

Genotype x Environment Interaction and Stability Analysis for Yield and its Components in Selected Cassava (Manihot Esculenta Crantz) Genotypes in Southern Tanzania

A.C. Kundy[1*] G.S. Mkamilo[1] R.N.Misangu[2]
1.Naliendele Agricultural Research Institute, P.O. Box 509, Mtwara, Tanzania
2.Department of Crop Science and Production, Sokoine University of Agriculture, P.O.Box 3005 Morogoro Tanzania
*E-mail of the corresponding author: ackundya@hotmail.com

Abstract
The present investigation was carried out to study stability performance over three environments for root yield and its components in twelve genetically diverse genotypes of cassava using a Randomized Complete Block Design. The partitioning of (environment + genotype x environment) mean squares showed that environments (linear) differed significantly and were quite diverse with regards to their effects on the performance of genotypes for root yield and majority of yield components. Stable genotypes were identified for wider environments and specific environments with high per se performance (over general mean) for root yield per plant. The investigation revealed that the genotypes Kiroba (21.72 t ha^{-1}) and NDL 2006/487 (19.5 t ha^{-1}) were desirable and relatively stable across the environments. Other genotypes NDL 2006/850 was suitable for favourable situations, while genotypes NDL 2006/104 and NDL 2006/283 were suited to poor environments for root yield.
Keywords: G X E Interaction, Stability Analysis, Cassava, Root Yield, Yield Components

1.0 Introduction

Cassava (*Manihot esculenta* Crantz) is from the family *Euphobeaceae*. It is among the most important root crops worldwide and provides food for one billion people (Bokanga, 2001; Nuwamanya *et al.,* 2009). It is an important food crop in developing countries, and it is the fourth source of calories, after rice, sugar cane and maize worldwide (Akinwale *et al.,* 2010). The edible roots supply energy for more than 500 million people worldwide (Ceballos *et al.,* 2006). It is a perennial crop, native to America and grown in agro ecologies which differ in rainfall, temperature regimes and soil types (Olsen and Schaal, 2001). Cassava constitutes an essential part of the diet of most tropical countries of the world (Calle *et al.,* 2005). In Africa the crop is the most important staple food grown and plays a major role in the effort to alleviate food crisis (Hahn and Keyer, 1985).

The success of cassava in Africa, as a food security crop is largely because of its ability and capacity to yield well in drought-prone, marginal wastelands under poor management where other crops would fail. Despite cassava's ability to grow in marginal areas (Mkumbira *et al.,* 2003), large differential genotypic responses occur under varying environmental conditions. This phenomenon is referred to as genotype x environment interactions (G x E), which is a routine occurrence in plant breeding programmes. Recent studies on genotype by environment interactions in some economic crops include the work by Akinyele and Osekita (2011), Sakin *et al.,* (2011), Ngeve *et al.,* (2005) and Kilic *et al.,* (2009). Both the genotype and the environment determine the phenotype of an individual. The effects of these two factors, however, are not always additive because of the interaction between them. The large G x E variation usually impairs the accuracy of yield estimation and reduces the relationship between genotypic and phenotypic values (Ssemakula and Dixon, 2007). G x E due to different responses of genotypes in diverse environments, makes choosing the superior genotypes difficult in plant breeding programmes. Traditionally plant breeders tend to select genotypes that show stable performance as defined by minimal G x E effects across a number of locations and/or years. The term stability is sometimes used to characterize a genotype which shows a relatively constant yield independent of changing environmental conditions. On the basis of this idea, genotypes with a minimal variance for yield across different environments are considered stable.

This study was therefore, designed to evaluate the influence of genotype (G), environment (E) and G x E interaction on fresh root yield, root number, dry matter content, starch content, root size, plant height, number of branches per plant, stem girth, harvest index, cassava mosaic disease and cassava brown streak disease of nine (9) newly developed cassava genotypes across three agro-ecological zones of Southern Tanzania, namely; Coastal low land (Naliendele-Mtwara), Masasi-Ruangwa plains (Mkumba-Nachingwea) and Makonde plateau (Mtopwa-Newala).

Cassava being the second most important food crop after maize in Tanzania, it is however faced with production constraints from pests, diseases, poor agronomic practices and inadequacy of extension services to farmers (Lema and Hemskeerk, 1996; Msabaha *et al*., 1988). Low yield of cassava in the Southern zone of Tanzania is caused by many factors, including diseases and pests. Halima (2005) found out that, the yield of cassava under farmers' conditions was 5 – 10 t ha^{-1}, whereas attainable yield under research conditions was above 20 t ha^{-1}. Use of local varieties which are susceptible to diseases and with poor genetic traits are among those factors contributing to low yield. Efforts on screening for genotypes with high yield potential and tolerant to biotic and abiotic stresses have been done, resulting in production of many improved genotypes, but farmers have not yet benefited from these outcomes. This may be due to the fact that, the performance of such improved genotypes has not been tested/evaluated for recommendations in different agro ecologies of the Southern zone (Banzigarer and Cooper, 2001; Ceccarelli *et al.,* 2003; Haugernd and Collinson, 1990; Witcombe, 1996; Baidu-Forson, 1997; Morris and Bellon, 2004). There is a lack of information on the magnitude of G x E effect on yield and yield components of improved cassava genotypes in the Southern zone of Tanzania.

The early growth and development of cassava depends very much on genetic and environmental factors. Most of the community in the Southern zone depends on cassava crop as their main source of food. At Naliendele Agricultural Research Institute (NARI) for example, many improved genotypes and few varieties have been developed, but no recommendations for cassava varieties/genotypes have been made, with exception of one variety, Naliendele. Naliendele variety was tolerant to Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD). In recent years, Naliendele variety has lost its trait for diseases resistance, CBSD & CMD, which has caused a bad situation to the community of cassava dependent people. The newly developed genotypes at NARI are now in final stages of breeding; therefore testing them and providing recommendations of suitable ones to different agro ecologies was one step forward in solving the problem.

3.0 Materials and Methods

3.1 Experimental Sites and Materials

The experiment was conducted during the 2011/2012 cropping season in the Southern zone of Tanzania in three agro ecologies. Coastal low land plains (in Mtwara urban) located at 10° 22'S and 40° 10'E, 120m above sea level; Masasi-Ruangwa plains (in Lindi rural) located at 10° 20′S and 38°46′E, 465m above sea level and Makonde plateau (in Mtwara rural) located at 10° 41'S 39° 23'E, 760m above sea level.

Nine newly improved cassava genotypes, one old improved variety (Naliendele as a control), one ex-Rufiji variety (Kiroba) and 1 landrace (Albert) were used in this study (Table 1). Albert, was used both as a check and a CBSD disease spreader. Limbanga was used as CMD disease spreader. Albert and Limbanga were planted around the replications as a source of inoculum (spreader of the diseases) at all locations. The improved genotypes were obtained from Naliendele Agricultural Research Institute - Mtwara, while the local ones were from farmers' fields.

Table 1: Cassava genotypes used in this study, their origin and status

	Genotype	Source	Status
1	NDL 2006/104	NARI	Tolerant to CBSD &CMD
2	NDL 2006/850	NARI	Tolerant to CBSD &CMD
3	NDL 2006/487	NARI	Tolerant to CBSD &CMD
4	NDL 2006/283	NARI	Tolerant to CBSD &CMD
5	NDL 2006/738	NARI	Tolerant to CBSD &CMD
6	NDL 2006/438	NARI	Tolerant to CBSD &CMD
7	NDL 2006/741	NARI	Tolerant to CBSD &CMD
8	NDL 2006/840	NARI	Tolerant to CBSD &CMD
9	NDL 2006/030	NARI	Tolerant to CBSD &CMD
10	NALIENDELE	NARI	Susceptible to CBSD &CMD and check
11	KIROBA	Ex-Rufiji	Tolerant to CBSD & CMD and check
12	ALBERT	Farmers	Local (Check in all sites)

3.2 Experimental design

A split-split plot experiment in a Randomized Complete Block Design (RCBD) was used to carry out the study. Weeding regime as a crop management practice was used in each location, weeding once (W_1) and weeding twice (W_2), in order to create micro environments for stability analysis. The experiment consisted of three factors, location as main factor A, crop management (weeding regime) as sub factor B and genotype as sub-sub factor C. Nine newly developed genotypes and three other varieties with three replications in each location spaced at 1 m x 1 m, 4 rows planted with 7 plants per row and a plot size of 7m long and 4m wide were used.

3.3 Statistical Analysis

Indostat/Windostat version 8.5 and Genstat version 14 statistical softwares were used for analysis. Means of treatments were compared using Duncan's Multiple Range Test at 0.001 and 0.05 levels of significance.

4.0 Results and Discusion

4.1 Effect of locations on root yield and its components

4.1.1 Cassava root yield

The results from this studyshowed variations in cassava root yield among genotypes within and across locations. The mean root yield across locations ranged from 7.32 – 21.72 t ha^{-1}. However the analysis for root yield revealed that, Kiroba and NDL 2006/487 were identified as superior yielding genotypes across the locations (Table 4). NDL 2006/487 showed wider adaptability across the locations, while Kiroba showed instability in root yield performance. This implies that NDL 2006/487 can be grown in any of the three locations, while Kiroba is favourable for Nachingwea site (Figures 1 – 4). The superiority for these treatments existed probably because these two varieties had consistently high number of roots per plant across the locations and furthermore the two genotypes were less affected by diseases. These results agree with previous study by Ntuwurunga *et al.,* (2001), who reported that, cassava root yield increases as plant root number increases. Variation among locations on root yield was observed on NDL 2006/850 and NDL 2006/738 and therefore regarded as unstable genotypes. Stable genotype, for root yield, across the locations were NDL 2006/438 and NDL 2006/741, although the latter recorded lower yields across the locations.

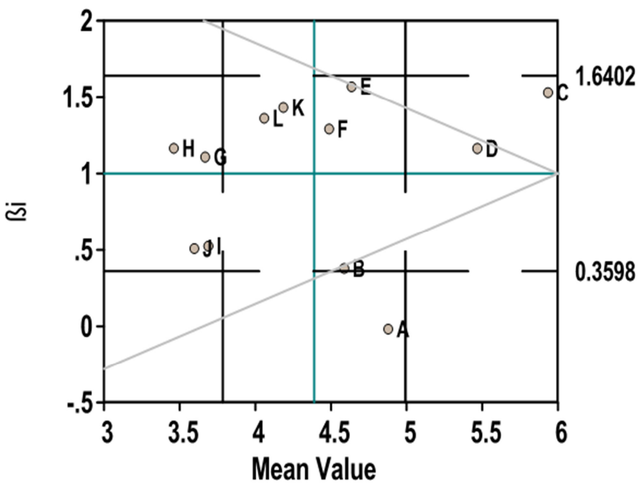

Figure 1: b–values against roots per plant mean values

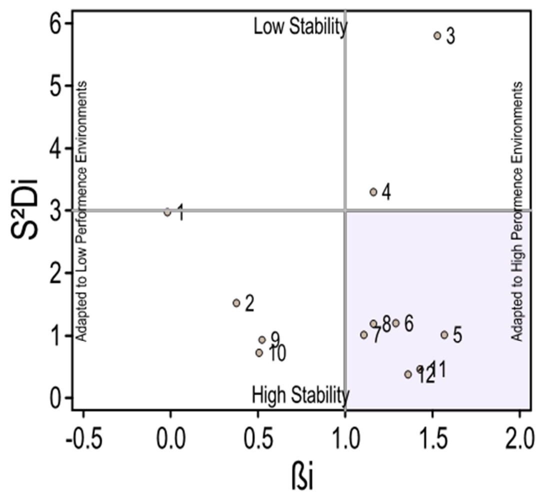

Figure 2: S^2d values against b – values for

KEY:

1 = Albert, 2 = Kiroba, 3 = Naliendele, 4 = NDL 2006/030, 5 = NDL 2006/104, 6 =NDL 2006/283, 7 = NDL 2006/438, 8 = NDL 2006/487, 9 = NDL 2006/738, 10 = NDL 2006/741, 11 = NDL 2006/840, 12 = NDL 2006/850.

A = Albert, B = Kiroba, C = Naliendele, D = NDL 2006/030, E = NDL 2006/104, F =NDL 2006/283, G = NDL 2006/438, H = NDL 2006/487, I = NDL 2006/738, J = NDL 2006/741, K = NDL 2006/840, L = NDL 2006/850.

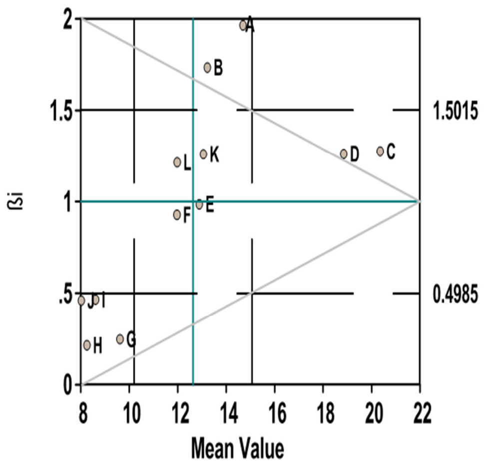

Figure 3: b–values against root yield mean values.

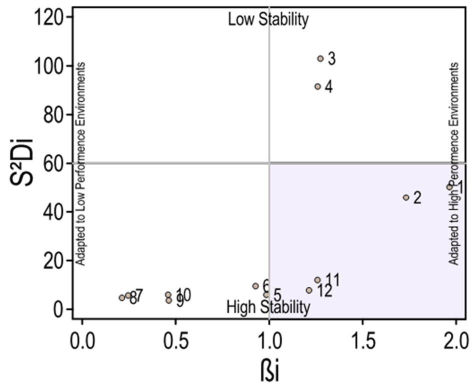

Figure 4: S^2d values against b–values for root yield.

KEY:
1 = Albert, 2 = Kiroba, 3 = Naliendele, 4 = NDL 2006/030, 5 = NDL 2006/104, 6 =NDL 2006/283, 7 = NDL 2006/438, 8 = NDL 2006/487, 9 = NDL 2006/738, 10 = NDL 2006/741, 11 = NDL 2006/840, 12 = NDL 2006/850.

A = Albert, B = Kiroba, C = Naliendele, D = NDL 2006/030, E = NDL 2006/104, F =NDL 2006/283, G = NDL 2006/438, H = NDL 2006/487, I = NDL 2006/738, J = NDL 2006/741, K = NDL 2006/840, L = NDL 2006/850.

Table 2: Stability parameters for root yield and some of its componets.

Variable		Code	Genotype	Mean	b -value	b-1	Rank	S^2d	Rank	R^2
Roots per plant	1	A	Albert	4.8794	0.018	-0.982	12	2.9678 ***	10	0.0001
	2	B	Kiroba	4.5889	0.377	-0.623	11	1.5177 ***	9	0.0882
	3	C	Naliendele	5.9350	1.529	0.529	9	5.7994 ***	12	0.3049
	4	D	NDL 2006/030	5.4678	1.162	0.162	2	3.2922 ***	11	0.3056
	5	E	NDL 2006/104	4.6378	1.569	0.569	10	1.0116 ***	6	0.708
	6	F	NDL 2006/283	4.4889	1.290	0.290	4	1.1990 ***	8	0.5846
	7	G	NDL 2006/438	3.6706	1.107	0.107	1	1.0104 ***	5	0.5473
	8	H	NDL 2006/487	3.4628	1.163	0.163	3	1.1862 ***	7	0.5358
	9	I	NDL 2006/738	3.6911	0.524	-0.476	7	0.9309 ***	4	0.226
	10	J	NDL 2006/741	3.5983	0.508	-0.492	8	0.7180 ***	3	0.2557
	11	K	NDL 2006/840	4.1861	1.429	0.429	6	0.4565 ***	2	0.7989
	12	L	NDL 2006/850	4.0600	1.360	0.360	5	0.3718 **	1	0.8085
		$\overline{X}$		**4.3888**	**1.003**	**0.003**	**6.5**	**1.7051**	**6.5**	**0.4303**
Root size	1	A	Albert	0.2372	0.1360*	-0.864	5	-0.004	8	0.0515
	2	B	Kiroba	0.2194	0.0790*	-0.921	9	-0.0049	11	0.0462
	3	C	Naliendele	0.2428	0.177	-0.823	4	0.0009	3	0.0211
	4	D	NDL 2006/030	0.2522	0.088	-0.912	6	0.0014	5	0.005
	5	E	NDL 2006/104	0.3417	2.342	1.342	10	0.0447 ***	12	0.3242
	6	F	NDL 2006/283	0.2356	1.213	0.213	3	-0.0022	6	0.6617
	7	G	NDL 2006/438	0.2306	-0.07	-1.07	8	-0.0027	7	0.0076
	8	H	NDL 2006/487	0.2244	0.059	-0.941	7	0.0012	4	0.0023
	9	I	NDL 2006/738	0.2556	3.1910*	2.191	11	0.0004	2	0.8831
	10	J	NDL 2006/741	0.2656	3.2500*	2.25	12	-0.0001	1	0.8963
	11	K	NDL 2006/840	0.2739	0.887	-0.113	1	-0.0042	9	0.7347
	12	L	NDL 2006/850	0.2783	0.806	-0.194	2	-0.0046	10	0.7599
		$\overline{X}$		**0.254775**	**0.68775**	**0.0131667**	**6.5**	**-0.0017091**	**6.5**	**0.3661**
Root yield	1	A	Albert	7.3211	1.962	0.962	12	50.28 ***		0.4827
	2	B	Kiroba	21.7223	1.7311	0.7311	9	45.86 ***	9	0.3152
	3	C	Naliendele	11.454	1.2832	0.2832	6	102.93 ***	12	0.8113
	4	D	NDL 2006/030	8.9501	1.2612	0.2612	5	91.45 ***	11	0.7105
	5	E	NDL 2006/104	12.8924	0.9971	-0.0029	1	5.87***	4	0.591
	6	F	NDL 2006/283	10.8811	0.934	-0.066	2	9.53 ***	7	0.8354
	7	G	NDL 2006/438	20.6121	0.2581	-0.7419	10	5.68 ***	3	0.3361
	8	H	NDL 2006/487	17.5331	0.2132	-0.7868	11	4.73 ***	2	0.6896
	9	I	NDL 2006/738	13.4734	0.4687	-0.5313	7	3.61 ***	1	0.7849
	10	J	NDL 2006/741	8.9362	0.4553	-0.5447	8	5.88 ***	5	0.2161
	11	K	NDL 2006/840	13.0732	1.261	0.261	4	12.00 ***	8	0.1957
	12	L	NDL 2006/850	14.1722	1.2132	0.2132	3	7.77 ***	6	0.6545
		$\overline{X}$		**13.4092**	**1.0031**	**0.003175**	**6.5**	**28.7992**	**6.5**	**0.5519**

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Generally the trend for the root yield (Figure 5) was not consistent with increase in altitude, as the yields were higher at Nachingwea located 465 masl, followed by the yields at Naliendele located at 120 masl and lastly Mtopwa which is located at relatively high altitudes 760 masl. These results are in agreement with observations by Ntawurunga and Dixon, (2010) that experienced the same trend of root yield at different altitudes. This is because cassava performs better in mid altitudes, as compared to low and high altitudes where temperatures are very high and very low respectively (Ntawurunga, 2000). Therefore the differences in yield among the three locations could be due to differences in temperature; where at Mtopwa site the temperatures are relatively low and therefore the rate of growth and root filling needs longer time for the crop to attain its optimum yield, while at Naliendele the temperatures are very high to an extent that both plant growth and root expansion are retarded. However selecting the best performing genotypes and locating them to the most suitable locations remains a necessary criterion for the best yield results.

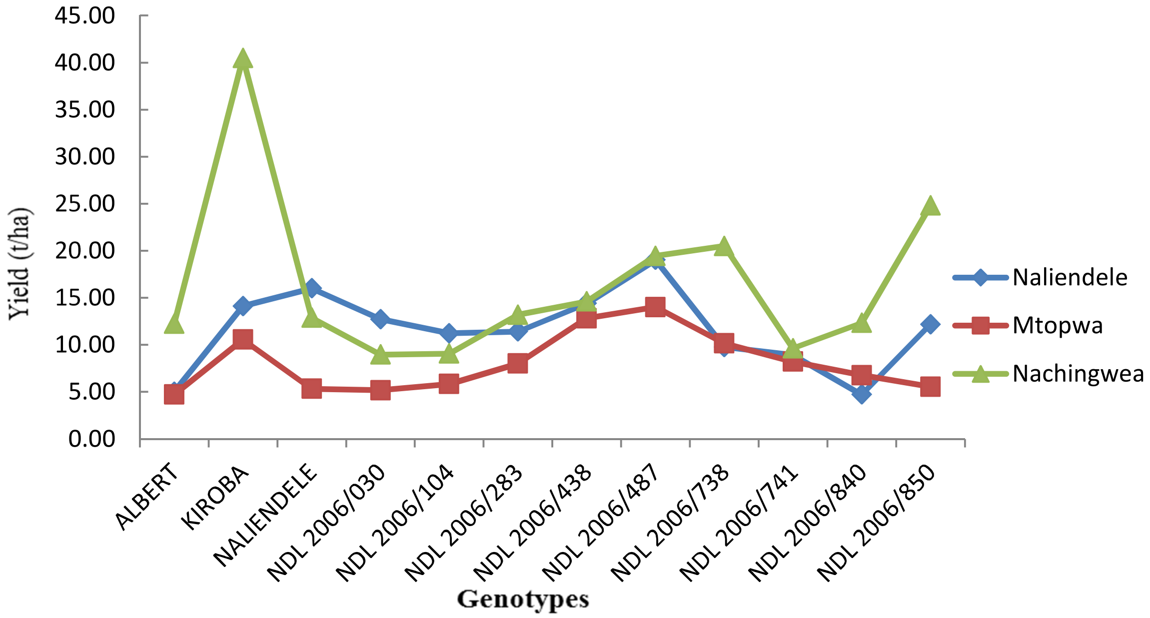

Figure 5: Effects of location on cassava root yield (t ha^{-1}) grown at Naliendele (low altitude), Nachingwea (mid altitude) and Mtopwa (high altitude)

The variety Kiroba was on average considered as the best for root yield across the three locations and specifically for Nachingwea (Table 4), while genotype NDL 2006/487 was more suitable for Naliendele and Mtopwa. Based on these results therefore, Nachingwea was the most suitable location for cassava root yield production, as this location had suitable conditions for cassava growth and development (Appendix 1). The weather data agrees partially (in this season), with optimum conditions for cassava growth and production as those suggested by (Nassar and Ortiz, 2007).

The performance of yield and yield components at all locations were below the expected ones (Kundy *et al.,* 2014) as most of the newly selected genotypes were expected to yield about 18 t ha^{-1} and above. Mkamilo *et al.,* (2010) in unpublished research reports, reported that, these genotypes when tested in Advanced Yield Trials, had root yields ranging between 18 - 25 t ha^{-1}. This low performance may be attributed to the weather conditions that prevailed during the cropping season 2011/2012 (Appendix 1), which was not optimum. These results do not conform to the optimum conditions for cassava growth and development. According to Nassar and Ortiz, 2007, cassava performs better in low land tropics requiring a warm temperature (24^{oC} – 27^{oC}), moist climate and rainfall between 1000mm – 1500mm per annum.

4.1.2 Plant height

At Nachingwea, genotypes had the tallest cassava plants as compared to the two locations. This could be due to the fact that Nachingwea had good rainfall and optimum temperatures (Appendix 1) which had favoured plant growth compared to Naliendele and Mtopwa. Genotype NDL 2006/850 had the highest plant height across the locations and also gave highest plant heights at Nachingwea and Mtopwa. Plants with high heights do not guarantee high yields as plant height is not among the main factors contributing to yield (Ntawurunga *et al.,* 2001). Also this is supported in this experiment whereby Kiroba had low to medium plant heights, but with high to highest root yields. The overall mean number of plant height was 144.9 cm. These results are within the range of cassava plant height of 100 to 400 cm (Ekanayake *et al.,* 1997; Tan and Cock, 1979).

4.1.3 Number of branches per plant

This variable showed significant variations within and across locations. Nachingwea had many plants with many branches per plant compared to other sites. High number of plants with high number of branches at Nachingwea was supported by the good moisture availability (Appendix 1), which favoured both vegetative growth and root yield. The number of branches per plant varied from 1.15 to 4.17 in the three locations. This differed a little bit from the results obtained by Villamayor, (1983) in research done at Philippines' Root Crop Research and Training Center, where number of branches per plant ranged between 1.6 and 2.0. The overall highest number of branches per plant was recorded on the treatment Kiroba. High number of branches per plant is not an indicator for high root yield, as the correlation between number of branches per plant was positive non – significant (0.0947). To support this, NDL 2006/487 had the lowest number of branches per plant within and across the locations, however it was among the best yielders; whereas NDL 2006/741 had higher numbers of branches per plant, but it was the least yielder, indicating that selection for high yield would require other parameters apart from number of branches per plant.

4.1.4 Stem girth

This parameter showed significant variations within and across locations. Naliendele had many plants with wider stem girths compared to the other two locations. The widest value of plant stem girth was recorded on Naliendele variety at Naliendele site. Higher plant stem girths at Naliendele could be contributed by the moderate moisture content, as compared to Mtopwa and Nachingwea, experienced during plant growth (Appendix 1). The stem girth ranged between 2.79 and 6.17 cm. This agrees with study done by Ikeh *et al.,* (2012), who reported that cassava stem girths ranged between 3.10 and 5.80 cm. Stem girth had positively and highly significant correlation with yield (r = 0.481**) indicating that, improvement of stem girth will also improve root yield. This agrees with findings by Ntawurunga *et al., (*2001), who reported that, stem girth is among the main yield components contributing to root yield.

4.1.5 Number of roots per plant

Based on this study, it was observed that the mean number of roots per plant varied significantly within and across locations. Nachingwea had plants with many roots compared to other locations. The differences may have been caused by distribution of rainfall and temperature in these locations. Nachingwea received more rainfall as compared to Naliendele and Mtopwa. Furthermore, the temperatures for Nachingwea during the 2011/2012 cropping season (Appendix 1), favoured growth and development of cassava and hence many roots per plant. Number of roots per plant varied from 1.63 to 10.03. These results were below the number of roots per plant obtained by Cock, (1985) at CIAT, which were in the range of 5 to 20 roots per plant. This remarkable difference between these two experiments may be due to different environmental conditions. The sites under this study are in dry environments, and according to Cock, (1979), fewer storage roots are formed in drier environments. Kiroba, NDL 2006/438 and NDL 2006/487 gave better performance at Nachingwea, indicating that, these three genotypes were suitable in that location for good number of roots per plant and ultimately high yields. This variable had a positively and highly significant correlation with yield (0.7053***).

4.1.6 Root size per plant

Mean weight in kilograms of roots revealed significant variations within and across locations. Nachingwea had the highest mean weight of roots per plant compared to other sites. In this study, across the locations root size ranged between 0.19 kg and 0.38 kg, which agrees with study conducted by Alfredo, (1997), who reported that weight of a single cassava root varied from 0.17 to 2.35 kg. Albert, NDL 2006/283, NDL 2006/438, and NDL 2006/487 appeared to be stable in terms of performance with respect to this character and had average to high values. These genotypes had (b -1) values of 0.213, -1.07 and 0.941 respectively as an indication of their stability. This suggests that, these genotypes had wider adaptability in terms of root size. Genotype NDL 2006/741 appeared to be unstable with inconsistent performance from one location to another with a (b -1) value of 2.25 (Table 2).

4.1.7 Harvest Index

With respect to harvest index, genotypes varied significantly within and across locations. The highest harvest index was obtained from Kiroba at Naliendele, while the overall highest harvest was obtained on NDL 2006/738. This highest value of harvest index at Naliendele, probably may be due to low rainfall (Appendix 1) received in this area, and therefore made the accumulation of water in the shoots to be low; which resulted to low shoot weight, low total weight and hence high harvest index. With respect to Kiroba having the highest harvest index at Naliendele, this may be due to the short and reduced aerial parts of Kiroba, which was 116 cm tall with average of 7 roots per plant as compared to NDL 2006/850 (144 cm tall) with average of 4 roots per plant. The harvest index values ranged between 0.57 and 0.84. This was in contrast with what was observed by Joseph *et al.,* (2011) who reported a range of 42.33 – 54.54 % in hybrids (crosses) and 14.30 – 37.83 % in parents of those crosses. This big difference in harvest index probably has been contributed by variations in genetical traits, as harvest index in cassava is little affected by the environment and is a good indicator of the potential performance of a genotype across agro-ecological zones (Kawano, 1990).

4.2 Effect of locations on cassava major diseases on the Cassava Genotypes

4.2.1 Cassava brown streak disease

Significant variations were observed among the treatments at all locations. The highest disease incidence and severity were observed at Nachingwea on the variety Albert. The higher occurrence of the disease in Nachingwea compared to other locations can be due to location specific problem, as Nachingwea is known to be one of the high pressure disease areas in southern Tanzania (Hillocks, 1997). Albert was a stable susceptible variety which consistently recorded the highest disease incidences and severities across the locations. Probably, this is due to the genetical make up of this variety, which is highly susceptible to CBSD, as this disease is also transmitted through dissemination of infected planting materials. Other treatments that showed significant effect on this disease were Naliendele at Nachingwea and NDL 2006/283 at Naliendele sites.

4.2.2 Cassava mosaic disease

Based on the results of this study, it was observed that the mean CMD varied significantly within and across locations. Nachingwea had the highest disease incidence and severity recorded on the genotype NDL 2006/741. The highest incidences and severity at Nachingwea is probably due to location as disease spread between plants is by whitefly and can be rapid in some areas with high occurrence of this vector (Hillocks and Thresh, 2000). NDL 2006/741 was susceptible across the locations as it was consistently affected by the CMD. Genotypes Naliendele (at Naliendele and Nachingwea), NDL 2006/104 (at Naliendele) and NDL 2006/840 (at Naliendele) also showed significant disease symptoms. The observed differences in CMD incidence and severity among the genotypes could be due to genetic differences. This is because according to Hillocks and Thresh (2000), the variations between cassava lines/genotypes diseases are inherited from planting materials and hence, genetically controlled. This suggests that, for the tolerant newly developed genotypes, there is a room for using them both directly for cassava root production and or using them in breeding programs as parents.

Table 3: Summary of location effects for the different variables

Location	RYD	PHT	BPL	SGH	RPL	RTZ	HI	CBI %	CBS	CMI %	CMS	NEC	DM %	STH %	PTN %
Naliendele	11.62	136.04	2.72	5.25	4.78	0.21	0.65	10.97	1.24	21.53	1.41	1.60	36.75	20.36	0.67
Mtopwa	8.10	96.89	2.49	3.37	3.21	0.25	0.65	11.89	1.30	8.34	1.19	1.31	37.92	21.21	0.88
Nachingwea	18.18	158.00	2.75	4.59	5.18	0.31	0.76	11.79	1.25	11.60	1.30	1.51	38.22	21.47	0.78
Mean	**12.63**	**130.31**	**2.65**	**4.40**	**4.39**	**0.26**	**0.69**	**11.55**	**1.26**	**13.82**	**1.30**	**1.47**	**37.63**	**21.01**	**0.78**

Where: RYD = Root yield, PHT = Plant height, BPL = Branches per plant, SGH = Stem girth, RPL = Roots per plant, RTZ = Root size, HI = Harvest index, CBSI% = Cassava brown streak disease incidence, CBS = Cassava brown streak disease severity, CMI = Cassava mosaic disease incidence, NEC = Root necrosis, DM% = Dry matter, STH = Starch and PTN = Protein

Table 4: Means for root yield in cassava genotypes at Naliendele, Mtopwa and Nachingwea locations

Genotype	Naliendele	Mtopwa	Nachingwea
ALBERT	5.00^{h}	4.71^{f}	12.23^{efg}
KIROBA	14.11^{dc}	10.56^{c}	40.48^{a}
NALIENDELE	16.00^{b}	5.33^{f}	12.87^{ef}
NDL 2006/030	12.72^{ed}	5.17^{f}	8.97^{g}
NDL 2006/104	11.22^{fe}	5.83^{ef}	9.06^{g}
NDL 2006/283	11.42^{e}	8.02^{d}	13.20^{e}
NDL 2006/438	14.40^{c}	12.83^{b}	14.61^{e}
NDL 2006/487	19.02^{a}	14.02^{a}	19.45^{d}
NDL 2006/738	9.77^{gf}	10.15^{c}	20.50^{d}
NDL 2006/741	8.92^{g}	8.22^{d}	9.63^{fg}
NDL 2006/840	4.71^{h}	6.78^{e}	12.33^{efg}
NDL 2006/850	12.17^{e}	5.55^{f}	24.80^{c}
Overall mean	**11.62**	**8.10**	**18.18**
s.e	1.32	0.98	0.91
c.v. (%)	11.40	12.10	5.00

Means with the same superscript letter(s) in the same column are not significantly different ($P \leq 0.05$) following separation by Duncan's Multiple Range Test.

Table 5: Means for yield and growth parameters in cassava genotypes under combined analysis

Genotype	PHT	BRP	STG	RTP	RTS	HI	RTY
ALBERT	134.20^{bc}	2.93^{bcd}	4.12^{ef}	3.64^{fgh}	0.24^{bcd}	0.67^{bc}	7.32^{g}
KIROBA	116.90^{ef}	**3.71^{a}**	**4.85^{a}**	**7.03^{a}**	0.28^{bcd}	0.73^{ab}	**21.72^{a}**
NALIENDELE	123.40^{de}	2.86^{cd}	4.27^{def}	5.24^{c}	0.20^{d}	0.67^{bc}	11.40^{e}
NDL 2006/030	126.30^{d}	2.80^{cde}	4.07^{f}	3.33^{h}	0.22^{cd}	0.68^{abc}	8.95^{f}
NDL 2006/104	130.20^{cd}	2.97^{bc}	4.59^{bc}	3.52^{gh}	0.19^{d}	0.67^{abc}	8.71^{f}
NDL 2006/283	137.80^{ab}	2.48^{efg}	4.37^{cde}	4.17^{de}	0.25^{bcd}	0.69^{abc}	10.88^{e}
NDL 2006/438	143.40^{a}	2.51^{efg}	4.32^{def}	5.83^{b}	0.22^{cd}	0.71^{abc}	18.61^{c}
NDL 2006/487	138.80^{ab}	1.22^{h}	4.71^{ab}	4.37^{d}	0.22^{cd}	0.60^{d}	19.50^{b}
NDL 2006/738	129.20^{cd}	2.59^{def}	4.43^{cd}	3.89^{efg}	**0.38^{a}**	**0.74^{a}**	13.47^{d}
NDL 2006/741	112.60^{f}	3.24^{b}	4.35^{cde}	3.81^{efg}	0.23^{cd}	0.66^{c}	8.93^{f}
NDL 2006/840	126.40^{d}	2.21^{g}	4.28^{def}	3.77^{efg}	0.33^{ab}	0.68^{abc}	7.94^{fg}
NDL 2006/850	**144.90^{a}**	2.28^{fg}	4.87^{a}	4.07^{def}	0.30^{abc}	0.71^{abc}	14.17^{d}
Overall mean	**130.32**	**2.65**	**4.44**	**4.39**	**0.25**	**0.68**	**12.63**
s.e	10.36	0.48	0.36	0.59	0.13	0.08	1.49
c.v. (%)	8.00	18.10	8.10	13.40	12.10	11.90	11.80

Means with the same superscript letter(s) in the same column are not significantly different ($P \leq 0.05$) following separation by Duncan's Multiple Range Test.

Key: PHT = Plant height (cm), BRP = Number of branches per plant, STG = Stem girth (cm), RTP = Number of roots per plant, RTS = Root size (kg), HI = Harvest index and RYD = Root yield (t ha^{-1}).

Table 6: Means for CBSD incidence, CBSD severity, CMD incidence and CMD severity at Naliendele, Mtopwa and Nachingwea locations

Genotype	CBS DI			CBS DS			CM DI			CM DS		
	Naliendele	**Mtopwa**	**Nachingwea**	**Naliendele**	**Mtopwa**	**Nachingwea**	**Naliendele**	**Mtopwa**	**Nachingwea**	**Naliendele**	**Mtopwa**	**Nachingwea**
ALBERT	**96.67^{a}**	**93.33 a**	**100.00^{a}**	**2.90^{a}**	**2.97^{a}**	**3.00^{a}**	0.00^{e}	0.00^{c}	1.67^{c}	1.00^{d}	1.00^{c}	1.00^{c}
KIROBA	0.00^{c}	0.17^{b}	0.00^{d}	1.00^{c}	1.01^{b}	1.00^{d}	0.00^{e}	0.00^{c}	0.00^{c}	1.00^{d}	1.00^{c}	1.00^{c}
NALIENDELE	0.00^{c}	0.00^{b}	33.21^{b}	1.00^{c}	1.00^{b}	1.84^{b}	83.33^{b}	0.00^{c}	32.52^{b}	**2.67^{b}**	1.00^{c}	1.80^{b}
NDL 2006/030	0.00^{c}	4.17^{b}	0.00^{d}	1.00^{c}	1.17^{b}	1.00^{d}	26.31^{d}	0.00^{c}	0.00^{c}	1.00^{d}	1.11^{c}	1.00^{c}
NDL 2006/104	0.00^{c}	4.17^{b}	0.00^{d}	1.00^{c}	1.17^{b}	1.00^{d}	0.00^{e}	3.00b c	4.56^{c}	1.00^{d}	1.00^{c}	1.04^{c}
NDL 2006/283	35.03^{b}	0.00^{b}	0.00^{d}	1.96^{b}	1.00^{b}	1.00^{d}	0.00^{e}	0.00^{c}	2.38^{c}	1.00^{d}	1.04^{c}	1.11^{c}
NDL 2006/438	0.00^{c}	16.67 b	0.00^{d}	1.00^{c}	1.33^{b}	1.00^{d}	0.00^{e}	2.08^{bc}	2.22^{c}	1.00^{d}	1.00^{c}	1.28^{c}
NDL 2006/487	0.00^{c}	0.00^{b}	0.00^{d}	1.00^{c}	1.00^{b}	1.00^{d}	0.00^{e}	0.00^{c}	0.00^{c}	1.00^{d}	1.00^{c}	1.00^{c}
NDL 2006/738	0.00^{c}	8.33^{b}	0.00^{d}	1.00^{c}	1.42^{b}	1.00^{d}	31.66^{c}	0.00^{c}	0.00^{c}	1.54^{c}	1.00^{c}	1.00^{c}
NDL 2006/741	0.00^{c}	7.50^{b}	0.00^{d}	1.00^{c}	1.18^{b}	1.00^{d}	**93.00^{a}**	**87.50 a**	**95.83^{a}**	2.48^{a}	**2.87^{a}**	**3.17^{a}**
NDL 2006/840	0.00^{c}	4.17^{b}	0.00^{d}	1.00^{c}	1.23^{b}	1.00^{d}	24.08^{d}	0.00^{c}	0.00^{c}	1.35^{c}	1.29^{b}	1.00^{c}
NDL 2006/850	0.00^{c}	4.17^{b}	8.33^{c}	1.00^{c}	1.13^{b}	1.13^{c}	0.00^{e}	7.5	0.00^{c}	1.00^{d}	1.00^{c}	1.00^{c}
Overall mean	**10.97**	**11.89**	**11.79**	**1.24**	**1.30**	**1.25**	**21.53**	**8.34**	**11.6**	**1.41**	**1.19**	**1.30**
s.e	1.95	2.34	3.99	0.07	0.33	0.11	3.43	2.01	2.44	0.18	0.14	0.24
c.v. (%)	17.8	25.50	23.80	5.70	19.70	8.50	15.90	30.10	28.30	13.00	11.70	18.60

Means with the same superscript letter(s) in the same column are not significantly different ($P \leq 0.05$) following separation by Duncan's Multiple Range Test.

5.0 Conclusion and Recommendations

Among the genotypes used in this study, variety Kiroba and genotype NDL 2006/487, showed high mean root yield, and were not significantly affected by diseases. Furthermore, variety Naliendele and genotype NDL 2006/438, although significantly affected by diseases, had high mean root yields at Naliendele and Nachingwea respectively. This showed that these varieties are tolerant to diseases. Furthermore Kiroba, Naliendele, NDL 2006/487 and NDL 2006/438 were stable over the environments and therefore can be used in the breeding programs for the development of high yielding stable genotypes over different environments for future use.

For cassava root yield production, it is recommended to grow Kiroba at Nachingwea and genotype NDL 2006/487 to be grown at Naliendele and Mtopwa sites where they performed best. For future G x E experiments, it is recommended to employ the aspect of seasons or years in order to have reliable and precise information on given varieties or genotypes. Also, further investigations on G x E interactions at important crop growth stages for yield, yield components and biochemical profiles would help to develop strategies that integrate traditional plant breeding with modern molecular marker based selection for tailoring cassava genotypes/cultivars for higher yield and target environments.

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Appendix 1:Rainfall and temperature data recorded at different locations during 2011/12 cropping season

	Rainfall (mm)			Temperature (°C)		
Month	Naliendele	Mtopwa	Nachingwea	Naliendele	Mtopwa	Nachingwea
January	216.3	257.5	240.9	28.2	22	24.84
February	81.4	136.5	113.5	29.9	23.3	25.52
March	260.3	347.3	297.8	28.8	21.7	24.9
April	84.4	98.4	108.5	28.7	20	24.8
May	63.3	7.5	98.1	29	19.4	24.1
June	3.9	0	11	28.3	18.9	25.4
July	13.5	3	0	28.5	20	25.6
August	6.3	12.5	1.2	28.7	22	24.9
Total	**729.4**	**862.7**	**870**			