Stability and Environmental Responses of Topcross Hybrids, Varietal Hybrids and Open-Pollinating Cultivars of Maize[1]

M.O. Adeyemo*, M.A.B. Fakorede**

ABSTRACT

Thirty-five genotypes of maize (*Zea mays* L.) consisting of 21 topcross hybrids, seven varietal hybrids and seven open-pollinating cultivars were evaluated for yield stability and environmental response. The relationships among the several indices that have been proposed by earlier workers for measuring cultivar responses and stability of production under variable environments were also investigated. The study was conducted in the rain forest zone of southwestern Nigeria. Genotypes differed significantly for environmental responses and stability of performance. When regression coefficients (b-values) and deviation mean squares from regression (S^2d-values) were independently used as measures of stability, 26 and 28 genotypes respectively were considered stable in performance as compared with only 20 when both parameters were used. Mean yields across environments for the three groups of genotypes were significantly correlated with b; but associations of mean yield with the stability parameters S^2d and coefficient of determination (r^2) were not significant. The r^2 had significant negative correlation with S^2d and significant positive correlation with b, but the correlation between S^2d and b was not significant.

COMPENDIO

Se evaluó la estabilidad productiva y la respuesta al ambiente de 35 genotipos de maíz (*Zea mays* L.) 21 de los que eran mestizos híbridos, siete variedades híbridas y siete cultivares de polinización abierta. Se investigaron las relaciones entre los varios índices que han sido propuestos por otros investigadores que han medido respuestas de los cultivares y estabilidad de producción bajo condiciones ambientales variables. El estudio se llevó a cabo en la zona del bosque lluvioso del suroeste de Nigeria. Hubo diferencias significativas entre los genotipos en la respuesta al ambiente y su estabilidad de comportamiento. Cuando se usaron en forma independiente los coeficientes de regresión (valores b) y la desviación de los cuadrados medios (S^2 valores d) como medidas de estabilidad, 26 y 28 genotipos respectivamente, resultaron estables en comparación con 20 genotipos, al usar los dos parámetros. Las productividades promedio para tres grupos de genotipos a través de los ambientes fueron significativamente correlacionadas con b; pero las comparaciones de los promedios de productividad con el parámetro de estabilidad S^2d y el cociente de determinación (r^2) no fueron significativas. Se encontró una correlación negativa significativa entre r^2 y S^2d y una correlación significativa positiva con b, pero la correlación entre S^2d y b no fue significativa.

INTRODUCTION

The regression technique is one of the methods employed in analysing genotype x environment (G x E) interactions of crop genotypes. This method was first proposed by Yates and Cochran (11) and modified by Finlay and Wilkinson (6) who used b-values (regression coefficients) as measures of both stability and adaptation. Following a similar method, Eberthart and Russell (2) used b-values as measures of environmental response and deviations from regression (S^2d) as measures of stability. A few other indices have been proposed for measuring response of crop cultivars and stability of production in variable environments. Pinthus (9) proposed the coefficient of determination, r^2, as an index of production stability in variable environments. Thus, r^2 measures the proportion of a variety's production variation that is attributable to linear regression. Also, Langer *et al.* (7) suggested two indices related to ranges in productivity for evaluating production response of genotypes. These were designated as R_1 and R_2. R_1 is the difference between the minimum and maximum yields of a variety in a series of environments, whereas R_2 is the difference between the yield of a variety in the lowest and highest production environments. Thus, r^2 of Pinthus (9) and R_1 and R_2 of Langer *et al.* (7) respectively, would appear to have similar utilities as S^2d and b of Eberthart and Russell (2), and perhaps could be used as alternatives.

Current emphasis of maize improvement programs in Nigeria is on the development of high-yielding hybrid varieties. Preliminary studies conducted by the University of Ife (now Obafemi Awolowo University) maize improvement program, indicated that varietal hybrids which are more productive than the open-pollinated cultivars currently grown by farmers could be developed (1). Generally, maize cultivars released to farmers in the rainforest zone of Nigeria must show a rather wide adaptation to variable production environments. Meanwhile, topcross hybrids of some promising inbred lines have been developed in the program to identify inbreds with high general combining ability. We were also interested in characterising

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* Department of Crop Production, University of Agriculture, P.M.B. 2373, Makurdi, NIGERIA

** Department of Plant Science, Obafemi Awolowo University, Ile-Ife, NIGERIA

the adaptation responses of the inbred lines as measured in topcross performance This research was undertaken to investigate the stability and adaptation responses of the three groups of maize genotypes; namely topcross hybrids, varietal hybrids and open-pollinating cultivars; and to evaluate the relationship among some alternative indices that have been proposed for assessing cultivar response and stability of production under variable environmental conditions.

MATERIALS AND METHODS

The open-pollinating cultivars (CV) evaluated in this study have been released to farmers. These cultivars were crossed by hand-pollination to produce the varietal hybrids (HY) used The topcross hybrids (TCH) were developed by crossing inbred lines (S_3 or S_4) from several base populations to an open-pollinating cultivar, FARZ 27, in an isolated crossing block. The experimental sites (Table 1) were all located within the rainforest zone of south-western Nigeria. A total of 35 genotypes, consisting of 21 TCH, 7 CV and 7 HY, were evaluated in 1982 and 1983 and the experiments were laid out and analysed

Table 1. The experimental sites with dates of planting and mean grain yield (t/ha).

Environment			Date planted	Mean yield (t/ha)
1982:	1.	Ife Univ. T&R Farm	14 April	7 03
	2.	Ife Univ. Comm Farm	30 April	5 48
	3	Ikole-Ekiti	22 April	7 47
	4.	Ikare-Akoko	22 April	6 77
	5	Ikenne	10 May	3 86
	6	Efon-Alaye	29 April	2 42
	7	Ife Univ. T&R Farm (Late season)	3 September	1 55
1983:	8	Ife Univ T&R Farm	4 May	5 08
	9	Ife Univ. T&R Farm	16 May	4 39
	10	Ikole-Ekiti	18 May	5.03
	11	Ikare-Akoko	8 July	2 20
	12	Ikenne	25 May	2.13

as randomized-complete-block designs with three replications

Single-row, single-plant-hill and 21-plant plots were used Each plot was 5 m long spaced 0.75 m apart and hills within the rows were spaced 0 25 m apart Each hill was planted with two kernels and was thinned to 1 stand/hill; approximate density was 53 333 plants/ha.

Prior to planting, conventional land preparation was done in all environments except Efon-Alaye where, due to lack of facilities, land preparation was done manually with the West African hoe Weeds were controlled by Lasso-Atrazine and supplemented with hand weeding as required during the growing seasons. Method and rate of fertilizer application varied from one environment to another, depending on local practices

The experiments were hand harvested Ears were shelled, and grain weight per plot was adjusted to 15% moisture and converted to ton per hectare (t/ha).

Stability analysis was performed for grain yield using the model of Eberhart and Russell (2) In order to assess their relative utilities as indices of production response and/or stability, simple correlation coefficients were computed among genotype means ($\bar{x}$), b-, S^2d and r^2 values for grain yield. Also, corretions of b with R_1 and R_2 were computed

RESULTS

Environmental means for grain yield are presented in Table 1 Mean grain yield ranged from 1 6 t/ha for environment 7 to 7.5 t/ha for environment 3. Analyses of variance combined for the 12 environments (E) and genotypes (G) used in this study were highly significant (data not shown). Also, there were highly significant genotype x environment (G x E) interactions. The genotypic and G x E interaction sources of variation were partitioned into, within and among genotype components Highly significant differences occurred within each of the three groups of genotypes. The hybrids combined (TCH + HY) were significantly different from the CV and there were significant differences between the TCH and HY. The three groups of genotypes had significant interactions with the environments, except CV x E which was not significant. Also (TCH vs HY) x E and (CV vs (TCH + HY)) x E were not significant. Thus, the differences between TCH and HY; and between CV and all hybrids combined were consistent and in the same direction, regardless of the environment in which they were grown. Mean grain yield was 4.9 t/ha (with range of 4.1 to 5.5 t/ha) for HY, 4.5 t/ha (3.7 to 5.4 t/ha) for TCH and 3.8 t/ha 2.5 to 4.9 t/ha) for CV.

Stability analyses (data not shown) partitioned the environment and G x E interaction variances into 1) mean squares due to regression of grain yield on the environmental indices i.e. G x E linear; 2) mean squares due to deviations from regression (pooled deviation); and 3) mean squares due to factors which were common to all environments but were in graduations from one environment to another i.e. E-linear. The pooled deviations mean squares was highly significant, thus indicating that the genotypes differed for stability of grain yield in the environments sampled.

Table 2 shows that four TCH, two CV and one HY had b-values greater than unity ($b > 1.0$– while 17 TCH, three CV and six HY had $b = 1.0$; and only two CV possessed b-value less than unity ($b < 1.0$). Furthermore, 17 TCH along with all of the CV and four HY possessed $S^2d = 0.0$ while only four TCH and three HY demonstrated significant S^2d ($S^2d \neq 0.0$). Among the genotypes with $b < 1.0$ or $b > 1.0$, only one TCH with $b > 1.0$ had $S^2d \neq 0.0$. Coefficient of determination (r^2-values) ranged from 0.61 to 0.96. Generally, entries with $S^2d \neq 0.0$ had $r^2 \leq 0.8$, except in two cases.

Simple linear correlation coefficients among mean grain yield ($\bar{x}$), environmental response index (b) and two stability paramenters (S^2d and r^2) are presented in Table 3. There were highly significant, positive correlations of $\bar{x}$ with b, and b with r^2, but the correlation of b with S^2d was not significant. Also, the correlations of $\bar{x}$ with S^2d and r^2 were not significant. Furthermore, a highly significant negative correlation between r^2 and S^2d was obtained. The correlations of b with the ranges R_1 and R_2 were highly significant and positive. Correlation coefficients obtained were 0.87 and 0.82 for R_1 and R_2, respectively.

DISCUSSION

Generally, varietal hybrids were superior to topcross hybrids and open-pollinating cultivars in grain yield. Robinson *et al* (10) suggested that "the heterosis from variety cross should be indicative of average hybrid performances of lines extracted from the parent, but maximum heterosis possible from a specific combination of selected inbred lines may be expected to exceed the variety cross heterosis." The superiority of varietal hybrids in this study showed that those which are more productive than open-pollinating varieties currently available could be devel-

Table 2. Mean grain yield ($\bar{x}$), regression coefficient (b), deviation from regression mean square (S^2d) and the coefficient of determination (r^2) for 35 genotypes of maize grown in 12 environments.

Genotype		$\bar{x}$ (t/ha)	b	S^2d	r^2
TCH	1	4.5	1.213+	0.3628	0.95
	2	4.6	1.030	0.5329	0.90
	3	4.3	0.973	0.8444	0.84
	4	5.1	1.163+	0.2992	0.95
	5	4.8	1.485+	2.0513**	0.83
	6	4.9	1.183+	0.3112	0.95
	7	4.0	0.987	0.7567	0.86
	8	4.7	1.055	0.5685	0.90
	9	4.5	1.021	0.3925	0.92
	10	4.0	0.828	0.6644	0.83
	11	4.6	1.029	0.7003	0.88
	12	4.5	1.171	0.9061	0.88
	13	4.5	0.971	1.0594*	0.80
	14	4.2	1.013	0.9316	0.84
	15	4.7	1.060	0.4002	0.93
	16	4.2	0.991	0.9899	0.82
	17	3.7	0.822	0.4891	0.86
	18	4.4	0.854	1.1077*	0.75
	19	4.3	0.860	0.6759	0.84
	20	5.4	0.798	1.0753*	0.73
	21	5.0	0.807	0.7133	0.81
CV	1	3.4	0.887	0.2947	0.93
	2	2.5	0.840	0.3772	0.90
	3	4.7	1.167+	0.2819	0.96
	4	4.9	1.286+	0.7670	0.91
	5	2.9	0.567+	0.4776	0.76
	6	4.2	0.677+	0.3875	0.85
	7	4.3	0.980	0.9349	0.83
HY	1	4.9	0.761	1.2182*	0.69
	2	4.9	0.742	1.5969**	0.61
	3	5.0	0.918	0.7398	0.84
	4	5.4	1.279	1.0604*	0.88
	5	5.5	1.393+	0.4100	0.96
	6	4.1	1.033	0.6078	0.89
	7	4.7	1.155	0.8951	0.87

+ b-value significantly different from 1.0 at 5% level of probability

*, ** $S^2d \neq 0.0$ at 5 and 1% levels of probability, respectively

Table 3. Correlation coefficients among mean grain yield ($\bar{x}$), adaptation index (b) and stability parameters (S^2d and r^2).

	$\bar{x}$	b	S^2d
b	0.49**		
S^2d	0.29	0.09	
r^2	0.01	0.63**	−0.69**

** Significantly different from zero at 1% level of probability oped If such hybrids still maintain high yield after more extensive yield evaluations, they may be released to farmers as an interim measure since the development of single- or double-cross hybrids is the ultimate goal in hybrid seed production. Furthermore, two of the open-pollinating cultivars (FARZ 27 and FARZ 34) with mean yields of 4 7 and 4.9 t/ha, respectively, demonstrated good response to high yield environments and exhibited stability of performance in the experimental environments Unfortunately, inbred lines from these two cultivars were not available for the topcross hybrids evaluated in the study. Also, the results of our study indicated that FARZ 27 and FARZ 34 would be suitable source populations for recurrent selection which is an integral part of our hybrid maize program Both cultivars are among those used as source populations for inbred-line extraction in the program

The highly significant differences among the experimental environments were expected because they differed in cropping history, tillage practices, prevailing climatic factors, insect pest infestation and disease infection during plant growth. For example, environment 5 and 6 had maize stem borer infestation, and land preparation prior to planting in environment 6 was relatively poor. Environment 7, which was planted during the late rainy season, had a rather severe infection of streak virus disease coupled with stem borer infestation. These factors and others that were specific to each environment may have caused the highly significant pooled deviations

Although all of the environments were located within the rainforest zone of Nigeria, it was expected (though not quantified due to lack of facilities in some locations) that climatic factors such as total amount and distribution of rainfall, temperature, solar radiation and relative humidity would exhibit considerable variation from one environment to another. These climatic factors have been reported to significantly influence grain yield of maize in the tropical rainforest zone (3). Also, although soil testing was not carried out prior to planting, the rate of fertilizer application varied from one environment to another, according to local practices. The climatic factors and soil fertility levels, along with other factors which were common to all environments but were in graduations from one environment to another, were measured by the linear component (E_{linear}) of the environmental variances, and this was found to be highly significant

Most (26 among 35) of the maize genotype used in this study exhibited b-values equal to unity and could therefore be considered to be well adapted to all environments The two open-pollinating cultivars with $b < 1.0$ demonstrated poor response to high-yield environments whereas the seven entries with $b > 1.0$ would be considered as showing better adaptation to high-yield environments Twenty-eight genotypes (17 TCH, 7 CV and 4 HY) demonstrated stability of grain yields as shown by their non-significant deviation mean squares from regression ($s^2d = 0$). Therefore the environmental response of these genotypes can be predicted on the basis of the linear model used for the analyses (2) On the contrary, the seven entries which demonstrated significant S^2d ($S^2d \neq 0.0$) were not stable in yield performance. In other words, some portion of the G x E interactions of these genotypes could not be explained with a linear model. If b-values and S^2d-values were independently used as measures of stability, 26 and 28 genotypes, respectively would be considered stable in performance as compared with only 20 if both parameters are used.

Furthermore, mean grain yield ($\bar{x}$) had a highly significant, positive correlation with b-values. Similar results have been reported by some other crop scientists (2, 5, 7, 8), even when physical factors were used as environmental indices (4) Such a correlation pattern may be a limitation to the use of b-values in measuring stability of response to various environments as proposed by Finlay and Wilkinson (6), since higher-yielding genotypes would always have higher b-values Furthermore, Finlay and Wilkinson (6) used b as a measure of both stability and adaptation while Eberhart and Russell (2) used both b and S^2d as measures of stability; and Pinthus (9) proposed r^2 as another index of stability In this study, b had significant positive correlation with r^2 and none with S^2d, whereas S^2d had significant negative correlation with r^2. Thus, there are no consistent relationships among the three measures of stability and they cannot therefore be said to have similar utilities. Perhaps it would be better to use b-values as measures of environmental response and S^2d as a measure of stability as done by Eberhart and Russell (2). This suggestion is buttressed by the observation that among the genotypes with $b < 1.0$ or $b > 1.0$, only one had $s^2d \neq 0.0$. Also, r^2 seemed to have some utility as a measure of stability since it showed highly significant correlation ($r = 0.69$) with S^2d. (Interestingly, neither S^2d nor r^2 showed significant correlation with $\bar{x}$ as did b). However, the level of correlation is rather too low (coefficient of determination $\simeq 0.49$) for any practical utility.

Both the R_1 and R_2 of Langer *et al.* (7) had significant positive correlations with b. As noted by these workers, R_2 would be more useful than R_1 because only two fairly extreme environments would be required to estimate R_2 The lowest-yielding environment in this study (environment 7) was the only one planted in the late rainy season. This, compared with the early rainy season, is generally characterised by lower level of moisture availability during plant growth, and higher incidences of disease infection and insect pest infestation. The relatively lower moisture availability may be due to the short duration of the season and the high intensity of incident solar rradiation which leads to higher evapotranspiration. For these reasons, among others, not much use is being made of the late rainy season for preliminary screening of the breeder's materials. However, the pattern of correlations of b with R_2 obtained in this study suggested that the late rainy season may prove to be of great utility in the preliminary evaluation of maize genotypes.

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