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GENOTYPE X ENVIRONMENT INTERACTIONS IN THREE MATURITY GROUPS OF MAIZE CULTIVARS

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ABSTRACT

Genotype x environment (GE) interactions are of interest to plant breeders because of their influence on progress from selection. This study was conducted to examine the effects of GE interactions for grain yield in three maturity groups of maize (*Zea mays* L.) cultivars adapted to the lowland tropics. Nine early (90-95 days), eight medium (105-110 days) and nine late (115-120 days) maturing maize cultivars were evaluated for grain yield potential in 32 to 36 environments across coastal savanna, forest, forest-savanna transition, and Guinea savanna zones of Ghana (Lat. 4° 44' - 11° 11' N, Long. 1° 11' E - 3° 11' W) from 1995 to 1998. Analyses of variance combined over locations and years within each maturity group indicated highly significant ($P < 0.01$) genotype x location x year interactions for yield in the three maturity groups. The genotype x year and genotype x location interactions were also significant in the intermediate and late maturity groups whereas only genotype x location interaction was significant in the early group. Spearman rank correlations, used to test the consistency of ranking of genotypes across locations, showed crossover interactions were important in all maturity groups and suggest the need to stratify the environment to minimize GE interactions. Sub-division of sites into variety testing zones corresponded to the major agro-ecologies in Ghana for the early and intermediate maturity groups but not the late group. The data also showed that testing using at least two replications per site at 10 locations in two years would be effective for identifying high-yielding genotypes across environments within each maturity group.

Key Words: Agro-ecologies, Ghana, maturity cycles, selection, *Zea mays*

ABSTRACT

Les intéractions entre génotypes et l'environnement (GE) sont d'un grand interêt pour les croiseurs de plantes à cause de leur influence sur le progrès de la sélection. Cette étude était conduite pour examiner les effets des intéractions GE sur le rendement de trois groupes matures des variétés du maïs (*Zea mays* L.) adaptées au zones basses des tropiques. Neuf variétés à maturité précose (90-95 jours), huit modérée (105-110 jours) et neuf à maturité retardées étaient évaluées pour le rendement potentiel en grain dans 32 et 36 environnements à travers la savane des côtes, forêt, transition savane-forêt, et la zone de savane du Guiné au Ghana (Lat 4°44'-11°11'N, long. 1°11'E-3°11'W) de 1995 en 1998. Les analyses des variances combinées des locations et années dans chaque groupe de maturité ont indiqué une intéractions significativement forte entre génotype – location-annéé pour le rendement dans les trois groupes de maturités. Les intéractions entre génotype-année et génotype-location étaient aussi significatives dans le groupe de maturité intermediaire et retardé alors que l'intéraction entre génotype et location était significative dans le groupe à maturité précose. Les rangs des corrélations de Spearman utilisés pour tester la consistence de classer les génotypes à travers les locations, montrèrent que les intéractions dues au croisement étaient importantes dans tous les groupes de maturité et suggèrent la nécessité de stratifier l'environnement pour minimizer les intéractions GE. La sub-division des sites en zones pour tester les variétés

correspondait à celle des zones écologiques du Ghana pour les groupes précose et intermediaire et pas les variétés à maturité retardée. Les données ont aussi montré que les tests utilisant 2 répétitions par site en 10 endroits pour une période de 10 ans seraient efficace pour identifier les génotypes au rendement élévé pour tous les environnements et chaque groupe de maturité.

Mots Clés: Agro-écologies, Ghana, cycles de maturité, sélection, *Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal in rain-fed production systems in West and Central Africa (CIMMYT, 1988). In most of the countries in this region, maize is grown in several agro-ecologies and cropping seasons that differ in the length of the growing season. For these reasons, different maturity groups of maize varieties are required to meet the needs of growers. In this region, varietal maturity is measured as the number of days from planting to physiological maturity of the kernel (Vasal *et al.*, 1994). For example, the varietal recommendations based on maturity cycles in Ghana are as follows:

(i) Extra-early (75 to 80 days) maturing varieties are recommended for planting in the interior savanna zones to be harvested early in the season as green maize or grain to fill the hunger-gap before the main harvest each year.

(ii) Early (90 to 95 days) maturing varieties are recommended for the drier coastal and interior savanna zones in the main season, and for the forest and forest-transition zones in the minor season.

(iii) Intermediate (105 to 110 days) maturing varieties are recommended for areas with long growing season such as the forest, transition, and Guinea savanna zones in the major season.

(iv) Late (115 to 120 days) varieties are recommended for higher yields in areas with longer growing season such as the forest, transition, and Guinea savanna zones in the major season.

The major task of breeding programs in the region, therefore, is to develop new maize genotypes of different maturity cycles that have high and stable performance across these multiple environments.

The relative performance of genotypes often changes from one environment to another and this differential response of genotypes to changes in the environment is referred to as genotype x environment (GE) interaction (Comstock and Moll, 1963). The existence of a large GE interaction poses a major problem in relating phenotypic performance to genetic constitution and hampers effective discrimination among contending genotypes (Comstock and Moll, 1963).

It is important to understand the nature of GE interaction to be able to design efficient strategies for testing and selecting superior genotypes. In order to reduce GE interaction effects, several workers have stratified the environments into testing zones and recommendation domains (Peterson, 1992; DeLacy *et al.*, 1990; Peterson and Pfeiffer, 1989; Horner and Frey, 1957; Liang *et al.*, 1966; Miller *et al.*, 1959). Such stratification is usually based on climatic data such as rainfall, temperature or growing degree days that define the length of the growing period in a particular environment.

Information on GE interaction in maize in West and Central Africa is limited. The few studies conducted in the region have reported the importance of interaction variance components usually for the late maturity group of maize cultivars (Fakorede and Opeke, 1986; Fakorede and Adeyemo, 1986). However, cultivars of different maturity cycles are evaluated simultaneously by breeding programs in the region in order to identify high and stable yielding genotypes within each maturity group for recommendation to farmers. For this reason, each breeding program needs to conduct three to four variety trials, depending on the maturity groups of interest. Because resources are limited, there is a need to conduct trials efficiently and information on GE interactions for the different maturity groups would be useful.

This study was conducted to determine the importance of GE interactions in early, intermediate, and late maturing maize cultivars and to estimate the number of tests required for the evaluation and selection of superior genotypes within each maturity group.

MATERIALS AND METHODS

Nine early, eight intermediate, and nine late maturing maize cultivars, comprising commercial varieties, experimental varieties and breeding populations, were evaluated in separate field experiments at Pokuase (5° 36' N, 00° 10' W) and Ohawu (6° 07' N, 0° 50' E) (coastal savanna ecology, coarse sandy-loam Dystrochrept), Fumesua (6° 41' N, 1° 28' W) and Kwadaso (6° 41' N, 1° 36' W) (forest ecology, coarse sandy-loam Paleustult), Ejura (7° 23' N, 1° 21' W) and Kpeve (6° 41' N, 0° 20' E) (transition ecology, fine-coarse sandy-loam, Oxisol), Damongo (9° 04' N, 1° 49' W), Nyankpala (9° 25' N, 0° 58' W) and Wa (10° 4' N, 2° 30' W) (Guinea savanna ecology, fine sand-loam Alfisol), and Manga (11° 01' N, 0° 16' W) (Sudan savanna ecology, fine sandy-loam Alfisol) from 1995 to 1998. The different maturity groups of the cultivars studied are presented in Table 1.

Zero-tillage was practiced in the coastal savanna, forest and transition zone sites, and this comprised application of Glyphosate at 1.5 kg a.i. ha^{-1} two weeks before planting the trials. In the Guinea and Sudan savanna zones, the fields were disc-ploughed, harrowed, and ridged before planting. A randomised complete block design with 4 replications was used at each site for each maturity group. A plot consisted of four 5-m rows of each cultivar in each replicate. Rows were spaced at 0.75 m apart and hills within the row were spaced at 0.4, 0.45 and 0.5 m for early, intermediate, and late cultivars, respectively. Sowing was in April each year in the coastal savanna, forest and transition zone sites and in June in the Guinea and Sudan savanna zones. Hills were over-planted but were thinned at establishment to two plants per hill to obtain target populations of 66,000, 56,000 and 50,000 plants ha^{-1} for the three maturity groups, respectively. Pre-emergence chemical weed control consisted of an application of a combination of Pendimethalin and Gesaprim at 1.5 kg a.i. ha^{-1} and 1.0 kg a.i. ha^{-1}, respectively at planting. Paraquat was applied at 1.0 kg a.i. ha^{-1} in addition to Pendimethalin and Gesaprim to control lush vegetation at planting. Hand weeding was also done as a follow-up weed control measure when necessary to keep the plots free of weeds. Fertilisation was by spot-application of 45 kg N ha^{-1} and 45 kg P_2O_5 ha^{-1} at 8-10 days after planting at all sites. Additional 45 kg N ha^{-1} was side-dressed using urea three to four weeks after planting.

Data were recorded from the two middle rows of the plot of each cultivar (genotype) on grain yield at 15% moisture. The data were analysed using the generalised linear model (GLM) procedure of statistical analysis system for windows (SAS Institute, 1996). The data were analysed by site (location) and combined over

TABLE 1. Characteristics of early, intermediate and late maturing maize cultivars evaluated at different locations in Ghana from 1995 to 1998

Early cultivars		Intermediate cultivars		Late cultivars	
Name	Material+	Name	Material+	Name	Material+
Dorke SR	Cultivar (OP)	GH2823-14OT	3-way hybrid	(GH24 x 1368) x 5012	3-way hybrid
NAES Pool 16 DT	EV (OP)	GH110-28	3-way hybrid	Okomasa	Cultivar (OP)
Safita-2	Cultivar (OP)	GH110-5	3-way hybrid	Dobidi	Cultivar (OP)
GH90-DYFP	Population	Obatanpa GH2823-88	Cultivar (OP)	(GH22x1368) x 5012	3-way hybrid
Dodzi	Cultivar (OP)	GH132-28	3-way hybrid	GH132-28	3-way hybrid
GH90-DWDP	Population	Abeleehi	Cultivar (OP)	GH110-5	3-way hybrid
EV EJ 9190DWDP	EV (OP)	Local variety	Cultivar (OP)	(GH3 X 1368) X 5012	3-way hybrid
EV FU 9190DWDP	EV (OP)			8321-18	Single cross
Local variety	Cultivar (OP)			Local variety	Cultivar (OP)

+ EV = Experimental variety
OP = Open-pollinated

sites and years, assuming that all effects were random (Steel *et al.*, 1997). The variance components [genotypic (σ^2_g), genotype x location (σ^2_{gl}), genotype x year (σ^2_{gy}), genotype x location x year (σ^2_{gly}), error (σ^2_e) variances] and their standard errors were estimated using the restricted maximum likelihood (REML) procedure. Rank correlations were determined between locations, years and location-year combinations for each maturity group using Spearman rank correlations (Steel *et al.*, 1997). The expected standard error of a genotype mean (SE_g) for estimating genotypic differences in all possible environments was computed as follows:

$$SE_g = [\sigma^2_{gy}/y + \sigma^2_{gl}/l + \sigma^2_{gly}/yl + \sigma^2_e/ryl]^{1/2},$$

where y, l, and r are number of years, locations, and replications used in the evaluations, respectively. By substituting estimated values of y, l, and r in the above equation, information as to the number of tests needed to evaluate cultivars for a desired level of precision, measured as the standard error, was obtained for the different maturity groups.

RESULTS AND DISCUSSION

Effects due to locations, years and genotypes were highly significant ($P < 0.01$) in the three maturity groups (Table 2). The genotype x year (GY) interaction was highly ($P<0.01$) significant in the intermediate maturity group and significant ($P<0.05$) in the late group. The GY interaction was not significant in the early group, indicating that the early varieties were more consistent in yield over the different years. Genotype x location (GL) interaction was significant in the early group and highly significant in the intermediate and late groups. The genotype x year x location (GYL) interaction was also highly significant in the three maturity groups. The significant GL, GY and GYL interactions showed that genotypes within the intermediate and late maturity groups responded differently to locations and years. Similarly, the significant GL and GYL interactions among the early varieties showed that genotypes within this maturity group responded differently to different locations and location-year combinations. These significant interactions implied that testing at different locations in different years would be necessary in order to identify high and stable yielding varieties within each maturity group.

Estimates of variance components and standard errors for grain yield in the three maturity groups are presented in Table 3. Significant genotypic variance was observed in all maturity groups, indicating that selection for superior yielding genotypes would be effective in each maturity group. In the early maturity group, the GYL interaction component of variance (σ^2_{gly}) and GL (σ^2_{gl}) were significant but the GY (σ^2_{gy}) component was not. In the medium and late maturity groups, σ^2_{gl}, σ^2_{gy} and σ^2_{gly} were all statistically significant. However, σ^2_{gly} was greater than the other interaction variance components in the early and late maturity groups. In all maturity groups, the

TABLE 2. Mean squares from the analyses of variance for grain yield (Mg ha^{-1}) combined over locations and years for three maturity groups of maize cultivars (genotypes) evaluated in Ghana from 1995 to 1998

Source of variation	Early		Intermediate		Late	
	df	MS	df	MS	df	MS
Year	3	73,649**	3	151,304**	3	133,860**
Location	7	125,224**	8	115,436**	7	64,120**
Year*location	21	20,151**	24	35,407**	21	33,815**
Rep(location year)	96	1,107	108	1,624	96	1,923
Genotypes	8	18,019**	7	85,765**	8	53,030
Genotype*year	24	1,421	21	6,175**	24	2,401*
Genotype*location	56	1,713*	56	2,755**	56	2,927**
Genotype*location*year	168	1,171**	168	1,189	168	1,313**
Error	768	429	756	779	768	700

* ** Significant at the 0.05 and 0.01 levels of probability, respectively

residual variance (σ^2_e) was by far greater than all the other variance components, suggesting the need to conduct replicated variety trials in multiple environments to enhance the selection of superior genotypes.

In GE interaction studies, it is more important to determine whether there are crossover interactions than if genotypic responses are parallel across environments (Baker, 1988). Since Spearman correlations are correlations of rank, they are a simple but effective means of determining the magnitude of crossovers or changes in rank of genotypic performance in test environments (Vogel *et al.*, 1993). Spearman correlations of ranks of genotype yields were high and significant among the four years in the late maturity group, indicating ranking of genotypes was consistent across years (Table 4). In the intermediate group, the rank correlations were significant, except between 1995 and 1996, and 1995 and 1997, indicating crossover interactions were important (Table 4). Spearman correlations were also high and significant between locations in 11 out of 28 cases in the early maturity group (Table 5), 27 out of 36 cases in the intermediate group (Table 6), and 9 out of 32 cases in the late group (Table 7). Though data are not presented, the rankings of genotypes for yield differed among locations in all maturity groups. Relatively, rankings across sites were more consistent for the intermediate than the other maturity groups. However, the local variety (land race) exhibited the lowest yield potential at all the test locations in each maturity group.

The overall mean yields across environments were 3.96 Mg ha^{-1} for the early, 5.43 Mg ha^{-1} for the intermediate, and 5.29 Mg ha^{-1} for the late maturity groups (Table 8). There was no significant yield difference between the intermediate and late groups. On the average, the intermediate and the late maturity groups significantly out-yielded the early group by 26.1%. The data support the higher yield potentials of intermediate and late varieties over early types in Ghana as reported in previous studies (Sallah *et al.*, 1997).

Many workers have suggested stratification of the target environment into variety testing zones or sub-regions in order to minimise GE interaction effects (Peterson and Pfeiffer, 1989; Peterson, 1992; DeLacy *et al.*, 1990). The results in the present study showed that GE interactions were important in the three maturity groups of maize

TABLE 3. Estimates of variance components and their standard errors for grain yield (Mg ha^{-1}) in three maturity groups of maize cultivars evaluated in Ghana from 1995 to 1998

Variances	Early cultivars	Intermediate cultivars	Late cultivars
σ^2_g	125.4 ± 70.5	541.8 ± 318.7	382.9 ± 207.3
σ^2_{gy}	0	138.5 ± 53.1	34.0 ± 22.1
σ^2_{gl}	33.9 ± 21.8	97.9 ± 33.5	100.9 ± 35.7
σ^2_{gly}	185.5 ± 32.4	102.4 ± 33.9	153.3 ± 36.9
σ^2_e	428.9 ± 21.9	779.2 ± 40.1	700.0 ± 35.7

TABLE 4. Spearman rank correlation coefficients for grain yield in two maturity groups of maize cultivars evaluated in Ghana from 1995 to 1998

Year	Intermediate cultivars	Late cultivars
1995 vs. 1996	0.55	0.75*
1995 vs. 1997	0.57	0.87**
1995 vs. 1998	0.71*	0.72*
1996 vs. 1997	0.88**	0.85**
1996 vs. 1998	0.76*	0.90**
1997 vs. 1998	0.90**	0.92**

* ** Significant at the 0.05 and the 0.01 levels of probability, respectively

TABLE 5. Spearman rank correlation coefficients for grain yields of early maize cultivars evaluated at eight sites in Ghana from 1995 to 1998

Location	Ejura	Kpeve	Damongo	Kwadaso	Nyankpala	Wa	Manga
Fumesua	0.367	0.267	0.267	0.400	0.183	0.133	0.433
Ejura		0.650	0.733*	0.500	0.417	0.467	0.483
Kpeve			0.700*	0.733*	0.683*	0.650	0.617
Damongo				0.717*	0.783	0.550	0.783*
Kwadaso					0.750*	0.767*	0.750*
Nyankpala						0.517	0.767*
Wa							0.783*

* Significant at the 0.05 levels

TABLE 6. Spearman rank correlation coefficients for grain yields of intermediate maize cultivars evaluated at nine sites in Ghana from 1995 to 1998

Location	Ejura	Fumesua	Kpeve	Kwadaso	Manga	Nyankpala	Pokuase	Wa
Damongo	0.857**	0.810*	0.619	0.881**	0.786*	0.905**	0.6904	0.810*
Ejura		0.714*	0.786*	0.976**	0.762*	0.952**	0.738*	0.833*
Fumesua			0.761*	0.761*	0.381	0.690	0.833*	0.690
Kpeve				0.810*	0.548	0.762*	0.929**	0.857**
Kwadaso					0.786*	0.976**	0.786*	0.857**
Manga						0.881**	0.548	0.833*
Nyankpala							0.762*	0.905**
Pokuase								0.905**

*, ** Significant at the 0.05 and the 0.01 levels of probability, respectively

TABLE 7. Spearman rank correlation coefficients for grain yields of late maize cultivars evaluated at eight sites in Ghana from 1995 to 1998

Location	Ejura	Fumesua	Kpeve	Kwadaso	Nyankpala	Pokuase	Wa
Damongo	0.817**	0.483	0.733*	0.850**	0.883**	0.650	0.683*
Ejura		0.467	0.567	0.967**	0.817**	0.567	0.250
Fumesua			0.200	0.633	0.650	0.617	0.550
Kpeve				0.550	0.683*	0.567	0.683*
Kwadaso					0.900**	0.633	0.367
Nyankpala						0.667	0.600
Pokuase							0.533

*. ** Significant at the 0.05 and the 0.01 levels of probability, respectively

TABLE 8. Means and ranges of grain yield (Mg ha^{-1}) in three maturity groups of maize cultivars evaluated in Ghana from 1995 to 1998

Maturity group	Mean	Range	CV%	LSD 0.05
Early	3.96	3.34 to 4.42	16.5	0.27
Intermediate	5.43	3.93 to 6.38	16.3	0.26
Late	5.29	3.94 to 6.12	16.1	0.29

varieties and sub-dividing the sites into testing zones will help minimize GL interactions. The magnitude of Spearman correlations (Tables 5-7) was used to group the sites into testing zones; sites with high correlations were placed in the same zone for each maturity group. In the early maturity group, the first zone comprises Ejura, Kpeve and Kwadaso; the second comprises Nyankpala, Damongo, Manga and Wa; and the third comprises Fumesua only. In the intermediate maturity group, the first zone comprises Ejura, Kpeve, Kwadaso, Fumesua and Pokuase while Damongo, Manga, Nyanpkala and Wa form the second zone. In the late maturity group, zone one consists of Damongo, Ejura, Kpeve, Kwadaso, Nyankpala and Wa and zone two consists of Fumesua and Pokuase. In the early and intermediate groups, the first zone covers sites in the forest, forest-savanna transition and coastal savanna zones in southern Ghana and the second zone is made up of locations in the Guinea and Sudan savanna zones in the northern part of the country. The delineation of sites into testing zones for the late maturity group did not correspond to the natural vegetation zones of southern and northern Ghana observed for the early and intermediate groups.

Sub-division of sites into testing zones is desirable for developing specific varieties for each zone. On the other hand, if the objective is to evolve new genotypes that have stable performance across environments, which is often the case, then the selection criterion should be based on data from all the environments of interest. The significant GL and GYL interactions observed in the early maturity group suggest a need for testing across multiple locations and years in order to accurately assess yield potential in the early genotypes. Similarly, GY, GL and GYL interactions were important in the medium and late maturity groups, indicating precise assessment of yield potential can only be achieved through multi-location evaluations in multiple years.

The magnitude of the variance of a genotype mean indicates the precision of estimates of genotypic performance. A low variance of a genotype mean is desirable but this is related to the extent of testing of the materials. However, availability of funds and other resources to the testing program would determine how much testing is practical to achieve a reasonable level of precision, measured by the standard error (Saeed *et al.*, 1984). Theoretical standard errors of a genotype mean were estimated for various combinations of number of replications per test and number of locations and years of testing within each maturity group and these are illustrated in Figures 1 to 3. In all groups, changing number of replications from 1 to 2 resulted in a large reduction in the standard error at any given number of locations per test (Fig. 1). Changing number of replications from 2 to 4 had minimal effect on the standard errors of a genotype mean within each maturity group. Maize breeding programs commonly use four replications in testing advanced materials, as used in this study. These results showed that there is little advantage in using more than two replications per site in such variety trials.

Increasing the number of years of testing from 1 to 2 resulted in considerable reductions in the standard errors of a genotype mean in the early (Fig. 2a), medium (Fig. 2b) and the late (Fig. 2c) maturity groups. Increasing number of years from 2 to 3 had only minimal effects on the standard error of a genotype mean in the three maturity groups (Fig. 2). Figure 3 illustrates the effects of increasing the number of years of testing at varying number of locations when number of replications = 4. When Figures 3a to 3c are compared with Figures 2a to 2c for the respective maturity groups, increasing number of replications to 4 and increasing number of years and test locations did not enhance the efficiency of testing beyond two replications per test. The data indicated that 2 years of testing in all three maturity groups are adequate for effective discrimination among contending genotypes.

Experience shows that it is generally more practical and less expensive to increase the number of locations in a year than increase the number of years of testing. The influence of number of test locations (sites) on the standard error of a genotype mean can be deduced from Figures 1a to 1c, 2a to 2c and 3a to 3c. All these Figures showed that the use of 10 locations in a year in the evaluations in each of the two years would help achieve a high level of precision in all three maturity groups of maize genotypes.

Results from this study showed that GE interactions contributed significantly to total yield

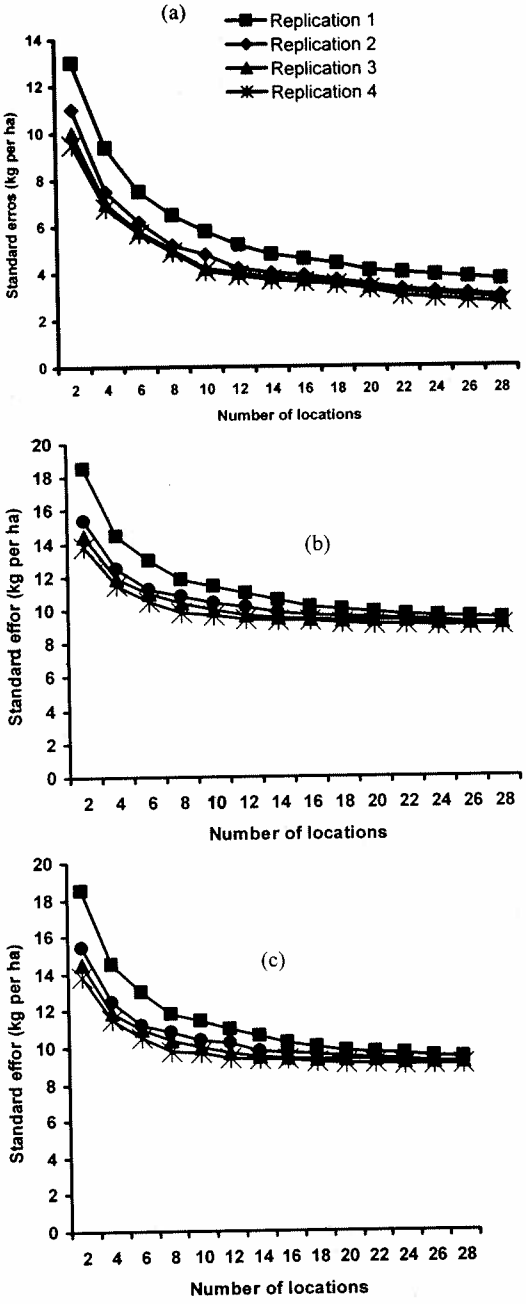

Figure 1. Expected standard errors of a genotype mean yield in the (a) early, (b) medium, and (c) late maturity groups for various assumed number of replications and locations when number of years = 2.

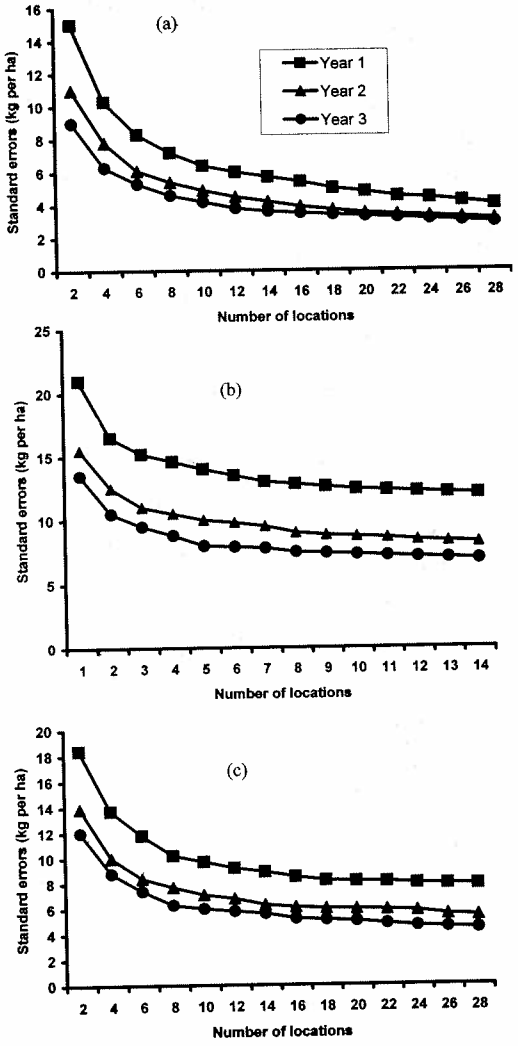

Figure 2. Expected standard errors of a genotype mean yield in the (a) early, (b) medium, and (c) late maturity groups for various assumed number of years and locations when number of replications = 2.

variance in the early, intermediate and late maturity groups of maize varieties in Ghana. The significant GE interactions suggest the need for multiple testing across locations and years within each maturity group in order to effectively assess yield potentials of genotypes. Precise assessment of yield potential in the maturity groups would require at least 2 years of testing at 10 sites in a year, using two replications per site.

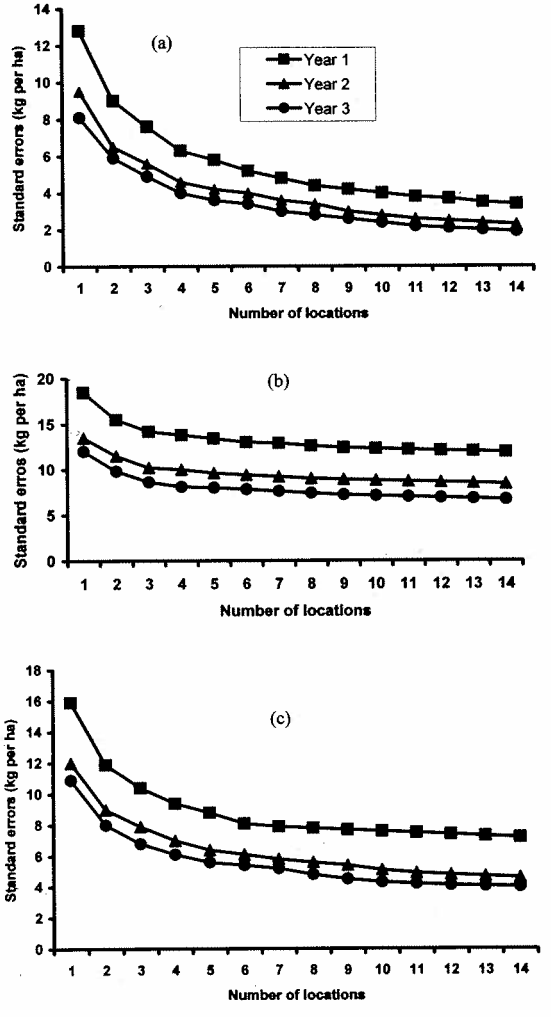

Figure 3. Expected standard errors of a genotype mean yield in the (a) early, (b) medium, and (c) late maturity groups for various assumed number of years and locations when number of replications = 4.

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