International Journal of Agriculture and Crop Sciences.
Available online at www.ijagcs.com
IJACS/2013/5-3/212-226
ISSN 2227-670X ©2013 IJACS Journal

IJACS

# Evaluation of Ugandan cassava germplasm for drought tolerance

**Turyagyenda F. Laban[1,2]*, Elizabeth B. Kizito[3], Yona Baguma[2] and David Osiru[1]**

1. School of Agricultural Sciences, Makerere University-Uganda P. O. Box 7062, Kampala [2]National Agriculture research Organization (NARO)-Uganda P. O. Box 295, Entebbe; [3]Department of Agricultural Sciences, Uganda Christian University, P. O. Box 4, Mukono

***Corresponding author email:*** labanturyagyenda@yahoo.com

**ABSTRACT:** Increased pressure on prime arable land for agriculture to meet food demand for global population has resulted in shifting agriculture to marginal areas where drought is frequent. Focusing research towards development of drought tolerant varieties is thus necessary. Replicated field trials for farmer preferred cassava genotypes were established to evaluate their morphological and yield trait responses and adaptability to moisture stress. Results showed significant ($P<0.05$) differences among genotypes for all the parameters evaluated. Moisture stress resulted in a decline in Harvest Index by 22.34%, Fresh Root Yield by 37.04%, Number of Roots by 19.43%, Dry matter content by 16.58%, Root starch content of 20.81%, Leaf Retention by 25.72% and Plant height by 16.62%. Results therefore, evidently showed that water stress has significant devastating effects on vegetative and yield parameters of cassava. Breeding strategies to develop drought tolerant cassava varieties to cope up with increased water scarcity and semi-arid conditions are thus paramount. Varietal variability in response to water stress reported is a cornerstone in the breeding process. Besides genetic effects were dominant indicating breeding objectives would be easily achieved. Genotypes MH96/0686, Magana, Yellow, TME 204, Nyamutukura, MH97/2961, NASE 1, NASE 2 and NASE 12 were least affected by drought and may provide gene sources for cassava improvement. Genotype x Location was significant ($P<0.05$) suggesting that rational distribution of genotypes to agro-ecological zones with different levels of drought stress is possible. Some genotypes had stable yield and its components suggesting that cassava can easily adapt to dry environments.

***Key words:*** Varietal variability; landraces; Leaf retention; Harvest Index; breeding

**Abbreviations:** AGB=Above Ground Biomass; BUL=Buliisa; CMD=Cassava Mosaic Disease; DMC=Dry matter content; FRY=Fresh root yield; GxL=Genotype by location; HI=Harvest Index; IITA=International Institute of Tropical Agriculture; KAB=Kabanyolo; LR=Leaf retention; MAP =Months after planting; NAK=Nakasongola; NR=Number of roots; PH=Plant height; RSC=Root starch content; VG=Vigour

## INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial crop native to tropical America (Olsen & Schaal, 2001). Along with maize, sugar cane and rice, the crop constitutes the most important source of energy in the diet for people living in the tropical countries where it is a staple for over 800 million people (Burns et al., 2010; Perez et al., 2011). The annual world crop production is estimated at 241 million tonnes of fresh roots (Bull et al., 2011) of which majority come from small-scale farmers from Africa and Asia. About 70% of world cassava root production is used for human consumption and the remaining is used for animal feed and industrial products, such as starch, glucose an alcohol (El-Sharkawy, 2004). The young leaves of cassava are also consumed as a vegetable in many African countries (Lancaster and Brooks, 1983; Hahn, 1988; Fregene et al., 2000) to provide proteins, calcium, iron and vitamins, supplementing predominantly starchy diets in poor communities.

Cassava production faces several constraints including diseases and pests, and environmental constraints. The major biotic constraints include cassava mealy bug and cassava bacterial blight (Boher and Verdier, 1994), Cassava mosaic disease (CMD) (Patil and Fauquet, 2009) and cassava brown streak disease (Hillocks and Jennings, 2003), while the major environmental stress to cassava production is drought (Perez et al., 2011; Bakayoko et al., 2009). Efforts to address biotic stress of cassava have had progress through breeding and selection for tolerance. For instance, molecular markers tightly associated with CMD resistance

gene (CMD2) have been used in marker assistance breeding for CMD resistance (Akano et al., 2002). Breeding for tolerance to cassava post harvest physiological deterioration has been recently reported (Morante et al., 2010). However, little progress has been made with respect to development of drought tolerant varieties. Yet, it has been reported that rainfall in eastern and southern Africa has declined by approximately 15% in the last 30 years, and droughts have become more frequent and severe than ever (Funk et al., 2008). This has had impact on food security in the region resulting in many households becoming food insecure. In 2008 alone, drought in the Horn of Africa (Djibouti, Ethiopia, Kenya, Somalia and Uganda) resulted in food insecurity for over 14,622,000 people compelling them to depend on World Food Program (WFP) for handouts (OCHA, 2008).

The increased global population has put a lot of pressure on the available arable land stretching agricultural production to unfavourable semi-arid zones (Baulcombe et al., 2009; Challinor et al., 2007). It is therefore necessary to develop crop technologies to sustain crop production and productivity under limited water resources. In this respect, cassava deserves attention because many of the world's poorest and most food insecure households that live in these areas are highly dependent on this crop as a contributing, if not the principal, source of food, nutrition, and cash income (Alexandratos 1995; Bergantin et al., 2004). Besides, cassava provides more returns per unit input than other root and tuber crops, has better adaptability to diverse and poor soil conditions and wide flexibility in planting and harvesting times (Sakai et al., 1994; Akoroda, 1995; Fregene et al., 2000). The adverse effects of drought to cassava production especially during stages of establishment have been reported (Agili and Pardales, 1999; Pardales et al., 2001; Santisopasri et al., 2001; Okogbenin et al., 2003; Anderson et al., 2004; Bergantin et al., 2004; Bakayoko et al., 2009; Perez et al., 2011). In Africa, the cultivation of cassava is often in hands of resource poor farmers who may not afford irrigation costs. This therefore, calls for a need to identify and develop cassava genotypes well adapted to semi-arid marginal areas, with special emphasis on drought tolerance.

The varietal variability among cassava genotypes in response to water stress, with some genotypes having high levels of drought tolerance and others susceptible (El-Sharkawy, 2007), can be exploited to identify and develop cassava varieties well adapted to marginal agro-ecological zones. Several physiological, morphological and biochemical traits associated with drought tolerance in cassava, including leaf gaseous exchange, accumulation and utilization of compatible osmolytes and leaf retention, have been reported (Lenis et al., 2006; Ssemakula and Dixon 2007; Mutegi, 2009; Subere at al., 2009). Nevertheless, in Uganda, information regarding genetic variability for drought tolerance among different farmer preferred cassava genotypes is limited. This information is an important resource to help cassava breeders to accurately identify drought tolerant genotypes to act as gene sources for breeding or to be directly used by farmers in drought prone areas. Development of improved crop varieties will without doubt result in improved food security and poverty alleviation among the resource-poor farmers living in semi-arid areas and is in line with Millennium Development Goal number one (MDG1), that calls for the world to reduce the proportion of people who suffer from poverty and hunger by half, before the year 2015 (UN, 2010).

This study evaluated improved and landrace cassava genotypes for their tolerance to drought under different field moisture regimes in the seasonally dry districts of Uganda, in order to; 1) identify drought tolerant cassava genotypes for direct utilization by farmers living in semi-arid agro-ecological zones of Uganda, and by breeders in breeding programs; 2) assess interaction of genotype by environment (G x E) for cassava important yield traits in Ugandan for rational distribution to different agro-ecological zones.

## MATERIALS AND METHODS

### *The study site*

The genotypes were evaluated in the fields in two drought prone sites in Buliisa and Nakasongola, and one site at Kabanyolo with normal rainfall used as reference. The mean annual rain fall in these districts during the experiment period was 1581 mm of rainfall in Nakasongola, 1052 mm in Buliisa and 2448 mm in Kabanyolo (used as a reference site). The distribution of rainfall during the experimental period is presented in Figure 1

### *Plant materials and experimental design*

Forty six cassava genotypes collected from 15 districts in Uganda were used in this study. The genotypes included 13 improved genotypes released by cassava breeding program of National Crops Resources Research Institute (NACRRI) of National Agriculture Research Organization (NARO) based at Namulonge in Uganda. Cassava cuttings of uniform length (20-30 cm) were planted in a Randomised Complete Block Design (RCBD) with two replications of 10 plants of each genotype. The plant spacing used was 1 m X 1m between plants and 2 metres between plots. A plot was made up of two rows of 5 plants each for each genotype. Two cropping seasons were planted, the first season in October 2008 and the second

season in October, 2009. Field evaluation was rain-fed, weeding was manually done with hand hoe, and neither pesticides nor fertilizers were applied.

***Data collection***

To examine cassava response to drought, the following traits were measured; fresh root yield (FRY), harvest index (HI), root starch content (RSC), number of roots (NR), leaf retention (LR), root dry matter content (DMC), plant height (PH), Vigour of sprouted seedlings (VG) and above ground biomass (AGB). Data were taken from four middle plants for each genotype and replication. The evaluated plants were tagged with coloured ribbons for easy identification. FRY, HI, RSC, NR, LR, DMC and AGB were measured at harvesting.

***HI***

This is a ratio of harvestable yield to the total biomass yield. At harvest, four plants per genotype were uprooted and harvestable roots carefully removed from each. For each genotype, weight of the roots and the above ground biomass (stems, branches and leaves) were determined separately. HI was computed as a ratio of weight of the harvestable roots to total biomass (root and above ground biomass)

$$\mathrm{HI} = \frac{\mathrm{Wr}}{\mathrm{Wr+Wab}} \qquad \textit{Where } W_r = \textit{Weight of roots, } W_{ab} = \textit{weight of above ground biomass}$$

***DMC and RSC***

DMC and RSC were estimated using specific gravity methodology (Kawano et al., 1987), as reported by Chavez et al. (2005). Briefly a sample of approximately 2-5 kg of roots was prepared from pool of roots for each genotype by cleaning to ensure that the roots are free from soil and other debris. The samples were put in perforated gunny bag and weighed in air using a spring balance (WA) kg. The same samples in the same bag were weighed with the roots submerged in water (WW) kg. DMC and RSC were estimated from the following formulae:

$$\text{DMC} = \left(\frac{\mathrm{WA}}{\mathrm{WA-WW}}\mathrm{X158.3}\right) - 142 \text{ and RSC} = \left(\frac{\mathrm{WA}}{\mathrm{WA-WW}}\mathrm{X112.1}\right) - 106.4$$

***LR***

Leaf retention was visually estimated as percentage proportion of leafy part of the stem to the total stem height for each plant (Fukuda et al., 2010).

***NR***

The number of roots was determined from four plants of each genotype from each replication. Harvestable roots from each plant were counted and recorded.

***PH***

The plant height was determined on the primary stem from the ground using a measuring stick calibrated in centimetres. The measurements were done 8 months after planting.

***VG***

Data on vigour was collected for the first planting season (2008) because drought set in early during crop establishment stage. Vigour data was collected to determine genotypes that were more sensitive to early drought. The vigour was scored on a sale of 0-3 modified from Bettina et al. (2007) (0=dead, 1=drying, 2 =wilting, 3=healthy) (Figure 2).

***Data analysis***

The data collected were subjected to different statistical analyses using GenStat Ver. 14.1 (GenStat, 2011). Mixed model was used with replications and environments/locations being treated as random effects while genotypes as fixed effects.

## RESULTS AND DISCSSION

***2008 Season***

Forty six genotypes were planted in 2008 planting season. All (100%) planted cuttings in the three sites sprouted. However, in drought prone districts of Buliisa and Nakasongola, most cassava plantlets that had sprouted succumbed to early drought during establishment and dried up. Similarly, in Kabanyolo drought started early and the performance of genotypes was poor. Results on the vigour performance/survival are

presented in Tables 1 and 2. No further data were collected from 2008 planting as most of the plants in drought prone sites died within three months. The rate at which genotypes died in response to drought was different, some dying in large numbers and earlier than others.

Buliisa was most hit by drought with mean of 85.27% loss in vigour performance of genotypes when compared with performance of the same genotypes grown at normal rainfall site at Kabanyolo. In Nakasongola, drought stress resulted in mean decline of 44.19% in vigour performance (Table 1). On average, genotypes in Buliisa and Nakasongola had a score of less than one indicating that they either had died or were drying. In Kabanyolo, despite early drought stress, some genotypes remained health with a score of more than 2. On the other hand, some genotypes performed better in drought prone districts than under normal rainfall at Kabanyolo in response to severe drought stress. Akena Genotype performed better in both Buliisa and Nakasongola than Kabanyolo. Yellow, Magana, MH97/2961, Mufumbachai, Ryahorore, NASE11 and Nyaraboke performed better in Nakasongola than in Kabanyolo.

The performance of genotypes averaged for the drought prone districts was compared to the performance of those at Kabanyolo and results are presented in Table 2. Drought stress resulted in 75.25% reduction in vigour performance. The five most outstanding genotypes in each of the three sites were; Kwatamumpare Nyapamitu, Buganda, Rwaburaru, Kidimo in Kabanyolo, TME204, NASE12, NASE1, Guaranda and MH97/2961 in Buliisa, and MH97/2961, Kwatamumpare, TME14, Tongolo and MH96/0686 in Nakasongola. The 2008 season provided information on the effect of severe drought during crop establishment stages. The results indicated that genotypes differed in the rate at which drought caused death. Some kept on growing for over three months of drought after planting while others died early after sprouting. The information generated is important for screening for drought tolerance because drought effects in cassava are severe during early stages of establishment than in later stages of development (Pardales and Esquibel, 1996; Perez et al., 2011). Genotypes whose seedlings died early after sprouting in drought prone areas but had high vigour at Kabanyolo may be regarded as susceptible while those that survived in all the sites or died later in the prone districts may be putative drought tolerant. Based on this, genotypes TME14, MH96/0686, Kwamtamumpare, Guaranda, MH97/2961, TME204, Tongolo, Bukalasa and Magana are reported as candidate drought tolerant genotypes for 2008 planting. Among these, TME14, MH97/2961, TME204 and MH96/0686 are improved genotypes from breeding programs while the rest are local genotypes. Bao, Nyalanda, Egabu, Icilicili, and Rwaburaru (all local genotypes) are here regarded as drought susceptible.

***2009 Season***

The mean squares (MS) indicated that genotype and location effects were highly significant ($P \leq 0.05$) for all the parameters evaluated (Table 3). This suggests that cassava genotypes evaluated has adequate genetic variability. El-Sharkawy, (2007) reported similar results when he subjected a range of cassava genotypes to water stress. He found that some genotypes had high levels of drought tolerance while others were susceptible. In addition, genotypic effects were dominant compared to location and genotype X location effects suggesting a strong genetic basis for the phenotypic differences observed among the genotypes. This further indicates that selection of desirable characters among these genotypes would lead to significant progress in cassava improvement schemes since genetic effects are dominant.

Genotype x Location was also highly significant ($P<0.01$) for all the parameters evaluated, except for AGB. This reflects genotypic differences towards adaptation to different agro-ecological zones and tolerance to water stress. The meteological data indicated that Nakasongola and Buliisa had less rainfall and Kabanyolo in Wakiso district had high rainfall regimes (Figure 1). Therefore, differences in performance of the genotypes at different locations can reasonably be attributed to rainfall differentials amongst sites. Rainfall has been reported as the critical factor in defining agro-ecological zones (Aina et al., 2007). Based on this, rational distribution of genotypes to areas with different rainfall regimes or different rainfall seasons is possible. Ethnic groups living in marginal agro-ecological zones would be guided by tolerance of genotypes to erratic rainfall conditions while farmers in agro-ecological zones with optimum growth conditions would be guided by factors such as high yield and tolerance to pests and diseases. The less adapted genotypes in drought-prone areas may be useful in areas with optimum rainfall or areas where drought stress is not critical.

***Effect water stress on Harvest Index***

Genotypes showed significant variation for HI at different locations. The mean HI at Buliisa, Kabanyolo and Nakasongola, respectively were 38%, 47% and 35%. There were significant reductions for HI in Buliisa and Nakasongola relative to Kabanyolo. Nakasongola was most affected with mean 25.53% decline while Buliisa had mean decline of 19.15% (Table 4). Overall, water stress resulted in mean decline of 22.34%. Eight genotypes (NASE 9, NASE 1, TME14, TME204, NASE2, MH96/0686 and Buganda) had least percentage reductions in HI in response to drought stress (Table 5). Harvest Index is ability to convert biomass into economic yield (Mutegi, 2009) and therefore reflects the partitioning efficiency of dry matter towards economic

root production. Mutegi (2009) reported that selections based on HI are stable across evaluation stages making HI an important trait in cassava breeding because it truly represents genotype's yield potential. Fukuda et al. (2010) reported that true genetic progress in cassava can be achieved through utilization of HI. The balance between the formation of leaves and the filling of roots is controlled by both genetic and environmental factors (El-Sharkawy and Cock, 1987). In this study, genotype effects were dominant indicating that the primary effect of the HI differences amongst the genotypes is attributable to genetic effects. Okogbenin et al. (2003), using different Nigerian cassava germplasm, reported that HI was not significantly different among locations with different water stress levels. All these studies indicate that differences in HI among genotypes are largely attributed to genetic effects and thus HI is an important trait in the selection of genotypes under water stress conditions.

Contrary to results obtained by Okogbenin et al. (2003), HI was significantly reduced by drought. With a few exceptions, lower HI was recorded in Buliisa and Nakasongola and high HI recorded at Kabanyolo. This suggests that poor growth conditions in drought stressed Buliisa and Nakasongola affected root bulking and hence resulted in poor assimilate partitioning. Similar observations were made by Cach et al. (2006), who reported highly significant genotype-by-environment effects on HI suggesting that HI is influenced by the interaction. Nevertheless, indirect selection for yield through HI is more effective than direct selection for yield itself especially in early evaluation and selection stages (Kawano et al., 1998). Recently, Perez et al. (2011) established that heritability for HI was significantly higher than for FRY justifying the importance of including HI as a selection criterion.

***Effect water stress on Fresh Root Yield***

Fresh root yield was significantly affected by water stress. Overall, there was a decline of 37.04% in yield performance of genotypes in drought areas. Mean yields were 13.93 t/ha at Kabanyolo, 8.5 t/ha at Buliisa and 9.04 t/ha at Nakasongola indicating mean yield loss of 38.98% for Buliisa and 35.10% for Nakasongola when compared with their performance at Kabanyolo (Table 4). This suggests yield instability among cassava genotypes over environments with different moisture stress levels. Yield stability is important and requires genotypes that do not produce high yield only in favourable conditions but can also produce high yields under water stress conditions (Mutegi, 2009). In this study, water stress resulted in overall mean decline of 37.04% in total fresh yield. This decline is not far different from decline of 22% reported by Okogbenin et al., (2003) using Nigerian IITA improved genotypes. Connor and Palta (1981) also reported that water stress after 1-5 MAP led to reduction in storage root yield by 32-60%. The critical period for water deficient in cassava is 1-5 MAP, which coincides with the stages of root initiation and tuberization (Connor and Palta, 1981; Aina et al., 2007). Notwithstanding, some genotypes had stable yields across the locations while others were adversely affected. The effect of drought was least for genotypes; TME 204, NASE 9, TME 14, Akena, NASE 1, Yellow, MH96/0686 and NASE2 (Table 5) indicating that these genotypes may be tolerant to water stress. On the other hand, Pilipil, Mercury and Nyalanda, all of them landraces, were most affected with a decline of 80.49%, 79.99% and 78.95% in fresh root yield, respectively and are probably susceptible.

The study also revealed that cassava, under favourable conditions is highly productive with high mean storage root yield of 13.9 t/ha in Kabanyolo, which is above the reported average yield of 12.7 t/ha for Uganda, 12.4 t/ha for Africa and 10.2 t/ha for world (FAO, 2010). The yield obtained in this study is within the range reported by similar studies on cassava. El-Sharkawy (1993) reported cassava yields of 8-16 t/ha of fresh roots with landraces in marginal areas without application of agrochemicals. Burns et al. (2010) reported that African subsistence farmers achieve yields of 8–10 tonnes of fresh roots per hectare over a 12–18 month crop cycle. In Indonesia and Thailand yield of 18–23 t/ha has been recorded (Burns et al., 2010). The results obtained from this study and elsewhere indicate that the yield potential of 90 tonnes per hectare reported in Colombia under ideal conditions (El-Sharkawy, 1993), are yet to be achieved.

***Effect water stress on Number of roots***

Significant differences were observed among the genotypes and locations for number of roots. There was also significant genotype by location effect (G x L) on the root number (Table 3). The highest mean number of roots was recorded at Kabanyolo site with a mean of 5.97 roots per plant, while Buliisa and Nakasongola recorded a mean of 4.31 and 5.31 roots per plant, respectively. There was a decline in number of roots per plant by 27.81% for Buliisa and 11.06% for Nakasongola relative to number of roots per plant for Kabanyolo. Overall, drought resulted in a decline of 19.43% in number of roots when the performance of genotypes at drought prone sites combined was compared with reference site, Kabanyolo. The root number was less affected by drought in; Rwaburaru, Magana, NASE12, NASE11, Kidimo and MH96/0686, with less than 1% decline (Table 5) suggesting that these genotypes may be stable in response to moisture stress. The highest decline (53.3%) in number of roots due to drought was recorded in Nyalanda indicating that it very sensitive to water stress.

***Effect water stress on above ground Biomass***

Fresh shoot yield or above ground biomass (AGB) was significantly different among the genotypes and across the locations. However, there was no G x L effect on AGB. The mean AGB was 12 t/ha for Buliisa, 15.23 t/ha for Kabanyolo and 14.28 t/ha for Nakasongola. Twelve genotypes (Rwaburaru, Tongolo2, TME 204, NASE 3, Ryahorore, Yellow, Akena, NASE 11, Nyapamitu, Omongole, Nyakakwa and Namulalu) performed slightly better in drought prone districts than in normal rainfall district. However, other than Akena and NASE11, overall yield performance both in dry and normal rainfall environment was low. The eleven high shoot yielding genotypes included MH96/0686, Akena, TME14, NASE 9, NASE 11, NASE 12, Nyamutukura, MH97/2961, Mufumbachai, Buganda and Guaranda in that order. The above ground biomass production is important in the production of animal feed and planting materials. This trait is therefore especially important in areas where animal feed supply is critical during the dry season to supply forage and where planting materials are scarce. Different reports indicate similar trend of the effect of water stress on AGB. Okogbenin et al. (2003) reported a decline of 37% in shoot growth in cassava using improved genotypes in Nigeria. The lack of G x L effect on AGB suggests that the trait is affected by moisture stress than other environmental factors at the locations. In this study, AGB could have been underestimated because fallen leaves were not included in its determination as it was difficult to determine which leaves fell from which plant/genotype in the field trial and this could have affected the results.

***Effect water stress on Root dry matter content***

There was significant variation amongst genotypes and locations and their interaction (Table 3). The mean DMC was 33.52% for Buliisa, 40.52% for Kabanyolo and 34.08 for Nakasongola. Relative to the reference location, Kabanyolo, mean root dry matter content decreased by 17.28% for Buliisa and 15.89 % for Nakasongola. The overall effect of drought on DMC was low (16.58%). Three improved genotypes; NASE2, MH96/0686, MH97/2961 and one landrace variety known as Nyamutukura had stable and high DMC in both dry and normal rainfall sites suggesting that their DMC was not affected by water stress. Dry matter production and partitioning is an important root yield parameter in cassava and can be an important selection criterion in breeding programmes for enhanced yield (Lahai and Ekanayake 2009; Aigbe and Remison 2010a). Total dry matter production provides a good estimate of the degree of adaptation of a genotype to the environment in which it is grown (Kamara et al., 2003). The simultaneously development of foliage and storage roots in cassava, (Cock, 1984; Mutegi, 2009) creates competition for photosynthetic assimilates between roots and foliage, and therefore appropriate partitioning of dry matter is important. An ideal cultivar would be one that has rapid shoot growth to ensure full photosynthetic structures before storage root initiation to reduce internal competition for assimilates.

The DMC values obtained in this study are within the range that has been reported elsewhere. Raji et al. (2007) and Akinwale et al. (2009), reported average DMC ranging from 30.03% -39.2% using Nigerian Germplasm while Westby (2002) reported that DMC in cassava varies from 20-45% depending on variety and environmental conditions and health of the plant. Bakayoko et al. (2009) reported that percentage root dry matter content is high when the water stress does not exceed one month's period in the first 6 months of planting indicating the importance of rainfall especially, during the early development stage. This study revealed that the magnitude of genotype X location interaction was much smaller than that of the genotype effect suggesting that genetic effects override environmental effects in influencing DMC partitioning.

The genotypes with high dry matter content in storage roots (MH96/0686, NASE2, Nyamutukura and MH97/2961) also recorded high fresh root yields suggesting higher root shoot ratio for the genotypes. Thus more photosynthate was preferentially allocated to storage roots of MH96/0686, NASE2, Nyamutukura and MH97/2961 to produce high root yields in all locations. Similar results have been reported by Lahai et al. (1999) who found higher root yields for cultivars that allocated higher proportion of DMC to storage roots than those that accumulated higher DMC in stems. Lahai and Ekanayake (2009) reported that drought stress reduced dry matter allocation to storage roots and increased its partitioning to rootstocks, fibrous roots and stems.

***Effect water stress on Root starch content***

Starch production varied from genotype to genotype and location to location. The mean starch production was highest in Kabanyolo (22.85%) and lowest at Buliisa (17.90%). Genotype X location effect was also significant (Table 3). Relative to Kabanyolo, there was a decrease in root starch content of 21.66% for Buliisa and 19.96% for Nakasongola. Overall, drought stress reduced starch content by 20.81%. Like for DMC, four genotypes; NASE2, MH96/0686, MH97/2961 and Nyamutukura had stable and high starch content in both dry and normal rainfall sites (Table 5). Starch content in cassava roots is important especially for cassava processed products such as starch flour and powder (Aigbe and Remison 2010b). Starch is also an important raw material for a number of industries including textiles, paper, adhesives, pharmaceuticals and food (Aigbe

and Remison 2010b). It has been postulated that water stress diminishes photosynthetic carbon fixation (Okogbenin et al., 2011) and this may affect starch partitioning in storage roots. It is also probable that the starch reserves in storage roots could be depleted through respiration during prolonged water stress.

***Effect water stress on Plant height***

Genotypes and locations significantly varied among themselves for plant height (Table 3). The means of plant height in centimetres for all genotypes at the three locations were 170.30, 141.40 and 142.60 for Kabanyolo, Buliisa and Nakasongola, respectively. G X L effects were also significant. Compared to Kabanyolo, drought stress reduced plant height by 16.97% and 16.27% for Buliisa and Nakasongola, respectively. Genotypes; TME 204, Njule, NASE 12, Nyamutukura, TME 14, Bao, Yellow, Rugogoma and Nyakakwa, were more stable with less than 6% decline in plant height in drought environment. Previous studies reported similar results of stunted growth in cassava as result of water stress. Aina et al. (2007) using Nigerian cassava germplasm reported a decline of 41% while Bergantin et al. (2004) using a range of cassava genotypes in Philippine reported a decline of 62.05%. Pardales and Esquibel (1996) and Agili and Pardales (1997) earlier showed that shoot development in cassava is highly suppressed when juvenile plants are exposed to prolonged limited soil water condition.

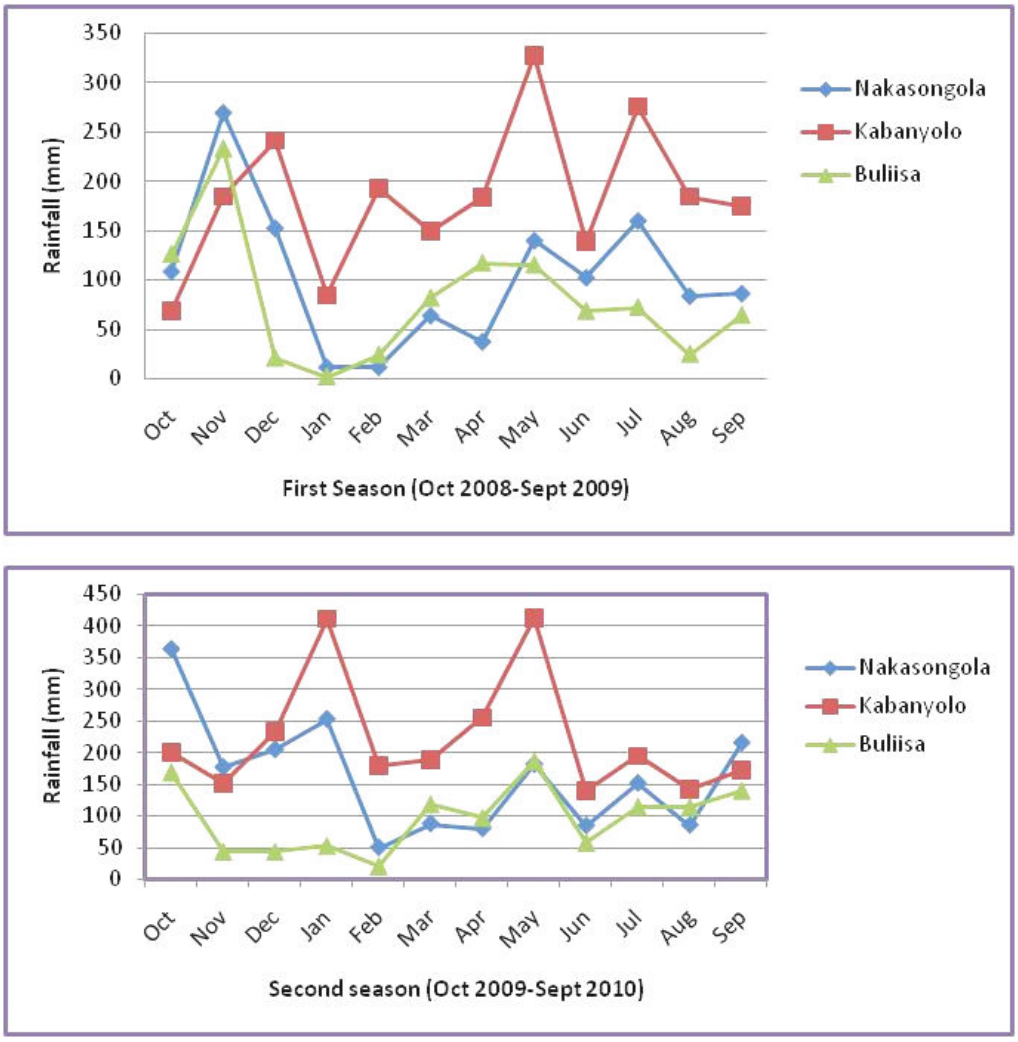


Figure 1. Rainfall distribution at experimental sites during two experimental periods

***Effect water stress on Leaf retention***

The highest mean leaf retention was recorded in Kabanyolo (67.69%) and the least in Buliisa (43.92%) while in Nakasongola leaf retention was 56.65%. Relative to normal rainfall site at Kabanyolo, there was a decline of 35.12% and 16.31% in leaf retention for Buliisa and Nakasongola, respectively. The decline in leaf retention in response to water stress can be attributed to shedding of leaves by plants to minimise water loss through transpiration. Rivero et al. (2007) reported that drought accelerates leaf senescence, leading to a decrease in canopy size, loss in photosynthesis and reduced yields. Leaf retention has been reported as one of the desired traits in achieving high yields in crops under limited moisture (Lenis et al., 2006). Lenis et al. (2006) reported that cassava genotypes with greater leaf longevity produced high total fresh biomass and a 33% higher root dry matter compared to drought susceptible genotypes. Cultivars with high LR or stay green trait are potentially drought tolerant and therefore may be suitable genotypes for marginal areas where rainfall is unreliable. In this study, genotypes; Nyakakwa, NASE 12, TME204, Nyamutukura, TME14, MH97/2961, MH96/0686 and Njule had least reductions in LR across locations (Table 5) and therefore may be putative drought tolerant.

It is desirable to breed and select for high leaf retention when developing genotypes adapted to dry areas. Rivero et al. (2007) were able to enhance drought tolerance by delaying drought-induced leaf senescence in tobacco through transformation using isopentenyl transferase gene. The suppression of drought-induced leaf senescence resulted in outstanding drought tolerance with vigorous growth and high yield of transgenic plants after a long drought period that killed the control plants. Production of drought-tolerant crops able to grow under restricted water regimes without reduction of yield would minimize drought-related losses and ensure food production in water-limited lands (Rivero et al., 2007).

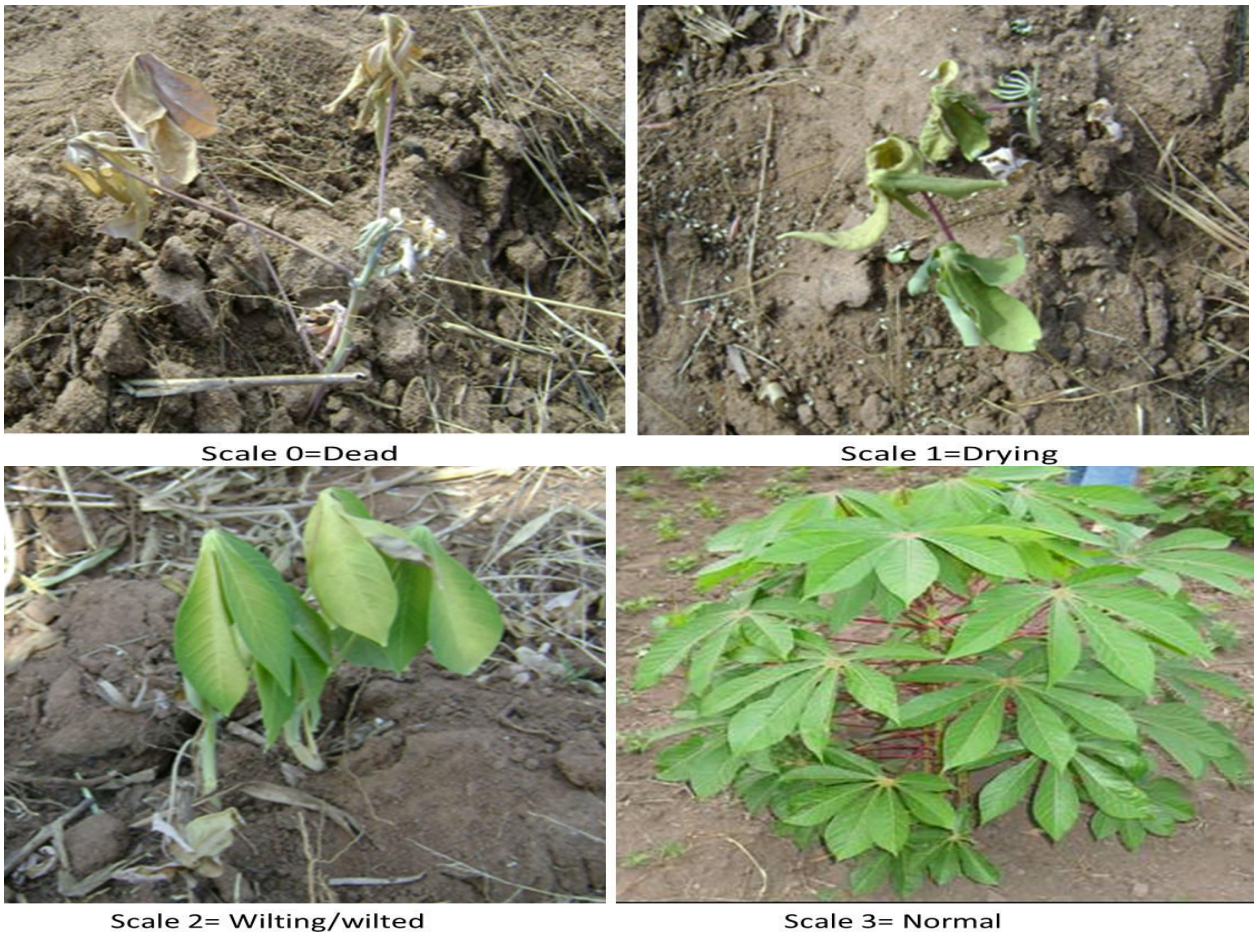


Figure 2. Scales used to score vigour performance of genotypes in response to drought stress

Table 1. Vigour performance of 46 cassava genotypes planted at three different locations.

| Genotype | Kabanyolo | Buliisa | % difference | Nakasongola | % difference |
|---|---|---|---|---|---|
| Akena | 0.19 | 0.20 | -5.26 | 0.40 | -110.53 |
| AladoAlado | 0.50 | 0.08 | 84.00 | 0.35 | 30.00 |
| Bao | 1.50 | 0.07 | 95.33 | 0.22 | 85.33 |
| Buganda | 2.19 | 0.40 | 81.74 | 0.35 | 84.02 |
| Bukalasa | 1.25 | 0.35 | 72.00 | 0.87 | 30.40 |
| Ditu | 2.00 | 0.35 | 82.50 | 0.60 | 70.00 |
| Icilecili | 1.09 | 0.12 | 88.99 | 0.35 | 67.89 |
| Egabu | 1.06 | 0.05 | 95.28 | 0.45 | 57.55 |
| Guaranda | 1.81 | 0.45 | 75.14 | 1.17 | 35.36 |
| Kabwa | 1.66 | 0.37 | 77.71 | 0.60 | 63.86 |
| Kidimo | 2.16 | 0.20 | 90.74 | 1.00 | 53.70 |
| Kwatamumpare | 2.59 | 0.22 | 91.51 | 1.62 | 37.45 |
| Luderudu | 0.78 | 0.05 | 93.59 | 0.77 | 1.28 |
| Lugbara | 1.44 | 0.00 | 100.00 | 0.97 | 32.64 |
| Maburu | 1.41 | 0.02 | 98.58 | 0.92 | 34.75 |
| Magana | 0.94 | 0.20 | 78.72 | 1.00 | -6.38 |
| Mercury | 1.12 | 0.05 | 95.54 | 0.72 | 35.71 |
| MH96/0686 | 1.91 | 0.10 | 94.76 | 1.17 | 38.74 |
| MH97/2961 | 1.55 | 0.42 | 72.90 | 1.78 | -14.84 |
| MufumbaChai | 0.69 | 0.20 | 71.01 | 0.78 | -13.04 |
| Musita | 1.44 | 0.00 | 100.00 | 0.75 | 47.92 |
| Namukoni | 1.56 | 0.05 | 96.79 | 0.60 | 61.54 |
| Namulalu | 0.59 | 0.02 | 96.61 | 0.27 | 54.24 |
| NASE1 | 0.97 | 0.47 | 51.55 | 0.32 | 67.01 |
| NASE11 | 0.31 | 0.05 | 83.87 | 0.57 | -83.87 |
| NASE12 | 1.53 | 0.57 | 62.75 | 0.52 | 66.01 |
| NASE2 | 0.56 | 0.13 | 76.79 | 0.35 | 37.50 |
| NASE3 | 0.37 | 0.08 | 78.38 | 0.37 | 0.00 |
| NASE9 | 0.87 | 0.05 | 94.25 | 0.57 | 34.48 |
| Njule | 1.19 | 0.39 | 67.23 | 0.47 | 60.50 |
| Nyakakwa | 1.25 | 0.20 | 84.00 | 0.95 | 24.00 |
| Nyalanda | 1.63 | 0.07 | 95.71 | 0.35 | 78.53 |
| Nyamutukura | 1.91 | 0.15 | 92.15 | 0.75 | 60.73 |
| Nyapamitu | 2.41 | 0.02 | 99.17 | 0.45 | 81.33 |
| Nyaraboke | 0.06 | 0.00 | 100.00 | 0.27 | -350.00 |
| Nyarare | 1.50 | 0.10 | 93.33 | 0.62 | 58.67 |
| Omongole | 1.09 | 0.17 | 84.40 | 0.87 | 20.18 |
| Pilipili | 0.87 | 0.13 | 85.06 | 0.80 | 8.05 |
| Rugogoma | 1.63 | 0.05 | 96.93 | 0.87 | 46.63 |
| Rwaburaru | 2.19 | 0.07 | 96.80 | 0.55 | 74.89 |
| Ryahorore | 0.62 | 0.32 | 48.39 | 0.85 | -37.10 |
| TME14 | 1.69 | 0.32 | 81.07 | 1.53 | 9.47 |
| TME204 | 1.16 | 0.87 | 25.00 | 0.72 | 37.93 |
| Tongolo | 2.13 | 0.12 | 94.37 | 1.18 | 44.60 |
| Tongolo2 | 1.41 | 0.27 | 80.85 | 0.60 | 57.45 |
| Yellow | 0.56 | 0.17 | 69.64 | 0.95 | -69.64 |
| Mean | 1.29 | 0.19 | 85.27 | 0.72 | 44.19 |
| SE=0.81 | | | | | |

Percent difference=percent difference between the reference site and the treatment site=(R-T)/R*100) where Kabanyolo (KAB) was regarded as reference (R) and Buliisa (BUL) and Nakasongola (NAK) as treatment sites (T)

Table 2. Vigor performance of 46 cassava genotypes for two different environments

| Genotype | Stress* | Reference | % difference | Genotype | Stress | Reference | % difference |
|---|---|---|---|---|---|---|---|
| Akena | 0.30 | 0.19 | -57.89 | NASE1 | 0.40 | 0.97 | 58.76 |
| AladoAlado | 0.21 | 0.50 | 58.00 | NASE11 | 0.31 | 0.31 | 0.00 |
| Bao | 0.15 | 1.50 | 90.00 | NASE12 | 0.55 | 1.53 | 64.05 |
| Buganda | 0.37 | 2.19 | 83.11 | NASE2 | 0.24 | 0.56 | 57.14 |
| Bukalasa | 0.61 | 1.25 | 51.20 | NASE3 | 0.22 | 0.37 | 40.54 |
| Ditu | 0.47 | 2.00 | 76.50 | NASE9 | 0.31 | 0.87 | 64.37 |
| Icilicili | 0.24 | 1.09 | 77.98 | Njule | 0.44 | 1.19 | 63.03 |
| Egabu | 0.25 | 1.06 | 76.42 | Nyakakwa | 0.57 | 1.25 | 54.40 |
| Guaranda | 0.81 | 1.81 | 55.25 | Nyalanda | 0.21 | 1.63 | 87.12 |
| Kabwa | 0.49 | 1.66 | 70.48 | Nyamutukura | 0.45 | 1.91 | 76.44 |
| Kidimo | 0.60 | 2.16 | 72.22 | Nyapamitu | 0.24 | 2.41 | 90.04 |
| Kwatamumpare | 0.92 | 2.59 | 64.48 | Nyaraboke | 0.14 | 0.06 | -133.33 |
| Luderudu | 0.41 | 0.78 | 47.44 | Nyarare | 0.36 | 1.50 | 76.00 |
| Lugbara | 0.49 | 1.44 | 65.97 | Omongole | 0.52 | 1.09 | 52.29 |
| Maburu | 0.47 | 1.41 | 66.67 | Pilipili | 0.46 | 0.87 | 47.13 |
| Magana | 0.60 | 0.94 | 36.17 | Rugogoma | 0.46 | 1.63 | 71.78 |
| Mercury | 0.39 | 1.12 | 65.18 | Rwaburaru | 0.31 | 2.19 | 85.84 |
| MH96/0686 | 0.64 | 1.91 | 66.49 | Ryahorore | 0.59 | 0.62 | 4.84 |
| MH97/2961 | 1.10 | 1.55 | 29.03 | TME14 | 0.92 | 1.69 | 45.56 |
| MufumbaChai | 0.55 | 0.69 | 20.29 | TME204 | 0.80 | 1.16 | 31.03 |
| Musita | 0.37 | 1.44 | 74.31 | Tongolo | 0.65 | 2.13 | 69.48 |
| Namukoni | 0.32 | 1.56 | 79.49 | Tongolo2 | 0.44 | 1.41 | 68.79 |
| Namulalu | 0.15 | 0.59 | 74.58 | Yellow | 0.56 | 0.56 | 0.00 |
| | | | | Mean | 0.47 | 1.37 | 65.29 |
| | | | | LSD | 0.55 | 0.24 | |

*averaged over two moisture stress environments; Percent difference=percent difference between the reference site and the treatment site=(R-T)/R*100) where Kabanyolo (KAB) was regarded as reference (R) and Buliisa (BUL) and Nakasongola (NAK) as treatment sites (T)

Table 3. Mean squares from analysis of variance (ANOVA) for RCBD field experiment

| Mean squares | | | | |
|---|---|---|---|---|
| Source of variation | Genotype (df=45) | Location (df=2) | Genotype x Location (df=90) | error |
| VG [a] | 8.92*** | 482.17*** | 4.70*** | 0.66 |
| HI | 0.10*** | 0.97*** | 0.02*** | 0.01 |
| NR | 52.61*** | 191.11*** | 5.66*** | 3.68 |
| DMC | 271.19*** | 1390.27*** | 120.23*** | 87.04 |
| RSC | 135.99*** | 697.19*** | 60.29*** | 43.65 |
| FRY | 436.05*** | 2341.99*** | 49.30*** | 35.22 |
| AGB | 243.92*** | 612.74*** | 48.29 | 49.65 |
| LR | 576.70*** | 45313.10*** | 292.60*** | 158.50 |
| PH | 7923.70*** | 87903.10*** | 2640.30*** | 893.70 |

[a] Data collected from 2008 planting, ***significant difference at P≤0.05

Table 4. Means and percentage difference of cassava genotypes for VG, DMC, RSC, NR, HI, LR and PH for filed data for different locations

| Site | VG[a] | % Diff | AGB | % Diff | HI | % Diff | FRY | % Diff | NR | % Diff |
|---|---|---|---|---|---|---|---|---|---|---|
| KAB | 1.30 | | 15.23 | | 0.47 | | 13.93 | | 5.97 | |
| BUL | 0.20 | 84.91 | 12.00 | 21.21 | 0.38 | 19.15 | 8.50 | 38.98 | 4.31 | 27.81 |
| NAK | 0.73 | 43.76 | 14.28 | 6.24 | 0.35 | 25.53 | 9.04 | 35.10 | 5.31 | 11.06 |
| LSD (5%) | 0.06 | | 1.24 | | 0.02 | | 1.04 | | 0.32 | |

Table 4. cont'd

| Site | DMC | % Diff | RSC | % Diff | LR | % Diff | PH | % Diff |
|---|---|---|---|---|---|---|---|---|
| KAB | 40.52 | | 22.85 | | 67.69 | | 170.30 | |
| BUL | 33.52 | 17.28 | 17.90 | 21.66 | 43.92 | 35.12 | 141.40 | 16.97 |
| NAK | 34.08 | 15.89 | 18.29 | 19.96 | 56.65 | 16.31 | 142.60 | 16.27 |
| LSD (5%) | 2.72 | | 1.93 | | 1.92 | | 4.55 | |

LSD=least significant difference at P≤0.05. % Diff=Percent difference between the reference site and the treatment site=(R-T)/R*100) where Kabanyolo (KAB) was regarded as reference (R) and Buliisa (BUL) and Nakasongola (NAK) as treatment sites (T)

Table 5. Means of traits measured for 46 genotypes in stressed and reference environments

| Variety | Above ground Biomass | | Harvest Index | | Fresh Root yield (t/Ha | | Number of root | | Dry Matter content | | Root starch content | | Leaf retention | | Plant height | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stress* | Ref | Stress | Ref | Stress | Ref | Stress | Ref | Stress | Ref | Stress | Ref | Stress | Ref | Stress | Ref |
| Akena | 21.08 | 19.17 | 0.42 | 0.46 | 15.33 | 16.06 | 6.67 | 7.83 | 37.85 | 34.93 | 20.96 | 18.90 | 60.10 | 74.73 | 166.12 | 188.00 |
| Aladoalado | 11.39 | 15.67 | 0.38 | 0.51 | 7.03 | 16.83 | 4.33 | 5.50 | 20.72 | 38.18 | 8.83 | 21.20 | 58.45 | 77.47 | 135.63 | 177.63 |
| Bao | 11.17 | 19.67 | 0.31 | 0.47 | 5.09 | 19.33 | 3.08 | 6.50 | 39.90 | 40.74 | 22.41 | 23.01 | 34.90 | 70.43 | 159.46 | 166.88 |
| Buganda | 16.88 | 24.22 | 0.40 | 0.40 | 11.97 | 17.11 | 2.75 | 5.50 | 34.35 | 28.32 | 18.48 | 14.21 | 40.76 | 74.40 | 142.31 | 161.88 |
| Bukalasa | 12.29 | 13.33 | 0.27 | 0.48 | 4.88 | 11.67 | 3.17 | 4.33 | 26.26 | 35.70 | 12.75 | 19.44 | 43.06 | 71.58 | 138.87 | 204.17 |
| Ditu | 11.19 | 11.61 | 0.33 | 0.36 | 5.81 | 6.89 | 3.83 | 4.33 | 30.79 | 48.13 | 15.96 | 28.24 | 52.38 | 70.72 | 141.07 | 165.63 |
| Icilicili | 9.00 | 16.83 | 0.28 | 0.45 | 4.24 | 16.44 | 3.92 | 6.33 | 26.45 | 45.29 | 12.89 | 26.23 | 42.96 | 80.86 | 142.07 | 207.50 |
| Egabu | 9.63 | 10.75 | 0.26 | 0.38 | 2.30 | 8.58 | 3.00 | 3.67 | 27.18 | 38.96 | 13.40 | 21.74 | 50.31 | 73.82 | 125.71 | 189.00 |
| Guaranda | 16.64 | 16.83 | 0.26 | 0.46 | 6.28 | 13.89 | 3.17 | 5.67 | 36.70 | 28.31 | 20.15 | 14.21 | 50.74 | 75.49 | 149.85 | 196.88 |
| Kabwa | 11.81 | 14.60 | 0.35 | 0.46 | 6.89 | 12.27 | 3.42 | 4.50 | 36.48 | 42.91 | 19.99 | 24.54 | 44.82 | 65.85 | 152.60 | 182.50 |
| Kidimo | 8.97 | 12.17 | 0.26 | 0.48 | 2.93 | 12.78 | 3.58 | 3.50 | 28.35 | 40.27 | 14.24 | 22.67 | 46.99 | 65.65 | 137.73 | 192.50 |
| Kwatamumpare | 6.88 | 11.11 | 0.27 | 0.39 | 2.42 | 7.06 | 2.08 | 4.00 | 23.60 | 46.95 | 10.87 | 27.41 | 53.81 | 69.98 | 123.23 | 153.75 |
| Luderudu | 9.82 | 13.67 | 0.29 | 0.40 | 4.09 | 10.72 | 3.50 | 4.33 | 29.32 | 40.60 | 14.92 | 22.91 | 54.41 | 68.59 | 144.23 | 163.13 |
| Lugbara | 8.96 | 12.72 | 0.32 | 0.38 | 3.92 | 7.56 | 3.50 | 4.33 | 32.89 | 42.83 | 17.45 | 24.48 | 47.09 | 75.06 | 142.85 | 172.50 |
| Maburu | 9.67 | 13.61 | 0.31 | 0.39 | 4.64 | 8.67 | 3.08 | 6.67 | 27.31 | 36.68 | 13.50 | 20.13 | 46.68 | 60.32 | 165.08 | 200.75 |
| Magana | 15.28 | 16.28 | 0.52 | 0.56 | 17.58 | 19.94 | 7.58 | 5.67 | 36.63 | 50.10 | 20.10 | 29.63 | 58.44 | 72.68 | 153.13 | 184.75 |
| Mercury | 9.89 | 21.89 | 0.30 | 0.48 | 3.89 | 19.44 | 3.92 | 4.83 | 37.24 | 50.73 | 20.53 | 30.08 | 50.35 | 62.67 | 164.81 | 210.63 |
| MH96/0686 | 22.50 | 24.94 | 0.48 | 0.48 | 21.00 | 22.39 | 9.92 | 10.00 | 54.81 | 56.16 | 32.97 | 33.93 | 63.91 | 72.65 | 135.31 | 164.13 |
| MH97/2961 | 18.06 | 20.22 | 0.51 | 0.52 | 19.42 | 22.28 | 7.67 | 9.83 | 46.85 | 51.10 | 27.33 | 30.34 | 54.79 | 62.04 | 146.60 | 173.88 |
| Mufumbachai | 17.22 | 17.50 | 0.31 | 0.43 | 8.97 | 15.28 | 5.42 | 7.50 | 30.54 | 41.74 | 15.78 | 23.72 | 55.52 | 69.02 | 137.67 | 184.17 |
| Musita | 11.61 | 13.06 | 0.40 | 0.53 | 8.33 | 15.39 | 6.58 | 7.33 | 38.29 | 53.17 | 21.27 | 31.81 | 49.42 | 66.22 | 125.50 | 160.63 |
| Namukoni | 11.03 | 14.28 | 0.40 | 0.56 | 7.43 | 16.67 | 5.00 | 5.33 | 33.77 | 44.88 | 18.07 | 25.94 | 48.20 | 65.84 | 112.13 | 154.14 |
| Namulalu | 14.73 | 14.50 | 0.36 | 0.50 | 7.64 | 14.50 | 3.75 | 4.67 | 27.50 | 31.07 | 13.63 | 16.16 | 53.31 | 64.67 | 140.15 | 158.75 |

Table 5 cont'd

| Variety | Above ground Biomass | | Harvest Index | | Fresh Root yield (t/Ha | | Number of root | | Dry Matter content | | Root starch content | | Leaf retention | | Plant height | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stress* | Ref | Stress | Ref | Stress | Ref | Stress | Ref | Stress | Ref | Stress | Ref | Stress | Ref | Stress | Ref |
| NASE1 | 15.61 | 20.78 | 0.54 | 0.46 | 17.79 | 18.67 | 5.25 | 6.50 | 31.75 | 32.98 | 16.64 | 17.51 | 50.61 | 72.55 | 135.63 | 164.38 |
| NASE11 | 19.91 | 18.47 | 0.34 | 0.54 | 10.91 | 22.53 | 5.75 | 4.67 | 35.22 | 33.62 | 19.10 | 17.96 | 50.05 | 67.89 | 138.29 | 153.88 |
| NASE12 | 19.19 | 19.28 | 0.46 | 0.58 | 16.86 | 23.33 | 8.75 | 6.67 | 34.35 | 47.67 | 18.48 | 27.91 | 53.92 | 58.11 | 121.15 | 121.00 |
| NASE2 | 15.97 | 19.61 | 0.48 | 0.45 | 15.36 | 14.67 | 6.67 | 8.17 | 49.42 | 57.19 | 29.15 | 34.66 | 52.27 | 63.05 | 118.92 | 137.38 |
| NASE3 | 15.89 | 13.47 | 0.49 | 0.59 | 14.89 | 19.33 | 6.50 | 8.33 | 36.82 | 42.93 | 20.23 | 24.56 | 51.59 | 61.04 | 144.38 | 174.25 |
| NASE9 | 20.83 | 24.56 | 0.45 | 0.38 | 16.11 | 13.72 | 4.58 | 6.00 | 30.68 | 38.46 | 15.89 | 21.39 | 53.11 | 68.45 | 168.21 | 184.38 |
| Njule | 14.31 | 14.56 | 0.22 | 0.44 | 2.92 | 11.78 | 3.67 | 4.67 | 27.35 | 21.06 | 13.52 | 9.07 | 52.32 | 59.69 | 137.69 | 132.88 |
| Nyakakwa | 13.22 | 13.00 | 0.38 | 0.51 | 6.59 | 13.94 | 6.33 | 7.33 | 33.82 | 66.81 | 18.11 | 41.47 | 55.93 | 58.96 | 152.92 | 162.13 |
| Nyalanda | 5.94 | 14.17 | 0.30 | 0.47 | 2.69 | 12.78 | 3.58 | 7.67 | 24.28 | 43.25 | 11.35 | 24.78 | 44.56 | 74.34 | 159.81 | 181.88 |
| Nyamutukura | 18.63 | 18.67 | 0.47 | 0.53 | 14.79 | 19.87 | 4.83 | 4.83 | 45.27 | 49.10 | 26.22 | 28.93 | 58.51 | 65.50 | 177.00 | 179.00 |
| Nyapamitu | 8.41 | 8.00 | 0.25 | 0.43 | 2.20 | 6.67 | 3.67 | 5.00 | 34.75 | 36.03 | 18.76 | 19.67 | 51.63 | 61.60 | 146.25 | 190.00 |
| Nyaraboke | 9.67 | 11.00 | 0.24 | 0.40 | 2.89 | 7.56 | 4.08 | 4.33 | 33.06 | 36.64 | 17.57 | 20.11 | 48.51 | 68.37 | 131.75 | 165.50 |
| Nyarare | 10.91 | 11.11 | 0.36 | 0.48 | 6.70 | 10.78 | 3.50 | 5.00 | 27.88 | 26.22 | 13.90 | 12.72 | 49.33 | 73.94 | 133.15 | 154.38 |
| Omongole | 10.89 | 10.44 | 0.33 | 0.40 | 4.81 | 8.22 | 6.08 | 7.33 | 29.71 | 43.09 | 15.20 | 24.67 | 42.55 | 57.66 | 84.94 | 116.88 |
| Pilipili | 9.64 | 11.44 | 0.25 | 0.47 | 2.06 | 10.56 | 3.25 | 5.50 | 50.57 | 39.32 | 29.97 | 22.00 | 50.13 | 67.02 | 140.50 | 175.00 |
| Rugogoma | 10.09 | 12.07 | 0.30 | 0.52 | 4.76 | 11.87 | 2.67 | 4.83 | 21.45 | 36.09 | 9.34 | 19.71 | 51.45 | 61.24 | 149.36 | 157.67 |
| Rwaburaru | 15.42 | 11.94 | 0.23 | 0.38 | 4.33 | 6.50 | 4.08 | 2.67 | 42.04 | 25.08 | 23.93 | 11.92 | 47.57 | 64.48 | 131.36 | 185.50 |
| Ryahorore | 9.78 | 8.39 | 0.30 | 0.53 | 4.15 | 9.39 | 4.58 | 4.83 | 41.37 | 30.89 | 23.45 | 16.03 | 55.52 | 79.89 | 126.85 | 157.50 |
| TME14 | 16.22 | 17.00 | 0.50 | 0.46 | 15.72 | 15.00 | 5.92 | 8.17 | 34.16 | 23.24 | 18.35 | 10.61 | 57.67 | 65.02 | 130.44 | 132.88 |
| TME204 | 15.92 | 13.44 | 0.55 | 0.52 | 19.56 | 14.56 | 7.83 | 8.33 | 31.53 | 48.79 | 16.49 | 28.71 | 59.78 | 66.47 | 169.06 | 156.25 |
| Tongolo | 9.86 | 11.39 | 0.33 | 0.44 | 6.36 | 8.50 | 3.67 | 4.17 | 23.77 | 32.08 | 10.99 | 16.87 | 39.85 | 53.84 | 127.44 | 144.13 |
| Tongolo2 | 12.73 | 10.44 | 0.30 | 0.35 | 5.50 | 6.83 | 4.75 | 7.17 | 32.23 | 50.19 | 16.98 | 29.70 | 42.50 | 54.67 | 193.13 | 243.25 |
| Yellow | 14.44 | 12.94 | 0.51 | 0.56 | 16.00 | 16.89 | 8.25 | 10.00 | 39.60 | 35.31 | 22.20 | 19.16 | 60.68 | 78.34 | 150.00 | 158.13 |
| Mean | 13.24 | 15.10 | 0.36 | 0.47 | 8.61 | 13.82 | 4.81 | 5.96 | 33.80 | 40.52 | 18.09 | 22.85 | 50.90 | 67.67 | 142.40 | 170.48 |
| CV | 50.99 | 51.04 | 34.57 | 24.85 | 59.35 | 51.40 | 41.72 | 32.19 | 26.73 | 26.38 | 35.37 | 33.12 | 28.33 | 18.55 | 22.85 | 18.25 |
| Se | 6.83 | 7.72 | 0.13 | 0.12 | 5.24 | 7.09 | 2.01 | 1.92 | 9.04 | 10.69 | 6.40 | 7.57 | 14.43 | 12.55 | 32.51 | 31.06 |

Stress= mean performance in stressed environments; Ref=normal rainfall environments used as reference

## CONCLUSIONS AND RECOMMENDATIONS

Water stress adversely affects cassava's vegetative growth and productivity. Water stress resulted in mean decline of 22.34% in HI, 37.04% in mean yield, 19.43% in number of roots, 16.56% in DMC, and a mean decline of 20.81% in starch content. It is therefore important that cassava breeding efforts be aimed at production of drought tolerant genotypes if cassava cultivation is to be successfully extended to the increasing arid /marginal areas. The study also revealed large genetic variability among cassava genotypes in response to drought. This variability can be effectively utilised in breeding to achieve appreciable progress in production of drought tolerant genotypes. The information generated from this study is important for breeders for selecting parents with traits associated with drought tolerance.

The effect of moisture stress was more pronounced on root yield parameters than shoot growth, indicating that the mechanisms through which cassava tolerates drought stress leads to temporary halt in the partitioning of assimilate for root bulking and thus adversely affecting economic yield.

Though cassava can survive conditions of moisture stress where other crops could not (Fukai and Hammer, 1987), unfavourable moisture conditions adversely affect its economic yield than its vegetative growth.

It is recommended that studies to understand genetic inheritance of drought tolerance among different cassava genotypes be undertaken to understand the heritability of this important trait. Genotypes MH96/0686, Magana, Yellow, TME 14, NASE1, NASE2, TME 204, Nyamutukura, MH97/2961 and NASE 12 performed better across locations for important drought tolerance traits (HI, LR, FRY and NR) and these are recommended as gene sources for cassava improvement programs and farmers that target at maximizing root productivity under stressful environmental conditions. The farmers' preferred landraces Nyalanda, Icilicili, Bao and Pilipili are susceptible to drought and would require genetic improvement.

## ACKNOWLEDGEMENTS

Sincere thanks to National Council of Science and Technology in Uganda for funding. Supplementary funds were obtained from National Agricultural Research Organization (NARO). We would also like to extend our sincere thanks to Jenipher Bisikwa, Agnes Nadutu, Bosco Chemyek, Daniel Olol, and Susan Acen for their assistance at various stages of implementation of this study.

## REFERENCES

Agili SM, Pardales JR. 1999. Influence of moisture and allelopathic regimes in the soil on development of cassava and mycorrhizal infection of its roots during establishment period. Philipp J Crop Sci 22: 99-105.

Agili SM, Pardales JR Jr. 1997. Influence of moisture and allelopathic regimes in the soil on the development of cassava and mycorrhizal infection of its roots during establishment period. Philipp J Crop Sci 22: 99-105

Aigbe SO, Remison SU. 2010a. Influence of root rot on dry matter partition of three cassava cultivars planted in different agro-ecological environment. Asian J plant pathol 4(2):82-89.

Aigbe SO, Remison SU. 2010b. The Influence of root rot on root starch content of cassava planted in different ecological Environments of Nigeria. Nigerian Ann Nat Sci 10 (1): 60- 70

Aina OO, Dixon AGO, Akinrinde EA. 2007. Effect of soil moisture stress on growth and yield of cassava in Nigeria. Pakistan J Biol Sci 10(18): 3085-3090.

Akano AO, Dixon AGO, Mba C, Barrera E, Fregene M. 2002. Genetic mapping of a dominant gene conferring resistance to cassava mosaic disease. Theor Appl Genet 105:521–525

Akinwale MG, Akinyele BO, Dixon AGO, Odiyi AC. 2009. Genetic variability among cassava genotypes in three agro-ecology zones of Nigeria. African Crop Sci Conference Proc 9:541–546.

Akoroda MO. 1995. Alleviating hunger in Africa with root and tuber crops. African Journal of Root Tuber Crops 1: 41-43.

Alexandratos N. 1995. World agriculture: towards 2010 an FAO study. Chichester, UK: Wiley.

Anderson JV D, Fregene MA, Jorge V, Mba C, Lopez C, Restrpo S, Soto M, Piegu B, Verdier V, Cooke R, Thome J, Horvath PD. 2004. An EST resource for cassava and other species of Euphorbiacea. Plant Mol Breed 56:527-539.

Bakayoko S, Tschannen A, Nindjin C, Dao D, Girardin O, ASSA A. 2009. Impact of water stress on fresh tuber yield and dry matter content of cassava (Manihot esculenta Crantz) in Côte d'Ivoire. African J Agric Res 4 (1):021-027

Baulcombe D, Crute I, Davies B, Dunwell J, Gale M, Jones J, Pretty J, Sutherland W, Toulmin C, Green N. 2009. Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture; The Royal Society: London, UK. .

Bergantin VR, Yamauchi A, Pardales JR Jr, Bolatete DM Jr. 2004. Screening cassava genotypes for resistance to water deficit during crop establishment. Philipp J Crop Sci 29(1): 29-39

Bettina MJE, Melvin TT, Thomas AK. 2007. Visual assessment of wilting as a measure of leaf water potential and seedling drought survival. Journal of Tropical Ecology 23:497-500.

Boher B, Verdier V. 1994. Cassava bacterial blight in Africa: the state of knowledge and implications for designing control strategies. African Crop Sci J 2:505–509.

Bull ES, Ndunguru J, Gruissem W, Beeching JR, Vanderschuren H. 2011. Cassava: constraints to production and the transfer of biotechnology to African laboratories. Plant Cell Rep 30:779–787

Burns A, Gleadow R, Cliff J, Zacarias A, Cavagnaro T. 2010**.** Cassava: The Drought, War and Famine Crop in a Changing World. Sustainability 2: 3572-3607

Cach NT, Lens JI, Perez JC, Morante N, Calle F, Ceballos H. 2006. Inheritance of useful traits in cassava grown in sub humid conditions. Plant Breeding 125: 177-182.

Challinor A, Wheeler T, Garforth C, Craufurd P, Kassam A. 2007. Assessing the vulnerability of food crop systems in Africa to climate change. Climatic Change, 83:831-399.

Chavez AL, Sa´nchez T, Jaramillo G, Bedoya JM, Echeverry J, Bolan˜os EA, Ceballos H, Iglesias CA. 2005. Variation of quality traits in cassava roots evaluated in landraces and improved clones. Euphytica 143:125–133

Cock JH. 1984. Cassava. In: Goldworthy, F.R. and N.M. Fisher (Eds.); The Physiology of Tropical Crops, pp. 540-552. Wiley, Chichester, UK.

Connor DJ, Palta J. 1981. Response of cassava to water shortage. III. Stomatal control of plant water status. Field Crops Res 4:297-311.

El-Sharkawy MA, Cock JH. 1987. Response of cassava to water stress. Plant and Soil 100:345–360.

El-Sharkawy MA. 1993. Drought tolerant cassava for Africa, Asia and Latin America: breeding projects work to stabilize productivity without increasing pressures on limited natural resources. Bio Sci 43:441–451.

El-Sharkawy MA. 2004. Cassava biology and physiology. Plant Molecular Biology, 56:481–501

El-Sharkawy MA. 2007. Physiological characteristics of cassava tolerance to prolonged drought in the tropics: Implications for breeding cultivars adapted to seasonally dry and semiarid environments. Brazilian J Plant Physiol 19(4):257-286,

FAO 2010. Food and Agriculture Organization of the United Nations. FAOSTAT. http://faostat.fao.org/

Fregene M, Bernal A, Duque M, Dixon AGO, Tohme J. 2000. AFLP analysis of African cassava (Manihot esculenta Crantz) germplasm resistant to the cassava mosaic disease (CMD). Theor Appl Genet 100: 678-685.

Fukai S, Hammer GL. 1987. A simulation model of the growth of the cassava crop and its use to estimate productivity in Northern Australia. Agricultural Systems, 23:237-257

Fukuda WMG, Guevara CL, Kawuki R, Ferguson ME. 2010. Selected morphological and agronomic descriptors for the characterization of cassava. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. 19 pp.

Funk C, Dettinger MD, Michaelsen JC, Verdin JP, Brown M, Barlow M, Hoell A. 2008. Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proc Natl Acad Sci, USA, 105, 11081-11086.

Genstat. 2011. GENSTAT 14th Edition. Lawes Agricultural Trust.

Hahn SK. 1988. Overview of traditional processing and utilisation of cassava in Africa. In: Hahn, S.K., L. Reynolds and G.N. Egbunike (eds.). Proceedings of workshop of the potential utilisation of cassava as livestock feed in Africa, Ibadan, Nigeria. IITA/ILCA/Univ.pp.16-27.

Hillocks RJ, Jennings DL. 2003. Cassava brown streak disease: a review of present knowledge and research needs. Integrated Journal Pest Management 49:225–234

Kamara AY, Menkir A, Badu-Apraku B, Ibikunle O. 2003. The influence of drought stress on growth, yield and yield components of some maize genotypes, J Agric Sci 141: 43-50.

Kawano K, Goncalves WMF, Cenpukdee U. 1987. Genetic and environmental effects on dry matter content of cassava root. Crop Sci, 27:69–74.

Kawano K, Narintaroporn K, Narintaroporn P, Sukarharm S, Limsila A, Limsila J, Suparhan D, Sawarat V, Watanonta W. 1998. Yield improvement in a multistage breeding program for cassava. Crop Sci 38: 325-332

Lahai MT, George JB, Ekanayake IJ. 1999. Cassava (Manihot esculenta Crantz) growth indices, root yield and its components in upland and inland valley ecologies of Sierra Leone. J Agron Crop Sci 182: 239-247.

Lahai TM, Ekanayake IJ. 2009. Accumulation and distribution of dry matter in relation to root yield of cassava under a fluctuating water table in inland valley ecology. African J Biotech 8 (19): 4895-4905

Lancaster PA, Brooks JE. 1983. Cassava leaves as human food. Econ Bot, 37: 331-348.

Lenis JI, Calle F, Jaramillo G, Perez JC, Ceballos H, Cock JH. 2006. Leaf retention and cassava productivity. Field Crops Res 95:126-134.

Lokko Y, Anderson JV, Rudd S, Raji A, Horvath D, Mikel MA, Kim R, Liu L, Hernandez A, Dixon AGO, Ingelbrecht IL. 2007. Characterization of an 18,166 EST dataset for cassava (Manihot esculenta) enriched for drought-responsive genes. Plant Cell Rep, 26:1605-1618.

Morante N, Sanchez T, Ceballos H, Calle F, Perez JC, Egesi C, Cuambe CE, Escobar AF, Ortiz D, Chavez AL, Fregene M. 2010. Tolerance to postharvest physiological deterioration in cassava roots. Crop Sci 50:1333-1338

Mutegi-Murori RW. 2009. Towards identifying the physiological and molecular basis of drought tolerance in cassava (Manihot esculenta Crantz). PhD Thesis. Georg-August University Gottingen. pp147

OCHA. 2008. Eastern Africa Preparedness and Response to Drought and Impact of Soaring Food Prices. Summary Report presented to the Regional Humanitarian Partnership Team (RHPT) and Donors, Nairobi. Accessed at http://www.google.co.kr/url?sa=t&rct=j&q=impact%20of%20drought%20on%20food%20security%20in%20east%20africa&source=web&cd=3&ved=0CD4QFjAC&url=http%3A%2F%2Fochaonline.un.org%2FOchaLinkClick.aspx%3Flink%3Docha%26docId%3D1091962&ei=HY0PUKjZOKmg0QXc04CYBQ&usg=AFQjCNGW1QOORIHeRStGuETF3X_tE03epg&cad=rjt on 25th July, 2012.

Okogbenin E, Ekanayake IJ, Porto MCM. 2003. Genotypic variability in adaptation responses of selected clones of cassava to drought stress in the Sudan savanna zone of Nigeria. J Agron Crop Sci 189, 376-389.

Okogbenin E, Setter TL, Ferguson ME, Mutegi R, Alves AC, Ceballos H, Fregene M. 2011. Phenotyping cassava for adaptation to drought. In P Monneveux, J-M Ribaut, eds. Drought Phenotyping in Crops: From Theory to Practice. CIMMYT/Generation Challenge Programme, Mexico City. pp 381-400.

Olsen KM, Schaal BA. 2001. Microsatellite variation in cassava (Manihot esculenta, Euphorbiaceae) and its wild relatives: Further evidence for a southern Amanzonian origin of domestication. American J Bot 88:131–142.

Pardales JR Jr, Esquibel CB. 1996. Effect of drought during the establishment period on the root system development of cassava. Japanese J Crop Sci 65(1): 93-97

Pardales JR Jr, Yamauchi A, Belmonte DV Jr, Esquibel CB. 2001. Dynamics of root development in root crops in relation to the prevailing moisture stress in the soil. In Proceedings of the 6th symposium of the International Society of root research, Nagoya, Japan, November. pp 72-73

Patil BL, Fauquet CM. 2009. Cassava mosaic geminiviruses: actual knowledge and perspectives. Mol Plant Pathol 10:685–701

Perez JC, Lenis JI, Calle F, Morante N, Sanchez T, Debouck D, Ceballos H. 2011. Genetic variability of root peel thickness and its influence in extractable starch from cassava (Manihot esculenta Crantz) roots. Plant Breeding, doi:10.1111/j.1439-0523.2011.01873.x

Raji AA, Ladeinde TAO, Dixon AGO. 2007. Agronomic traits and tuber quality attributes of farmer grown cassava landraces in Nigeria. J Trop Agric 45 (1-2): 9-13,

Rivero MR, Kojima M, Gepstein A, Sakakibara H, Mittler R, Gepstein S, Blumwald E. 2007. Delayed leaf senescence induces extreme drought tolerance in a flowering plant. The Proc Natl Acad Sci 104( 49): 19631–19636

Saini HS, Westgate ME. 2000. Reproductive development in grain crops during drought. Advances in Agronomy, 68:59–96.
Sakai T, Nakagawa-Murata Y, Uritani I, Data ES. 1994. Occurrence and characteristics of stress metabolites in cassava roots. In: I. Uritani, V. V. Garcia, and E. M. T. Mendoza (eds), Postharvest Biochemistry of Plant Food Materials in the Tropics, pp. 95-110. Japan Science Society Press, Tokyo.
Santisopasri V, Kurotjanawong K, Chotineeranat S, Piyachomkwan K, Sriroth K, Oates CG. 2001. Impact of water stress on yield and quality of cassava starch. Industrial Crops and Products, 13:115-29.
Ssemakula G, Dixon A. 2007. Genotype X environment interaction, stability and agronomic performance of carotenoid-rich cassava clones. Scientific Research and Essay, 2 (9): 390-399,
Subere JOQ, Bolatete D, Bergantin R, Pardales A, Belmonte JJ, Mariscal A, Sebidos R, Yamauchi A. 2009. Genotypic Variation in Responses of Cassava (Manihot esculenta Crantz) to Drought and Rewatering: Root System Development. Plant Production Science, 12(4): 462-474
United Nations, 2010. Millennium development goals. UN Department of Public Information, Rome. http://www.un.org/millenniumgoals. Accessed Novembr, 2011
Westby A. 2002. Cassava utilization, storage and small-scale processing. In: Cassava: biology, production and utilization (Hillocks RJ, Thresh JM and Bellotti AC, eds). CABI Publishing, New York, USA, pp 281–300.