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Plant growth and yield stability of orange fleshed sweet potato (*Ipomoea batatas*) genotypes in three agro-ecological zones of Malawi

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ABSTRACT

An on-farm study was conducted to evaluate plant growth, tuber yield and stability of orange fleshed sweet potato (OFSP) genotypes in three agro-ecological zones of Malawi. The study sites were Maseya in Chikhwawa District representing low altitude areas with hot climate; Bunda in Lilongwe District representing medium altitude with warm climate and Bembeke in Dedza District representing high altitude areas with cool climate. Genotypes LU06/0527, LU06/0252, LU06/0428, LU06/0299, LU06/0258, BV/009, Kenya and Zondeni were evaluated in the trials. At each location, three farmers conducted the trials laid out in a Randomized Complete Block Design with three replicates on each farmer's field. Analysis of variance on the main effects of genotypes and environments as well as Interaction Principal Component Analysis (IPCA) for the residual multiplication interaction between genotypes and environments were conducted. Results revealed significant differences in vine length, leaf area and tuber yield among the genotypes evaluated as well as across the trial sites. Genotype LU06/0428 produced the highest leaf area of 130.9 cm² followed by BV/009 with 97.7 cm². LU06/0527 was the highest tuber yielding genotype with 20.7 t/ha. Stability analysis found that Zondeni was the most stable variety across the sites. Bunda was the highest tuber yielding and unstable site while Maseya was the lowest yielding and unstable site.

Keywords: Agro-ecological zones, On-farm, Sweet potato, Vine length, Yield stability

INTRODUCTION

Sweet potato (*Ipomoea batatas*) is an important tuber crop in sub-saharan Africa and ranks second after cassava in Malawi (Chipungu et al., 1999). It ranks as the world's seventh most important crop with an estimated annual production of 300 million metric tons grown on 19 million hectares of land (Amamgbo and Nwachukwu, 2008; Kwach et al., 2010; Laurie et al., 2013; Muthoni et al., 2011).

In Malawi, sweet potato production has increased in recent years due to its substantial ability to tolerate drought conditions commonly experienced in the country (Moyo et al., 2004). The crop is mainly consumed in form

of tubers, which are either boiled or roasted on open fire (Chipungu, 2008; MOAFS, 2007). Farmers gain income through selling of the tubers to urban areas of Malawi. Sweet potato leaves are used as vegetables rich in essential minerals, vitamins and other compounds. Williams et al. (2013) reported that sweet potato leaves contain chlorogenic acids, a phenolic compound responsible for suppressing obesity in humans. They also contain considerably higher amounts of minerals such as P, N, K, Mg, Cu, Fe and Zn than what is contained in commonly cultivated vegetables (Shi et al., 2008). Livestock farmers in Malawi use sweet potato vines to

feed goats and cattle (Moyo et al., 2004). The vines contain proteins and minerals required in the livestock feeding diet (Kebede et al., 2008).

Among the varieties being grown in Malawi, the orange-fleshed sweet potato varieties are gaining great attention as a means of reducing common health related problems in low income communities associated with vitamin A deficiency in the country (Chipungu et al., 1999). The varieties are believed to be the least expensive source of dietary vitamin A available to poor families (Stathers, 2005; Laurie et al., 2013). This is due to their high nutritive value of beta-carotene content, a precursor to vitamin A synthesis (Ukpabi et al., 2012).

Despite the benefits obtained from sweet potato production, the country faces challenges to successfully grow the crop. One of the major challenges is lack of improved orange-fleshed sweet potato varieties. Currently, it is estimated that over 95% of sweet potatoes produced in Malawi are white or cream fleshed (Chipungu, 2008). These varieties are low in beta-carotene content as well as low vines and tuber yield (Chipungu et al., 2009; MOAFS, 2007). The varieties do not yield consistently across agro-ecological zones of Malawi as such their reliability to supply adequate quantities for national requirement is not guaranteed (Chipungu et al., 2009). Sweet potato production in Malawi is also challenged by incidences of diseases and pests. One major disease in Malawi is the sweet potato virus disease (SPVD), a disease responsible for yield loss of as high as 98% under complex multiple viral attacks in the field (MOAFS, 2007). Sweet potato weevil (*Cylas formicarius*) attack is a pest challenge faced by Malawian farmers causing considerable yield and quality loss to sweet potatoes (MOAFS, 2007).

To contribute towards the solution of low tuber and vine yields obtained by farmers in Malawi, an on-farm study was carried out using orange-fleshed sweet potato genotypes to evaluate vine growth, tuber yield and stability in three agro-ecological zones of Malawi. The study used sweet potato cultivars, which had been tested for growth and yield attributes during a series of on-station trials at Kasinthula Research Station in Malawi.

MATERIALS AND METHODS

Site selection

The study was conducted in Malawi at three sites representing three agro-ecological zones of Malawi. The sites were Bembeke in Dedza District representing high altitude, cool and wet plateau zone, Bunda in Lilongwe District representing middle altitude warm plain zone and Maseya in Chikhwawa District representing low altitude

hot and dry agro ecological zone (Table 1). The agro ecological zones were selected based on altitude, soil conditions, temperatures and amount of rainfall (Saka et al., 2006).

Farmer selection and planting materials

In each site, three farmers were identified to carry out the trials. Preference was given to farmers that had been growing sweet potatoes in the sites for the previous five years since they could easily follow the trial procedures. Eight orange-fleshed sweet potato genotypes sourced from Kasinthula Agricultural Research Station in Chikhwawa District, namely LU06/0299, LU06/0258, LU06/527, BV/009, LU06/0252, LU06/0428, Zonden and Kenya, were used in the study. Zonden and Kenya, already released varieties being grown by farmers, were used as checks. Detailed genotypes descriptions are contained in Table 2.

Experimental design

On each farmer's field, the trial was laid out in a Randomized Complete Block Design (RCBD) with three replicates. For each genotype, three ridges measuring 4 m long and 0.75 m between ridges were used. Data was collected on the second ridge after discarding 0.5 m length on both ends of the ridge. Vines of length 25-30 cm were planted at spacing of 0.3 m between plants on each row. Treatments were randomly allocated to plots in each replicate. Before planting, soil samples from representative field locations were collected to a depth of 0–30 cm for physical and chemical analysis (data not reported).

Management of experimental plots

Farmers in each site planted on similar dates as follows; 13th September for farmers in Maseya, 14th September for farmers in Bembeke and those at Bunda planted on 15th September, 2011. The trials were irrigated during the initial phase as they fell in the dry season of Malawi. Irrigation was done before planting and thereafter three times per week from mid September to end November, 2011 when it was stopped at the onset of planting rains until harvesting. Weeding using hoes was done as soon as weeds appeared particularly during the first month. Thereafter hand weeding was done to avoid disturbing the vines. No chemicals were applied to control weeds, pests and diseases but monitoring of pests and diseases incidence was done.

Table 1. Description of locality and elevation in metres above sea level (masl) of the sites

Trial site	Locality	Average temperature	Soil type	Elevation (masl)	Average rainfall (mm/annum)
Maseya	16° 04' S 34° 80' E	29.5°C	Alfisols	200	600
Bunda	14° 12' S 33° 46' E	20.0°C	Lithosols	1200	1030
Bembeke	14° 35' E 34° 43' S	15.0°C	Lithosols	1600	1500

Table 2. Genotype source, growth habit, skin and flesh colours, maturity in Months After Planting (MAP) and potential yield (t/ha)

* Data obtained from on-station results conducted during the initial stages of the genotypes evaluation

Genotype	Female parent/ Source	Growth habit	Skin colour	Flesh colour	Maturity * (MAP)	Potential yield * (t/ha)
BV/009	LU96/374	Spreading	Cream	Deep orange	5	20-25
LU06/0252	Mafutha from RSA	Spreading	Purple	Pale orange	5	25-30
LU06/0258	Kakoma (TIS 3017) from IITA	Spreading	Cream	Yellow	5	20-25
LU06/0299	Kakoma (TIS 3017)	Spreading	Cream	Yellow	5	20-25
LU06/0428	Mugamba (Mogamba, CIP, Nairobi)	Spreading	Cream	Pale orange	3.5	30-35
LU06/0527	Kenya (SPN/O)	Spreading	Orange	Orange	5	30-35
Kenya (SPN/O)	Introduced cultivar	Semi-erect	Cream	Pale yellow	4 to 5	25-30
Zonden	Local cultivar	Erect	Orange	Deep orange	5	10-15

Data collection and analysis

Data was collected on vine growth (cm), leaf area (cm²), tuber yield (t/ha), ground area cover, pests and diseases scores (data not presented). Vine growth was collected monthly for entire growing period and the final recording was during harvesting while leaf area was collected two months after planting (MAP). Vine length was measured using a meter rule. Leaf area was determined by tracing leaf on the graph paper whereas ground area cover was measured using a 0.75 m by 0.3 m wooden quadrant.

Data analysis was done using Genstat 14th Edition statistical package where Anova was carried out on treatment means and Additive Main Effects and Multiplicative Interaction Models (AMMI) model (Gauch, 1993) was used to carry out stability analysis of the genotypes and environments. The model is more efficient in determining the most stable and high yielding genotypes in multi-environment trials compared to other methods. As reported by Egesi and Asiedu, (2002), the model uses the analysis of variance (ANOVA) approach

to study the main effects of genotypes and environments. It also uses an Interaction Principal Component Analysis (IPCA) for the residual multiplication interaction between genotypes and environments. Genotypes with IPCA scores near zero show little interaction across environments depicting stable characteristics. Genotypes that appear to far right side of grand mean yield are high yielding while those to far left side are low yielding hence below average performance (Abidin et al., 2005; Mwale et al., 2009)

RESULTS

The results showed significant differences in vine length among the genotypes as well as across the experimental sites. Zonden, a check variety, produced the longest vines with a cumulative mean of 146.0 cm across the sites. The longest measurements for the genotype, which were 168.7 cm and 166.0 cm, were recorded at Bunda and Maseya sites respectively (Table 3).

Table 3. Vine length (cm) of sweet potato genotypes across three sites

Genotype	Site			Mean
	Bunda	Bembeke	Maseya	
BV/009	132.7	100.3	151.3	128.1
LU06/0252	166.0	119.4	143.3	142.9
LU06/0258	128.0	103.7	110.7	114.1
LU06/0299	121.2	99.0	184.3	134.8
LU06/0428	144.7	115.1	143.3	134.4
LU06/0527	49.5	50.7	66.0	55.4
Zondeni	168.7	103.3	166.0	146.0
Kenya	112.7	95.1	117.3	108.4
Mean	127.9	98.3	135.3	120.5
Genotype	P <0.001	LSD	= 16.8	
Sites	P<0.001	LSD	= 10.3	
G x E	P=0.003	LSD	= 29.1	
CV (%)	= 14.7			

The genotype was followed by LU06/0252 which measured 142.9 cm and the shortest vine length was 55.4 cm produced by LU06/0527. Across the sites, the cumulative vines lengths were longest at Maseya, which measured 135.3 cm followed by 127.9 cm and 98.3 cm for Bunda and Bembeke respectively (Table 3).

Vine growth rate among genotypes showed that LU06/0527 had the least growth rate while LU06/0252 and LU06/0299 had highest growth rates of up to 1.65cm/day and this was attained during the third month after planting (Figure 1). The growth rate was slow during the first month (1 MAP), fastest during the second month and slowed down in the last months of growth (3 MAP and 4 MAP) forming a sigmoid growth curve in most of the genotypes. Except for LU06/0527, which had a lowest growth rate ranging from 0.4cm/day in the first month to 0.6cm during the fourth month of its growth, the rest of the sweet potato genotypes produced higher vine growth rate ranging from 0.75cm/day during the first month to 1.65cm/day attained in the third month after planting before stagnating thereafter (Figure 1). Kenya showed a drastic increase in growth rate from 0.8cm/day during the first month to 1.2cm/day during the second month but remained constant thereafter until final recording.

Genotype LU06/0428 produced the highest leaf area of 130.9 cm² followed by BV/009 with 97.7 cm² while Kenya produced the least leaf area of 40.3 cm² and was not significantly different to LU06/0252 and Zondeni,

which recorded 42.2 and 46.8 cm² respectively. Across sites, the results showed that genotypes produced highest cumulative leaf area of 87.0 cm² at Maseya followed by Bunda with 63.5 cm² and the lowest was 58.0 cm² at Bembeke (Table 4).

Significant differences (P<0.001) among genotypes were also observed for tuber yield of sweet potatoes in the trials. LU06/0527 recorded the highest yield of 30.1 t/ha at Bunda surpassing Kenya, the second highest yielding genotype in the location, by almost 9 t/ha as the latter yielded 21.3 t/ha (Table 5). The genotype was also highest yielding in Maseya and Bembeke attaining 18.3 and 13.9 t/ha, respectively. Across locations, genotypes LU06/0252, LU06/0428, Kenya and LU06/0258 yielded 12.5 t/ha, 11.7 t/ha, 11.5 t/ha and 10.5 t/ha, respectively. Zondeni was the lowest tuber yielding variety, which attained only 6.4 t/ha (Table 5). The highest overall tuber yield was attained at Bunda of 15.7 t/ha followed by 10.5 t/ha at Bembeke while Maseya attained an overall tuber yield of 8.2 t/ha.

When stability analysis was performed for genotypes and environments, the effects due to genotypes, environments and their interactions were highly significant (p<0.001) and contributed 34.8 %, 21.8 % and 43.4 % respectively to the variations in root yield (Table 6).

When the interaction between genotype and environment was decomposed into interaction principle components (IPCA), the IPCA1 and IPCA2 accounted

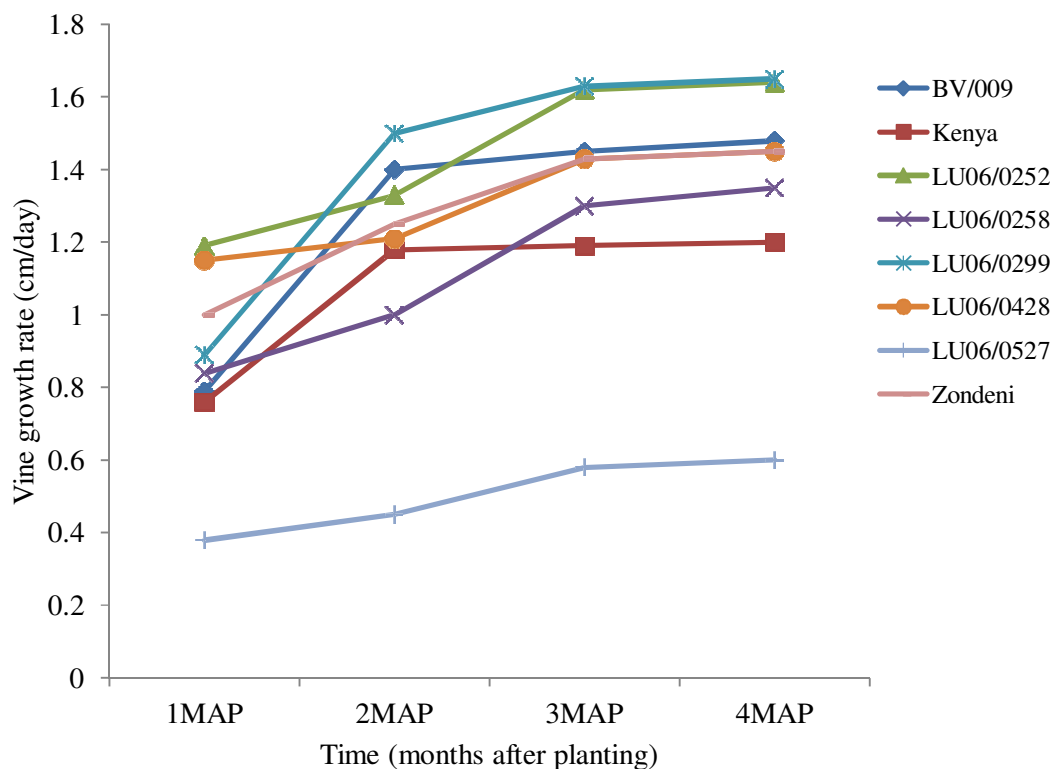


Figure 1. Vine growth rate among sweet potato genotypes across three sites

Table 4. Leaf area (cm²) of sweet potato genotypes across three sites

Genotype	Site			Mean
	Bunda	Bembeke	Maseya	
BV/009	94.7	89.7	108.7	97.7
LU06/0252	30.3	25.7	70.7	42.2
LU06/0258	55.7	64.3	91.7	70.6
LU06/0299	59.7	43.0	70.0	57.6
LU06/0428	132.7	101.0	159.0	130.9
LU06/0527	58.0	50.0	102.3	70.1
Zondeni	39.3	55.0	46.0	46.8
Kenya	37.7	35.3	48.0	40.3
Mean	63.5	58.0	87.0	69.5

Genotype	P< 0.001	LSD	= 8.9
Sites	P< 0.001	LSD	= 5.5
G x E	P< 0.001	LSD	= 15.5
CV (%)	= 3.0		

Table 5. Tuber yield (t/ha) of sweet potato genotypes across three sites

Genotype	Site			Mean
	Bunda	Bembeke	Maseya	
BV/009	16.9	8.1	3.7	9.6
LU06/0252	19.1	11.7	6.6	12.5
LU06/0258	4.4	11.7	15.4	10.5
LU06/0299	14.7	6.6	4.4	8.6
LU06/0428	10.3	9.5	15.4	11.7
LU06/0527	30.1	13.9	18.3	20.7
Zonderi	8.8	9.5	0.7	6.4
Kenya	21.3	12.5	0.7	11.5
Mean	15.7	10.5	8.2	11.4
Genotype	P< 0.001	LSD	= 4.8	
Sites	P< 0.001	LSD	= 2.9	
G x E	P< 0.001	LSD	= 8.3	
CV (%)	= 44.0			

Table 6. Analysis of variance (ANOVA) of tuber yield according to additive main effects and multiplicative interactions (AMMI)

Source of variation (SOV)	Degrees of freedom (DF)	Sum of squares (SS)	Mean squares (MS)	Explained variation (%)
Total	71	4475.0	63.0	
Genotypes	7	1138.4	162.6***	34.8
Environments	2	714.1	357.1***	21.8
Reps (within E)	6	164.3	27.4	
GxE interaction	14	1420.1	101.4***	43.4
IPCA 1	8	1142.9	142.9***	80.5
IPCA 2	6	277.2	46.2	19.5
Error	42	1037.9	24.7	

***denotes significant at 0.001 level

for 80.5 % and 19.5 % respectively. Therefore, the biplot of IPCA1 against tuber yield was used to explain stability of genotypes across the study sites.

In the bi-plots, Zonderi was the most stable variety on yield while genotypes LU06/252, LU06/0428 and LU06/0527 had higher yields than the rest (Figure 2).

Genotypes LU06/0428 and LU06/0258 showed negative interaction while the rest except Zonderi had positive interaction. Maseya was the lowest yielding site with negative interaction while Bunda was the highest yielding site with positive interaction and Bembeke was a moderately stable site.

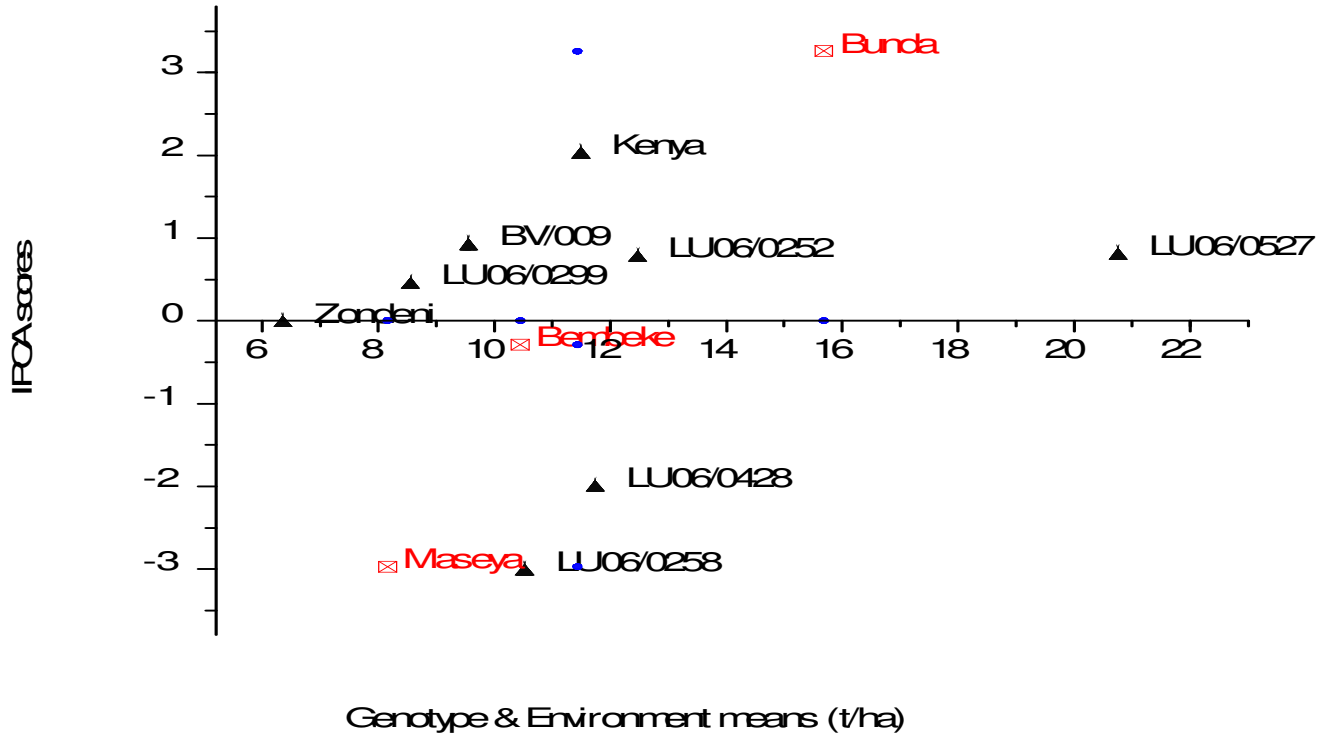


Figure 2. Biplot of IPCA 1 scores against total tuber yield (t/ha) for eight genotypes grown in three locations

DISCUSSION

The results showed that significant differences were recorded in vine length, growth rate, leaf area as well as tuber yield among genotypes. The longest vine length was recorded from Zondeni and was followed by LU06/0252. This indicates that apart from tuber yield benefits obtained from these two genotypes, they can also be used as a good vine source especially where production is aimed at producing sweet potato vines. The vines can be used as forage for ruminants feeding due to their richness in proteins and minerals needed in livestock feeds (Ahmed et al., 2012; Gonzales et al., 2003; Giang et al., 2004; Kebede et al., 2008).

LU06/0527 had the least vine growth rate as well as lowest vine length in the trial compared to the rest of the genotypes. Coincidentally, the genotype produced the highest tuber yield across the sites. The results show that the genotype converted most of its photosynthetic products into carbohydrates stored in tubers below ground. Most of the carbohydrate accumulated by the cultivar was being translocated to the roots and not the top parts for vine growth. The increase in tuber yield at the expense of vine growth was also reported by Parwada et al., (2011). Kareem (2013) reported that sweet potato

tuber yield was highest in cultivars that had recorded low vine length. This entails that cultivars that produce high tuber yields are likely to produce low vine yield as well as low vine growth rate.

Highest vine growth rate was recorded in LU06/0252 and LU06/0299 and this was attained in the second and third months after planting. The trend in the growth rate was slowest in the fourth month and formed a sigmoid shape from the first month to the final month before harvesting. The results agree with Yeng et al. (2012) who reported an increased growth and dry matter accumulation during the first weeks of sweet potato growth and reduction during the final weeks before harvesting. Ahmed et al. (2012) also indicated that reduced growth of sweet potatoes is realized towards fourth and fifth months after planting. This could be due to reduced nutrient uptake and ageing of the vines as they reach maturity and any further growth beyond this stage results in reduction of nutrient and dry matter accumulation (Etella and Kalio, 2011).

Genotype LU06/0428 produced the largest leaf area followed by BV/009. The two genotypes were also among those with moderate vine length in the trials. The large leaf area combined with longer vine length give an advantage to sweet potatoes during establishment in the

field. A genotype with large leaf area can easily trap sunlight and hence carry out better photosynthesis required for carbohydrates synthesis in the plant than those with small leaf area (Kareem, 2013; Ahmed et al., 2012; Van den Berge and Laurie, 2004). This gives an opportunity for the crop to even smother weeds that can reduce yield and quality of the tubers when left unchecked in the field (Laurie and Niederwieser, 2004; MOAFS, 2007; Moyo et al., 2004; Workayehu et al., 2011).

Genotype LU06/0527 was the highest yielding across sites while Zondenani was consistently lowest tuber yielding variety. It should be noted that Zondenani had longest vine length which might have affected tuber development. The differences in tuber yield could be attributed to genetic variations among genotypes in partitioning photosynthates. Differences in yield due to the genetic makeup among genotypes have also been reported in other sweet potato trials (Chipungu et al., 1999; Nedunchezhiyan et al., 2007) as well as other crops such as common beans (*Phaseolus vulgaris*) (Mwale et al., 2008; Mwale et al., 2009; Chataika et al., 2010).

The environment may also have affected the yield potential of the genotypes. Cold and very hot environments reduce tuber yield while moderate or warm climatic environment promotes tuber yield (Ngailo et al., 2013). Tuber yield across sites showed that genotypes yielded highly at Bunda, which had moderate temperature while the yield at Maseya was the lowest. According to Chipungu et al., (1999) and Nedunchezhiyan et al., (2007), tuber size, number of tubers per plant and stand count are strongly related to tuber yield and these are highly affected by changes in environmental conditions. Temperatures greater than 28 °C re-direct photosynthates towards fibrous roots formation more than to storage roots (Eguchi et al., 2003). Also, some studies suggest that high temperatures trigger Indoleacetic Acid (IAA) oxidase activity that causes reduction in formation of storage root and growth while increasing gibberellic acid (GA) that promotes vine growth (Chan, 1988; DuPooly and DuPooly, 1989; Kelm et al., 2000).

When genotype and environment means were plotted against the interaction principle component analysis (IPCA) scores, genotypes LU06/0428 and LU06/0258 as well as Maseya and Bembeke environments showed negative interaction in the bi-plot while Bunda environment and the rest of the genotypes showed positive interaction. Bunda environment was also high yielding but unstable as it appeared on far right side and away from the zero line of IPCA scores while Maseya was low yielding and unstable site due to its position on far left and below the zero line of IPCA ordinate. High yielding environments fall on the right side of the bi-plot and unstable environments are plotted away from zero line of the IPCA scores (Egesi and Asiedu, 2002; Hassanpanah, 2010). Bunda could also be an ideal site for genotype

selection as high yielding and unstable sites are ideal for high yielding genotype selection (Chataika et al., 2010).

Genotypes LU06/0428 and LU06/0258 were plotted in the same region with Maseya as they all fell in the negative region of the IPCA scores. This indicates that the two genotypes could be best suited in Maseya environment since they all had negative signs of IPCA scores and were plotted close together on the bi-plot (Manrique and Hermann, 2000; Mulema et al., 2008). Genotypes LU06/0527, BV/009, LU06/0252, LU06/0299 and LU06/0527 had low IPCA scores thus showing that they were moderately stable. The moderate stability and high yielding results for LU06/0527 shown in the trial indicate that it could be a potential sweet potato genotype that can contribute to addressing low tuber yield experienced by farmers in Malawi (Moyo et al., 2004; Chipungu, 2008).

The bi-plot showed that Zondenani was the most stable genotype across the locations in tuber yield since the most stable genotypes are located close to or along the zero line of IPCA ordinates (Mwale et al., 2008). Stable and high yielding traits are among the major agronomic characteristics required by farmers in sweet potato adoption as such varieties that can have both of these characteristics would likely be accepted by farmers (Mulema et al., 2008; Hassanpanah, 2010). Differences in tuber yield stability have also been reported in other research trials (Mbwaga et al., 2007; Ndirigwe et al., 2007; Mcharo and Ndolo, 2013; Nakitandwe et al., 2005).

CONCLUSION AND RECOMMENDATION

The findings showed significant variations in vine length, leaf area, sweet potato tuber yield and stability among genotypes in the trial. Bunda was the highest yielding and unstable site which could be used as a potential site for high yielding genotypes evaluation. With exception of check varieties, some promising lines such as LU06/0252 and LU06/0428, which produced longer vines and large leaf area respectively, were identified in the trial and they can benefit farmers aimed at growing sweet potatoes for vine production. LU06/0527 was identified as the highest tuber yielding genotype and moderate stable in the trial and can be beneficial to growers aimed at producing sweet potatoes for tuber production. Since the results were obtained during one year trial, it may be ideal to recommend the replication of the trial over two or more seasons to increase the validity of the findings. However, it is also important to note that following the results of this research and other subsequent similar researches conducted by Kasinthula Research Station in Malawi, genotypes LU06/0527; LU06/0428 and LU06/252 have so far been released to farmers for commercial and subsistence production.

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