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RESEARCH ARTICLE

Determination of Stability and G × E Interaction of Legume and Cereal Genotypes in Different Agro-Ecologies of Central Tanzania

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ABSTRACT

Legumes and cereals are essential components of sustainable agricultural production systems and are vital in sustaining food, nutrition, income security as well as improving soil health status in the semi-arid tropics. Field experiments were conducted during the 2019-2020 cropping season in different sub agro-ecologies of central Tanzania to determine stability and genotype x environment interaction (GEI) of legume and cereal genotypes for grain yield in the different sub agro-ecologies. An incomplete randomized block design with farmers as replications was used at each sub agro-ecology. Grain yield data of the fourteen genotypes in total of the four crops (groundnut, pigeon pea, sorghum and pearl millet) was collected. Results from the experiments generally revealed that G x M x E interactions were insignificant ($p \leq 0.05$) in terms of grain yield for all the crop genotypes studied. Among the groundnut and pigeon pea genotypes, significant differences were observed across the sub-ecologies while significant genotypic effects were observed in both sorghum and pearl millet genotypes. Although early planting outperformed late planting for the crop genotypes tested in terms of grain yield, non-significant differences in planting dates were observed. Furthermore, crop genotypes in the high potential generally out performed those under the moderate and low potential sub-ecologies. The above findings revealed that genotypes ICGV-SM 05650, ICEAP 00040, GAMBELA 1107 and IP8774 with superior grain yield performance were more adapted thus, recommended for deployment in these sub agro-ecologies of central Tanzania.

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INTRODUCTION

Legumes and cereals are main components of sustainable agricultural production systems of developing countries especially in the sub-Saharan Africa (SSA) (Ojiewo et al., 2019). In the semi-arid tropics (SAT) particularly central Tanzania, they have been vital in sustaining food, nutrition, income security as well as improving soil health status (Okori, 2014). However, low production of these crops has been observed in the region mainly due to weather and other natural disaster-related challenges which lower the crop yields (Okori, 2014). This calls for a need to develop varieties possessing stable performance as genotypes in segregated generations with allelic variation express themselves differently in response to different environments (Gauch and Zobel, 1996).

Using strong adaptation and yield stability in legume and cereal genotypes allows plant breeders to develop high yielding and well-adapted genotypes. But GEIs complicate this purpose (Rad et al., 2013). GEI worries plant breeders because it limits selection gains and makes identifying superior genotypes difficult. GEI helps identify target genotypes (Kamila et al., 2016). Kang (1998) discussed GEI. Determining GEI causes is crucial for effective selection and evaluation networks (Ramburan and Zhou, 2011).

Genomics can help discover high-yielding cultivars and sites that best match the intended environment (Yan et al., 2001; Wachira et al., 2002). Stable cultivars or genotypes can adapt to a number of environments. It is just G and GE that matter in meaningful cultivar evaluation and selection (Yan and Kang, 2003; Kaya et al., 2006). Many research uses the AMMI and GGE models (Gauch, 2006). In the AMMI approach, genotypic and environmental scores are separated (Bocianowski et al., 2019; Zobel et al., 1988). This study focused on legume and cereal genotype GxE interaction and agroecological stability.

MATERIALS AND METHODS

The study was conducted during the 2019-2020 cropping season in the Central zone of Tanzania in three sub agro-ecologies i.e., high potential zone (Manyusi and Mlali villages in Kongwa district) which receives ≥500mm of rainfall; moderate potential zone (Njoro-1 and Njoro-2 villages in Kiteto district) which receives ≥ 400-500mm of rainfall and low potential zone (Laikala and Moleti villages in Kongwa district) which receives ≤ 350mm of rainfall (Hoeschle-Zeledon, 2019). Kongwa district lies between latitudes 5° 30’ to 6° 00’ S and longitudes 36°15’ to 36°00’ E with altitude stretching between 900 and 1000 masl (URT, 2016). Kiteto district lies between latitudes of 05°52'00'S and longitudes of 36°51'00'E with altitude stretching between 500 and 1200 masl. The average day and night temperature is 22°C. The cool months are March, April, May and June while the hot months are July, August, September, October and November (PO-RALG, 2018). These areas consist of mainly well-drained sandy loamy soils (see Appendix 1) with low fertility and are characterized by unimodel and unreliable rainfall of 300-800mm/year with a December-March cropping season (URT, 2007; MAFC, 2014; Msuya, 2015).

Ten elite genotypes in total (of groundnut, pigeon pea, sorghum and pearl millet) proposed for release and four local checks (one for each crop) were used in this study (Table 1). The elite genotypes were obtained MALAWI including one local check (ICEAP 00040) and the remaining three local checks were obtained from the local market in Dodoma.

One experiment was laid down in each village in the high potential (Manyusi and Mlali); moderate potential (Njoro-1 and Njoro-2) and low potential (Laikala and Moleti) sub ecologies to test the effect of one sub agro-ecological condition in Kongwa and Kiteto districts. A total of 4 crops (sorghum, pearl millet, groundnut and pigeon pea) with test varieties were evaluated against the local landrace. The groundnut experiments were conducted in all the sub ecologies, pigeon pea in the high and moderate, sorghum in the high and low while pearl millet occurred in the low potential sub ecology. Two planting dates (early planting vs 2 weeks after first planting) were executed under each environment. All experiments at these sites were established following an incomplete randomized block design with two farmers selected per sub agro-ecology as replications. The plot size was 7 rows, 8 m long spaced at 75 cm between ridges. The field layout of the sole crops and intercrops are as shown in Appendix 3 and Appendix 4 respectively.

Grain yield data assessed based on the whole plot (12 m^2) was collected in kg $plot^{-1}$ and then converted to hectare (10 000 m^2) to determine the grain yield in kg ha^{-1}. Grain yield data was analyzed by using GenStat statistical package 16th Edition in order to determine genotype by management by environment interaction of the test materials.

Table 1. Description of test materials used in the study

	Crop	Genotype	Maturity duration (days)	Source
1.	Groundnut	ICGV-SM 02724	Medium (120)	ICRISAT-MALAWI
		ICGV-SM 05650	Short (90)	ICRISAT-MALAWI
		LOCAL CHECK (Mnanje)	Short (110)	DODOMA MARKET
2.	Pigeon pea	ICEAP 00554	Medium (150-180)	ICRISAT-MALAWI
		ICEAP 00557	Medium (150-180)	ICRISAT-MALAWI
		CHECK- ICEAP 00040 (Mali)	Long (190-240)	ICRISAT-MALAWI
3.	Sorghum	GAMBELLA 1107	Short (70)	ICRISAT-MALAWI
		IESV 92028 DL	Medium (90)	ICRISAT-MALAWI
		IESV 23010 DL	Medium (90)	ICRISAT-MALAWI
		LOCAL CHECK (Lugugu)	Long (110)	DODOMA MARKET
4.	Pearl millet	IP 8774	Short (70)	ICRISAT-MALAWI
		SDMV 96053	Medium (90)	ICRISAT-MALAWI
		SDMV 94005	Medium (90)	ICRISAT-MALAWI
		LOCAL CHECK (Uwele)	Long (110)	DODOMA MARKET

Table 2. General treatment structure

Crops	Varieties	Environments	Time of planting
1. Groundnut	V_1, V_2, Vc	1. Low potential	1. Early planting
2. Pigeon pea	V_1, V_2, Vc	2. Moderate potential	2. Late planting
3. Sorghum	V_1, V_2, V_3, Vc	3. High potential	
4. Pearl millet	V_1, V_2, V_3, V_c		

V_c - Local check

RESULTS

Groundnut

Significant differences in reaction of genotypes (ICGV-SM 05650, ICGV-SM 02724 and check) were found among the genotypes and across the three sub ecologies, while non-significant differences in planting dates were observed as shown in Table 3. Genotype x management x environment (GME) interaction on the other hand showed non-significant differences (P ≤ 0.05) for sub ecology x planting date, sub ecology x genotype, planting date x genotype and sub ecology x planting date x genotype interactions. Nonetheless, early planting outperformed late planting in all the sub ecologies. Genotype performance was superior in the high potential compared to the other sub ecologies. ICGV-SM 05650 genotype with the highest yield of 2484.00 kg ha^{-1} ranked first in all the potential agro-ecologies. In the high potential sub-ecology however, its relative yield losses were higher (30.51%) compared to the Local landrace with 11.30% yield losses due to late planting. In the moderate potential, ICGV-SM 05650 genotype registered higher (36.78%) yield losses compared to 17.22% of the Local landrace and in the low potential agro-ecology the Local landrace had higher (52.69%) compared 50.48% of ICGV-SM 05650 genotype.

Table 3. Genotype × environment interaction of selected elite groundnut genotypes

Sub ecology	Management	Genotype	Yield (kg ha^{-1})	Yield loss (%)
High	Early planting	ICGV- SM 02724	1577.42	0
		ICGV- SM 05650	2484.00	0
		Local check	2067.50	0
	Late planting	ICGV- SM 02724	1500.33	4.89
		ICGV- SM 05650	1726.17	30.51
		Local check	1833.83	11.30
Moderate	Early planting	ICGV- SM 02724	537.75	0
		ICGV- SM 05650	1242.58	0
		Local check	709.67	0
	Late planting	ICGV- SM 02724	474.64	11.74
		ICGV- SM 05650	785.56	36.78
		Local check	587.43	17.22
Low	Early planting	ICGV- SM 02724	883.83	0
		ICGV- SM 05650	1989.17	0
		Local check	914.42	0
	Late planting	ICGV- SM 02724	457.50	48.24
		ICGV- SM 05650	985.00	50.48
		Local check	432.64	52.69

Fpr-Sub ecology (SE) = <0.001; Fpr-Planting date (PD) = 0.066; Fpr-Genotype (G) = 0.013; Fpr -SE x PD = 0.538, Fpr - SE x G = 0.656; Fpr - PD x G = 0.300; Fpr -SE x PD x G = 0.998. The statistics restricted to yield not yield loss.

Pigeon pea

Significant differences of the genotypes (ICEAP 00554, ICEAP 00557 and ICEAP 00040-Local) across the two sub ecologies were observed in Table 4. Genotype x management x environment (GME) interaction on the other hand showed non-significant differences ($P \leq 0.05$) for sub ecology x planting date, sub ecology x genotype, planting date x genotype and sub ecology x planting date x genotype interactions. Within the high potential sub-ecology, ICEAP 00557 genotype registered high yield losses of 61.94%, ICEAP 00554 (36.63%) and ICEAP 00040 (14.85%) due to late planting. While in the moderate potential sub-ecology, ICEAP 00554 genotype registered 81.73%, ICEAP 00040 (63.08%) and ICEAP 00557 (57.01%) yield losses due to late planting. Genotype ICEAP 00040 with relatively higher yields of 841.67 kg ha^{-1} ranked second in the high potential and first (984.13 kg ha^{-1}) in the moderate potential sub-ecology.

Table 4. Genotype × environment interaction of selected elite pigeon pea genotypes

Sub ecology	Management	Genotype	Yield (kg/ha)	Yield loss (%)
High	Early planting	ICEAP 00554	841.67	0
		ICEAP 00557	1116.67	0
		ICEAP 00040- Mali	841.67	0
	Late planting	ICEAP 00554	533.33	36.63
		ICEAP 00557	425.00	61.94

		ICEAP 00040- Mali	716.67	14.85
Moderate	Early planting	ICEAP 00554	796.33	0
		ICEAP 00557	326.51	0
		ICEAP 00040- Mali	984.13	0
	Late planting	ICEAP 00554	145.49	81.73
		ICEAP 00557	140.37	57.01
		ICEAP 00040- Mali	363.33	63.08

Fpr-Sub ecology (SE) = 0.013; Fpr-Planting date (PD) = 0.065; Fpr-Genotype (G) = 0.371; Fpr -SE x PD = 0.679; Fpr - SE x G = 0.381; Fpr - PD x G = 0.940; Fpr -SE x PD x G = 0.265. The statistics restricted to yield not yield loss.

Sorghum

Significant differences in reaction (P ≤ 0.05) of the genotypes (GAMBELLA 1107, IESV 92028 DL, IESV 23010 DL and Local check) were found across the two sub ecologies, while non-significant differences were observed between sub ecologies and planting dates respectively as shown in Table 5. Genotype x management x environment (GME) interaction on the other hand showed non-significant differences for sub ecology x planting date, sub ecology x genotype, planting date x genotype and sub ecology x planting date x genotype interactions. The local landrace (Lugugu) lost up to 71.42% of its grain yield when planted late in the high potential sub-ecology compared to 32.85% for IESV 23010 DL, 32.71% for IESV 92028 and 12.66% for GAMBELLA 1107. While in the low potential sub-ecology, the local landrace lost about 21.21% of its grain yield, IESV 23010 DL (11.42%), IESV 92028 DL (39.31%) and GAMBELLA 1107 (3.67%) when late planted. GAMBELLA 1107 with the highest yield of 1517.00 kg ha^{-1} ranked first in both potential sub-ecologies. The lowest yield losses in GAMBELLA 1107 compared to the Local landrace demonstrates the advantage of elite genotypes even under harsh conditions.

Table 5. Genotype × environment interaction of selected elite sorghum genotypes

Sub ecology	Management	Genotype	Yield (kg/ha)	Yield loss (%)
High	Early planting	GAMBELLA 1107	1517	0
		IESV 92028 DL	908	0
		IESV 23010 DL	1242	0
		Local Check	875	0
	Late planting	GAMBELLA 1107	1325	12.66
		IESV 92028 DL	611	32.71
		IESV 23010 DL	834	32.85
		Local Check	250	71.42
Low	Early planting	GAMBELLA 1107	654	0
		IESV 23010 DL	407	0
		IESV 92028 DL	499	0
		Local Check	481	0
	Late planting	GAMBELLA 1107	630	3.67
		IESV 23010 DL	247	39.31
		IESV 92028 DL	556	11.42
		Local Check	379	21.21

Fpr-Sub ecology (SE) = 0.098; Fpr-Planting date (PD) = 0.719; Fpr-Genotype (G) = 0.034; Fpr -SE x PD = 0.789; Fpr - SE x G = 0.362; Fpr - PD x G = 0.898; Fpr -SE x PD x G = 0.919. The statistics restricted to yield not yield loss.

Pearl millet

Significant differences of the genotypes (IP 8774, SDMV 94005, SDMV 96053 and Local check) were observed in Table 6. Genotype x management (GM) interaction on the other hand showed non-significant differences (P ≤ 0.05) for planting date x genotype interactions. The local landrace (Uwele) lost up to 25% of its grain yield when planted late compared to

38.26% for SDMV 94005, 11.20% for SDMV 96053 and 38.10% for IP 8774. IP 8774 genotype with grain yield of 1296.30 kg ha^{-1} ranked first and the local landrace (345.68 kg ha^{-1}) ranked last.

Table 6. Genotype × interaction of selected elite pearl millet genotypes in low potential agro-ecology

Management	Genotype	Yield (kg ha^{-1})	Yield loss (%)
Early planting	IP 8774	1296.30	0
	SDMV 96053	861.73	0
	SDMV 94005	1019.75	0
	Local Check	345.68	0
Late planting	IP 8774	802.47	38.10
	SDMV 96053	765.43	11.20
	SDMV 94005	629.63	38.26
	Local Check	432.10	25.00

Fpr-Planting date (PD) = 0.065; Fpr-Genotype (G) = 0.015; Fpr - PD x G = 0.253. The statistics restricted to yield not yield loss.

DISCUSSION

G x M x E interaction on grain yield of legume and cereal genotypes

Generally, non-significant G x M x E interactions existed in the genotypes of all the four crops indicating that all these test materials were stable in these varying potential sub-ecologies. In groundnuts, significant differences in genotype reactions of the test materials and across the sub ecologies were observed. Genotype ICGV-SM 05650 outperformed the other genotypes in all the sub-ecologies showing that this elite material is more adapted to these semi-arid environments and hence can be deployed to all these villages. These results agree with previous reports by Hoeschle-Zeledon (2019).

For pigeon pea, significant differences were observed in both sub-ecologies, while non-significant genotypic effects occurred in the three genotypes tested confirming the fact that all these materials are improved. Nevertheless, ICEAP 00040- Mali had relatively higher yields (984.13 kg ha^{-1}) compared to ICEAP 00554 (796.33 kg ha^{-1}) and ICEAP 00557 (326.51 kg ha^{-1}) in the moderate potential sub-ecology. The findings agree with Hoeschle-Zeledon (2019). Significant genotypic effects were observed in the four sorghum test materials evaluated. GAMBELLA 1107 had superior grain yield performance compared to the other genotypes. Hoeschle-Zeledon (2019), also reported similar findings that GAMBELLA 1107 was more stable and adapted to these semi-arid environments compared to the other genotypes implying that it was the most drought resistance genotype.

As for the pearl millet, significant genotypic reactions were observed in the four genotypes although non-significant differences occurred due to planting dates. IP 8774 out yielded the other genotypes with grain yield of 1296.30 kg ha^{-1} and the local check had lower grain yield of 345.68 kg ha^{-1}. This agrees with Hoeschle-Zeledon (2019) who reported that IP 8774 an extra early maturing genotype performed well in Laikala and Moleti villages. The local check and SDMV 94005 were low yielding in these villages.

Grain yield stability of legume and cereal genotypes

In this study based on the genotype x management x environment interactions of the selected elite legume and cereal genotypes, non-significant G x M x E interactions existed in the genotypes of all the four crops indicating that all these test materials were stable in these varying potential sub-ecologies. These findings agree with previous studies reported by Hoeschle-Zeledon (2019) who stated that elite materials proposed for release were stable with superior genetics.

CONCLUSION

The study revealed that the test materials used were stable as there was no significant G x M x E interactions in the genotypes of all the four crops studied. Generally, early planting outperformed late planting for all the test materials in the crops evaluated. Furthermore, genotypes in the high potential sub-ecology outperformed those in the moderate and low potential sub-ecologies as expected. The above findings recommend genotypes ICGV-SM 05650 (groundnut), ICEAP 00040 (pigeon pea), GAMBELLA 1107 (sorghum) and IP8774 (pearl millet) for use or deployment in these varying potential sub-ecologies due to their superior performance in the respective potential sub-ecologies.

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