

Original Research Paper

Mega Environment Identification for Soybean [*Glycine max* L. Merrill] in Zambia

ABSTRACT

Aim: To identify the existence of soybean mega -environments and also identify soybean genotypes with specific and general adaptability in the agro- ecological regions of Zambia.

Study design: A Randomized Complete Block Design with four (4) replications at each location was used to carry out the experiment. Each plot had 4 rows of 6 m long each.

Place and Duration of Study: A multi- environment was carried out in the 2013/2014 agricultural season in four locations (Golden Valley Agricultural Research Trust (GART), Kabwe, Msekera and Masumba Research stations) in agro -ecological regions 1 and 2 of Zambia.

Materials and Methods: The experimental material consisted of 15 genotypes of soybeans viz., TGX 1740-2F (G1), TGX 1830-20E (G2), TGX 1835-10E (G3), TGX 1887-65F (G4), TGX 1904-6F (G5), TGX 1987-11F (G6), TGX 1987-23F (G7), TGX 1988-9F (G8), TGX 1988-18F (G9), 1988-22F (G10), TGX 1989-60F (G11), TGX 1990-129F (G12), Magoye (G13), Safari (G14) and Lukanga (G15). Planting was done at different times depending on the onset of the rains and hand weeding. Fertilization with basal dressing at a rate of 200kg/ha compound D was done with no inoculation for all the genotypes at planting across all locations. Data collection started when the crop had reached 50% flowering and the other parameters were recorded when the crop had reached maturity. The data collection procedure followed that by Ngalanuet al., (21). Data analysis was done using Genstat version 16 and GGE biplot.

Results: The results showed the existence of three mega- environments namely Kabwe/Msekera, GART and Masumba. Kabwe was found to be the most ideal environment for soybean production with Masumba being the worst. Kabwe was also the most discriminating location for testing of genotypes. Masumba was highly discriminating but not ideal. The genotypes yield mean score was 1239 Kg/ha and TGX 1988-22F was the highest yielding genotype with 1517 kg/ha and the lowest was TGX 1835-10E with 418 kg/ha. In terms of variability in accordance to GGE biplot, Safari was the most variable and the most stable was TGX 1988-22F. Therefore, the study concluded that the best genotype for general adaptability was the variety TGX 1988-22F which was ideal across all the locations as it was high yielding and stable. Six genotypes had a yield which was below the mean performance of the genotypes across all the locations; these were Lukanga, TGX 1835-10E, TGX 1830-20E, TGX 1988-18F, TGX 1987-23F and TGX 1987-11F. The mega-

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environment Kabwe/Msekera had TGX 1988-22F as the winning genotype, GART had safari and Masumba had Magoye.

Conclusion: The results justified the need for carrying out Multi-environment trials in the country for soybean genotypes.

Keywords: GGE Biplot, Genotype x Environment Interaction, Mega environment

1. INTRODUCTION

Soybeans is one of the most important cultivated crops in the world with about 6% of the world's arable land dedicated to its production (11). The increase in production of soybeans is being spurred by the growth of edible oil consumption in the developing countries (7). The increase has been concentrated in South America, USA, and Asia. Africa has however lagged behind, producing less than 1% of world production. Zambia being one of the African countries with the high-potential arable land has yet to make significant strides in increasing soybean production (8). Production has remained concentrated in the agro-ecological region II of Zambia which also had had variations in crop performance. The current study was done to understand the existence of soybean mega-environments and also identify soybean genotypes with specific and general adaptability in the agro-ecological regions of Zambia.

Genotype by environment interaction is the change in the relative performance of a character of two or more genotypes measured in two or more environments (4, 10). Genotypes by environment interactions are ascribed to differences in sensitivity, which means that a given environmental difference affects some genotypes more than others (6). Therefore, information on variety stability to varied environments is very important in isolating genotypes which are responsive to better environments and maintain satisfactory yields under poor management (5). Among the ways that have been used in an effort to resolve this problem is that of grouping environments into mega-environments by way of genotype response. A mega-environment is defined as a subset of locations that consistently share the best set of genotypes and the regions are relatively homogenous with similar biotic and abiotic stresses and cropping system requirements (30). The pattern of genotype response allows partitioning of test sites into mega-environments and ideal environments based on their discriminating ability (27).

Genotype x environment interactions in soybeans like in many other important crops has been widely studied. Some of the aspects studied are comparison of the discriminating powers of GGE to the AMMI model in soybean selection (1), the effects of genotype by environment interaction on soybean agronomic traits (32), stability of Soybean isoflavone content (20), Genotype by Environment and stability for grain yield and nutritional quality (9) and Soybean stability across several soil pH environments (15). Soybean nutritional factors such as oil and protein content have been studied for stability due to their importance in human nutrition (32) and the studies carried out have shown that oil

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Comment [A3]: Soybean ...not soybeans...check throughout the manuscript

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41 and protein in soybeans are apart from the genotype strongly affected by the environment and the
42 genotype by environment interaction (9).

43 Though several traits have been studied on soybean genotype x environment interaction, yield was
44 found to be the most sensitive trait to genetic by environment interactions (27) and efforts to resolve
45 this has received attention from researchers in an attempt to assess the adaptability and stability of
46 soybean.

47 Since no such work has been done for soybeans in Zambia, this study was done to identify the
48 existence of soybean mega-environments. The output from this study would improve soybean
49 production and productivity by way of identifying areas which have a similar genotype response and
50 also genotypes which would perform well in the different mega-environments.

51 2. MATERIAL AND METHODS

52 The experimental material consisted of 15 genotypes of soybeans viz., TGX 1740-2F (G1), TGX
53 1830-20E (G2), TGX 1835-10E (G3), TGX 1887-65F (G4), TGX 1904-6F (G5), TGX 1987-11F (G6),

54 TGX 1987-23F (G7), TGX 1988-9F (G8), TGX 1988-18F (G9), 1988-22F (G10), TGX 1989-60F
55 (G11), TGX 1990-129F (G12), Magoye (G13), Safari (G14) and Lukanga (G15). The genotypes
56 consisted of 12 (TGX series) from the International Institute of Tropical Agriculture and 3 released
57 varieties, Magoye, Safari and Lukanga. The multi-environment trial was done in the 2013/2014
58 agricultural season in four locations; Masumba (13.22143 S, 31.92812 E), GART (14.49684 S,
59 28.09979 E), Kabwe Research Station (14.39472 S, 28.49474 E) and Msekera Research Station
60 (13.38 S, 32.34 E).

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62 **Figure 1: Map of Zambia Showing the Trial Locations**

63 Composite Soil samples were collected at all the 4 locations up to a depth of 30 cm and analysis was
 64 done at the University of Zambia Soil laboratories. Average monthly temperatures and rainfall data
 65 were collected for all the locations during growing period. The data in **Table 1** shows the rainfall and
 66 temperature figures for the research locations during the crop growing period.

67 **Table 1: Mean Monthly meteorological data for the four locations over the study period**

68

Month	Location	Mean temp(°C)	Total Monthly Rainfall(mm)
December	Masumba	35.6	106.9
	Msekera	31.6	143.1
	Kabwe	24.9	191.7
	GART	25.2	307.6
January	Masumba	31.8	246.3
	Msekera	28.5	306.5
	Kabwe	23.5	204.2
	GART	25.1	69.2
February	Masumba	31.8	214.1
	Msekera	28.5	407.8
	Kabwe	22.95	97
	GART	24.4	99.4
March	Masumba	33	75.5
	Msekera	30.1	216.8
	Kabwe	22.95	88.4
	GART	24.1	65.1
April	Masumba	32.2	0
	Msekera	28.8	23.5
	Kabwe	21.3	2
	GART	22.4	60.2

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70 The experimental design was a Randomized Complete Block Design (RCBD) with 4 replications at
 71 each location under rain fed conditions. Each plot had 4 rows and each 6 meters long. An inter row
 72 spacing of 50cm and intra row spacing of 5cm were used. Planting was done at different times

73 depending on the onset of the rains and judicious weed control was done to eliminate weed
74 competition. Fertilization with compound D fertilizer (N= 10, P₂O = 20, K₂O = 10, S = 6-8) at a rate of
75 200kg/ha was done with no inoculation for all the lines across all locations.

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76 Data collection started when the crop had reached 50% flowering and most of the other parameters
77 were recorded when the crop had reached maturity. At maturity the entire two (2) middle rows were
78 harvested and data on grain yield was calculated on the two rows. The other parameters recorded at
79 physiological maturity were Plant Height, Number of pods per plant, stand count at harvest, 100 seed
80 weight, and number of seeds per pod following procedures by Ngalanu et al., (21).

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81 A Combined Analysis of Variance across locations for each of the parameters recorded was done
82 using Genstat version 16 to determine the magnitude of the main effects and interactions. With
83 respect to yield, a further analysis was done using GGE biplot (29). This was applied for visual
84 examination of the genotype by environment interactions. The GGE biplots were constructed using
85 the first two principal components (PC1 and PC2).

86 3. RESULTS AND DISCUSSION

87

88 3.1 RESULTS

Comment [A16]: where is data on soils for the sites?

89 3.1. 1 Analysis of Variance

90 There were significant differences (p=.05) among locations with respect to yield, days to 50%
91 flowering, Plant height, 100 seed weight and pods per plant. Significant differences (p=.05) were also
92 obtained among genotypes with respect to yield, days to 50% flowering, plant height and 100 seed
93 weight (Table 2). There were also significant (p=.05) genotype x environments interactions for yield,
94 days to 50% flowering, plant height and 100 seed weight.

Comment [A17]: at the same location, across locations or both, if you expound on this perhaps the first sentence might be deleted....

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Table 2: Analysis of variance for the various studied traits

Comment [A18]: Where is the actual data...yield, plant height, 100 seed weight

Source of Variation	Degree of Freedom	Yield	D_50% F	Plant_H	100 Seed_W	PPP
Location	3	127.09**	88.36**	72.987*	37.81**	52.33**
Reps	3	3.16	3.29	2.91	1.13	0.11
Reps/Location	9	3.05	1.02	2.68	0.74	1.09
Genotype	14	9.53**	71.02**	13.48**	12.24**	0.98
Locaton * Genotype	42	3.64*	3.29*	3.49*	3.49*	1.54
Residual	167					
Total	238					

98 Note * and ** indicates statistical significance at the 0.05 and 0.01 levels of probability respectively.

3.1.2 Mega Environment Identification

Figure 2 is a scatter plot which shows the yield response analysis for identification of mega-environments. The winning genotype in each of those mega-environments was identified. A polygon was drawn on genotypes that are furthest from the biplot origin so that all the other genotypes are contained within the polygon. Then perpendicular lines to each side of the polygon were drawn starting from the biplot origin (30). Based on the interpretations of the polygon view on the biplot; the genotypes on the vertices are either the worst or the best yielding genotypes (5). The perpendicular lines in the polygons are equality lines between adjacent genotypes (30). Therefore the study results show that for the locations Kabwe and Msekera, TGX 1988-22F (G10) was the best genotype, Safari (G14) was the best for GART and the genotype Magoye (G13) was the best performer for Masumba. Based on the GGE principle that any number of environments with the same “winning” genotype form a mega-environment, the results in figure 2 show 3 mega-environments. The mega-environments were Kabwe/Msekera, GART and Masumba.

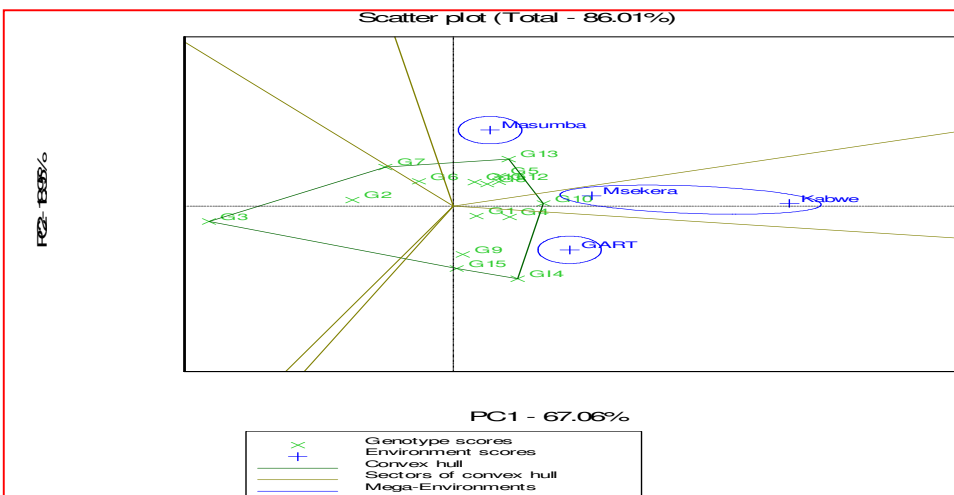


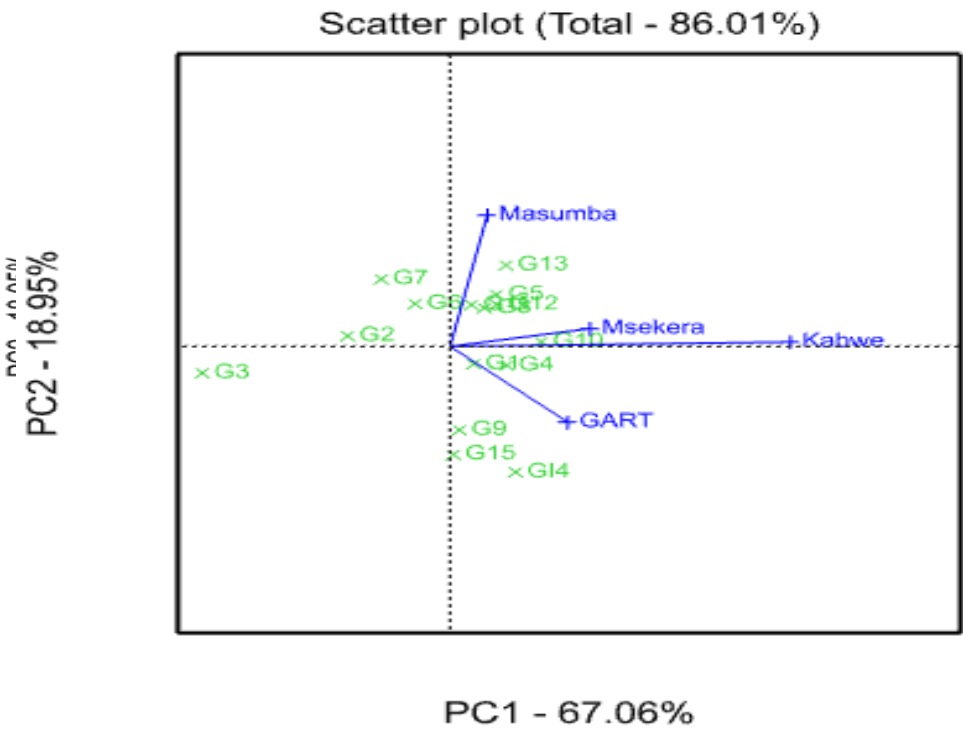
Figure 2: The GGE biplot showing the mega-environments and “which won where pattern” among the genotypes.

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3.1.3 Discriminating ability determination

Results in figure 3 show the discriminating ability of the locations. The lengths of the environment vectors on the vector view biplot approximate the standard deviation within each environment, which is the measure of the discriminating ability (31). The results in figure 3 show that Kabwe is the most discriminating environment followed by Masumba and the least is Msekera.

120



121 Figure 3: Vector View GGE biplot showing the discriminating abilities of the locations

122

123 **3.1.4 Representative location identification**

124

125 The GGE biplot in figure 4 below shows the relative ranking of the locations relative to the ideal. The
126 average environment is represented by the center of the concentric circles (15). The average
127 environment has the average coordinates of all test environments and AEA is the line that passes through
128 the average environment and the biplot origin (31). This average environment should project the average
129 performance of the target environment (28). The environment closest to the center of the concentric
130 circles is the most representatives of the locations. The results below show Kabwe to be the most
131 representative environment followed by Msekera while Masumba is the least representative of the test
132 sites.

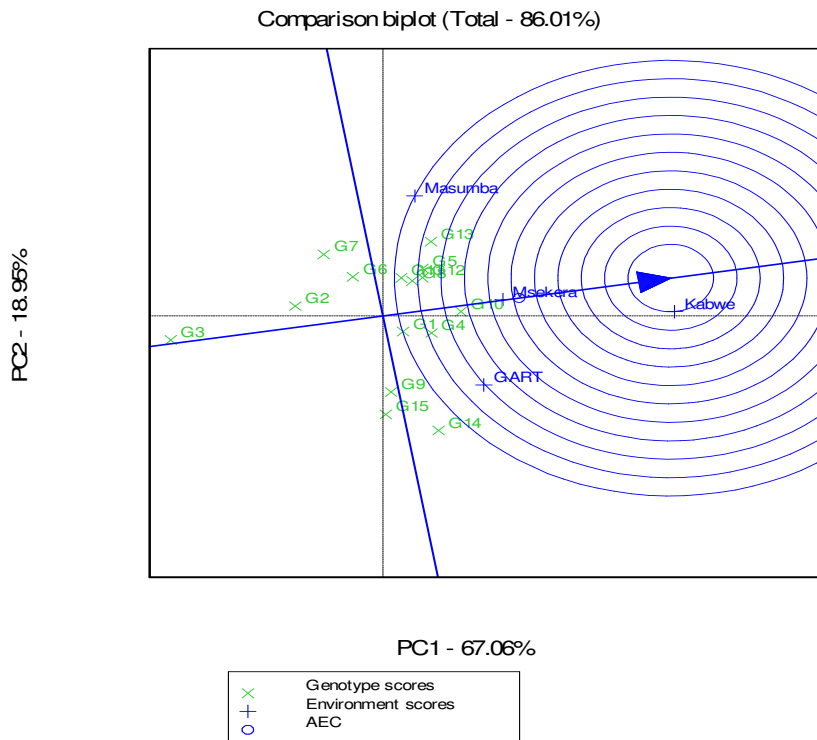


Figure 4: Relative ranking of the locations to the ideal environment

3.1.5 Ideal test environment identification

The ideal test environment/location for soybean genotypes in Zambia was identified based on the results from figure 3 and 4. An ideal test environment should be both discriminating and representative (28). Kabwe was identified as an ideal test environment since it was both discriminating and representative of the test environments/locations. A Location like Msekera was representative but was not discriminating hence making it not an ideal environment. Masumba and GART were discriminative environments but not representative.

3.1.6 Genotype yield and stability determination

The result in figure 5 below show the relative yields of the genotypes and their stability. The ideal genotype should have high mean performance coupled with high stability to give wide adaptability in the target region (5). The average yield of a genotype is approximated by the projections of their markers on

the AEC x-axis while the stability is determined by the projection onto the AEC ordinate line (y-axis) (29). The single arrowed Average Environmental coordinate (AEC) points to higher mean seed yield across locations. The perpendicular line to the AEC which is the Average Environmental Ordinate (AEO) points to greater variability (Poor stability) in both directions (5). The results in figure 5 show that TGX 1988-22F is the highest yielding genotype and the lowest is TGX 1835-10E. In terms of variability, Safari was the most variable and the genotypes TGX 1835-10E and TGX 1830-20E were nonresponsive (highly stable). In choosing the best genotypes for general adaptability the variety TGX 1988-22F is the most ideal across all the environments as it is high yielding and stable. Six genotypes have yield which is below the mean performance of the genotypes across all the environments; these are Lukanga, TGX 1835-10E, TGX 1830-20E, TGX 1988-18F, TGX 1987-23F and TGX 1987-11F.

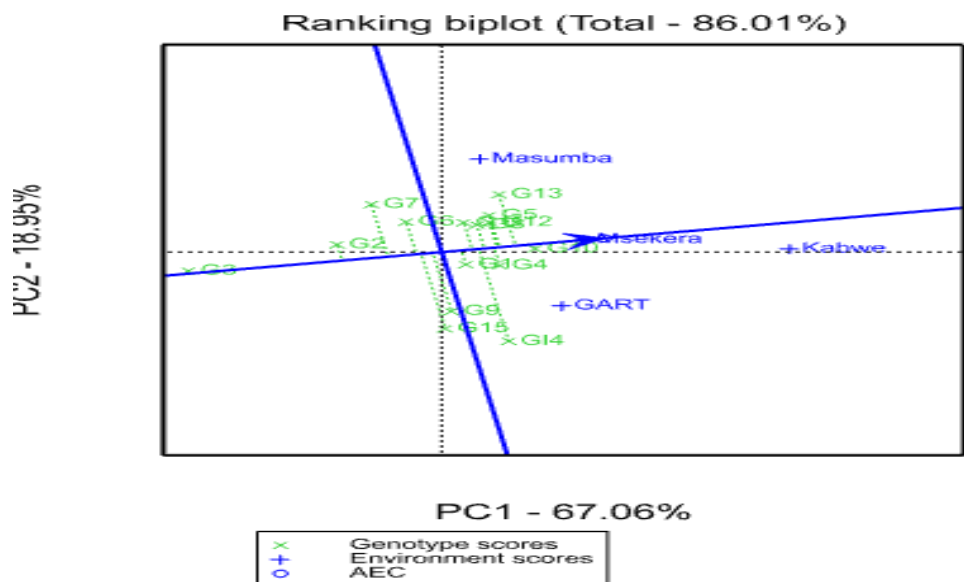


Figure 5: Average Environmental Coordinate view showing the mean performance and stability of genotypes in seed yield.

3.2 DISCUSSION

3.2.1 Morphological Characteristics

Plant height varied among locations and genotypes with the character being influenced by location as testified by the significant genotype x location interactions. The significant differences among locations can be attributed to the individual and combined effects of edaphic and climatic factors. These results are contrary to what Khaswa et al., (18) reported that areas with relatively high P tended to have taller

169 soybeans plants. GART in this study had one of the lowest levels of soil P but had the tallest plants.
 170 Similarly, the highest rainfall recorded was at Msekera but this location had the shortest plants. Hartman
 171 et al., (11) noted that drought is among the major causes of reduced growth and also lead to yield loss in
 172 soybeans. Current study results do not confirm the effect of low soil moisture as shortest plants were at
 173 Msekera that had the highest rainfall. The differences in location ambient temperature at the locations
 174 during planting are the only plausible cause for the differences in plant height among the locations. GART
 175 had temperature of 25.2 °C compared to Masumba and Msekera that had higher temperatures of 31.6 °C
 176 and 35.5 °C, respectively. Temperature has been found to affect plant growth (26) and specifically, high
 177 temperatures have been known to affect photosynthesis by way of damaging the photosystem ii found in
 178 the thylakoid membranes of the chloroplasts thereby reducing the availability of photo assimilates needed for
 179 good growth (13).

180 The differences observed among genotypes for plant height could also be partly attributed to genetic
 181 differences and indeed to differential response to locational factors. The genotype differences behavior
 182 for soybeans attributed to inherent genetic factors and hereditary variation of the cultivars was found in
 183 the soybeans study by Kandil et al., (17).

184 The other morphological trait studied was days to 50 % flowering. There were significant differences
 185 among locations and among genotypes for 50% flowering. Indeed significant interactions were observed
 186 between genotypes and locations. The location Masumba had the shortest days to 50 % flowering while
 187 on the other hand, Kabwe had the longest days to 50% flowering. Soybean could have flowered early in
 188 Masumba due to the high temperatures consistently recorded at the location during the farming season.
 189 These temperatures were seconded by temperatures at Msekera. Soybean is a thermo sensitive crop
 190 and its growth rate and blooming dates are affected by temperature from germination onwards. Junior et
 191 al., (16) reported that temperatures above 30 degrees celsius during the vegetative stage hastens
 192 flowering in soybeans.

193 3.2.2. Yield and Yield components

194 The results showed significant differences for location, genotypes and the interaction for yield and the
 195 yield component seed size. There were however only significant differences for locations on the Pods per
 196 plant. There are supposedly many reasons for the differences observed in yield since yield is a
 197 quantitative trait hence interplay of many factors are responsible for the differences (12).

198 The locations in the study had major temperature differences over the growing season. The recorded high
 199 temperatures at Masumba followed by Msekera could be attributed to the lower yields (2, 3) at these
 200 locations. Such temperatures induce heat stresses that adversely affect soybean yields (26).
 201 Temperature requirements for Soybean like in many other crops differ according to the stage of plant
 202 growth. Hemantaranjan et al., (13) found that general crop yields are predicted to decrease approximately

Comment [A20]: where is data on soil for the sites

Comment [A21]: where is the soil data?

Comment [A22]: High rainfall does not necessarily translate to high moisture content in the soil...we need to have soil texture and OC data as well as water infiltration rates here as well as water retention capacity of the soil...what if there was high runoff, leaching of the water or perhaps water logging the statement there for is highly defective...

Comment [A23]: A plausible argument would be hastened crop growth and development under high temperature please check Dougher and Bugbee 1997, EFFECT OF LAMP TYPE AND TEMPERATURE ON DEVELOPMENT, CARBON PARTITIONING AND YIELD OF SOYBEAN

Comment [A24]: Grain yield?

Comment [A25]: Just seed size I guess?

203 10% for every one-degree increase in temperature above the optimum. Studies in cereals have also
204 found that heat stress induces a decrease of the duration of developmental phases leading to fewer
205 organs, smaller organs, reduced light perception over the shortened life cycle and perturbation of the
206 processes related to carbon assimilation (24, 22). In the current study, Masumba and Msekera had fewer
207 numbers of pods compared to Kabwe and GART. Indeed temperatures at Masumba and Msekera were
208 significantly higher than those at GART and Kabwe. These results are in agreement with Avila et al., (1)
209 who found that to obtain the greatest number of pods, Soybeans need mild temperatures of up to 26
210 degrees Celsius and higher temperatures were found to reduce the number of pods.

211 The observed 100 seed weight at Masumba, against the emerging negative effect of temperature on
212 growth and development of soybeans, suggest that enhanced flowering while associated with reduced
213 organs, seed weight was not negatively affected. Masumba and Msekera had the heaviest
214 seeds. This could be attributed to sufficient photo assimilates available to the reduced sink (Pods per plant)
215 in the two locations. This assertion is in agreement with Liu et al., (19) whose findings suggest that there
216 is an increase in the seed size in the presence of reduced pod load in soybeans. The results could be
217 attributed to the internal mechanism that moderates the final seed size in soybeans (19). The
218 photosynthate would, therefore, have allowed optimal pod filling hence the highest weight. The
219 relationship of the reduction of number of pods to the yield is consistent with other findings who reported
220 that reduction of pods will directly lead to the reduction in yield since number of pods is one of the most
221 important yield components in soybean (24).

222 3.2.3 Characterisation of the Environments

223 The highly significant differences contributed by the environment indicate that Zambia is highly variable
224 from location to location. The results are in agreement with the findings by Setimela et al., (23). These
225 results justify the need for carrying out Multi-environment trials in the country for the genotypes. Besides
226 the locations, there were significant differences among the genotypes which would suggest that
227 genotypes are favored by specific locations. The specificity of soybean genotypes to specific locations is
228 consistent with the findings of Tukamuhabwa et al., (27). The genotype by environment interactions
229 showed significant differences for almost all the traits under study apart from pods per plant. The
230 significant genotype by environment interactions especially on yield justified a study for mega-
231 environment identification. The study identified three mega-environments in the two agro-ecological
232 regions studied. The existence of more than one mega-environment in Zambia was also found in the
233 maize studies by Setimela et al., (23).

234 In essence, all environments are useful provided they are discriminative as they can be used to select
235 superior genotypes (28, 31).

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Comment [A27]: reword...ie findings by other researchers who reported...

Comment [A28]: refer to my comment on site versus mega environment...it seems you were a conducting a multilocation study not a mega environment study as the title suggests...

Comment [A29]: ????? locations????

3.2.4 Characterisation of the genotypes

The check varieties Safari and Lukanga did not have a good overall mean performance relative to Magoye despite not having significant differences. Both varieties performed very well at Golden Valley Agricultural Trust (GART) and Kabwe research station. The two genotypes (Lukanga and Safari) are not self-nodulating (not promiscuous) hence the fact that they were not inoculated with Rhizobium would partially explain their poor performance in the locations Msekera and Masumba.

Comment [A30]: If the differences were not significant it means there was no difference in their performance

Genotypes TGX 1830-20E and TGX 1835-10E had poor germination across all locations. These genotypes were the worst performing lines in the trials and ultimately the yield. Their poor performance was more to their genotype as compared to the environment as shown in the GGE biplot analysis (Figure 4). The results showed that the two were least responsive genotypes to the environments. Though some of the IITA lines have been released in other countries as self-nodulating soybean lines (25), their performance in Zambia was not consistent with their performance elsewhere i.e. TGX 1835-10E and TGX-20E. The only IITA promiscuous variety which has been released in other countries and was able to perform well was TGX 1740-2F. The poor performance of the genotype TGX 1835-10E was also found by other researchers (14).

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4. CONCLUSION

The study found three (3) mega-environments viz. Kabwe/Msekera, Masumba and Golden Valley Agriculture Research Trust. Kabwe/Msekera had TGx 1988-22F as the winning genotype, GART had safari as the winning genotype with genotypes TGx 1740-2F, TGx 1887-65F, TGx 1988-18F and Lukanga showing preferential performance. Masumba recorded Magoye as the winning genotype. The genotypes TGX 1835-10E, TGX 1830-20E, TGX 1988-18F, TGX 1987-23F and TGX 1987-11F performed poorly across all locations. This shows that the genotypes are not suitable for the Zambian environment studied.

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The performance of genotypes varied across the locations mainly due to the environmental conditions and also due to the inherent genotype characteristics. The trial established that most of the yield variance in soybeans was due to the environment variance component. Thus it was possible to determine and group the locations from most suitable which were Kabwe, GART, Msekera and the worst performing being Masumba.

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