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A multivariate analysis of variance (MANOVA) of the performance of sorghum lines in different agro-ecological regions of Zimbabwe

D. Maposa[1*], E. Mudimu[2] and O. Ngwenya[3]

[1]Department of Statistics and Operations Research, University of Limpopo, Turfloop Campus, Private Bag X1106, Sovenga 0727, South Africa.
[2]Department of Decision Sciences, University of South Africa, P. O. Box 392, UNISA, Pretoria 0003, South Africa.
[3]Department of Applied Mathematics, National University of Science and Technology, Zimbabwe.

This study presents a multi-environment trial to evaluate the performance of sorghum lines in a target population of environments in Zimbabwe. The study attempts to determine whether genotypic variation and/or genotype-environment interaction have a significant effect on sorghum performance. It also attempts to determine whether the promising sorghum lines perform better than the established varieties with the aim of selecting promising sorghum lines of superior performance. To analyse the data, multivariate analysis of variance is used in this study. Results show that both environment and genotypic variation contribute to differences in sorghum line performance. Results in two of the selected sites (Kadoma and Matopos) suggest that sorghum lines significantly differ in their performance due to genotypic make-up. It is concluded that environment is the major contributor to differences in sorghum performance though genotypic make-up also play a part. Provisionally, promising lines of superior performance are NL9411 and NL9907.

Key words: Multi-environment, MANOVA, resettled farmers, sorghum production, genotype-environment.

INTRODUCTION

Sorghum and millet are important food crops in moisture-stressed regions of the world; they are staple crops for millions in Africa and Asia (Tuinstra, 2008; Christiansen and Frederick, 2004). According to the statistics from the Food and Agriculture Organisation (FAO), the average annual global production of sorghum during the triennium, 1977-1979 was 68.7 million tones. Over 52 million hectares were planted each year with numerous varieties and hybrids of sorghum. The annual millet production during the same period was 34.3 million tones from an area of 53.8 million hectares. Thus, sorghum and millet contribute annually over 100 million tones to the global food budget (FAOSTAT data, 2004; Hulse, 1995). The area planted with sorghum increased markedly during the late 1960s. This increase has been largely

due to the fact that the rainfall was well below average and insufficient for maize production (Jean du Plessis, 2008; Mertz, 2008; Lacy et al., 2006). Recently, more emphasis has been given to increase food production in the communal areas where sorghum is the third most important crop after maize and pearl millet. Farmers in low-rainfall areas are encouraged to grow sorghum as it contributes to household food security (Navi et al., 2005; Lacy, 2004; Mbwanda, 1987; Shumba, 1984). Agricultural scientists are contributing to the transformation of sorghum from a subsistence crop to a value-added cash crop since population growth rate continue to exceed rate of increase of cereal production capacity.

In Zimbabwe, most of the sorghum is grown in the communal lands and to a greater or lesser extent in all provinces. It is extensively grown in the west and south of Bulawayo and mostly grown in Matabeleland South, Matabeleland North, Mashonaland Central, Manicaland and in the Sebungwe region parallel to Lake Kariba (Koza et al., 2000; Vogel, 1994; Pritchard and

*Corresponding author. E-mail: danmaposa@gmail.com. Tel: +27(0)152682792/2435.

Munowenyu, 1988; Shumba, 1984). Nearly 67% of the area under sorghum is in Natural Region IV, followed by Natural Regions III and V with about 15% each. More recently, sorghum has been grown on a large scale in Mashonaland West in the Norton, Chegutu and Kadoma areas. In Masvingo Province, it is grown in Nyajira, Sengwe, Bikita, Matibi areas as well as in Marondera. Nearly 75% of the communal areas are located in Natural Regions IV and V where rainfall is low and erratic. Hence, sorghum and millet, which yield at least some grain even in years of low rainfall, are grown (Almodares et al., 2005; Baumhardt et al., 2005; Mbwanda, 1987). Various factors that appear to constrain a more widespread acceptance and use of sorghum include tedious and lengthy traditional methods of household preparation, lack of commercially processed sorghum foods, commercial mills for decortications, grinding and fractionation. In order to increase the yields of small grain cereals, research on the development of high yielding stable cultivars and hybrids, improved agronomic practices aimed at maximizing yield and the design of simple implements for grain processing needs to be intensified (Alemu et al., 2005; Awika et al., 2005; Setimela et al., 2005; Lacy, 2004).

The land resettlement programme in Zimbabwe has resulted in many farmers acquiring land and engaging in agriculture as a way of raising income to improve their livelihoods. In farm development, an individual farmer awarded a piece of land has the challenge to do proper planning so that a feasible solution with minimum resources available may be arrived at. The choice of appropriate sorghum lines will help the farmer to raise income from sales and re-invest it into the system for self-sustenance rather than depending on loans for farming activities and other investment plans (Christiansen et al., 2004; Yapi et al., 2000).

Not all sorghum lines perform best in equal amount of rainfall and spectral of temperature and soils. This is a cause of concern as it gives farmers problems in selecting promising sorghum lines for early maturity and high yielding. The incidence of genotype by environment (G*E) interaction complicates selection of genotypes (sorghum lines) with superior performance. Multi-environment trials (METs) are widely used by plant breeders to evaluate performance of genotype for a target population of environments (Abu Assar et al., 2005; Audilakshmi and Aruna (2005), Audilakshmi et al., 2005, a, b; Folkertsma et al., 2005).

In this study, the main focus is on the assessment of the performance of different sorghum lines in different agro-ecological regions. The objective of this study is to determine whether location (environment) has a significant effect on sorghum performance and also to determine whether promising sorghum lines perform better than the established varieties. This study also attempts to select promising lines for early maturity and high quality, and recommend them to farmers.

MATERIALS AND METHODS

Experimental sites

The experimental trials were conducted in Matopos, Kadoma, Sandveld, Gwebi and Makoholi Research Stations. The description of the experimental sites is presented in Table 1.

Data management

The following information and abbreviations were used in the recording of field data.

1. GCOL-Grain color: recording the color of grain on the panicle as either Red (R), Brown (B), Pearl White (PW), Chalky White (CW), Speckled (S)
2. DMA-Days to 50% flowering: Number of days from planting until half the number of plants in a plot has started blooming (show exerted stigmas).
3. DPM-Days to physiological maturity: Number of days from planting until a black layer has been formed above the hilar region of the seed.
4. PTH-Plant height (cm): Measuring the distance from the base of the plant to the tip of the main head (panicle). Taking an average height of 10 plants.
5. EXSN-Exertion (cm): Measuring the distance from the flag leaf to the base of the head (panicle). Taking an average of 10 points.
6. HHW-Harvested Head Weight (g): After harvesting the net plot, measures the weight of harvested heads before threshing to the nearest gram.
7. GYD-Grain yield (g): After threshing and adequate drying, record the grain weight per net plot to the nearest gram.
8. WTS-Weight of 1000 seeds (g): Weighing 1000 seeds and recording the weight in grams.
9. MOST-Moisture %: Measuring the moisture soon after grain weight and recording to the nearest one decimal.

Agronomic scores (AS) are as follows: 1 (very good), 2 (good), 3 (average), 4 (poor), 5 (very poor). The scores are done considering traits such as standibility, size of head and shape, plant height, grain quality and disease attack on the ratings.

Experimental design

A multi-environmental trial was conducted over five environments/ sites in Zimbabwe, using a total of sixteen sorghum lines. These sixteen sorghum lines included two released (standard/control) varieties namely; SV4 and SV2. The remaining fourteen sorghum lines were the promising lines namely; SDSL9000, NL9803, NL9907, NL9921, NL9411, NL9926, NL9902, NL9901, NL9809, NL9923, NL9964, NL9932, NL9804 and NL9412.

The sorghum lines were grown at each location in a randomized complete block design with three replications and four rows/plot. The plots were 2 rows × 0.75 m × 4 m = 6 m^2 in size, with 0.75 m between rows and plants. The inrow spacing was 0.2 m, while the length of row was 5 m. The blocks are the sites (locations) and the treatments are the sorghum lines (Carmi et al., 2005; Milken and Johnson, 1997).

Description of established sorghum varieties

The characteristics of the established sorghum varieties SV4 and SV2 are such that both varieties are semi-dwarf open pollinated and have good milling qualities of up to 70%. The average heights for the two varieties are 1.30 m and between 1.4 and 1.6 m

respectively. Physiological maturity for SV4 is within 113 to 127days and SV2 is between 110 to 115 days. The major difference between the two varieties is that SV2 has a characteristic thin stem and pearl white grain while SV4 has a hard corneous, whole white bold grain type. The panicle for SV4 is big and semi-compact with good exertion (12 – 16 cm). SV4 generally does not tiller but SV2 has an average of 1.5 tillers per plant. In yield trials conducted over several seasons and locations, SV4 has shown a high yield potential of between 3.4 and 9.0 tons/ha and SV2 ranges between 3 and 6 tons/ha. Both varieties are highly adaptable and can be grown in all sorghum growing regions depending on the amount of rainfall. SV4 grows well with rainfall of 300 – 900 mm/year that should be well distributed and SV2 can be grown in any area with an average rainfall between 250 and 750 mm (Soleri et al., 2004; Dahlberg, 2000).

Plant management

Basal fertilizer for root formation and root growth was applied to the ground before planting. Sorghum line seeds were sown on the 19 of December 2005. Weeding was done on the 23 of January, 8 of February and 6 of March 2006. Plants were thinned to maintain the recommended space in between them on the 11 of January and the 3 of February 2006. Top dressing fertilizer for flowering and pollination was applied to the plants on the 10 of February 2006. Hand harvesting was done on 6 June 2006. Threshing and weighing of yields was the last activity.

Statistical methodology

The data to be analysed comprise of independent variables represented by the treatments, locations and dependent variables represented by the response namely: yield, harvested head weight and plant height. We wish to observe the effects of the treatments on three dependent variables simultaneously. We are also mainly interested in the multiple analyses of variance on the individual response variable but we want to control the probability of rejecting one or more of the numerous null hypotheses when they are all true (Cliff, 1987). The scenarios given here would best be achieved if and only if multivariate analysis of variance (MANOVA) in a randomized complete block design is employed. The statistical model for a completely randomized block design is

$Y_{ijk} = \mu + \tau_i + \beta_j + \varepsilon_{ijk}$

Where; Y_{ijk} is the kth observation in the ith treatment and j^{th} block, μ is overall mean for all observations, τ_i is the ith treatment, β_j is the jth block, ε_{ijk} is the error term.

The main advantage of RCBD is that, if blocking is effective, then an RCBD experiment gives more precise conclusions than a CRD that uses the same experimental units. MANOVA is an extension of analysis of variance (ANOVA) to accommodate more than one dependent variable. The unique aspect of MANOVA is that the variate optimally combines the multiple dependent measures into a single value that maximizes the differences across the groups. MANOVA provides additional insights into the effects of independent variables on dependent variables that are not provided by ANOVA (Kleinbaun et al., 1998; Sharma, 1996).

MANOVA has three main assumptions. The first and most fundamental assumption in MANOVA is normality, referring to the shape of the data distribution for an individual metric variable and its correspondence to the normal distribution, the benchmark for statistical methods. Although univariate normality does not guarantee multivariate normality, if all variables meet this requirement, then any departure from multivariate normality are usually inconsequential.

According to research for ANOVA and MANOVA, violation of the normality assumption does not have an appreciable effect on Type I error and it affects the power of the test statistic (Johnson and Wichern, 1998).

The second assumption is that the covariance matrices for all treatments must be equal. The requirement of equivalence is a strict test because instead of equal variances for a single variance in ANOVA, the MANOVA test examines all elements of the covariance matrix of the dependent variables. Fortunately, a violation of this assumption has minimal impact if the groups are of approximately equal size (Holloway and Dunn, 1967). Therefore, every effort should be made to have equal cell sizes (Alin and Kurt, 2006), as is the case with the data used in this study.

The third and last assumption is that the observations must be independent. This assumption has a substantial effect on significance level and power of a test. Independence is desirable because the variance of the dependent variable being explained in the dependence relationship should not be concentrated in only a limited range of the independent values. Research has indicated that for correlated observations, the actual alpha level could be as much as ten times the nominal alpha level (Scariano and Davenport, 1986), and the effect worsens as the sample size increases. Glass and Hopkins (1984) made the following statement regarding the conditions under which the independence assumption is most unlikely violated: "whenever the treatment is individually administered, observations are independent".

Multivariate analysis of variance (MANOVA) significance tests

Wilk's Lambda (Λ) Test statistic is a test statistic used in MANOVA to test whether there are differences between the means of the identified groups of subjects on a combination of dependant variables, that is, it is used to test the null hypothesis.

$$H_0 = \begin{pmatrix} \mu_{11} \\ \mu_{21} \\ \mu_{31} \end{pmatrix} = \begin{pmatrix} \mu_{12} \\ \mu_{22} \\ \mu_{32} \end{pmatrix} = ... = \begin{pmatrix} \mu_{1g} \\ \mu_{2g} \\ \mu_{3g} \end{pmatrix},$$

Where; μ_{ig} ($i = 1,2,3$) is the population mean for the variable yield, plant height and harvested head weight respectively for all g. To test if there are no differences between treatment mean vectors of the g ($g = 16$) treatments, we make use of the quantity

$$\Lambda = \frac{\mid S_{error} \mid}{\mid S_{effect} + S_{error} \mid}$$

Wilk's Lambda is the test statistic preferred for MANOVA and it works closely with the F-test (Tabachnick and Fidell, 1996). An estimate of *F* can be calculated through the following equation:

$$F_{approximate} = \left(\frac{1 - \sqrt{\Lambda}}{\sqrt{\Lambda}} \right) \left(\frac{n - g - 1}{g - 1} \right),$$

Table 1. Description of the experimental sites.

Location	Drainage	pH	Soil texture	Max Temp (°C)	Min Temp (°C)	Annual Rainfall (mm)	Altitude (m)	LPG	Longitude (degrees)
Matopos	MD	High	Fine	25	12	591	1416	4	28.5
Makoholi	MWD	Medium	Medium	26	13	628	1111	5	30.8
Kadoma	MWD	High	Fine	28	14	735	1107	5	29.9
Gwebi	MWD	High	Fine	29	15	740	1110	5	30.1
Sandveld	MD	Medium	Medium	25	13	570	1450	4	28.1

MD: Moderately drained; MWD: moderately well drained; LPG: length of growing period.

Table 2. Summary of results for locations across the sorghum lines.

Location	Grain yield, mean (g)	Head weight, mean (g)	Plant height, mean (cm)	F-ratio for lines/ location
Gwebi	1371	2112	161.7	1.56 ns
Kadoma	2688	3413	171.6	2.43*
Makoholi	479	788	96.6	0.73 ns
Matopos	1086	1358	146.5	2.75*
Sandveld	1016	1485	134.6	0.41 ns
Grand mean	1328	1831	142.2	
F-ratio location	199.19**	153.17**	149.63**	
S.E.D	82.8	114.5	3.37	

MANOVA Tests results for location: Wilk's Lambda: 0.08715, Approximate Chi sq: 536.83 on 12 d.f., Approximate F test: 72.86** on 12 and 577 d.f., Pillai-Bartlett trace: 1.369, Roy's maximum root test: 0.8333, Lawley-Hotelling trace: 5.800. Note: **, * significant differences at the 1% and 5% level of significance respectively. ns stands for not significant at 5% level of significance. S.E.D stands for standard error for differences.

Where; n = total sample size and g is number of treatments (Rencher, 1998; Hair et al., 1995). ,,,,,,

RESULTS

A statistical package called Genstat was used to analyse the data. Genstat is among the most powerful statistical packages such as SPSS, SAS and MINITAB used in research institutions. The results from the Genstat output are presented and discussed in this section.

Effect of location (environment) on performance of sorghum lines (varieties)

The effect of location on sorghum varieties in terms of grain yield, harvested head weight and plant height is presented in Table 2.

Grain yield

The results presented in Table 2 show that the highest mean yields were experienced in Kadoma and Gwebi (2688 and1371 g respectively), which are greater than the grand mean (1328 g). This could be due to high rainfall in those areas and well-drained soils. Makoholi recorded the lowest mean yield of 479 g. The lowest mean yield in Makoholi can be attributed to its soil texture and pH which possibly resulted in water-logging due to heavy rains received in 2005 - 2006 season, otherwise it had average amount of rainfall similar to Gwebi and Kadoma. Matopos and Sandveld had an average mean yield (1087 and 1016 g respectively) due to the fact that they are in the same region with a difference in soil types.

The differences in mean yield due to location are confirmed by the F-ratio for grain yield. Since the computed F-ratio (199.19) lies in the critical region, $(F_{4,220}^{0.05} = 2.37)$, at 5% level of significance we reject H_0 and conclude that there is overwhelming evidence of significant differences in the mean yield due to location.

Harvested head weight

Gwebi and Kadoma had the highest means for harvested head weight (2112 and 3413 g respectively), due to the high rainfall and well-drained soils, while Makoholi recorded the least mean harvested head weight (788 g) which is less than the grand mean (1831 g) which could also be due to its soil pH and texture as well as water-logging. Sandveld and Matopos had an average head weight (1485 and 1358 g respectively), again for thesame
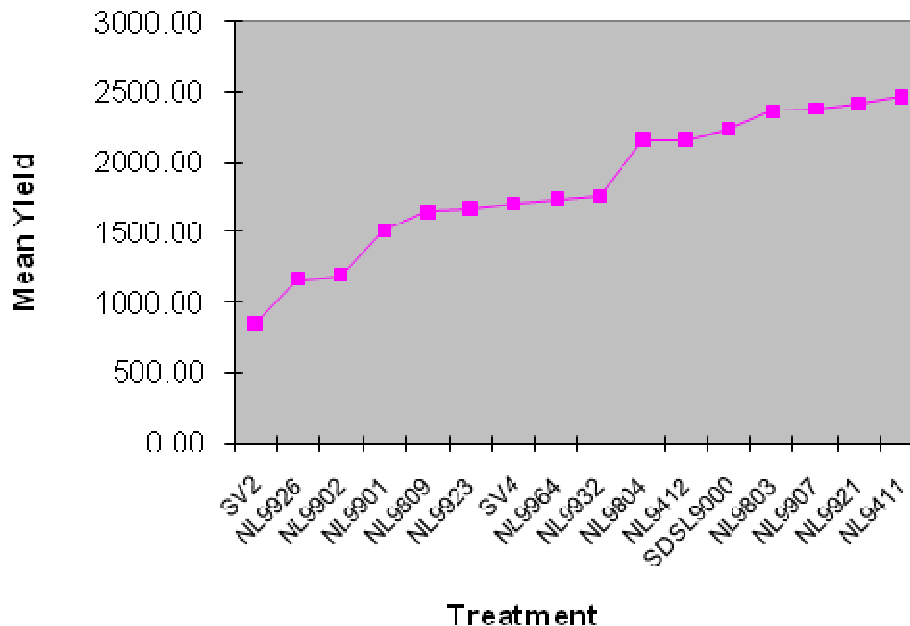
Figure 1. Performance of sorghum lines in terms of yield in Matopos Research Station.

same reason that the two locations are in the same region with a difference in soil types.

Since the computed F-ratio (153.17) lies in the critical region, $(F_{4,220}^{0.05} = 2.37)$, at 5% level of significance, we reject H_0 and conclude that there is overwhelming evidence of significant differences in the mean harvested head weight due to locations.

Plant height

The crops in Gwebi and Kadoma had the highest mean plant heights (161.7 and 171.6 cm respectively) which are greater than the grand mean (142.2 cm), while Makoholi had a least mean plant height (96.6 cm), less than the grand mean. Matopos and Sandveld had average mean plant height (146.5 and 134.6 cm respectively). The differences found in plant height due to location could be attributed to the same reasons as those given for yield. The computed F-ratio (149.63) lies in the critical region, $(F_{4,220}^{0.05} = 2.37)$, hence at 5% level of significance we reject H_0 and conclude that the locations have highly significant differences with respect to plant height.

Performance of sorghum lines at different locations

The F-ratios for the effects of the performance of sorghum lines at each location are also presented in Table 2. From the F-ratios given, we find that only Kadoma and Matopos have significantly different sorghum line (treatment) means at 5% level of significance. Sorghum lines in Gwebi, Makoholi and Sandveld do not exhibit significant different means therefore we have no reason to look for best lines in these locations. Figures 1 and 2 present the performance of sorghum lines in Matopos and Kadoma. Figure 2 shows that the best performing sorghum lines in Kadoma are SV4, NL9907, NL9411 and NL9923 whereas NL9809 and NL9803 are the worst performers.

Figure 1 shows that the best performing sorghum lines in Matopos are NL9411, NL9921, NL9907 and NL9803 while SV2, NL9926, and NL9902 are the worst performers.

Effect of sorghum lines on grain yield, head weight and plant height

Table 3 presents results for the performance of sorghum lines (treatments) across the five locations with respect to yield, plant height and head weight. We found out that the computed F-ratios (1.89, 2.09 and 4.73 respectively for grain yield, harvested head weight and plant height) all lie in the critical region $(F_{15220}^{0.05} = 1.67)$ at the 5% level of significance. We therefore reject H_0 (that is, the treatments have equal means) and conclude that the sorghum lines have significant differences with respect to yield, harvested head weight and plant height.

The best performing sorghum lines with respect to grain
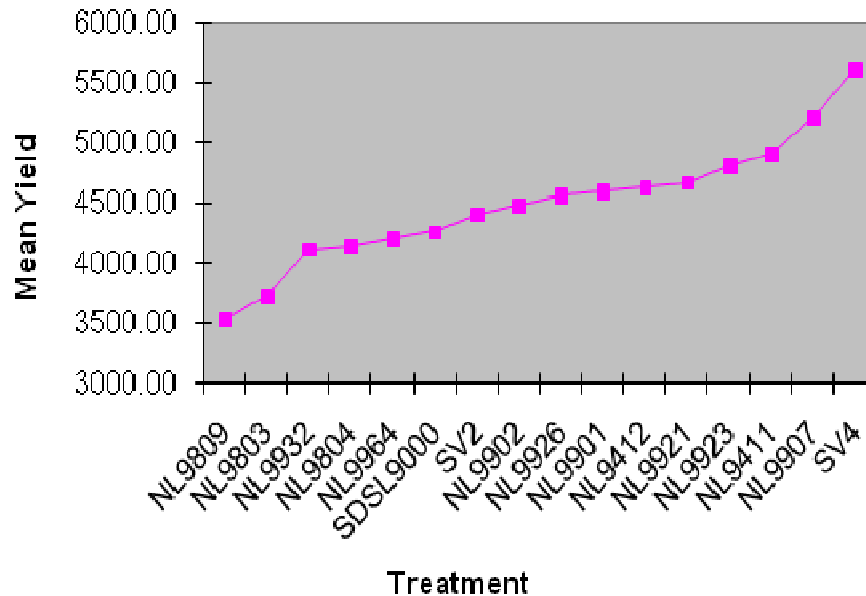
Figure 2. Performance of sorghum lines in terms of yield in Kadoma Research Station.

grain yield are NL9411, NL9412, NL9803, NL9901, NL9907, NL9921 and SV4. All these have means that are greater than the grand mean yield, while the rest of the sorghum lines have means that are less than the grand mean yield. It is interesting to find that SV2 is among the sorghum lines whose means is less than the grand mean. This is an indication that farmers are likely to gain from the promising lines in terms of yield and eventually drop SV2 in favour of some promising new varieties.

With respect to harvested head weight, the sorghum lines with means greater than the grand mean are NL9411, NL9803, NL9907, NL9921, NL9926, NL9932 and NL9964. The rest of the sorghum lines have means for harvested head weight less than the grand mean. However, it must be noted that the mean for SV4 is not significantly different from the grand mean and this can easily be deduced by noting that the difference between the mean of SV4 and grand mean is less than the standard error of differences (S.E.D). This confirms that the established variety SV4 is not a bad performer in terms of harvested head weight.

Sorghum lines that performed above average in terms of plant height were NL9411, NL9412, NL9923, NL9964, SDSL90004 and SV2. Here we find that SV2 is among the best performers in terms of plant height. Once again we noted that the mean of SV4 is not significantly different from the grand mean.

Among the promising sorghum lines, we find that the best performing and most consistent in terms of yield, harvested head weight and plant height are NL9411, NL9907, NL9803, NL9921, NL9412 and NL9964 in respective order of performance. The differences found among sorghum lines could be attributed to genotypic make-up.

Wilk's Lambda and F-test for the matrices of location and line

From Table 3, Wilk's Lambda ($\wedge$) is 0.5830 for sorghum lines and the approximate F-test is 2.87 which is significant at 5% level of significance. This means that the differences in the performance of sorghum lines are partly due to their genotypic make-up. For location, Wilk's Lambda ($\wedge$) is 0.08715 and the approximate F-test is 72.86 which clearly shows overwhelming evidence of significant differences in the performance of sorghum lines that are attributed to location (environment). These findings cement the fact that both location and genotypic make-up play a major role in making a decision about sorghum production.

DISCUSSION

In this study, we looked at the performance of sorghum these lines with the lines at five different sites as a way of getting best performing lines. We also compared established lines SV2 and SV4 as a way of controlling the experimental trial. We found that Gwebi, Makoholi and Sandveld had no outstanding promising lines and therefore we can not recommend the farmers in these areas to switch to the promising lines. We recommend farmers in these areas to continue growing the established varieties and at the same time the research, particularly in these sites, should continue until an optimal solution has been found.

Sorghum lines NL9411, NL9921, NL9907 and NL9803 were found to have superior performance in Matopos and SV4, NL9907 and NL9411 in Kadoma. Lines NL9411 and

Table 3. Summary of results for sorghum lines across the locations**.**

Lines	Grain yield (mean), (g)	Head weight (mean), (g)	Plant height (mean), (cm)
NL9411	1522	2254	152.6
NL9412	1418	1762	142.5
NL9803	1474	2186	139.7
NL9804	1288	1802	135.3
NL9809	1022	1611	133.3
NL9901	1336	1764	137.9
NL9902	1191	1563	132.5
NL9907	1557	2078	137.3
NL9921	1446	1942	141.8
NL9923	1322	1697	144.1
NL9926	1296	1833	130.9
NL9932	1318	1861	136.9
NL9964	1279	1891	161.8
SDSL90004	1304	1775	148.3
SV2	1094	1484	160.1
SV4	1386	1795	139.9
Grand Mean	1328	1831	142.2
F-ratio for Lines	1.89*	2.09*	4.73*
S.E.D	148.1	204.8	6.02

MANOVA Tests results for sorghum line: Wilk's Lambda: 0.5830, Approximate Chi sq: 121.67 on 45 d.f., Approximate F test: 2.87* on 45 and 648 d.f., Pillai-Bartlett trace: 0.4856, Roy's maximum root test: 0.2551, Lawley-Hotelling trace: 0.6034. Note: *Significantly different at the 5% level of significance. S.E.D stands for standard error for differences.

NL9907 appear at both sites and were also found earlier in this study to top the list of best performers in terms of grain yield, plant height and harvested head weight. In view of this, farmers in these areas can be recommended to start growing these lines together with the established variety SV4 especially those in Kadoma (Kofoid et al., 2005). However, based on the findings of this study, it will be too premature to make a conclusion on whether promising lines perform better than the established lines. Conclusion on this matter will be deferred to further studies until we have established stability, adaptability and consistency of the promising sorghum lines (Kilcer et al., 2005; Cleveland, 2001; Gauch, 1988).

This study has also confirmed that the issue of location is of paramount importance in sorghum production. Results of this study have revealed overwhelming evidence of significant differences in yield, plant height and harvested head weight due to location (environment). We have found that Gwebi and Kadoma had the highest mean grain yield, head weight and plant height which could be attributed to high rainfall and well-drained soils in these locations. On the other hand, Makoholi had the least mean grain yield, harvested head weight and plant height due to its soil pH and texture as well as water-logging. Sandveld and Matopos who are in the same agro-ecological region both had average mean grain yield, harvested head weight and plant height. Indeed common knowledge dictates that plants that produce quality grain yield must have good plant height and harvested head weight. This explains why the five locations were very consistent in their effects on the three aspects of sorghum namely: grain yield, plant height and head weight.

We conclude that the performance of sorghum lines can not be wholly attributed to genotypic make-up, but to a combination of both genotypic make-up and site. When farmers are making decisions about sorghum production they should first consider the environment (location), that is, the agro-ecological region, amount of rainfall received annually, soil texture and pH before considering the sorghum varieties of superior performance in that location. Based on the findings of this study, we conclude that lines NL9411 and NL9907 are promising to be very adaptable and consistent in performance, and the two lines are promising to be of superior performance.

This study paves way for several opportunities for research. The experimental trial should be studied over a period of at least five seasons in order to make concrete conclusions on the promising sorghum lines based on quality, early maturity, stability and adaptability. Other studies can also look at ways of improving soil pH and texture for the affected regions.

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