots\ldots\ldots + e_{it}}$

Where:

Y = Maize output (kg/ha);

β_1, β_2 ……., β_6 = Coefficient of variables X_1, X_2……, X_6, respectively

X_1 = Total rainfall (mm) during growing season

X_2 = Mean maximum temperature (^{0}C)

X_3= Mean minimum temperature (^{0}C)

X_4= Relative humidity (mmHg)

X_5= Sunshine hours (Hrs)

e_{it} = unexplained variables

2.5.3 Economic Analysis

The data obtained on the cost of farm inputs and revenues from the output of maize were analysed using addition, mean and percentages. Gross margin was used to determine the profitability of the DT maize production. The assumption was that, the farmers are rural dwellers that inherited the farmland and depend only on hoes, cutlasses and hiring of tractor for tillage operations. Those farm tools had negligible depreciation and so were ignored in the computation of costs of production. Gross Margin was obtained by deducting total cost from total revenue. Efficiency of DT maize enterprise was calculated by dividing total cost by total revenue and multiplying by 100. The benefit-cost ratio was obtained by dividing benefit by cost

3.0 RESULTS

3.1 Field performance of early maturing DT OPVs maize genotypes

Results from the combined analyses of variance show significant differences among the levels of all sources of variation except genotypes. The environment accounted for 75.54% of the total mean squares while the principal component (PC) axis 1 and 2 accounted for 8.44% and 5.56%, respectively (Table 4). Grain yield across the environments that exceeded the Nigeria average maize grain yield of 2.09 ton/ha by 100% ranged from 5.30 ton/ha for TZE-W DT Str C_4 to7.17 ton/ha for TZE-Y DT Str C_4. However, there were no significant ($P \geq 0.05$) differences in grain yield among the seven top ranking genotypes (Table 5).

The discriminativeness versus representativeness view of the GGE biplot of environments was used to show the relative performance across test locations (Fig.2). The GGE biplot explained 74.7% of genotype main effects and G x E interaction. The primary (PC1) and secondary (PC2) components explained 51.9 and 22.8% of genotype main effects and G x E interaction, respectively. The small circle is the average-environment axis (AEA), and the arrow pointing to it is used to indicate the direction of the AEA (Setimela *et al.*, 2007). The locations that have shorter vectors are less informative in contrast to those with longer vectors. Therefore, Ballah and Ilorin were the most discriminating locations whereas the most representative locations are those locations with smaller angles with AEA. The most representative locations are Ilorin and Ballah.

The mean versus stability view of GGE biplot shows the relative mean performance and stability of early OPVs (Fig. 3). The double-arrowed line ranks the genotypes according to their mean performance that is it approximates the contribution of each genotype to the main effects of genotypes (G). Similarly, the line with the small circle defined by the average PC1 and PC2 scores across the environment and thus, it expresses the genotype's contribution to GE and represent the genotypic stability (consistent rank across environment) or its instability (in consistent rank

across environment). Yan (2001) defined ideal genotypes to have high project towards the double-arrowed line and near zero projection onto the line with the AEA.

Table 4. AMMI model for grain yield (ton/ha) of early maturing DT OPVs Maize during 2007-2009 growing seasons across different locations in SGS of Nigeria

Source	DF	SS	MS	F value	F pr
Genotypes	13	12908655	992973	1.36	0.2043
Environments	5	68932959	13786592	18.86	<0.001
Interactions	65	47521002	731092		
IPC1	17	26175406	1539730	8.30	<0.001
IPC2	15	15224005	1014934	5.47	<0.001
Residuals	33	6121591	185503		

DF= degree of freedom, SS=sum of square, MS=mean sum of square, F pr = probability level

Table 5. Grain yield (ton/ha) of early maturing DT OPVs Maize during 2007-2009 growing seasons across different locations in SGS of Nigeria

	Environment						
Genotype	**Ballah**	**Ejiba**	**Ilorin**	**Kishi**	**Mokwa**	**Oke-oyi**	**Mean^{ns}**
A	5.77	7.37	8.19	8.91	6.18	5.86	7.05
B	10.76	4.33	8.84	10.04	4.05	4.97	7.17
C	3.04	6.79	6.83	8.42	8.42	5.17	6.57
D	3.04	7.77	5.83	3.57	3.57	11.23	6.23
E	4.15	8.23	3.69	4.69	4.69	5.73	6.32
F	2.86	9.12	5.26	4.56	4.56	4.57	5.30
G	5.77	5.84	6.14	4.02	4.02	3.80	5.90
Mean**	5.07^{c}	7.06^{ab}	6.39^{bc}	8.76^{a}	5.07^{c}	5.91^{bc}	

A= TZE Comp 3 DT CO F3, **B**= TZE- Y DT STR C4, **C**= TZE Comp 3 DT CO F2, **D**= EVDT-Y 2000 STR CO, **E**= TZE Comp 3 DT CO F5, **F**= TZE-W DT STR C4, **G**= TZE Comp 3 DT CO F4

** Significant at the 0.01 probability level; ns = non-significant;
Mean followed by similar letters are not significantly different at the 0.05 probability level based on least significant difference (LSD) test.

Therefore, TZE-Y-DT Str C_4 had the highest and unstable grain mean performance across the environments, TZE-Comp-3-DT-Co F_3 is highly stable with low yielding as compared to the former while TZE-Comp-3-DT-Co F_4 is unstable and low yielding across the environments.

Fig. 4 is a polygon view of GGE biplot showing which early OPVs yielded the most at which environment. The genotypes that were farthest from the biplot origin TZE-Y-DT-Str-C_4, TZE-Comp-3-DT-Co-F_2, TZE-W-DT-Str-C_4 and EVDT-Y-2000-Str-Co formed the corners of the polygon. The line that starts from the biplot origin and perpendicular to the sides of the polygon divided the biplot into six sectors. Out the six sectors, only five have locations within them suggesting possible five different mega-environments exist and these locations are: Ballah, Ilorin, and Kishi constitutes the first mega-environment with TZE-Y-DT-Str-C_4 as the highest mean performed genotype, the second mega-environment is Mokwa with TZE-Comp-3-DT-Co-F_2 as the best yielding and stable genotype while TZE-W-DT-Str-C4 at Eijba and EVDT-Y-2000-Str-Co at Oke-Oyi made up the fourth and fifth mega-environment, respectively.

3.2 Field performance of intermediate/late maturing DT OPVs maize genotypes

Based on the combined analysis of variance, a significant effect of genotype was not observed on the grain yield of intermediate/late OPVs but environment and interaction were highly significant. The environment significantly explained about 87% while the interaction (PC1 and PC2) accounted for 7.68% of the means square (Table 6). There was no significant ($P \geq 0.05$) difference in grain yield among the seven top ranking genotypes while Kishi, Oke-oyi and Ilorin had similar and significantly high mean grain yield across seven locations during 2007-2009 cropping seasons (Table 7).

Similarly, environment significantly explained 91.63% of the mean squares while interaction accounted for 4.93% during 2010-2012 growing seasons (Table 8) while nine top ranking genotypes were similar in grain yield which

ranged from 5.03 to 6.04 ton/ha whereas Mokwa had significantly higher grain yield (7.12 ton/ha) compared to other locations (Table 9).

The discriminativeness versus representativeness view of the GGE biplot (Fig.5) shows that GGE biplot explained 80.1% of genotype main effects and G x E interaction while PC1 and PC2 explained 54.9 and 25.2% of genotype main effects and G x E interaction, respectively. Badeggi, Kishi and Ilorin were the most discriminating locations based on their vector length whereas the most representative locations is Ballah during 2007-2009 seasons (Fig 5A). Fig. 5B shows that Ilorin is the most discriminating and representing location during 2010-2012 seasons across three locations where GGE biplot accounted for 94.4% of genotype main effect and GE interaction.

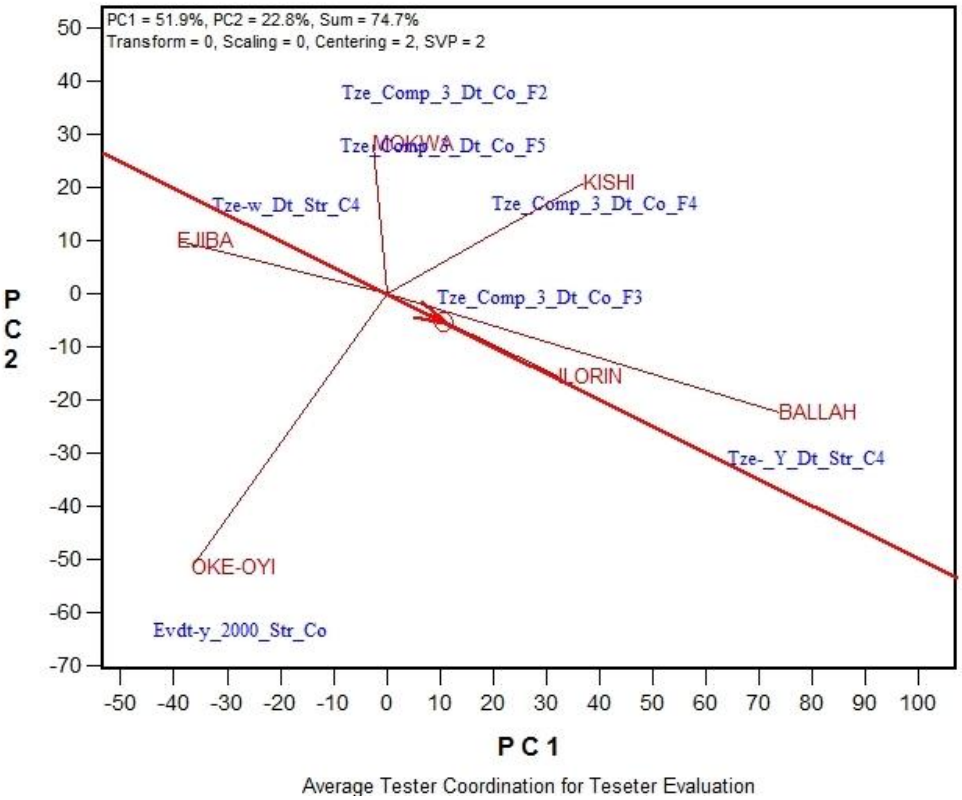


Figure 2. Discriminativeness vs representativeness of test locations across the years for early maturing DT OPVs maize between 2007 and 2009.

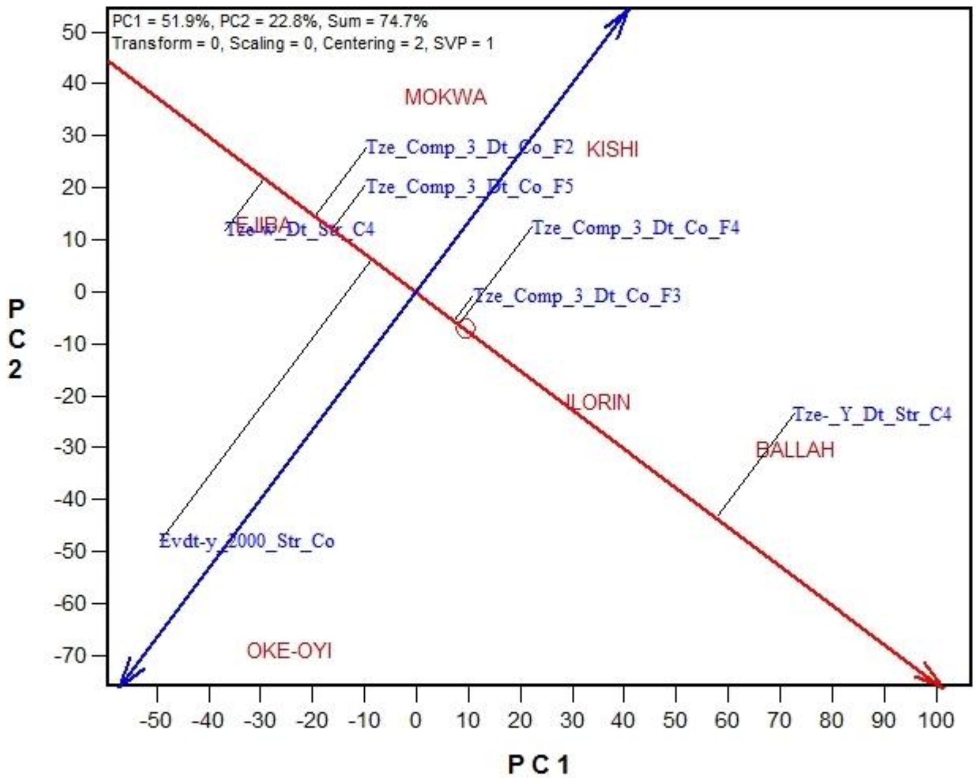


Figure 3. Mean performance and stability for grain yield across years and test locations for early maturing DT OPVs maize between 2007 and 2009.

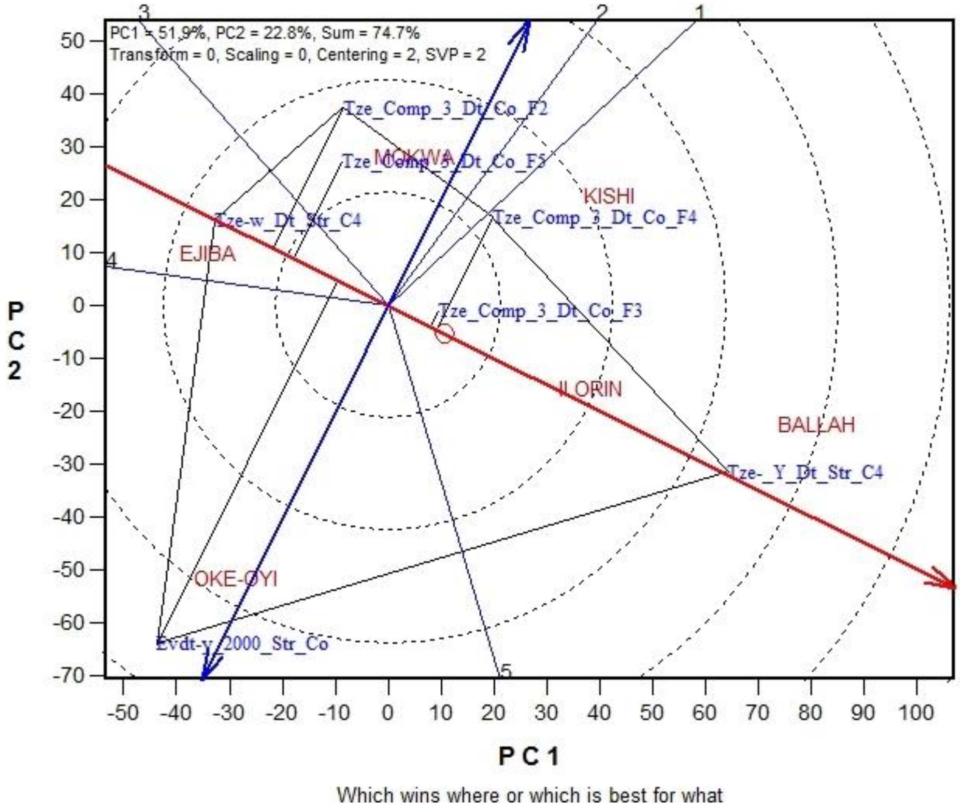


Figure 4. The polygon view of GGE biplot, showing which maize early OPVs won in which locations

Table 6. AMMI model Grain yield (ton/ha) of intermediate/late maturing DT OPVs Maize during 2007-2009 growing seasons across different locations in SGS of Nigeria

Source	DF	SS	MS	F value	F pr
Genotypes	7	1421720	203103	0.76	0.6262
Environments	6	58021594	9670266	36.02	<0.001
Interactions	42	11274973	268452		
IPC1	12	5534087	461174	5.04	<0.001
IPC2	20	3909172	390917	4.27	<0.0028
Residuals	20	1831714	91586		

DF= degree of freedom, SS=sum of square, MS=mean sum of square, F pr = probability level

Table 7. Grain yield (ton/ha) of intermediate/late maturing DT OPVs Maize during 2007-2009 growing seasons across different locations in SGS of Nigeria

	Environment							
Genotype	**Ballah**	**Badeggi**	**Ejiba**	**Ilorin**	**Kishi**	**Mokwa**	**Oke-oyi**	**Mean^{ns}**
A	5.28	2.41	4.17	7.79	9.36	3.63	7.07	5.67
B	6.19	1.94	3.99	6.93	6.46	3.73	7.09	5.19
C	5.88	1.74	3.71	7.04	6.29	2.21	7.02	4.84
D	2.87	1.17	4.17	5.55	8.52	2.99	7.38	4.66
E	2.67	2.18	3.77	9.52	8.62	2.56	7.47	5.25
F	6.09	2.61	3.73	5.77	7.47	3.54	6.59	5.12
G	5.81	2.45	4.26	7.60	7.92	2.91	7.68	5.52
Mean**	4.97^{b}	2.07^{d}	3.97^{bc}	7.17^{a}	7.80^{a}	3.08^{cd}	7.19^{a}	

A= DT-SR-W CO F2, **B**= DT-SYN-1-W, **C**= SUWAN-1-SR-SYN,
D= TZB-SR, **E**= TZL COMP 1-W- C6 F2, **F**= TZUTSY-W-STR-SYN,
G= White DT STR SYN

** Significant at the 0.01 probability level; ns = non-significant;
Mean followed by similar letters are not significantly different at the 0.05 probability level based on least significant difference (LSD) test.

Table 8. AMMI model Grain yield (ton/ha) of intermediate/late maturing DT OPVs Maize during 2010-2012 growing seasons across different locations in SGS of Nigeria

Source	**DF**	**SS**	**MSs**	**F value**	**F pr**
Genotypes	14	4150147	296439	0.64	0.8197
Environments	5	130498115	26099623	56.62	<0.001
Interactions	70	32269232	460989		
IPC1	18	16477366	915409	4.15	<0.001
IPC2	16	7849529	490596	2.22	<0.0232
Residuals	36	7942338	220621		

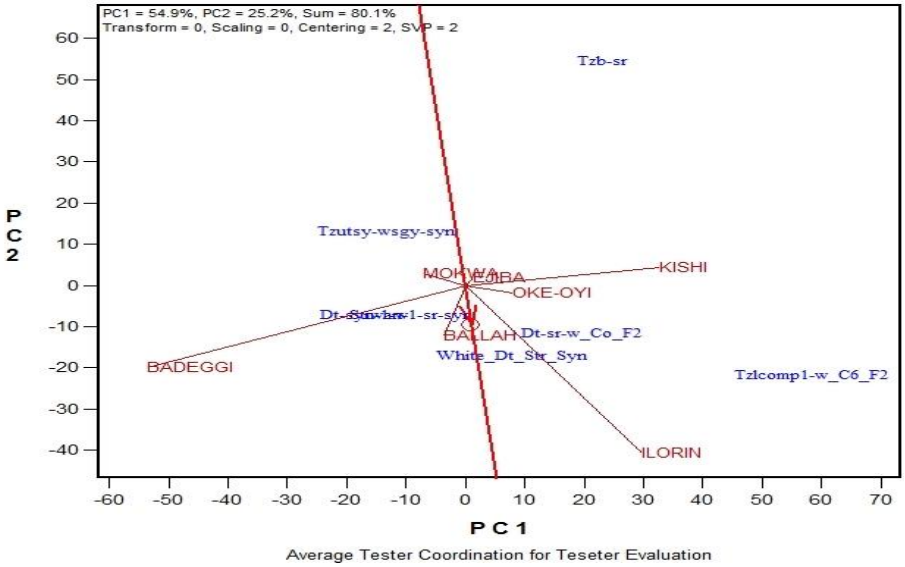
DF= degree of freedom, SS=sum of square, MS=mean sum of square, F pr = probability level

Table 9. Grain yield (ton/ha) of intermediate/late maturing DT OPVs Maize during 2010-2012 growing seasons across different locations in SGS of Nigeria

	Environment			
Genotype	**Badeggi**	**Ilorin**	**Mokwa**	**Mean^{ns}**
DT-STR-Y-SYN2	3.34	4.79	6.95	5.03
IWD C3 SYN F2	3.84	5.62	6.17	5.21
TZL COMP3 C3 DT	3.43	4.69	8.15	5.42
IWD C3 SYN/DT-SYN-1-W	3.74	6.03	6.63	5.47
(White DT STR SYN/IWD C3 SYN)F2	4.27	5.18	6.95	5.47
DT-STR-W C2	3.09	6.79	6.53	5.47
DT-STR-W SYN C2	2.97	6.76	6.82	5.52
(White DT STR SYN/TZL COMP1-W)F2	3.74	5.47	7.76	5.65
TZL COMP4 C3 DT	4.54	5.49	8.09	6.04
Mean**	3.66^{c}	5.65^{b}	7.12^{a}	

** Significant at the 0.01 probability level; ns = non-significant;
Mean followed by similar letters are not significantly different at the 0.05 probability level based on least significant difference (LSD) test.

A.



B

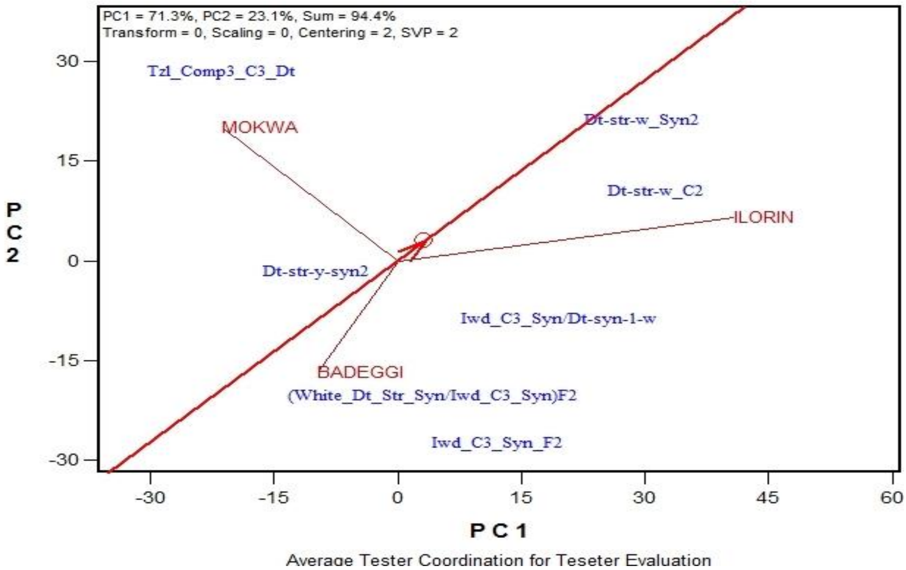
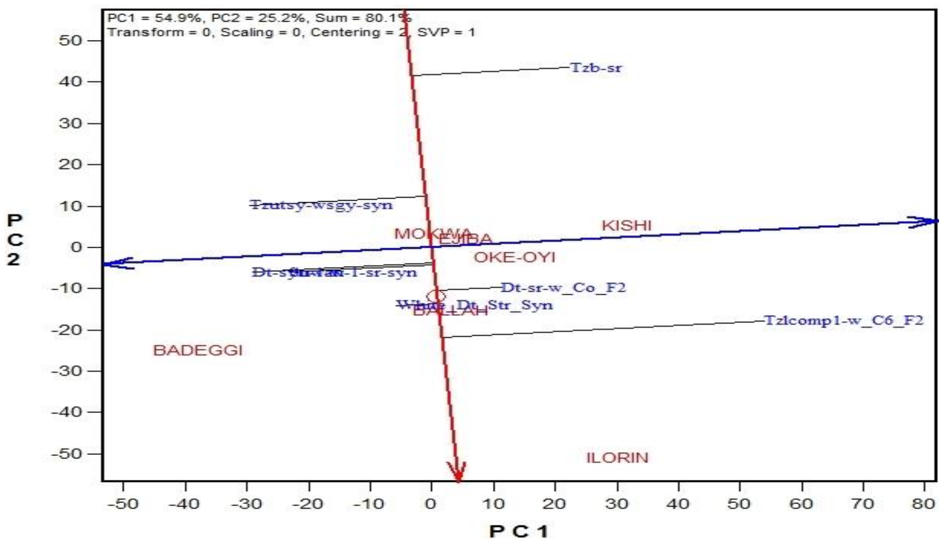


Figure 5. Discriminativeness vs representativeness of test locations across the years for intermediate/late OPVs between 2007-2009 (A) and 2010-2012(B)

The mean performance and stability across locations in 2007-2009 seasons (Fig. 6A) shows that TZl-comp 1-W C_6-F 2 is high yielding but unstable genotypes while DT-Sr-W-Co_F_2 and White-DT-Str-Syn are the most stable and high yielding genotypes. The 2010-2012 evaluation showed that DT-Str-W-Syn 2 and DT-Sr-W-C_2 are high yielding but less stable. Genotype White-DT-Str-Syn/IWD-C_3-syn F_2 is the most stable but the low yielding.

Fig. 7A had five sectors but only three have locations within them suggesting possible three different mega-environments exist and these locations are: Ejiba, Oke-oyi, Ilorin and Kishi constitute the first mega-environment with TZI-comp-1-W-C_6 F_2 as the highest mean performed genotype while Dt-Sr-W-C_6-F_2 is the most stable, the second mega-environment is Ballah with White-DT-Str-Syn as the best yielding and stable genotype while the last mega-environment consisted of Mokwa and Badeggi with Suwan-1-Sr-Syn and TZU-TSY-W-Str-Syn as the best yielding genotypes. A genotype or environment that is located at the center of the circle or closest to the hypothetical is considered a superior genotype or ideal environment with high grain yield and good yield stability (Shiri, 2013). Therefore, Ejiba is the most ideal environment while Mokwa and Oke-oyi are the closest while White-DT-Str-Syn and Dt-Sr-W-C_6-F_2 are most stable and high yielding genotypes across locations. Similarly, Fig. 7B had five sectors divided into three mega-environments with each location as a mega-environment. Badeggi is the ideal test environment while DT-Str-Y-Syn2 and IWD-C_3-Syn/DT-Syn-1-W are the ideal genotypes.

A



B

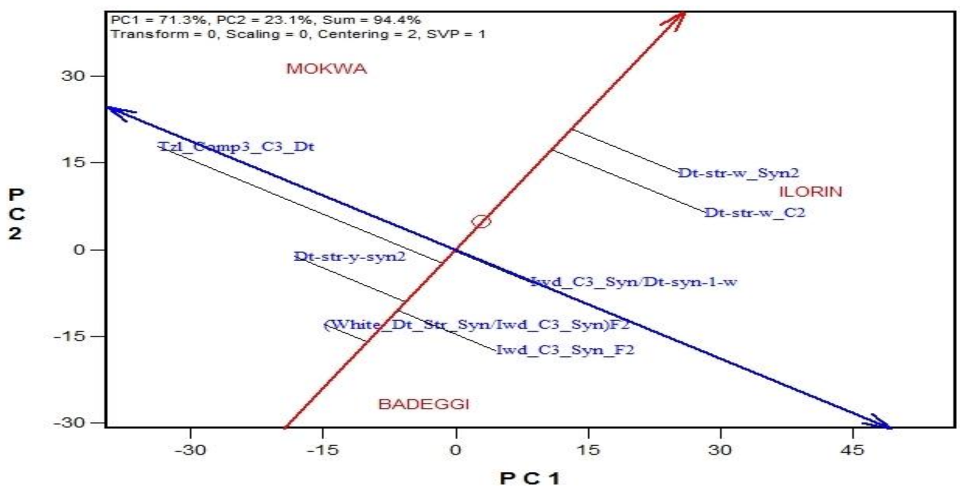
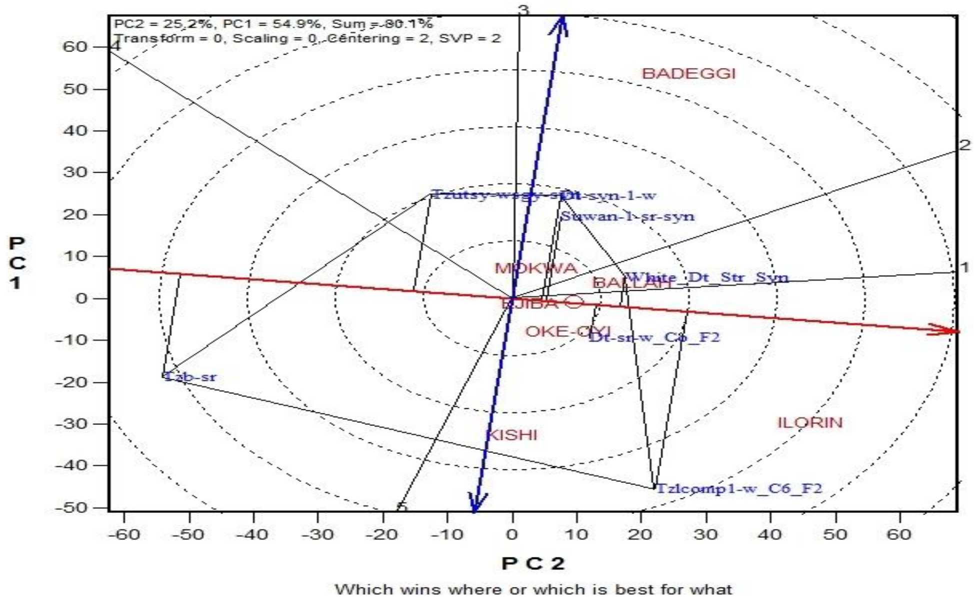


Figure 6. Mean performance and stability across years and location for grain yield of intermediate/late OPVs between 2007-2009 (A) and 2010-2012(B).

A



B

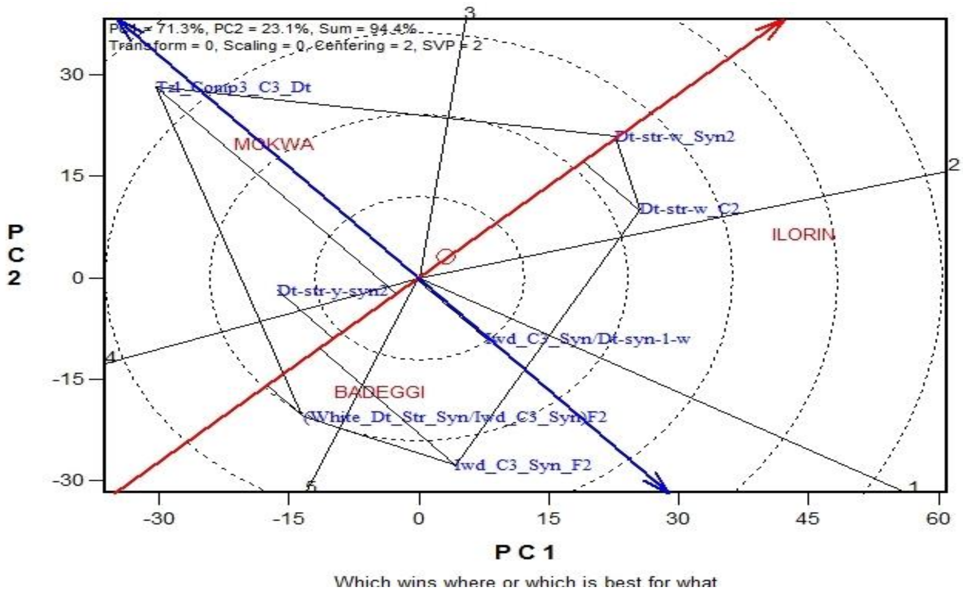


Figure 7. The polygon view of GGE biplot showing which OPVs won in which location for intermediate/late DT OPVs maize between 2007-2009 (A) and 2010-2012(B).

3.3 Field performance of early maturing DT maize hybrid

The combined analysis of variance (Table 10) showed differences statistically significant (ρ≥0.05)) among environments and GE interaction during the 2009-2011 trials. Based on the relative contribution of mean squares, the environment effect had the highest contribution of 94.38%, followed by PC1 and PC2, 3.12% and 0.79%, respectively. The mean grain yield of the three top ranking genotypes across the environments was significant (ρ≥0.05) while no significant difference was observed across the genotypes. The mean grain ranged from 8.34 ton/ha to 10.98 ton/ha across the hybrids and from 2.79 to 15.78 ton/ha across locations (Table 11).

The 2012-2014 early maturing DT hybrid trials followed similar trend as in 2009-2011 seasons. The environment accounted for 82.31% and GE interaction had 11.06% of the total mean square (Table 12). The mean grain yield of the five top ranking genotypes ranged from 9.23-9.61 ton/ha while Mokwa in 2012 had significantly high mean grain yield of 12.66 ton/ha and statistically low mean grain yield (3.69 ton/ha) was recorded at Ilorin in 2013 (Table 13).

The discriminativeness versus representativeness of test location is shown in Fig. 8. The PC1 and PC2 explained 100% of the GGE during the 2009-2011 trials (Fig 7 A) and Ilorin is the most discriminating and representative location. In 2012-2014 trials, 87.3% was the sum contribution of PC1 and PC2 to GGE effects, Mokwa in 2012 was the most discriminating location due to the length of the vector while Ilorin across the years was the most representative location (Fig.8B). Ilorin is therefore, the most discriminating and representative location for early DT hybrid.

In 2009-2011, no genotype was identified which had high grain yield and stability in performance but TZE-Y-Pop-DT-Str-C_4 x TZEI 11 was close to ideal while in 2012-2014, hybrid 2012 TZE-Y-DT-C_4 Str-C_5 was the ideal genotype and TZE-W-Pop-DT-C_4-Str-C_5 was close to the ideal (Fig. 9).

Fig.10A shows two mega-environments in 2009-2011 trials which includes: Badeggi, Ejiba and Ilorin as a mega-environment with TZE-Y-Pop-DT-Str-C_4 x TZEI 11 as the best performing hybrid and Mokwa as the second mega-environment and TZEI-24 x TZEI-17 as the best yielding hybrid. The 2012-2014 genotype evaluation was divided into five mega-environments and each with the best performing hybrid (Fig. 10B).

3.4 Field performance of extra early maturing DT maize hybrid

The combined analysis of variance for the extra early maturing hybrid trials evaluated during 2009 and 2010 growing seasons showed significant differences ($\rho \geq 0.05$)) among environments and GE interaction except genotypes. The environment accounted for 94.33% of the GE effects while PC1 and PC2 contributed 3.17% and 0.79%, respectively (Table 14). The mean grain yield of the eight top ranking genotypes across the environments was significant ($\rho \geq 0.05$) while no significant difference was observed across the genotypes. The mean grain ranged from 9.06 ton/ha to 10.48 ton/ha across the hybrids and from 6.57 to 16.78 ton/ha across locations (Table 15).

Similarly, the 2011 - 2012 trials followed the same trend as in 2009-2010 seasons. The environment accounted for 90.59% and GE interaction had 5.57% of the total mean square (Table 16). The mean grain yield of the seven top ranking genotypes ranged from 9.21-11.76 ton/ha while Kishi had significantly high mean grain yield of 14.27 ton/ha and statistically low mean grain yield (5.74 ton/ha) was recorded at Mokwa (Table 17).

Fig. 11 shows that Kishi is the most discriminating and representative in both trials. Ballah is close to Kishi during the 2009-2010 growing seasons. Hybrid TZEEI-W-Pop-Str-C_5 x TZEEI 14 is the highest yielding genotype but unstable while TZEEI -3 x TZEEI 46 is the most stable and high yielding genotype (Fig. 11A). Similarly, in 2011-2012, (TZEEI 4 x TZEEI 14) x (TZEEI 29 x TZEEI 49) is high yielding hybrid but unstable. About three hybrids genotypes are stable but low yielding genotypes (Fig. 12B)

The polygons that view who won where, shows that, Ballah and Kishi are ideals environments while TZEEI -3 x TZEEI 46 and TZEEI-W-Pop-Str-C_5 x TZEEI 14 are the ideal genotypes (Fig. 12A). The 2011-2012 growing

seasons, Kishi and hybrid (TZEEI 4 x TZEEI 14) x (TZEEI 29 x TZEEI 49) were the ideal environment and genotype, respectively.

Table 10. AMMI model for grain yield (ton/ha) of early maturing DT maize hybrids during 2009-2011 growing seasons across different locations in SGS of Nigeria

Source	DF	SS	MS	F value	F pr
Genotypes	21	9094535	433073	0.64	0.8841
Environments	6	423472280	70578713	103.82	<0.001
Interactions	126	85658723	679831		
IPC1	26	61565692	2367911	18.35	<0.001
IPC2	24	14284629	595193	4.61	<0.001
Residuals	76	9808401	129058		

DF= degree of freedom, SS=sum of square, MS=mean sum of square, F pr = probability level

Table 11. Grain yield (ton/ha) of early maturing DT maize hybrids during 2009-2011 growing seasons across different locations in SGS of Nigeria

	Environment				
Genotype	**Badeggi**	**Ejiba**	**Ilorin**	**Mokwa**	**Mean^{ns}**
TZE-Y Pop DT STR C4 x TZEI 11	14.31	8.74	19.59	13.06	10.98
TZEI 24 x TZEI 17	11.12	5.07	14.94	4.54	8.92
TZEI 8 x TZEI 17	11.99	6.01	12.82	2.53	8.34
Mean**	12.47^{a}	6.60^{b}	15.78^{a}	2.79^{b}	

** Significant at the 0.01 probability level; ns = non-significant;
Mean followed by similar letters are not significantly different at the 0.05 probability level based on least significant difference (LSD) test.

Table 12. AMMI model for grain yield (ton/ha) of early maturing DT hybrid Maize during 2012-2014 growing seasons across different locations in SGS of Nigeria

Source	DF	SS	MS	F value	2 F pr
Genotypes	26	100173654	3852833	0.74	0.8116
Environments	5	679043964	135808793	26.10	<0.001
Interactions	130	676341749	5202629		
IPC1	30	449073658	14969122	7.96	<0.001
IPC2	28	91820780	3279314		<0.031
Residuals	72	135447312	1881213		

DF= degree of freedom, SS=sum of square, MS=mean sum of square, F pr = probability level

Table 13. Grain yield (ton/ha) of early maturing DT hybrid Maize during 2012-2014 growing seasons across different locations in SGS, Nigeria

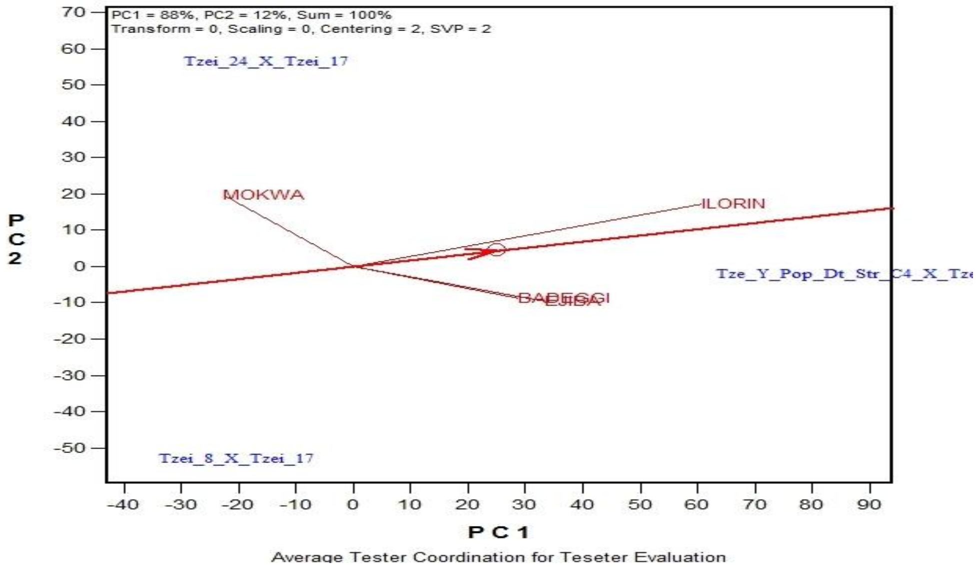
	Environment						
Genotype	**Ilorin 2012**	**Ilorin 2013**	**Ilorin 2014**	**Mokwa 2012**	**Mokwa 2013**	**Mokwa 2014**	**Mean^{ns}**
A	11.38	3.48	10.21	14.60	8.59	9.37	9.61
B	10.58	3.38	7.89	10.95	10.01	12.79	9.27
C	9.93	3.56	8.68	14.60	8.19	10.53	9.25
D	9.72	4.00	9.00	13.39	10.31	9.05	9.25
E	11.28	4.05	9.05	9.74	9.50	11.79	9.23
Mean**	10.58^{b}	3.69^{d}	8.97^{c}	12.66^{a}	9.32^{bc}	10.71^{b}	

A= TZE-W POP DT C4 STR C5; **B**= DT -W STR Synthetic; **C**= DTE STR-Y Syn Pop C2; **D**=2012 TZE-Y DT C4 STR C5; **E**= DTE STR-W Syn Pop C2

** Significant at the 0.01 probability level; ns = non-significant;

Mean followed by similar letters are not significantly different at the 0.05 probability level based on least significant difference (LSD) test.

A.



B

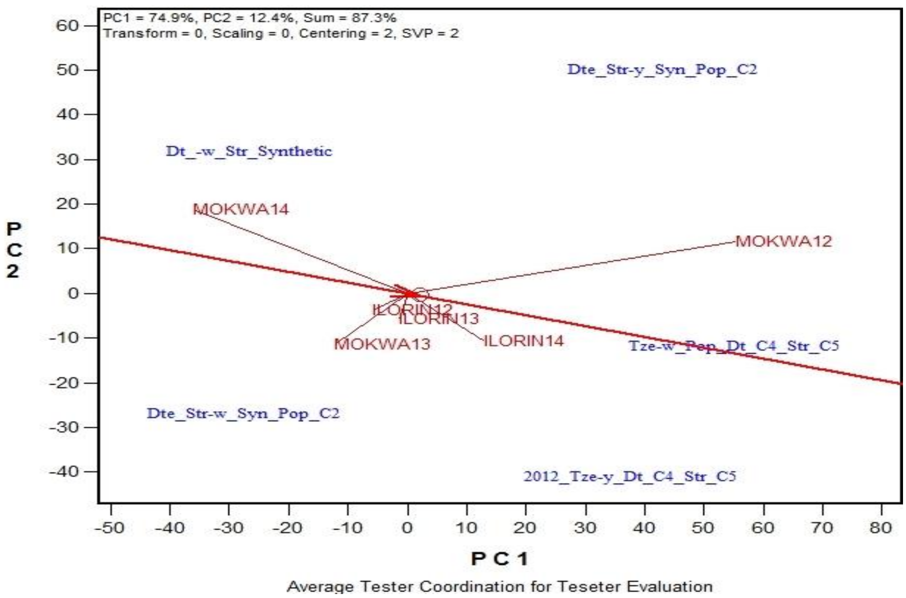
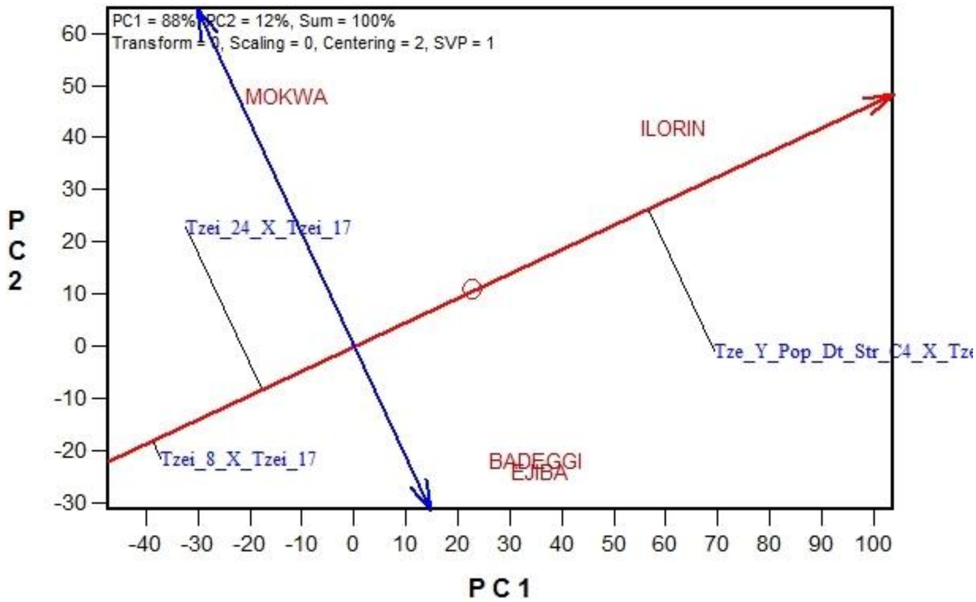


Figure 8. Discriminativeness vs representativeness of test locations across the years for early maturing DT hybrids between 2009-2011 (A) and 2012-2014(B).

A



B

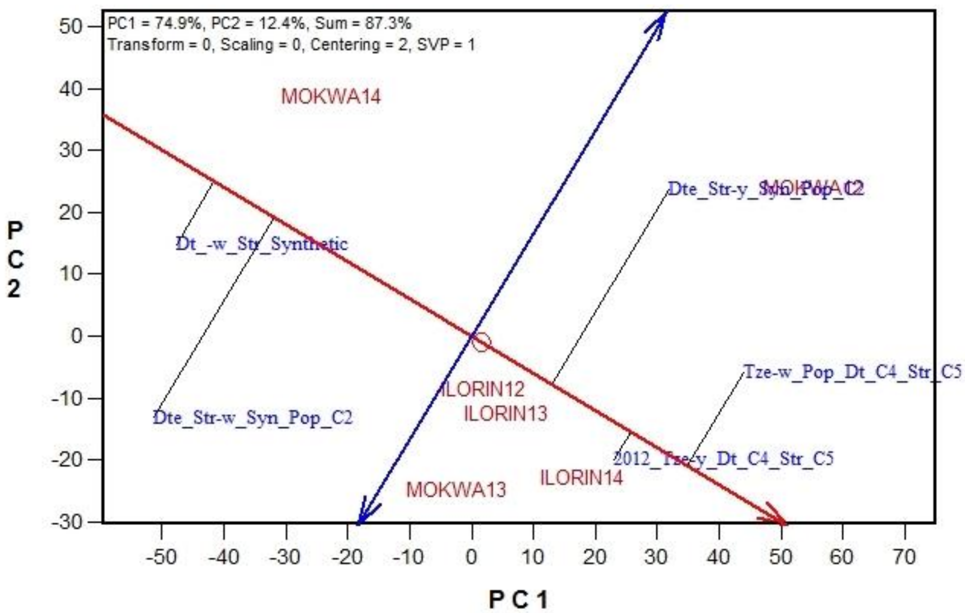
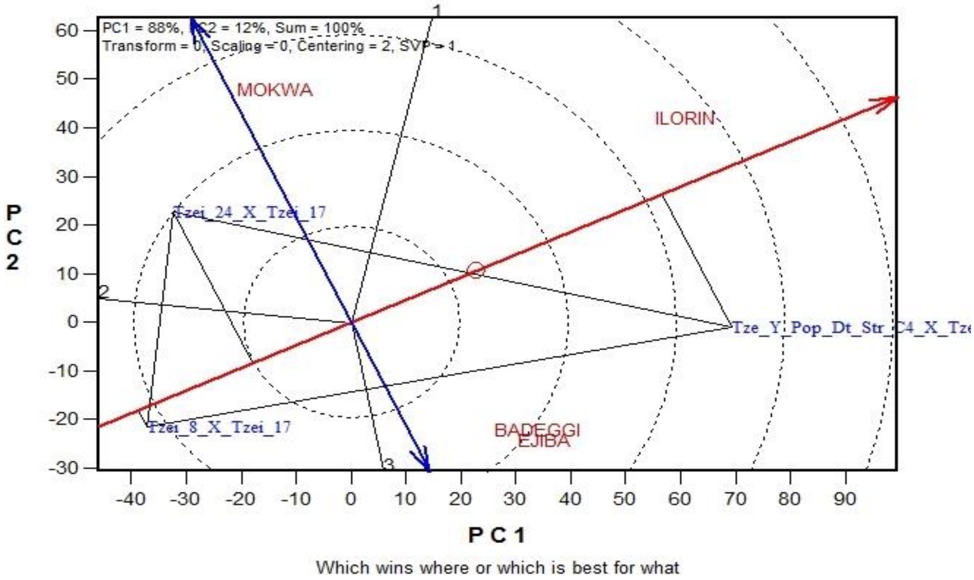


Figure 9. Mean performance, stability for grain yield across years and locations for early maturing DT hybrids between 2009-2011 (A) and 2012-2014(B)

A



B

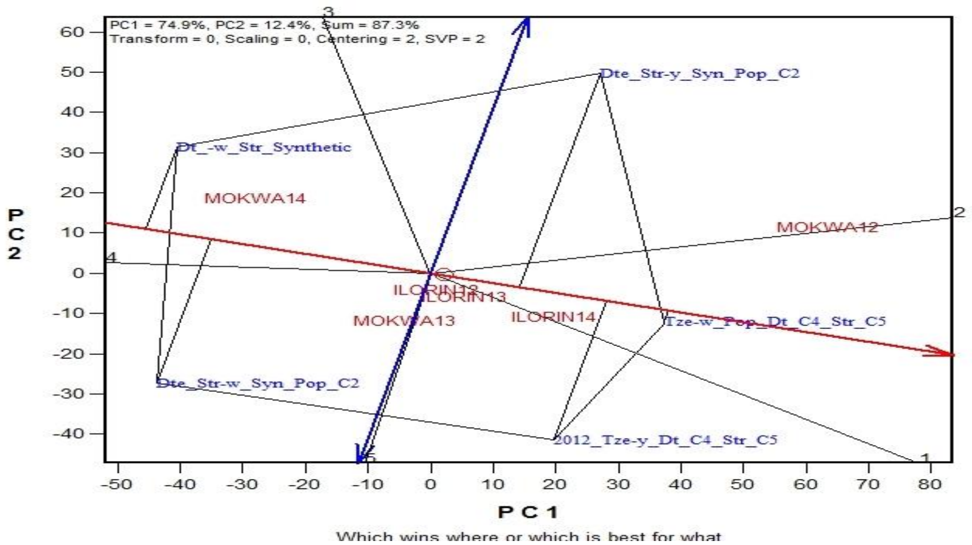


Figure 10. The polygon view of GGE biplot showing which OPVs won in which locations for early maturing DT hybrids between 2009-2011 (A) and 2012-2014(B).

Table 14. AMMI model for grain yield (ton/ha) of extra early white DT maize hybrids during 2009 and 2010 growing seasons across different locations in SGS, Nigeria

Source	DF	SS	MS	F. Value	F pr.
Genotypes	21	9094535	433073	0.64	0.8841
Environments	6	423472280	70578713	103.82	<0.001
Interactions	126	85658723	679831		
IPC1	26	61565692	2367911	18.35	<0.001
IPC2	24	14284629	595193	4.61	<0.001
Residuals	76	9808401	129058		

DF= degree of freedom, SS=sum of square, MS=mean sum of square, F pr = probability level.

Table 15. Grain yield (ton/ha) of extra early white DT maize hybrids during 2009 and 2010 growing seasons across different locations in SGS, Nigeria

	Environment				
Genotype	**Ballah**	**Ilorin**	**Kishi**	**Mokwa**	**Mean^{ns}**
A	9.11	7.89	19.16	5.77	10.48
B	8.55	8.46	16.48	6.07	9.89
C	7.58	5.84	16.74	9.09	9.81
D	8.88	6.35	18.09	5.88	9.79
E	8.74	3.49	17.27	8.61	9.53
F	7.68	5.86	14.29	9.37	9.30
G	6.89	8.88	16.59	4.72	9.27
H	8.66	5.78	15.58	6.32	9.06
Mean**	8.25^{b}	6.57^{b}	16.78^{a}	6.98^{b}	

A= TZEE-W Pop STR C5 x TZEEI 14, **B**= (TZEEI 29 x TZEEI 21) x (TZEEI 14 x TZEEI 37), **C**= (TZEEI 21 X TZEEI 14) X TZEEI 29, **D**= TZEEI 3 x TZEEI 46, **E**= TZEEI 29 x TZEEI 21, **F**= (TZEEI 29 x TZEEI 21) x TZEEI 55, **G**= (TZEEI 29 x TZEEI 37) x TZEEI 13, **H**= TZEE-W Pop STR C5 x TZEEI 46

** Significant at the 0.01 probability level; ns = non-significant;
Mean followed by similar letters are not significantly different at the 0.05 probability level based on least significant difference (LSD) test.

Table 16. AMMI model Grain yield (ton/ha) of extra early white DT hybrid Maize during 2011-2012 growing seasons across different locations in SGS, Nigeria

Source	DF	SS	MS	F value	F pr
Genotypes	27	18295916	677627	1.16	0.2748
Environments	7	257311129	36758733	63.06	<0.001
Interactions	189	110166153	582890		
IPC1	33	44542286	1349766	4.51	<0.001
IPC2	31	28202690	909764	3.04	<0.001
Residuals	125	37421176	299369		

DF= degree of freedom, SS=sum of square, MS=mean sum of square, F pr = probability level

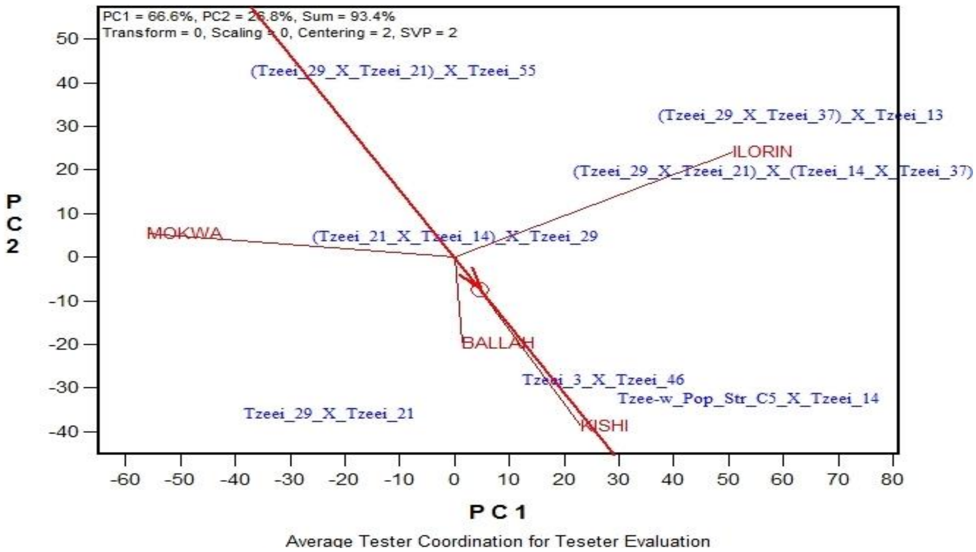
Table 17. Grain yield (ton/ha) of extra early white DT maize hybrids during 2011 and 2012 growing seasons across different locations in SGS, Nigeria

	Environment				
Genotype	**Ballah**	**Ilorin**	**Kishi**	**Mokwa**	**Mean^{ns}**
A	10.17	7.81	23.71	5.33	11.76
B	9.83	11.25	11.24	6.15	9.92
C	11.29	7.21	14.57	5.25	9.58
D	10.92	7.18	13.19	6.74	9.51
E	12.88	7.88	12.12	4.31	9.29
F	9.96	8.11	11.85	7.21	9.29
G	10.21	8.21	13.23	5.20	9.21
Mean**	10.75^{b}	8.24^{b}	14.27^{a}	5.74^{bc}	

A= (TZEEI 4 x TZEEI 14) x (TZEEI 29 X TZEEI 49), **B**= (TZEEI W Pop STR C5 x TZEEI 29, **C**= TZEE-W Pop STR C5 x TZEEI 14, **D**= (TZEEI 29 x TZEEI 21) x (TZEEI 14 x TZEEI 37), **E**= TZEE -W Pop STR C5 x TZEEI 14, **F**= TZEEI 4 x TZEEI 49) x TZEEI 29, **G**= TZEEI 29 x TZEEI 21) x (TZEEI 4 x TZEEI 14)

** Significant at the 0.01 probability level; ns = non-significant;
Mean followed by similar letters are not significantly different at the 0.05 probability level based on least significant difference (LSD) test.

A



B

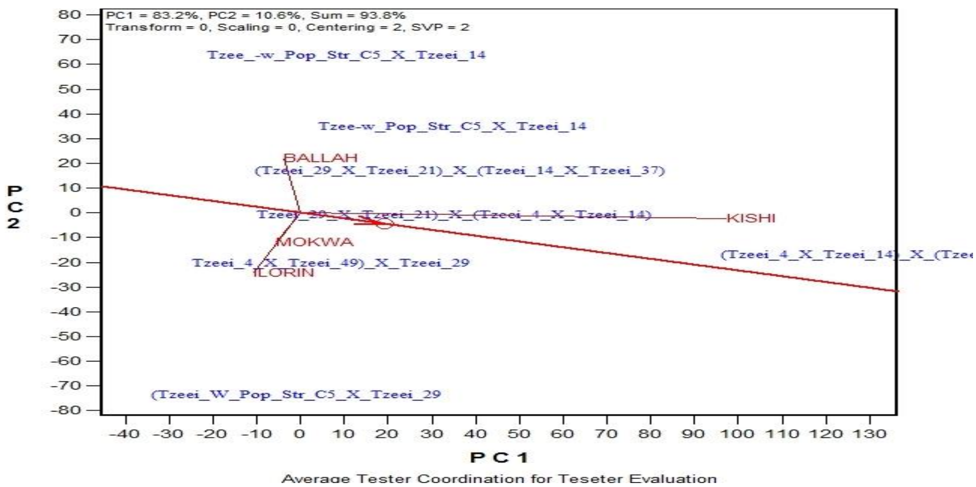
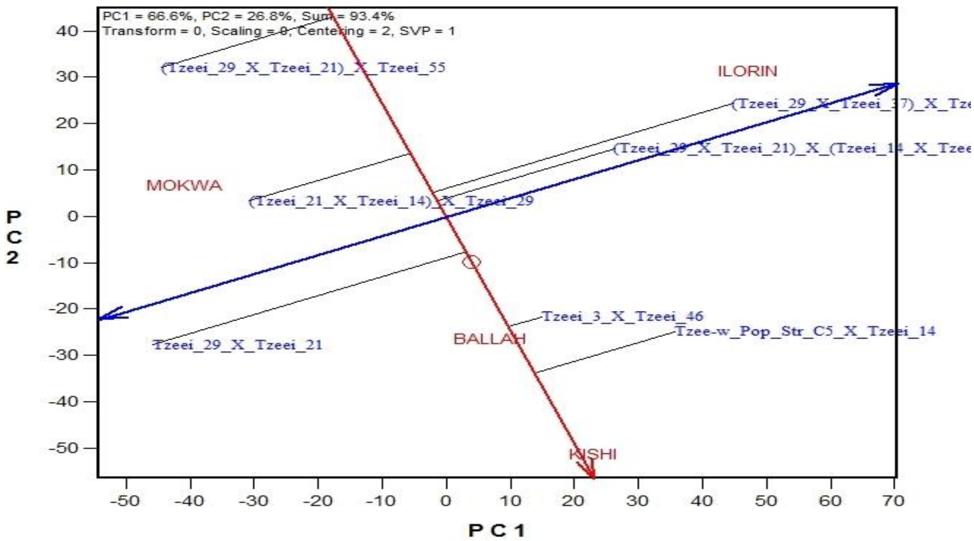


Figure 11. Discriminativeness vs representativeness of test locations across the years for extra early white DT hybrid maize between 2009-2010 (A) and 2011-2012(B).

A



B

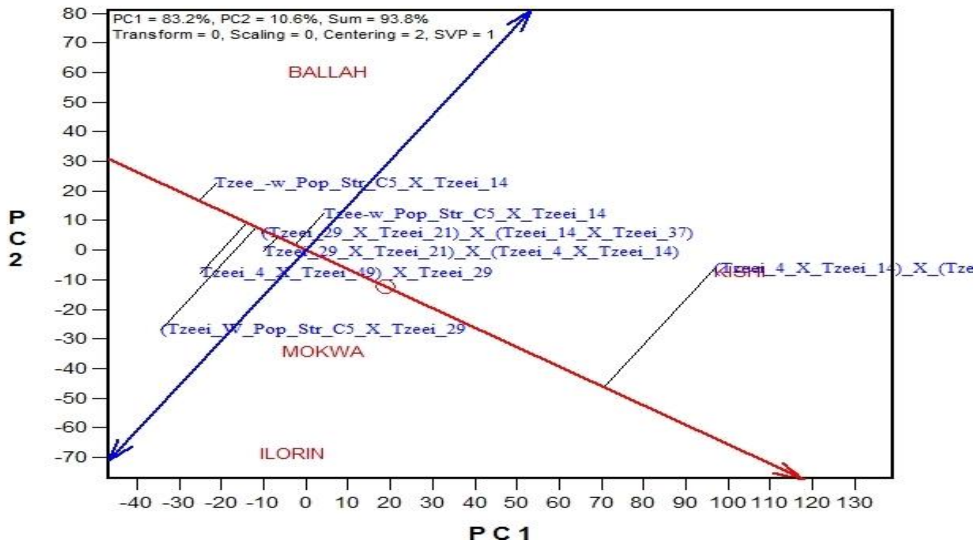
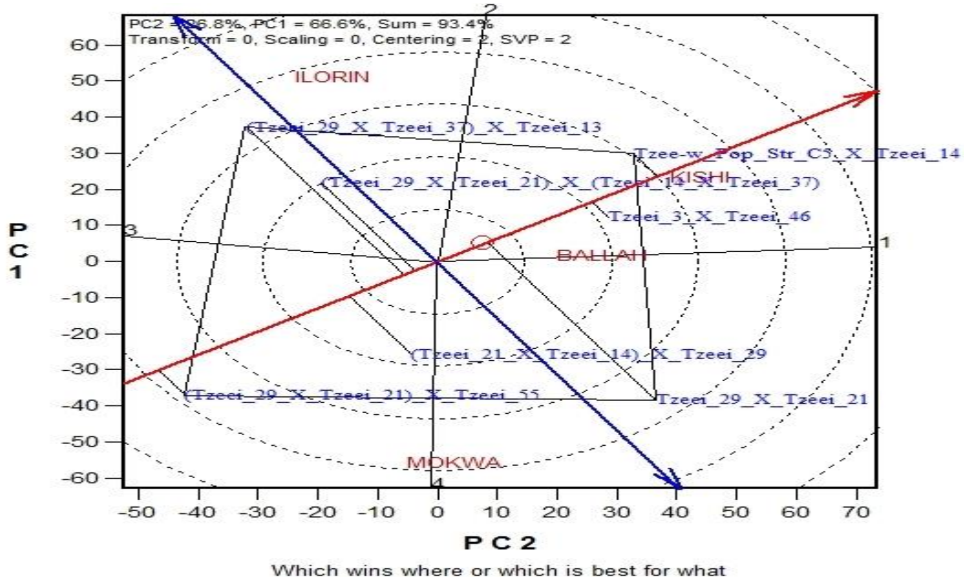


Figure 12. Mean performance, stability for grain yield across years and locations for extra early white DT hybrid maize between 2009-2010 (A) and 2011-2012(B).

A



B

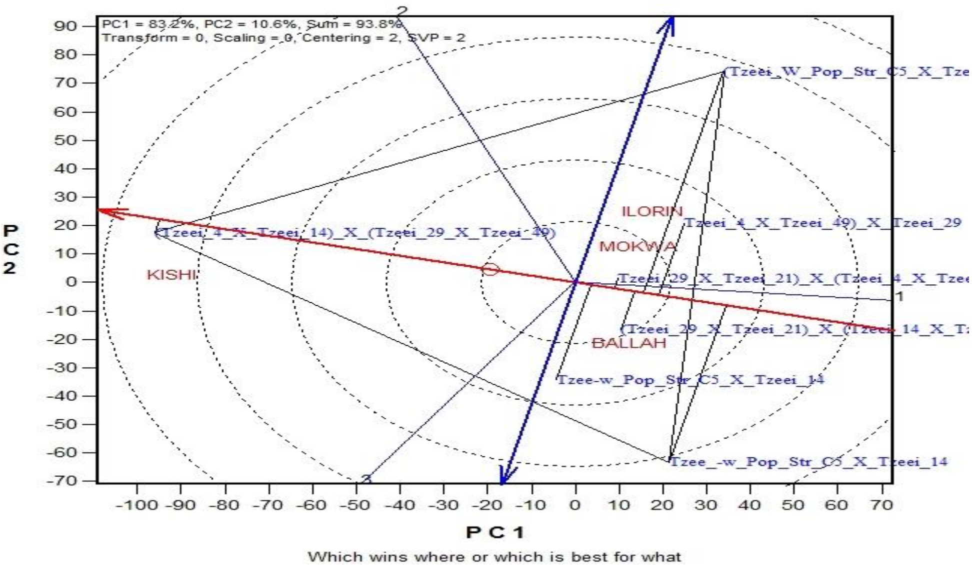


Figure 13. The polygon view of GGE biplot showing which OPVs won in which location for extra early white DT hybrid maize between 2009-2010 (A) and 2011-2012(B).

3.5 Impact of environmental changes on grain yield of DT maize in SGS, Nigeria

The estimation result from Table 18 reveals that the explanatory variables jointly account for approximately 98% changes in DT maize production. The remaining 2% due to other variables outside the regression model that also affect DT maize yield. The Durbin-Watson statistics illustrate (2.268) absence of auto-correlation and coincidentally, the goodness of fit for the regression remained low as indicated by the adjusted R^2 of 91.9%.

The result also shows that rainfall, maximum daily atmospheric temperature and the squared of rainfall, maximum temperature, relative humidity and sunshine hours were statistically significant in explaining changes in DT maize production as a result of environmental changes. The first-order variables showed rainfall and maximum temperature had positive and negative impact, respectively on grain yield of maize while the significant variables as shown by the non-linear (quadratic) model impacted positively on grain yield except squared maximum temperature and squared relative humidity.

Table 19 indicates that 64% effects of variability in rainfall and grain yield of DT maize can be largely explained by the factors estimated. The total annual rainfall and actual rainy days per annum could significantly explain the effect of rainfall variability in DT maize production and these factors had positive impact on grain yield. Although, amount of rainfall and number of rainy days during maize growing season were not significant but had negative influence on grain yield. The implications of the above is that, a unit increase in amount of annual rainfall and annual rainy days will increase the DT maize grain yield by 18% and 80% respectively, while increase in amount rainfall during growing season DT maize will decrease the yield by 23%, similar increase in DT growing season rainfall and rainy days will decrease DT maize grain yield by 1.4% and 31%, respectively.

Table 18. Regression result for effect of environmental changes on DT maize grain yield in SGS, Nigeria

Variable	Coefficient	Std. Error	t-stat	ρ≤0.05	95% Confidence Limit Lower	Upper	Correlation
Intercept	5625402.115	1020795.703	5.511	0.117	2376774.61	8874029.67	
Rainfall (RF)	32.310	5.980	5.403	0.012	13.25	51.34	-0.12448
Maximum Temperature (Tmax)	-314818.621	49657.868	-6.339	0.007	-472852.13	-156785.13	0.254658
Minimum Temperature (Tmin)	-508.978	2573.937	-0.198	0.856	-8700.30	7682.41	-0.18418
Relative Humidity (RH)	6492.651	7067.455	0.919	0.426	-15999.13	28984.40	0.361598
Sunshine Hours (SH)	-32473.435	29466.250	-1.102	0.350	-126248.11	61301.32	-0.15785
Squared Rainfall	0.019	0.003	-5.072	0.014	-0.03	-0.01	-0.18541
Squared Max. Temperature	-4263.290	673.424	6.330	0.007	2120.15	6406.42	0.250855
Squared Min. Temperature	-2.389	45.232	0.052	0.961	-141.55	146.33	-0.16724
Squared Relative Humidity	-38.080	42.457	-0.896	0.035	-173.19	97.03	0.341709
Squared Sunshine Hours	2849.590	2351.621	1.211	0.012	-4634.31	10333.49	-0.15503
RF x Tmax	10.323	7.061	1.461	0.203	-7.82	28.47	-0.02983
RF x Tmin	-4.084	3.489	-1.170	0.294	-13.05	4.88	-0.19305
RF x RH	-1.894	1.238	-1.529	0.186	-5.07	1.28	0.103065
RF x SH	-20.636	18.792	-1.098	0.322	-68.94	27.67	-0.19657
Tmax x Tmin	94.979	83.986	1.130	0.309	-120.91	310.87	-0.04749
Tmax x RH	-61.275	45.912	-1.334	0.239	-179.29	56.74	0.443742
Tmax x SH	-962.746	610.690	-1.576	0.175	-2532.57	607.08	-0.02995
RH x SH	620.067	383.907	1.615	0.167	-366.79	1606.93	0.125729

R=0.991, R^2 =0.981, Adj. R^2 = 0.919, SE= 492.799, Dustin-Watson= 2.268

Table 19. Regression result for effect of rainfall on DT maize grain yield in SGS, Nigeria

Variable	Coefficient	Std. Error	t-Stat	P≤0.05	*Confidence Limit* Lower 95%	Upper 95%	Correlation
Intercept	10026.167	10485.614	0.956	0.439	-35089.787	5514.121	
ARF	17.958	75.709	0.237	0.035	-307.792	343.707	-0.622
GSRF	-23.302	76.191	-0.306	0.789	-351.125	304.520	-0.631
DTGSRF	-1.357	14.628	-0.093	0.935	-64.298	61.584	-0.323
ARD	80.135	83.232	0.963	0.037	-277.984	438.254	-0.014
GSRD	-310.366	214.258	-1.449	0.284	-1232.243	611.512	0.096

R =0.803, R^2 = 0.644, Adj. R^2 = 0.110, SE = 1151.975, Durbin-Watson= 1.865

ARF=annual rainfall, GSRF=amount of rainfall during growing season, DTGSRF=amount of rainfall during DT growing period, ARD= actual rainy days, GSRD=rainy days during growing season

3.6 The economic impact of DT maize production in SGS, Nigeria

Table 20 shows the economic estimate based on the DT maize sole cropping and the result indicates that, the total production cost for OPVs is ₦122,000 (about US$ 613) per hectare while producing hybrids is about ₦500.00 higher than the estimation for OPVs.

The profit per hectare for OPVs ranged from ₦ 94,258.40 to ₦ 133,056.80 compared to an average of ₦283,908.80 profit obtained from hybrids production while the benefit-cost ratio for OPVs was estimated at 2.09 and 1.77 for early and intermediate/late maturing DT maize respectively, while the hybrids had an average of 3.32 which implies that every Naira invested on DT maize production generated revenue of ₦1.77-2.09 for OPVs and ₦

3.32 for hybrids. The production efficiency shows that 48-56% and 30% of all revenue generated for OPVs and hybrids respectively, went into cost of production.

Table 20. Economic analysis of cultivating DT maize in SGS of Nigeria

DT Maize	[1]Grain yield (kg/ha)	[2]Price (₦/kg)	Production Costs per hectare: [3]Seeds	Tillage	Inputs	Others	Total	Maize Output (₦)	Profit: ₦	US$	BCR	Production Efficiency (%)
Early DT OPVs	3188.21	80	4000	20000	60000	38000	122,000	255,056.80	133,056.80	668.46	2.09	47.83
Int/Late DT OPVs	2703.23	80	4000	20000	60000	38000	122,000	216,258.40	94,258.40	473.54	1.77	56.41
Early DT Hybrids	5057.81	80	4500	20000	60000	38000	122,500	404,624.80	282,124.80	1,417.36	3.30	30.27
Extra Early DT Hybrids	5102.41	80	4500	20000	60000	38000	122,500	408,192.80	285,692.80	1,435.28	3.33	30.01

[1] = 50% of experimental field yield, [2] = CBN Bulletin (2014), [3] = seed rate of 20kg/ha for OPVs and 15kg/ha for hybrids, BCR = benefit-cost ratio

4.0 DISCUSSION

4.1 Field performance of DT Maize genotypes and Ideal Environment

The grain yield across the environments ranged from 5029.69kg/ha to 7165.98kg/ha for the DT OPVs while the hybrids had 9234.77 -11755.18 kg/ha. However, there were no significant (P≥0.05) differences in grain yield among top ranking genotypes. This agreed with the reports of Badu-Apraku and Lum (2010); Badu-Apraku *et al* (2011). These differential responses of genotypes to varying environments constitute a major constraint to the identification of superior maize genotypes for adaptation. The environment contributed the largest sum of mean squares (above 70%) in this study which indicates a much wider range of environmental main effects over genotypic main effects and that the SGS region is highly variable from location to location while the non-significant difference detected among the top ranked genotypes is an indication that the drought stress at most of the environments used for the evaluation of the DT cultivars was not severe enough to allow the effective discrimination of drought tolerance. Similar findings were reported by Badu-Apraku *et al* (2013)

The presence of a highly significant GEI for grain yield of the DT genotypes is a confirmation of the need for the extensive testing of genotypes in multiple environments over years before recommendation. This also confirms the need for breeders and agronomist to take GEI into serious consideration in evaluating genotypes and to have an estimate of its magnitude, relative to the magnitude of G and E effects which affect grain yield.

The selection of promising DT genotypes under unpredictable abiotic stress such as drought is difficult because of the random occurrence and intensity of such conditions. It is therefore very important to gain a better understanding of the target agroecosystems used for the evaluation of DT genotypes and to determine if they could be subdivided into different mega-environments (Gauch and Zobel, 1997 defined a mega-environment as a portion of a crop species' growing region with a homogenous environment in

which some genotypes perform similarly) to facilitate a more meaningful cultivar evaluation and recommendation. For effective assessment of the usefulness of test locations, it is essential to first conduct a mega-environment analysis to ascertain whether all test locations for the DT regional trials belong to the same mega-environment or not, because test location and genotype evaluations become meaningful only when conducted within mega-environments (Yan *et al.,* 2011). Menkir (2003) used Geographic Information System (GIS) to analyse long-term data collected on seven climatic variables relevant to maize production to refine the stratification of the sub-region into well-defined agro ecological zones. GIS separated the locations into four distinct zones, namely, mid-altitude, rainforest, moist savannah, and dry savannah.

Setimela *et al*. (2007) used the maize data set of CIMMYT and agro-climatic data to identify maize mega-environments for sub-Saharan Africa including WCA. The WCA sub-region was stratified into four distinct groups: dry savannah, wet savannah, dry mid-altitude and wet mid-altitude. Badu-Apraku *et al.* (2008) and Badu-Apraku and Lum (2010) used the GGE biplot analysis to decompose the G×E in WCA and to obtain information on the early maturing maize cultivars that were suitable for *Striga*-infested and *Striga*-free environments and to investigate stability of cultivars in the various environments.

In this study, distinct mega-environments were identified for the evaluation of DT maize genotypes which was based neither on the drought stress achieved at the various locations nor on the agroecology. Based on one of the methods of Yan *et al*. (2007) locations with high genotype discrimination and representation of the mega-environments that are ideal or close to ideal were chosen for superior genotype selection. Mega-environments were selected which implies that their ranking of the genotype were highly correlated and that those environments provided similar information about the genotypes. Ideal location was selected within the mega-environments for the highly performed and stable genotypes.

4.2 Impact of climate change on DT Maize production

Although most of the African economies rely on agriculture for export revenues, employment, national income and rural livelihoods, agriculture still largely relies on small family farms and rainfed production, and fertility management based on natural methods. Limited resource endowment, low diffusion of irrigation and fertilizers, and susceptibility to droughts make agricultural growth in SSA challenging (Nin Pratt *et al.*, 2011). A recent study found that, among world regions, Africa ranks highest for drought-induced yield reductions, both under a baseline climate and under climate change (Li *et al*., 2009). This is particularly relevant for maize production because the crop is mainly dependent on rainfall, and as a result, more vulnerable to drought and to year-to-year yield fluctuations (Prasanna *et al*., 2011).

Water availability is consistently identified by farmers and small-holders as the main limiting factor for agriculture; total annual water amount is rarely insufficient for growing crops, especially in dry regions (Rockstrom *et al.,* 2007). In SGS of Nigeria, yields are constrained by long dry seasons, and strong weather variability and generally, unpredictability of rain during critical crop growth stages.

This study analyses the trend of climatic factors (rainfall, minimum and maximum temperature, humidity etc) in SGS of Nigeria, as one of the major regions contributing to the total maize output of the country with a high drought-prone ecologies. The results revealed that 35.7% changes in DT maize production can be explained by the estimated climate factors, and by rainfall, soil temperature and sunshine duration which significantly affect the grain yield of DT maize.

In earlier studies, Nyong (2008) observed that variability in rainfall characteristics has the potential to influence crop production significantly. Ibitoye *et al*. (2014) analyzed the effect of rainfall and temperature on maize yield in Kogi, SGS zone of Nigeria, and concluded that the volume of rainfall and the mean temperature may not necessarily determine the output of maize in the area of study rather the spread of the rainfall within the year could be an important determinant. In this study, the actual rain days

significantly affect maize grain yield, a unit increase in number rain days increase maize grain yield by 80% while similar increase in the total amount of annual rainfall will positively have 18% impact on maize grain yield. Thus, the distribution of annual rainfall amount over rain days has been the major determinant of maize yield in the SGS of Nigeria.

Although air temperature was not significant in this study probably due to the short period of assessment since the fluctuation is minimal across years, Lobell *et al.* (2011) reported that increasing maximum (day) temperatures have a greater, negative impact on maize grain yields than minimum (night) temperatures. Cairns *et al.* (2012) opined that the reproductive phase is the most sensitive growth stage to heat stress. In contrast to drought stress, the male reproductive tissue is more sensitive to heat stress than the female reproductive tissue. Temperature primarily affects growth by reducing the length of time the crop can intercept radiation and the duration of the grain filling period (Cicchino *et al.*, 2011) while soil temperature depends on the energy changes at its surface and the heat flux in the sub-superficial layers. The heat flux into the soil depends on the weather conditions, the presence of soil coverage and the physical properties of the soil profile.

4.3 Conclusion

This study concludes that:

(i) Genotype-Environment influences the ranking of genotypes in different environments with some locations better for genotypes evaluations than others;

(ii) TZE-Y-DT-Str-C_4 is the highest performed and stable early OPV across the environment, White-DT-Str-Syn and DT-Sr-W-Co-F_2 in 2007-2009 while DT-Str-W-Syn_2 and DT-Str-W-C_2 in 2010-2012 are the most stable and highest yielding intermediate/late maturing OPVs, ideal early DT hybrids were TZE-Y-Pop-DT-Str-C_4 x TZEI II, 2012 TZE-Y-DT-C_4 Str-C_5 and TZE-W-Pop-DT-C_4 Str-C_5 while ideal extra early hybrids includes TZEEI 3 x TZEEI 46, TZEI-W-Pop-Str-C_5 x TZEEI 14, and (TZEEI 4 x TZEEI 14) x (TZEEI 29 x TZEEI 49).

(iii) Test environments are divided into mega-environments as follows:

a. Early maturing DT OPVs had 4 mega-environments; (i) Ballah, Ilorin and Kishi, (ii) Mokwa, (iii) Ejiba and (iv) Oke-Oyi. Ilorin is the ideal location while Ballah is close to the ideal;

b. Intermediate/late maturing DT OPVs had three mega-environments: (i) Ejiba, Kishi, Ilorin, Oke-Oyi (ii) Ballah and (iii) Mokwa and Badeggi.

c. The early maturing DT hybrids had Ilorin, Badaggi and Ejiba constituting the first mega-environment and Mokwa as the second mega-environment with Ilorin as the ideal location; and

d. the extra-early maturing DT hybrids had two mega-environments, Ballah-Kishi and Ilorin-Mokwa with Kishi as the ideal location for evaluating extra-early DT maize hybrids;

(iii) The study shows that maize yields increase with more seasonal rainfall and decrease with higher temperatures. However, increased rainfall variability during the growing season reduces yields for maize.

(iv) The potential impacts of investing in drought tolerant maize in SGS zone of Nigeria shows an average economic return of US$ 571 and US$ 1426 per hectare for cultivating OPVs and hybrids, respectively. The production efficiency 30 - 52% was estimated for cultivating DT maize varieties.

Conclusively, it is clear that maize yield is intimately linked to both intra-annual variability and inter-annual trends of rainfall and associated climate factors. Thus, simultaneous considerations of technological improvements and the development of the overall availability and predictability of water resources are likely required to see sustainable improvements in maize production given projected climate trends and variability.

4.4 Recommendations

1. This study recommends that fewer but better locations that provide relevant information should be used for conducting multi-location trials. Thus, Ilorin/Ballah, Ejiba/Mokwa and Kishi/Badeggi are core test locations for evaluation of early OPVs, intermediate/late OPVs and Hybrids, respectively.

2. The following promising genotypes are recommended for further evaluation in farmer's fields: TZE-Y-DT-Str-C_4 (early OPV), White-DT-STR-SYN (intermediate/late maturing OPVs), TZE-W-Pop-DT STR-C_5 (early maturing hybrids) and the extra early genotypes is TZEEI 3 x TZEEI 46.

3. Reliance on rainfall increases the vulnerability of maize systems to climate variability and change. There is an urgent need to address policies and management strategies at both the regional and national levels for agriculture adaptation to climate change and to reduce the adverse effects of climate change on agricultural production.

4. The economic gain for DT maize production ranged between ₦94, 258.00- ₦285,692.00 per hectare and benefit-cost ratio was between1.77 - 3.33. This implies that DT maize production in SGS zone of Nigeria is profitable.

5. Aggressive promotional activities on DT certified seed use are required to create greater awareness and demand among farmers. This could be done, through field demonstrations, adequate publicity, field days, etc.

6. Provision of improved rural infrastructure would encourage private seed companies to expand sales networks to rural areas.

7. Finally, the current synergy between Growth Enhancement Scheme and DTMA project should be sustained.

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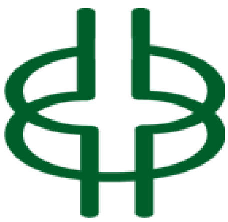
MATE MASIE

“What I hear, I keep”-Symbol of wisdom, knowledge and understanding.

NEA ONNIMNO SUA A, OHU

“He who does not know can know from learning, -Symbol of life-long education and continued quest for knowledge.



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