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Cultivar X Environment Interactions in Sorghum, *Sorghum bicolor* (L.) Moench

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Summary. The most significant and important interactions in 2, and 3-year sorghum zonal trials were location × year, cultivar × location and cultivar × location × year. Cultivar × year interaction was significant in one out of four ecologic zones used in the trials. The variance components were relatively small with the second order interaction variance component larger than the first order types involving cultivars. Environmental variance was the largest in all four zones.

Computations on theoretical standard error of cultivar means suggest that six replications, eight locations and four years is an ideal testing procedure in the Northern Guinea Savanna, while in the Sudan Savanna, the combination is better with four replications, eight locations and three years. The true value or performance of a variety is most effectively obtained by increasing the number of years, while increasing number of replications is the least effective.

Key words: Sorghum – Environment – Interaction – Variance components – Zonal trial – Stability

Introduction

The ultimate aim of a crop improvement program is the development of improved crop cultivars and their release for production. Before the cultivars are released as high yielding types, they are tested in multilocational and macroplot experiments for several years. Such zonal trials identify which cultivar is best for what environment. The Institute for Agricultural Research conducts the regular evaluation of new improved sorghum cultivars (varieties) at four distinct ecologic zones of the savanna region in Nigeria. These zones coincide with four maturity groupings.

The objectives of this paper are 1) to identify testing procedures appropriate for sorghum before new improved varieties are released, 2) to estimate stability and adaptation parameters for the sorghum varieties used and 3) to evaluate the amount and relative importance of various cultivar × environment interaction components in sorghum yield trials repeated over years and locations.

Materials and Methods

Data used were obtained from national sorghum state trials in four different ecologic zones, namely; Northern Sudan Savanna (NSS), Sudan Savanna (SS), Northern Guinea Savanna (NGS) and Southern Guinea Savanna (SGS). Three, four, five and three cultivars (pure line varieties) (Table 1) were evaluated in four locations each (Table 2) in NSS, SS, NGS and SGS, respectively, in 1975, 1976 and 1977. The cultivars 'H.P.3', 'H.P.8' and 'B.E.S.' are dwarf, early and non-photosensitive and adapted to the short growing season (90-110 days) of the NSS. The long-season 120-150 day cultivars 'RZI', 'KBL', 'KL 408' and 'KL 538' are semi-dwarf,

Table 1. Mean yield, stability and adaptation parameters for 15 cultivars used in 1975 – 77 yield trials in four sorghum ecologic zones

Cultivar	Zonal distribution	Mean Yield (t/ha)	Linear response (b value)	Deviation from regression	R^2
H.P.3	Northern Sudan Savanna	2.15	1.18 ± 0.12[a]	0.06	0.94
H.P.8	"	1.94	0.91 ± 0.01	0.04	0.94
B.E.S.	"	2.23	0.91 ± 0.18	0.15	0.81
RZI	Sudan Savanna	1.24	1.31 ± 0.19[a]	0.05	0.89
KBL	"	1.14	1.07 ± 0.07	0.01	0.97
KL 408	"	1.12	0.73 ± 0.15[a]	0.03	0.80
KL 538	"	1.15	0.88 ± 0.18[a]	0.05	0.80
S.L.181	Northern Guinea Savanna	1.92	1.15 ± 0.15	0.17	0.86
S.L.1499	"	2.25	1.16 ± 0.11[a]	0.10	0.91
S.L.187	"	2.29	1.28 ± 0.11[a]	0.09	0.93
SK 5912	"	2.33	0.96 ± 0.15	0.17	0.80
FFBL	"	1.72	0.46 ± 0.12[a]	0.11	0.60
C-7-4	Southern Guinea Savanna	1.30	1.12 ± 0.10	0.01	0.96
ML-4	"	1.34	0.98 ± 0.12	0.01	0.92
FDI	"	1.35	0.94 ± 0.11	0.01	0.92

[a] b values significantly different from 1.00 at 0.05 level of probability

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Table 2. Locations in Savanna ecological zones used in the 1975 – 77 sorghum variety trials

Zone	Location	Mean yield (t/ha)	Total rainfall for zone (mm)	Growing season for zone (days)
Northern Sudan Savanna	Maiduguri	2.46	600	90-110
	Damaturu	1.67		
	Gashua	1.63		
	Kano	2.66		
Sudan Savanna	Kafinsoli	1.01	750	120-150
	Gusau	1.05		
	Gwoza	0.96		
	Kano	1.64		
Northern Guinea Savanna	Maigana	1.73	1000	150-180
	Mubi	1.68		
	Saminaka	1.66		
	Samaru	3.34		
Southern Guinea Savanna	Wawa	1.08	1100	over 180
	Katsina Ala	1.14		
	Minna	1.36		
	Bara	1.75		

photosensitive and adapted to the SS. Cultivars 'S.L. 181', 'S.L. 1499', 'S.L. 187', 'SK 5912' and 'FFBL' are medium maturing (150-180 day), photosensitive and adapted to the NGS. In the NGS group the first three are very recent semi-dwarf varieties, while the last two are older varieties, tall and very tall, respectively. Cultivars 'C-7-4', 'ML-4' and 'FDI' are very tall (4 meters), photosensitive and very late (over 180 days to mature), and adapted to the very long growing season of the SGS.

Each experiment was replicated five times in a randomised complete block, with eight row plots 5.4 m long and 90 cm apart. The centre six rows were harvested for yields. The yield data were subjected to regression analysis to estimate adaptation parameters, including linear response (b), deviation from regression (s^2d) and the coefficient of determination (R^2). The individual cultivar response to changing environments (yield stability) was determined by regression of individual cultivar mean yields within each environment upon mean yield of all cultivars in that environment (Finlay and Wilkinson 1963). A regression coefficient greater than one indicates response to increasing favorable conditions with respect to site mean yield, while a coefficient less than one indicates no response.

The combined analyses of variance computed from data from all locations and years within each zone were used to estimate pertinent variance components. These were then used to calculate the theoretical variance of a cultivar mean with different combinations of replications, locations and years (Rasmusson and Lambert 1961) as:

$$G_{\bar{X}} = \frac{\bar{O}^2 gl}{l} + \frac{\bar{O}^2 gy}{y} + \frac{\bar{O}^2 gly}{ly} + \frac{\bar{O}^2 e}{rly}$$

From this relationship, the standard error of a cultivar mean was obtained. The form of analyses of variance with mean squares and their expectations follow that described by Comstock and Moll (1963).

Results and Discussion

A characterisation of the several cultivars tested in the different ecologic zones is shown in Table 1. Cultivar mean yields range from 1.12 t/ha in the Sudan Savanna (SS) to 2.33 t/ha in the Northern Guinea Savanna (NGS). A definite trend in the yielding ability of the cultivars was therefore indicated for the different ecologic zones (Tables 1, 2) with lowest yields in SS and the highest yields in NGS. It has been suggested (Finlay and Wilkinson 1963; Bilbro and Ray 1976) that in areas where management, soil or climatic variables cause definable and distinct differences in yield, the regression coefficient, b, should be used as an indicator of adaptation rather than stability. Stability, as described by Eberhart and Russell (1966), is applicable to high-yield environments. In the four savanna zones of Nigeria where sorghum is grown there are combinations of two or more factors that cause distinct differences in cultivar performance. In this paper, therefore, b is used as adaptation parameter; the deviation from regression, S^2d and the coefficient of determination, R^2, as stability parameters. A stable cultivar would have a very high R^2 value and very low or zero deviation from regression, $S^2d = 0$. 'H.P.3' in the NSS, 'RZI' in the SS, 'S.L. 1499' and 'S.L.187' in the NGS all have b values significantly greater than 1.00. The indication is that these varieties have the genetic potential to respond by high yields to increasingly favourable environments when available. Three varieties, 'K.L. 408', 'K.L. 538' in the SS and 'FFBL' in the NGS have b values significantly lower than 1.00 and are therefore better adapted to low-yield environments in their respective zones. The very low deviations from regression and high R^2 values for all the cultivars in the four zones indicate stability of performance. Two cultivars in the NSS ('H.P.3' and 'H.P.8') and all cultivars in the SGS are equally stable in their respective zones.

Two main effects (locations and years) were highly significant in all the zones except SGS for years (Tables 3, 4). This was to be expected because of the wide diversity between the four locations used for tests in the zones. No significant differences were observed among years in the

Table 3. Combined analysis of variance for grain yield (t/ha) of five cultivars grown in the Northern Guinea Savanna (NGS) for three years in the four locations

Source	d.f.	Mean square	Expected mean square
Locations (L)	3	54.26[a]	
Years (Y)	2	16.71[a]	
L × Y	6	5.56[a]	
Cultivars (G)	4	3.10[a]	$\sigma^2 e + 5\,\sigma^2 gly + 15\,\sigma^2 gl + 20\,\sigma^2 gy + 60\,\sigma^2 g$
G × L	12	1.60[a]	$\sigma^2 e + 5\,\sigma^2 gly + 15\,\sigma^2 gl$
G × Y	8	0.85[a]	$\sigma^2 e + 5\,\sigma^2 gly + 20\,\sigma^2 gy$
G × L × Y	24	0.66[a]	$\sigma^2 e + 5\,\sigma^2 gly$
Error	236	0.21	$\sigma^2 e$

[a] Significance at P = 0.01

Table 4. Combined analysis of variance for grain yield (t/ha) of cultivars grown in three zones (NSS, SGS and SS) for two years and in four locations

		Mean square			Mean square
Source	d.f.	NSS	SGS	d.f.	SS
Locations (L)	3	20.90[a]	3.03[a]	3	1.95[a]
Years (Y)	1	23.22[a]	0.57	1	4.19[a]
L × Y	3	5.36[a]	0.71[b]	3	1.01[a]
Cultivars (G)	2	0.63	0.04	3	0.28
G × L	6	0.30	0.05	9	0.28[b]
G × Y	2	0.29	0.05	3	0.26
G × L × Y	6	0.41	0.10	9	0.28[b]
Error	92	0.31	0.23	124	0.12

[a] Significance at P = 0.05
[b] Significance at P = 0.01

SGS and among the cultivars used in the NSS, SGS and SS. Cultivars were, however, significantly different in their performances in the NGS (Table 3). The location × year interaction was highly significant in all four zones, as was previously found for maize experiments in Nigeria (Obilana and Futunla 1976). Cultivar × location interaction was significant in only two zones (NGS and SS) while cultivar × year interaction was significant in only NGS. The presence of significant cultivar × location interactions suggested a differential response of the pure lines at different locations in the two zones. The lack of cultivar × year interactions is an indication of relative stability of the cultivars grown at present, over the years in the different zones. Significant genotype × location or genotype × environment interactions have been found in several countries for yield in different crops; for example, sorghum hybrids in India (Rao 1970) and USA (Liang and Walter 1966), sorghum random-mating populations in USA (Kofoid et al. 1978), wheat (Campbell and Laferver 1977), maize (Obilana and Fatunla 1976) and in several other crops, autogamous or allogamous. However, significant genotype × year interactions have been recorded for sorghum hybrids (Rao 1970; Liang and Walter 1966) and random-mating populations (Kofoid et al. 1978) different from what was observed for pure line genotypes in most of our savanna region. In two of the zones (NGS and SS) the second-order interaction, cultivar × location × year, was significant, as has been found by previous workers in other crops, for yield. The lack of significant first and second-order interactions with cultivars in the NSS and SGS is interesting. It could definitely not mean that there is no environmental interaction effect on the genotypes. The reason could probably be that the number of locations and years used was too few to be able to identify statistical differences and/or the locations chosen were too similar in the two zones.

Estimated variance components for cultivars ($\bar{O}^2$g) and cultivar × year ($\bar{O}^2$gy) were relatively too low in all zones. In most of the zones, the cultivar × location × year variance component ($\bar{O}^2$gly) was higher than the ($\bar{O}^2$gl) cultivar × location variance and the $\bar{O}^2$gy. In all the zones the environmental variance ($\bar{O}^2$e) was highest.

Similar to what was earlier reported by Eberhart and

Table 5. Estimates of variance components for yield (t/ha), and $r_{Y.E}$[a] from sorghum performance trials in four ecologic zones

Variance	Zone			
components	NSS	SS	NGS	SGS
σ^2g	0.01	0.00	0.02[a]	0.00
σ^2gl	−0.01	0.02[b]	0.06[a]	−0.01
σ^2gy	−0.01	0.01	0.01[a]	−0.00
σ^2gly	0.02	0.03[b]	0.09[a]	−0.13
σ^2e	0.31	0.12	0.21	0.23
$r_{Y.E}$	0.93	0.91	0.87	0.96

[a]$r_{Y.E}$ = correlation between mean yield and environmental index
[a] Significance at P = 0.01
[b] Significance at P = 0.05

Table 6. Theoretical standard errors of cultivar means under different testing methods

Combinations of replications	Ecologic zone	
locations and years	SS	NGS
2-4-2	0.148	0.211
2-4-3	0.126	0.186
2-4-4	0.114	0.172
2-6-2	0.126	0.177
2-6-3	0.108	0.155
2-6-4	0.098	0.144
2-8-2	0.114	0.157
2-8-3	0.098	0.138
2-8-4	0.089	0.125
4-4-2	0.134	0.195
4-4-3	0.114	0.174
4-4-4	0.110	0.162
4-6-2	0.100	0.164
4-6-3	0.100	0.146
4-6-4	0.089	0.136
4-8-2	0.105	0.146
4-8-3	0.089	0.130
4-8-4	0.084	0.120
6-4-2	0.126	0.189
6-4-3	0.110	0.169
6-4-4	0.105	0.159
6-6-2	0.110	0.159
6-6-3	0.095	0.142
6-6-4	0.089	0.133
6-8-2	0.105	0.142
6-8-3	0.089	0.127
6-8-4	0.084	0.118

Russell (1966) for maize, in this sorghum experiment the correlation between the mean yield and environmental index 'Y.E. in the NSS' SS, NGS and SGS (0.93, 0.91, 0.87 and 0.96, respectively) were very high and significant. When three estimates were used to calculate the errors for various combinations of replications, locations and years it was found that four replications, eight locations and three years in the SS, and six replications, eight locations and four years in the NGS, would allow about 5% differences in yield between cultivars to be detected (Table 6). The most effective way to reduce the standard error would be by increasing the number of locations and years and the least effective would be by increasing the number of replications.

When new cultivars have been developed it is important to release them for zonal acceptability tests and eventual production as soon as they show high performance in breeders' plots. Increasing the number of years for such tests has the disadvantage of delaying results, although as has been shown it is the most effective way of reducing error. Generally, increasing the number of replications tends to reduce error; and since it is practically cheaper to increase replications rather than locations or years, it could be recommended based on this experiment that reducing the locations from eight to six, and years from three to two with an increase in replication though not necessarily as shown in Table 6, would be adequate for the SS zone. Similarly, reducing years from four to three years would generally be adequate for the NGS zone. Increasing replications from four to six does not, however, reduce error in this experiment.

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