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Effect of Soil Moisture Stress on Growth and Yield of Cassava in Nigeria

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Abstract: Nine cassava genotypes were evaluated for their growth responses and adaptability to soil moisture stress on the field and in the screenhouse in Nigeria. Genotypes were evaluated in three savanna agroecologies in a randomized complete block design with three replicates. Screenhouse evaluation was conducted using three moisture regimes of 75, 50 and 25% Field Capacity (FC) in a two-factor factorial experiment in CRD with three replicates. Morphological and yield data were collected on the field and in the screenhouse. Results showed significant ($p<0.05$) difference among genotypes on the field and in the screenhouse. Field moisture stress led to a decline in plant height by 47%, stem girth by 15%, number of tubers by 95% and tuber yield by 87%. Screenhouse moisture condition of 25% FC led to a reduction in plant height by 12.6 and 21.2%, stem girth by 16.3 and 21.7%, number of roots by 94.5 and 88.7% and root weight by 93.3 and 94.9%, respectively at 16 and 30 WAP. Moisture stress therefore resulted into considerable reduction in both vegetative growth and yield of cassava genotypes. Therefore, a concerted effort in breeding cassava for drought tolerance is needed as cassava cultivation is expanding into nontraditional semiarid regions of sub-Saharan Africa. Germplasm introduced from Latin America (especially north-eastern Brazil) is providing a unique source of variability to further broaden the genetic base for drought tolerance in cassava.

Key words: Cassava, soil moisture stress, vegetative growth, root yield, field capacity

INTRODUCTION

Cassava (*Manihot esculenta* Crantz.) a superior producer of carbohydrates is well known for its wide adaptation to different edapho-climatic conditions. It is also highly productive in hot humid climates (Pounti-Kaerlas *et al*., 1997). Cassava can grow in areas with as little as 500 mm annual rainfall and can survive dry periods of 5-6 months. It is therefore widely distributed in the tropical and subtropical ecosystems of Africa with increasing cultivation under unfavorable environments due to its many advantages over other crops (El-Sharkawy, 1993). In Nigeria, the growing of cassava as a staple food crop is rapidly expanding from the humid rainforest in the south to the marginal lands of the Sudan savanna zone in the north. Nigeria has been the largest producer of cassava since 1990, with an estimated output of 31.4 million tonns (t) in 1995 and 38.17 million (t) in 2005 (FAO, 2005). As pressure on prime agricultural land is intensifying, greater food productivity can be achieved through the cultivation of marginal areas with less favorable climatic conditions (El-Sharkawy, 1993). There is therefore need to identify and develop cassava varieties that are well adapted to this region, with emphasis on drought tolerance (Ekanayeke *et al*., 1996). Cassava is known to adapt to conditions of soil water shortage through various mechanisms, such as shedding leaves, closing stomata, osmotic adjustment, increasing root length and decreasing the leaf area (El-Sharkawy, 1993). However, severe soil moisture stress can have adverse effects on crop yield as a result of its effects on plant phenology, phasic development, growth, assimilate partitioning, plant reproduction processes and root development (Agili and Pardales, 1999). Although the physiological responses of cassava to water stress and possible mechanisms underlying its tolerance to drought have been studied (El-Sharkawy and Cock, 1984), further work is needed to evaluate the performance of different genotypes under different levels of moisture stress to further broaden the genetic base for drought tolerance.

MATERIALS AND METHODS

Nine broad-based cassava genotypes (30572, 96/0326, 91/02324, 95/0211, 96/0016, 96/0304, 96/0529, 96/0565 and 96/1632) were evaluated on the field in three savanna agroecological zones of Nigeria for two cropping seasons (1999/2000 and 2000/2001). Each agroecology differ for climatic and soil characteristics; Mokwa located in the Southern Guinea savanna (lat. 9°29′N, long. 5° 04′E) with 1,200 mm mean annual rainfall and 201 days of growing period); Zaria (northern Guinea savanna) lat. 11°11′N, long. 7°38′E, 850 mm mean annual rainfall and 180 days of growing period and Mallamadori (Sudan savanna) lat. 11°78′N, long. 9°34′E, 650 mm mean annual rainfall with <150 days of growing period. Genotypes were

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also evaluated under screenhouse conditions at IITA, Ibadan, at three different moisture conditions to determine the effect of soil moisture stress on vegetative growth and yield. Field experiment was set up in a randomized complete block design with four replicates; plot size was 40 m^2 consisting of 4 rows of 10 plants per row at spacing of 1×1 m. Field evaluation was rainfed, weeding was done manually and neither pesticides nor fertilizers were applied. Morphological data were collected at 3, 6 and 9 Months After Planting (MAP) for the following parameters: Plant height, stem girth, number of nodes, height to first branching, leaf size, leaf retention and stay-green ability. Soil samples from each location were analyzed for soil physicochemical properties.

Screenhouse evaluation was done for 30 weeks at IITA, Ibadan, (7°26′N, 3°54′E). Minimum and maximum temperatures during this period ranged between 22 and 32°C while relative humidity was between 52 and 96%. Plants were established in large polythene bags 60 cm long and 106 cm wide in a 2-factor (3×9) factorial experiment in a completely randomized design with three replicates. Three moisture conditions, 75% (control) 50 and 25% Field Capacity (FC) constitute factor A, while the nine genotypes were factor B. The three moisture levels were used to simulate field conditions corresponding with field conditions. Seventy Five percent FC with mild or no soil moisture stress corresponds with Mokwa, 50% FC with moderate soil moisture stress with Zaria and 25% FC represents severe soil moisture stress conditions at Mallamadori. The soil for screenhouse experiment was classified as Ferric Luvisol with a sandy loam texture, pH (water) of 5.4, organic Carbon (C) 1.26%, total nitrogen (N) 0.12%, available phosphorus (P) 34.4 mg kg^{-1}, calcium (Ca) 5.9 cmol kg^{-1} and magnesium (Mg) 0.7 cmol kg^{-1}. Moisture conditions were introduced after 4 weeks of adequate moisture supply by irrigating the plants to 75, 50 and 25% FC following the procedures of Ingram (1993). Plants were watered once a week with 3.94 liters, equivalent to 75% FC, 2.63 L (50% FC) and 1.31 L (25% FC). Measurements on vegetative traits were taken at 8, 12, 14, 16, 20 and 30 Weeks After Planting (WAP) for plant height and stem girth. Other parameters were evaluated at 16 and 30 WAP and at harvest.

Statistical analysis: Field data were analyzed on plot mean basis using the Statistical Analytical System (SAS) version, 1996) to carry out Analysis of Variance (ANOVA) using the Generalized Linear Model (GLM) procedures for randomized complete block design with location and year factors considered as random and genotypes as fixed. Significant treatment means were separated by the Duncan New Multiple Range Test (DNMRT). Data from the screenhouse were also analyzed using SAS version 1996 to carry out ANOVA using the GLM procedures for a factorial experiment in a completely randomized design. Means were separated using the DNMRT.

RESULTS AND DISCUSSION

The soil physiochemical analysis (Table 1) showed that soils in the three locations have values below critical levels for most nutrient elements and hence are not so fertile. Means Squares (MS) from Analysis of Variance (ANOVA) for both the field evaluation and screenhouse experiment are shown in Table 2. Genotype and location effects showed highly significant mean squares ($p<0.01$) for most parameters evaluated on the field, while MS were significant ($p<0.01$) only for moisture conditions in the screenhouse. These reflect genotypic differences towards adaptation to different agroecological zones and tolerance to water stress conditions. Genotypic differences as location effect were significant on the field; the Anderson and

Table 1: Soil physical and chemical properties in three locations for two planting seasons 1999/2000 and 2000/2001 in Nigeria

	Planting season					
	Mokwa		Zaria		Mallamadori	
Soil properties	2000	2001	2000	2001	2000	2001
pH H_2O	5.90	5.80	5.70	5.70	5.60	6.00
Organic C (%) (*3*)	0.49	0.49	0.49	0.42	0.15	0.15
Total N (%) (*5*)	0.050	0.049	0.049	0.052	0.021	0.023
Avail P (mg kg^{-1}) (*7*)	3.40	3.20	1.50	1.50	7.00	9.00
Exch Ca (cmol kg^{-1}) (*0.6*)	1.50	1.50	2.70	2.30	1.30	1.30
Exch Mg (cmol kg^{-1}) (*0.25*)	0.40	0.40	1.20	1.00	0.40	0.40
Exch K (cmol kg^{-1}) (*0.18*)	0.10	0.10	0.30	0.30	0.20	0.20
Cu (ppm) (*5*)	1.30	1.30	1.50	1.80	1.00	1.00
Zn (ppm) (*30*)	1.30	1.20	1.30	4.20	1.60	1.00
Mn (ppm) (*50*)	64.30	68.30	28.40	30.30	17.00	17.00
Fe (ppm) (*60*)	10.50	12.40	20.50	22.50	3.30	7.70
Sand (%)	78.00	78.00	45.00	42.00	88.00	85.00
Silt (%)	15.00	13.10	15.00	13.00	5.00	5.00
Clay (%)	7.00	9.00	41.00	45.00	7.00	7.00
Textural class	Sandy loam		Sandy clay		Sandy soil	

Critical levels in parentheses and italicized

Table 2: Mean squares from Analysis of Variance (ANOVA) for field experiment (RCBD) and screenhouse experiment (factorial experiment)

	Mean squares			
	B/w clones (df = 8)	Loc×clone (df = 16)	Loc×clone× year (df = 15)	Error (df = 137)
Field experiment (RCBD)				
Plant height	2122.83***	252.27	275.26	218.91
Number of roots	16.8***	3.3***	5.2***	1.62
Stem girth	2.28	2.17**	2.18**	2.08
Leaf size	3511.56***	3186.55***	1234.38	990.75
No. of stands harvested	47.98***	29.30***	15.13**	6.06
Yield (t ha^{-1})	209.52***	90.05***	17.96**	8.85
Shoot weight (kg)	206.21***	78.72***	102.87***	36.38
Harvest index (HI)	0.20***	0.03***	0.02***	0.01
	Mean squares			
	B/w clones df = 8	wfc df = 2)	Clone× FC (df = 16)	Error (df = 26)
Screenhouse experiment (9×3 factorial in CRD)				
Plant height	386.80	17767.59***	878.35	485.03
No. of roots	3.64	74.45***	1.96	2.96
Stem girth	0.02	0.80***	0.01**	0.02
Root weight (kg)	0.32	8.26***	0.16	0.34
Root length (cm)	154.25	1850.48**	145.95	198.52
Shoot weight (kg)	0.01	0.50***	0.01	0.01

FC = Soil moisture field capacity, **, *** = Significant level at p<0.01 and 0.001

Table 3: Means and percentage difference of cassava genotypes for stem girth, plant height and root weight on the field and in the screenhouse

LOC/ TRT	Plant height (cm)	*Diff* (%)	Stem girth (cm)	*Diff* (%)	No. of roots	*Diff* (%)	Tuber yield	*Diff* (%)	Shoot weight (kg)	*Diff* (%)
Field experiment (t ha^{-1})										
MKW	168.98a		1.95a		6.81a		21.85a		2.24a	
ZRA	110.26b	*34.7*	1.83a	*6.2*	3.12c	*38.4*	5.63b	*72.4*	1.45b	*35.3*
MDR	89.86c	*46.8*	1.65b	*15.4*	4.10b	*94.5*	2.95c	*86.5*	0.69c	*69.3*
MEAN	123.03		1.81		4.68		10.14			
Screenhouse experiment (16 WAP) (kg $plant^{-1}$)										
75% FC	139.22a		1.37a		2.7a		0.19a		1.28	
50% FC	137.45a	*1.3*	1.32a	*3.4*	1.67b	*38.4*	0.11a	*41.3*	1.04	*18.8*
25% FC	121.64b	*12.6*	1.15b	*16.3*	0.15c	*94.5*	0.01b	*93.3*	0.52	*59.2*
MEAN	132.77		1.28		1.51		0.1		0.95	
(30 WAP)										
75% FC	229.44a		1.48a		3.59a		1.10a		0.53a	
50% FC	219.63a	*4.3*	1.36a	*7.8*	1.19b	*67.0*	0.26b	*76.0*	0.44b	*15.8*
25% FC	180.93b	*21.2*	1.16b	*21.7*	0.41c	*88.7*	0.06c	*94.9*	0.26c	*50.6*
MEAN	210.00		1.33		1.73		0.47		0.41	

Means with the same letter in the same column are not significantly different at p<0.05 DNMRT, Values in italics show percentage decrease (% diff) relative to the control (Mokwa is control for field experiment and 75% FC for screenhouse experiment), $Diff\ (\%) = \frac{\text{Control} - \text{trt}}{\text{Control}} \times 100$

screenhouse genotypes showed significant variation in their response to the different moisture conditions. The significance of genotype×environment effects suggests that genotypes may be selected for specific adaptation to drought-prone environments. Rainfall is the critical climatic factor that distinguishes the different agroecological zones. While Mokwa had sufficient rainfall and an appreciable length of growing period; Zaria and Mallamadori had less rainfall and a reduced number of growing days, signifying a high level of soil moisture stress in the two locations. Results showed that moisture stress had a significant devastating effect on both the vegetative growth and yield of cassava. There were significant reductions for all the parameters evaluated when the performance in Mokwa was compared to that in Zaria and Mallamadori. Mallamadori had the worst performance. Although cassava is drought tolerant and can survive where other crops cannot, in areas where dry periods last up to 5-6 months, results from the field study showed that moisture stress reduced total plant height by 35% in Zaria and 47% in Mallamadori, stem girth declined by 6% in Zaria and by 15% in Mallamadori. The impact of soil moisture stress was also significant among the screenhouse genotypes for both vegetative growth and tuber yield. A moisture regime of 25% FC, when compared with the control at 75% FC, led to a decline in plant height by 12.6% at 16 Weeks After Planting (WAP) and 21.2% at 30 WAP. Stem girth also declined by 16.3% at 16 WAP and 21.7% at 30 WAP (Table 3). Okogbenin *et al.* (2003) also reported a decline of 37% in shoot growth due to

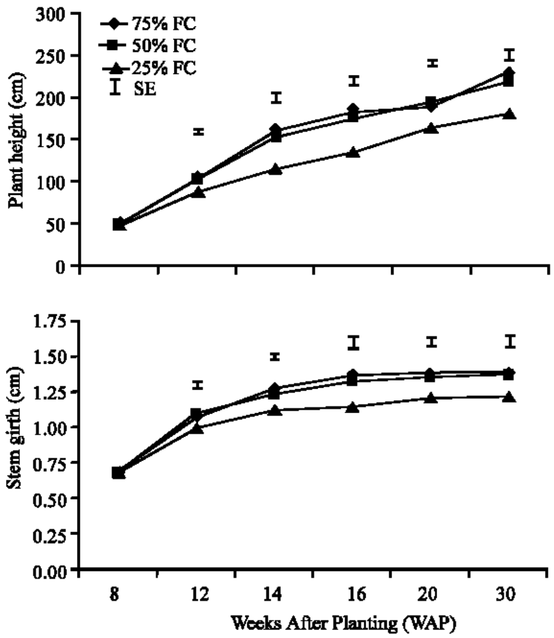

Fig. 1: Effect of different moisture conditions on plant height and stem girth for nine cassava genotypes evaluated under screenhouse conditions

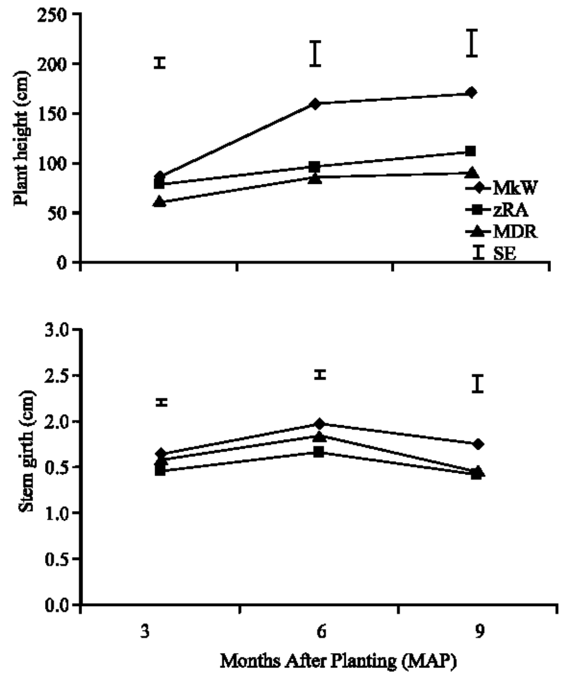

Fig. 2: Effect of different moisture conditions on plant height and stem girth for nine cassava genotypes evaluated in three locations in Nigeria

moisture stress and a decline in root yield of 22%. These results signify a more pronounced reduction for shoot growth than root yield which was contrary to the observations gathered in this study. Connor and Palta (1981) reported that water stress from 1 to 5 MAP led to reduction of storage root yield by 32 to 60%. The duration of the water deficit and the stage at which the plant is subjected to the moisture stress will therefore determine how serious the stress effect will be. The critical period for water deficit in cassava is from 1 to 5 MAP, which coincides with the stages of root initiation and tuberization. The cumulative effect of soil moisture stress was, however, more pronounced on the yield attributes of cassava than on vegetative growth. The number of tubers harvested declined by 38% in Zaria and 95% in Mallamadori while tuber yield declined by 72% in Zaria and by 87% in Mallamadori. Similar observations were made in the screenhouse where moisture content of 25% FC resulted in a decline in number of roots by 94.5% while shoot weight declined by 59.2% and tuber weight by 94.9%. Moisture stress effect was severe on yield parameters indicating that the mechanisms through which cassava tolerates drought conditions also would lead to a temporary halt in the partitioning of assimilates for root bulking, hence adversely affecting economic yield. Cassava, therefore, can survive conditions of moisture stress where other crops could not, but with adverse effects on economic yield in cassava (Fukai and Hammer, 1987). Similar observations have been reported in other agricultural and horticultural crops, such as sorghum (Chaudhuri and Kanemasu, 1982, Ravikumar *et al*., 2003) and tomato (Rudich *et al*., 1977). Cassava, under favorable environments is highly productive as shown in this study with high storage root yield of 22 t ha^{-1} in Mokwa. This was above the average yield of 11.9 t ha^{-1} reported for sub-Saharan Africa (Nweke *et al*., 1994) but was below the minimum range of 25 t ha^{-1} stipulated by the Food and Agriculture Organization (FAO, 1999). The lower productivity observed in this study could be attributed to the soil nutrient status that falls below the critical levels for the major nutrient elements of organic C, total N and exchangeable P in all the locations, therefore limiting the crop from reaching its maximum yield potential. There were pronounced effects due to moisture stress on both plant height and stem girth in the screenhouse (Fig. 1), but field experiment revealed more pronounced effect on plant height than on stem girth (Fig. 2). Genotypes showed significant variation in their ability to tolerate moisture stress with a decline in field performance ranging between 40 and 60% for plant height, 10 and 21% for stem girth and between 82 and 96% for tuber yield (Table 4). The decline among the screenhouse genotypes ranged between 9 and 36% for plant height and between 12 and

Table 4: Means and percentage difference of nine cassava genotypes for stem girth, plant height and root weight evaluated in three agroecological zones in Nigeria

	Plant height (cm)				Stem girth (cm)				Tuber yield (t ha^{-1})			
	MKW	ZRA	MDR	*Diff* (%)	MKW	ZRA	MDR	*Diff* (%)	MKW	ZRA	MDR	*Diff* (%)
30572	152.55	110.50	81.34	*46.70*	1.86	1.52	1.53	*17.40*	17.59	6.58	3.13	*82.2*
92/0326	185.65	93.33	75.47	*59.40*	1.69	1.51	1.53	*9.50*	26.97	5.19	1.11	*95.9*
91/02324	146.50	98.75	67.50	*53.90*	1.74	1.50	1.52	*12.50*	30.33	6.20	3.14	*89.7*
96/0211	165.42	110.56	80.18	*51.50*	1.86	1.60	1.58	*14.90*	18.89	1.95	1.56	*91.7*
96/0016	173.75	110.50	78.90	*54.60*	1.89	1.62	1.50	*20.70*	11.84	1.88	0.91	*92.3*
96/0304	180.54	121.11	73.65	*59.20*	1.80	1.52	1.51	*16.30*	26.72	9.61	4.92	*81.6*
96/0529	146.25	107.08	88.30	*39.60*	1.93	1.64	1.55	*19.90*	26.36	4.68	3.84	*85.4*
96/0565	188.07	125.61	76.90	*59.10*	1.88	1.62	1.54	*17.90*	12.33	4.33	2.13	*82.8*
96/1632	182.07	114.87	77.90	*57.20*	1.83	1.65	1.57	*14.30*	25.63	8.51	4.60	*82.1*
MEAN	141.9	89.06	77.79		1.83	1.58	1.54		21.85	5.43	2.82	
SE	4.09	4.75	2.01		0.03	0.02	0.01		2.42	0.93	0.52	

MKW = Mokwa, ZRA = Zaria, MDR = Mallamadori, $Diff\ (\%) = \frac{MKW - MDR}{MKW} \times \frac{100}{1}$

Table 5: Means and percentage difference of nine cassava genotypes for stem girth, plant height and root weight in the screenhouse at 30 WAP

	Plant height (cm)				Stem girth (cm)				Root weight (kg)/plant			
	T1	T2	T3	*Diff* (%)	T1	T2	T3	*Diff* (%)	T1	T2	T3	*Diff* (%)
30572	250.00	230.00	186.67	*25.3*	1.50	1.32	1.12	*25.5*	1.54	0.13	0.05	*97.0*
96/0326	226.67	211.67	153.33	*32.4*	1.57	1.38	1.09	*30.7*	1.16	0.40	0.00	*100.0*
91/02324	230.00	218.33	186.67	*18.8*	1.44	1.38	1.12	*22.0*	0.83	0.33	0.22	*73.5*
95/0211	221.67	183.33	203.33	*8.3*	1.36	1.33	1.20	*12.0*	1.89	0.47	0.13	*93.1*
96/0016	220.00	223.33	196.67	*10.6*	1.37	1.40	1.07	*22.0*	0.98	0.38	0.00	*100.0*
96/0304	236.67	221.67	166.67	*29.6*	1.49	1.40	1.21	*19.2*	0.87	0.18	0.00	*100.0*
96/0529	220.00	226.67	173.33	*21.2*	1.55	1.42	1.17	*24.6*	0.79	0.10	0.00	*100.0*
96/0565	223.33	218.33	203.33	*9.0*	1.57	1.38	1.24	*21.0*	1.26	0.49	0.06	*95.3*
96/1632	246.67	223.33	158.33	*35.8*	1.48	1.27	1.07	*27.9*	0.59	0.10	0.05	*91.5*
MEAN	230.56	217.41	180.93		1.48	1.36	1.14		1.10	0.29	0.06	
SE	4.04	4.89	6.67		0.03	0.02	0.02		0.15	0.06	0.03	

T1 = 75% FC, T2 = 50% FC, T3 = 25% FC, $Diff\ (\%) = \frac{Ti - T3}{T1} > \frac{100}{1}$

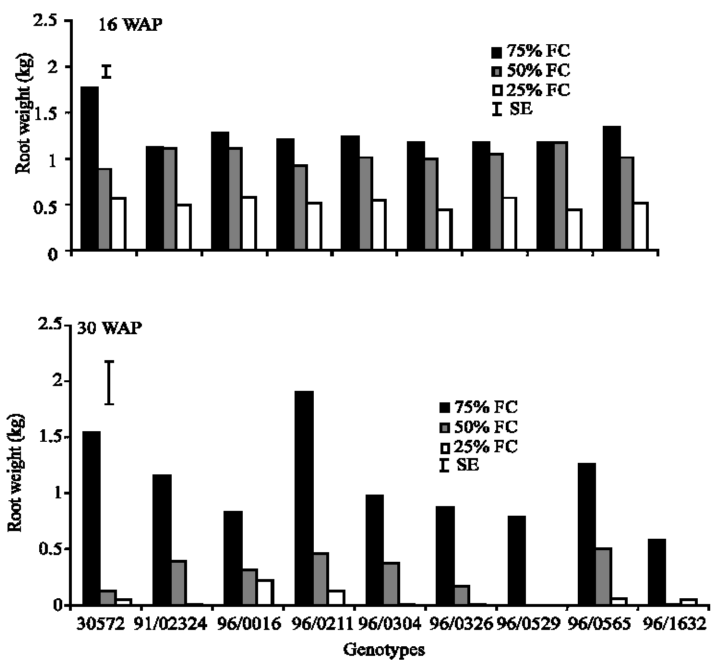

Fig. 3: Variation in fresh root yield for nine cassavas genotypes in the screenhouse at 16 and 30 WAP

31% for stem girth (Table 5). The effect of moisture stress on tuber yield was more pronounced at 30 WAP than at 16 WAP (Fig. 3).

CONCLUSIONS

Although cassava is drought tolerant, the repercussions of moisture stress are evident under very severe moisture stress, resulting in a severe effect on plant phenology, phasic development, growth, assimilate partitioning and plant reproduction processes. For the successful expansion of cassava production to the dry savanna regions of tropical Africa to be achieved, concerted efforts should be aimed at breeding for drought-tolerant genotypes. Although drought tolerance is considered to be a highly complex trait (Ravikumar *et al*., 2003), appreciable progress could be achieved by utilizing the vast genotypic variability that exists among the different genotypes for different traits and, specifically, variability for tolerance to soil moisture stress. Further studies to understand the inheritance pattern of drought tolerance among different cassava genotypes are thus necessary. Several studies that have been conducted on the genetic variability of the crop have resulted in little progress in understanding the inheritance pattern of several agronomically relevant traits, due to the heterozygous nature of the crop (Ceballos *et al*., 2006). By accumulating genes for drought stress tolerance in breeding material, many more genotypes adapted to the dry agroecologies with high yield potentials will be developed. Drought-tolerant materials introduced from Latin America and north-eastern Brazil are thus providing a new source of variability to further broaden the genetic base in cassava. Marker-aided analysis can also be used to elucidate the genetic control of this trait and to locate genes involved in water stress tolerance. The information from this study has significance for the maximization of productivity potential in drought-prone areas and for selecting parents with high breeding values.

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