GENOTIPIC DIFFERENCES IN PRODUCTIVITY AND NUTRIENT UPTAKE AND USE EFFICIENCY OF CASSAVA AS INFLUENCED BY PROLONGED WATER STRESS

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ABSTRACT

A 2-y field trial was conducted at CIAT experimental station at Santander de Quilichao, Cauca, Colombia, to study the effects of prolonged water stress on cassava (Manihot esculenta Crantz) productivity and on nutrient uptake and use efficiency. Four contrasting cultivars, CM 507-37, CM 523-7, M Col 1684 and CMC 40, were used with adequate fertilization and watering, except when water was excluded by covering the soil with plastic sheets from 2 to 6 months after planting (early stress), from 4 to 8 months after planting (mid-season stress) and from 6 to 12 months after planting (terminal stress). Sequential harvests were made at 2, 4, 6, 8 and 12 months after planting to determine LAI, top and root biomass production. At final harvest, N, P, K, Ca and Mg uptake in top and root biomass was determined. During both early and mid-season water stress, LAI, top and root biomass were significantly reduced in all cultivars. After recovery from stress, LAI was greatly enhanced with less dry matter allocated to stems and at final harvest root yields approached those in the controls. One cultivar, CMC 40 had greater final root yield under both stress treatments. Nutrient uptake in root and top biomass was significantly lower in early stress treatment in all cultivars resulting in higher nutrient use efficiency for root and total biomass production. Under mid-season water stress, only P and K uptake was lower, resulting in higher use efficiency of these two elements. Neither LAI nor top biomass was significantly affected by terminal stress, while root yield was lower in all cultivars except CMC 40 whose final root yield was significantly greater under stress. Nitrogen uptake was greater in root but lower in top biomass of all cultivars under terminal stress resulting in lower N use efficiency for total biomass production. CMC 40 was the only cultivar with consistently greater use efficiency of P, K, Ca and Mg for both root and total biomass production under terminal water stress.

Keywords: Cassava; *Manihot esculenta*; Leaf area index; Nutrient uptake; Root yield; Water stress.

COMPENDIO

DIFERENCIAS GENOTIPICAS EN PRODUCTIVIDAD, ABSORCION, EFICIENCIA EN EL USO DE LOS NUTRIENTES EN YUCA INFLUIDA POR EL ESTRES HIDRICO PROLONGADO

El experimento se llevó a cabo en CIAT Santander de Quilichao, Cauca Colombia con cuatro cultivares (CM 507-37, CM 523-7, MCol 1684 y CMC 40), se empleo un diseño de bloques al azar con cuatro tratamientos y cuatro repeticiones. Los tratamientos corresponden a tres épocas de inducción de estrés después de la siembra: temprano (2-6 meses), medio (4-8 meses), terminal (6-12 meses) y el control. Los tratamientos estrés temprano y medio presentaron reducción significativa en el Indice de área foliar (IAF), la producción de biomasa de la parte aérea y en la raiz; al suministrar riego, los cultivares se recuperaron y aumentó el IAF, se produjo menos materia seca en tallos y el rendimiento de raíces alcanzó el del control; el mayor rendimiento lo presentó la CMC–40. Los cultivares presentaron una absorción de nutrientes significativamente menor en el estrés temprano y por ende un mayor uso eficiente (UE) de nutrientes. El tratamiento estrés medio, presentó una menor absorción de P y K, lo que dio como resultado un mayor UE de estos dos elementos. El tratamiento estrés tardío no presentó efectos sobre el IAF ni la producción de biomasa en la parte aérea, mientras que el rendimiento de raíces fue menor en todos los cultivares excepto para CMC 40 cuyo rendimiento final fue significativamente mayor bajo condiciones de estrés. La absorción de N fue mayor en las raíces y menor en la parte aérea en el estrés terminal, con un menor UE del elemento. CMC 40 fue el único cultivar que presentó un UE mayor de P, K, Ca y Mg en las raíces y la parte aérea de la planta, en el estrés terminal.

Palabras claves: Yuca; *Manihot esculenta* ; IAF, Absorción de nutrientes ; Producción de raíces ; Estrés de agua.

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INTRODUCCION

In the tropics, and in absence of production constraints, potential productivity of cassava (*Manihot esculenta* Crantz) compares favorably with other major staple food and energy crops. Assuming one crop per year, cassava produces more calories per unit land than maize, sorghum and rice (El-Sharkawy, 1993). Experimental dry root yields, during 10 to 12 months, that were greater than 20 t ha^{-1} and total dry biomass greater than 30 t ha^{-1} were reported for several improved cassava cultivars under rainfed conditions with 3 to 4 months dry period in the Patia Valley, Cauca, Colombia (El-Sharkawy et al, 1990). High solar radiation (22 MJ m^{-2} day^{-1}), high atmospheric humidity (70%) and high mean annual temperature (28°C) were characteristics of this valley. Ramanujam (1990), also reported similar yields under irrigation in Kerala State, India. At this level of productivity, cassava extracts large amounts of nutrients from the soil that can exceed 150 kg ha^{-1} nitrogen (N), 25 kg ha^{-1} phosphorus (P), 160 kg ha^{-1} potassium (K), 100 kg ha^{-1} calcium (Ca) and 30 kg ha^{-1} magnesium (Mg) (Howeler and Cadavid, 1983; Ghosh et al, 1989; Howeler, 1991, 1994; Rhodes, 1995; Pellet and El-Sharkawy, 1997).

Although leaf litter that can exceeds 3 dry t ha^{-1} per year does contribute to the recycling of a significant amount of the total nutrient accumulated in biomass (Pellet and El-Sharkawy, 1997), the major portion of the absorbed nutrient are removed with the harvested storage roots and with the above-ground biomass. Harvested roots alone can export up to 67% of total absorbed K, 45% of P, 39% of N, 23% of Mg and 14% of Ca (Pellet and El-Sharkawy, 1997). Most cassava producers either burn or use the above-ground parts (stems and leaves) for animal feed and for fuel. Under these management practices, and with continuous cassava cultivation without fertilization, both soil fertility and cassava productivity decline over time (Howeler, 1991; Cadavid et al, 1998). To maintain soil fertility and, hence, productivity, annual applications of chemical fertilizer and/or crop residues are required (Cadavid et al, 1998). Short- and long-term fertilization trials in various types of soils in Colombia have shown remarkable cassava responses to chemical fertilizer application and to mulch with plant residues (Howeler and Cadavid, 1990; Howeler, 1991; Pellet and El-Sharkawy, 1993 a, b, 1997; Cadavid et al, 1998).

In stressful environments (i.e. low-fertility soils and/or prolonged water deficits), cassava reduces its total biomass production but maintains reasonable root yields (Cock and Howeler, 1978; Connor et al, 1981; El-Sharkawy and Cock, 1987; Cock and El-Sharkawy, 1988b; Yao et al, 1988; El-Sharkawy et al., 1992; Hershey and Jennings, 1992; El-Sharkawy, 1993; de Tafur et al., 1997 a, b).

Under these conditions cassava shifts dry matter allocation towards the storage roots and, hence, increases the harvest index (harvested roots/total biomass). In this case, the reduction in dry matter production is often more pronounced in top biomass as compared to the storage roots (Connor et al., 1981; El-Sharkawy and Cock, 1987; Yao et al, 1988; El-Sharkawy et al. 1992; Iglesias et al., 1996). This response might imply that nutrient use efficiency (expressed as the amounts of biomass produced per unit of nutrient extracted) is probably greater in the stressful environments as compared with favorable ones. As most of cassava production in the tropics occurs in low-fertility soils by resource.-limited farmers, optimizing productivity per unit nutrient absorbed should be favored against maximizing yield. To achieve this goal, breeding strategy should be designed to select for those genotypes that are more efficient in nutrient use in low-fertility soils and also respond to fertilization (Hershey and Jennings, 1992). The advantages of a such strategy are the stabilization of productivity without increasing pressures on limited natural resources and the insurance of high economic returns from applied fertilizer (El-Sharkawy, 1993). Pellet and El-Sharkawy (1993b, 1997) found genetic differences in nutrient uptake and use efficiency, particularly of P and K, under non-limiting rainfall and irrespective of fertilizer application.

Information on genetic differences in nutrient uptake and use efficiency of cassava under prolonged water deficit are scarce. Therefore, the objectives of this work were to study the effects of water deficit stress imposed at various stages of growth of four contrasting cassava cultivars on (1) growth, yield and biomass production, and on (2) nutrients uptake and use efficiency.

MATERIALS AND METHODS

Plant materials, experimental site and experimental design

The cultivars CM523-7 (ICA Catumare), CMC 40, M Col 1684 and CM 507-37 were used in a 2-year field trial. CM 523-7 and CMC 40 are commercial varieties with intermediate branching habit, whereas M Col 1684 (a commercial variety) and CM 507-37 (advanced CIAT breeding line) have early-branching habit. Mature stem cuttings, 0.2 m long, were selected each year from well-fertilized 10-month old mother plants which were grown on well-drained soils for production of propagation materials. The lower one-third of woody stems was used for cuttings which were soaked for 10 min in a fungicide-insecticide zinc-sulfate solution before planting (Veltkamp, 1985). On 22 May 1991 and on 7 May 1992, the cuttings were planted vertically on ridges at 1 m x 0.8 m to give a population density of 12,500 plants ha^{-1}. The trial was conducted at the CIAT Experimental Station at Santander de Quilichao, Cauca, Colombia (lat. 3°06'N, long. 76°31'W, altitude 990 m, mean annual temperature 24°C). The experimental site was under fallow and maize during the 2 preceding years. Before planting, the land was prepared by a disc plough in two directions and then was ridged at 1 m distance. The soil is classified as Inceptisol (FAO system) with clayey texture (about 71% clay, 25% silt and 4% sand).

It had a pH (H_2O) of 4.5, 2.79 mol C kg^{-1} (dry soil) and 0.41, 0.18, 0.4, 1.80, 9.50, 3.70 and 9.59 mmol kg^{-1} (dry soil) of NH_3, NO_3, P, K, Ca, Mg and Al, respectively. One month after planting, 50 N, 44 P, 84 K kg ha^{-1} in 1991 and 25 N, 22 P, 42 K kg ha^{-1} in 1992 were band-applied in the form of a compound N, P and K fertilizer at 10: 8.7: 16.7. In both growing seasons, 500 kg ha^{-1} of lime (20% $CaCO_3$ and 12% $MgCO_3$) were incorporated before planting.

The experiment was laid out in aS plit-plot design with four replications and the main plots were assigned to water treatments and the sub-plots to cultivars. The size of the subplots was 64 m^2.

Water treatments

The water regime consisted of four treatments. (1) Well-watered control, where the rainfall was supplemented with irrigation whenever there was water deficit (total irrigation was 460 mm in 1991/92 and 480 mm in 1992/93); (2) early water stress that was initiated at 2 months after planting by covering the soil with white plastic sheets (caliber 6) and terminated at 6 months after planting; (3) mid-season water stress that was initiated at 4 months after planting and terminated at 8 months after planting; (4) terminal water stress that was initiated at 6 months after planting and remained until the final harvest at 12 months after planting. In treatments (2) and (3), the plants were allowed to recuperate after the termination of water stress for the rest of the growing cycle with normal rainfall and supplementary irrigation whenever there was water deficit. For treatment (2), the supplementary irrigation was 495 mm in the 1991/92 season and 320 mm in the 1992/93 season. Whereas the supplementary irrigation for treatment (3) was 545 mm in the 1991/92 season and 430 mm in the 1992/93 season.

In all water treatments, the soil was at field capacity before initiation of stress. The plastic sheets were always checked for defects and leaks during the stress period and the water was swept manually within the shortest possible time after rainfall. Soil water content was monitored regularly with a neutron moisture meter at 0.2 m interval to a depth of 1.8 m in two access aluminum tubes within each plot. Meteorological data during the two growing seasons are presented in Table 1. In the 1991/92 season, the total rainfall was 1445 mm and pan evaporation was 1544 mm; whereas in the 1992/93 season, the total rainfall was 1323 mm and pan evaporation was 1519 mm. In the 1991/92 season rainfall was less than evaporation in June, July, August and December 1991 and in January and March 1992. In the 1992/93 season, there was water deficit from June to October 1992 and in February 1993.

Biomass and nutrient uptake determinations

Five sequential harvests of 6 protected plants per plot were made at 2, 4, 6, 8 and 12 months after planting in both growing seasons. Harvested plants were separated into leaves, petiols, stems and storage roots.

Fallen leaves were not included in biomass determination due to difficulties in collection during rainfall, hence, both total biomass and nutrient uptake were underestimated in this case. Samples of the various plant parts were chopped into small pieces and oven-dried at 75°C to a constant weight to determine dry matter. Subsamples of the dry matter of the different plant parts were ground through a 40-mesh screen Wiley laboratory mill. The nutrient contents of samples were determined according to Salinas and Garcia (1985) and Thomas et al (1967). Subsamples were digested in sulfuric acid and the contents of N and P in solution were determined colorimetrically on an autoanalyzer; K, Ca and Mg were determined by atomic absorption spectrometry. The nutrient uptake was calculated on basis of unit dry matter of harvested biomass and then was converted to kg nutrient ha^{-1}.

Leaf area index (LAI) was determined at each harvest using a 20-leaf sample from different canopy levels; its area was determined and then oven-dried to obtain specific leaf dry weight. The total dry weight of leaves from each harvest was converted to leaf area using the sample specific leaf weight (Veltkamp, 1985).

Results and discussion

Response to early water stress

Leaf area index (LAI) and biomass production

In both seasons, LAI was significantly smaller under water stress, with significant differences among cultivars (Table 2, harvests at 4 and 6 months). CM 507-37 and

TABLE 1. Mean monthly meteorological data at Santander de Quilichao during the 1991/1992 and 1992/1993 seasons

Month	Rainfall (mm)	Pan evaporation (mm)	Solar radiation (MJ m^{-2})	Temperature (°C)		
				Max.	Min.	Mean
			1991/1992			
May, 1991	147	122	493	29.2	19.5	24.1
June	52	116	521	29.9	19.2	24.5
July	38	116	530	29.9	18.1	24.1
August	80	121	528	30.4	16.4	24.3
September	152	151	811	30.8	18.0	24.6
October	161	135	544	29.9	17.8	23.7
November	190	110	417	29.0	18.6	23.4
December	116	128	513	29.8	18.5	24.4
January, 1992	66	146	537	30.0	18.2	24.6
February	181	129	449	30.3	18.8	24.4
March	68	145	498	31.3	19.2	25.2
April	194	125	459	30.0	19.0	24.6
			1992/1993			
May, 1992	174	120	446	29.6	19.3	24.4
June	41	123	479	30.2	18.4	25.1
July	56	133	522	29.8	17.0	24.5
August	24	139	465	31.0	17.4	25.2
September	98	135	501	30.0	18.0	24.4
October	77	133	496	29.7	18.1	24.3
November	134	120	430	29.1	18.1	23.4
December	129	119	478	29.5	18.9	24.1
January, 1993	131	137	533	29.6	18.1	24.1
February	86	117	441	29.8	18.1	24.0
March	121	123	455	29.8	18.4	23.6
April	252	120	460	29.4	18.8	23.7

CM 523-7, showed higher LAI as compared to CMC 40 and M Col 1684. The reduction in LAI under stress is known to be due, mainly, to restricted leaf formation and smaller leaf size (Connor and Cock, 1981; Porto, 1983; El-Sharkawy and Cock 1987; Cock and El-Sharkawy, 1988b; Yao et al, 1988). Connor and Cock (1981) and El-Sharkawy et al (1992) reported less leaf fall under stress as compared to well-watered plants. Two months after recovery from stress (Table 2, harvest at 8 months), LAI in previously stressed plants was generally higher than in the controls with significant differences only in the 1992/93 season. CMC 40 consistently showed significantly higher LAI in previously stressed plants in both seasons. However, in this cultivar LAI declined rapidly at 8 months in absence of water stress in both seasons. At final harvest (at 12 months), however, LAI in the controls were generally higher than in the previously stressed plants in all cultivars.

Top biomass (excluding fallen leaves) was also significantly smaller under stress, with significant differences among cultivars (Table 2). Differences among cultivars were more pronounced at 6 months after planting in both seasons. Under prolonged water stress, the cassava plant tends to restrict its top growth while increasing the proportion of dry matter allocated to storage roots (Connor et al, 1981; Cock and El-Sharkawy, 1988b; El-Sharkawy et al, 1992). Contrary to LAI, top biomass remained significantly lower during the recovery phase from stress up to final harvest in all cultivars and in both seasons (Table 2, harvests at 8 and 12 months). This indicates that cassava plant tends to increase leaf canopy formation after recovery from stress with less dry matter allocated to stems, hence enhancing leaf area ratio (El-Sharkawy and Cock, 1987; El-Sharkawy et al, 1992). Reducing dry matter allocation to stems reflects favorably on increasing the harvest index in

Table 2. Response of cassava root yield, top biomass and leaf area index (LAI) to early water stress (2-6 months after planting). Harvests at 2, 4, 6, 8 and 12 months after planting

Cultivar	Water Stress[a]	1991/1992					1992/1993				
		2	4[b]	6[b]	8	12	2	4[b]	6[b]	8	12
		Root yield (t ha^{-1} dry wt)					Root yield (t ha^{-1} dry wt)				
CM 507-37	-	0.01	1.4	6.8	12.1	16.2	0.01	1.0	5.6	8.7	12.0
CM 507-37	+	0.01	1.7	4.1	8.0	12.0	0.01	0.9	2.4	4.8	10.1
CM 523-7	-	0.01	1.6	7.0	10.9	14.4	0.01	1.4	6.7	10.0	13.1
CM 523-7	+	0.01	1.0	4.3	7.8	13.8	0.01	0.6	1.7	4.2	11.7
CMC 40	-	0.01	2.2	8.6	9.0	10.0	0.01	2.1	6.5	7.7	9.8
CMC 40	+	0.01	1.7	4.7	8.3	12.2	0.01	1.4	2.3	4.8	8.6
M Col 1684	-	0.01	1.5	7.9	12.7	14.3	0.01	1.2	5.5	9.4	12.9
M Col 1684	+	0.02	1.9	4.7	8.6	11.7	0.01	0.9	2.7	5.5	8.8
LSD 5% (Duncan)		0.01	0.4	1.3	2.3	2.2	NS[c]	0.3	0.9	1.1	2.9
		Top biomass (t ha^{-1} dry wt)					Top biomass (t ha^{-1} dry wt)				
CM 507-37	-	0.36	2.8	6.9	5.9	7.9	0.24	2.5	4.7	3.8	4.1
CM 507-37	+	0.42	1.9	1.1	3.2	2.8	0.20	1.8	1.7	3.0	2.5
CM 523-7	-	0.40	2.5	5.9	6.4	6.1	0.42	2.4	5.1	4.4	4.5
CM 523-7	+	0.42	2.0	0.8	3.4	4.3	0.34	1.7	1.4	2.5	4.0
CMC 40	-	0.43	2.6	7.1	6.6	9.0	0.34	2.6	4.9	4.5	6.9
CMC 40	+	0.42	1.8	2.2	4.0	4.5	0.29	1.7	1.7	2.8	3.2
M Col 1684	-	0.42	2.3	5.7	5.8	6.2	0.15	2.3	3.3	3.4	3.7
M Col 1684	+	0.46	1.7	2.4	3.0	2.3	0.17	1.4	1.6	2.9	2.0
LSD 5% (Duncan)		0.12	0.4	0.8	0.8	1.7	0.11	0.4	0.7	1.0	0.8
		LAI					LAI				
CM 507-37	-	0.6	3.3	4.4	1.3	3.0	0.4	2.4	3.3	0.7	2.0
CM 507-37	+	0.7	1.6	1.0	1.7	0.9	0.3	1.8	0.9	1.8	0.8
CM 523-7	-	0.9	2.4	4.6	2.0	1.8	0.7	2.2	3.3	1.3	1.8
CM 523-7	+	0.7	1.6	1.0	2.2	2.0	0.5	1.4	0.6	1.7	1.3
CMC 40	-	0.6	1.9	3.5	0.7	1.8	0.5	2.3	2.5	0.5	1.1
CMC 40	+	1.0	1.4	1.1	1.3	0.7	0.4	1.2	0.6	1.2	0.8
M Col 1684	-	0.6	1.9	3.5	1.7	1.7	0.3	2.1	2.2	0.8	1.5
M Col 1684	+	0.8	1.4	1.0	1.7	0.6	0.3	1.3	0.8	1.7	0.4
LSD 5% (Duncan)		0.4	0.5	0.6	0.6	0.7	0.2	0.3	0.3	0.5	0.4

[a] (-) Without stress; (+) With stress. Water was excluded during 4 months period starting at 2 months after planting by covering the soil with plastic sheets.

[b] Harvests during water stress.

[c] NS = Not significant at 5%

previously stressed plants (Connor et al, 1981; El-Sharkawy and Cock, 1987; El-Sharkawy et al, 1992). Such response may underlie the observed increase in root yield in previously stressed vigorous cultivars such as M Mex 59 (Connor et al, 1981). Furthermore, the increase in LAI with less dry matter invested in stems of previously stressed cassava may defy the notion of optimum LAI for root production (Cock et al., 1979; Cock and El-Sharkawy, 1988 a,b).

Root yield was significantly reduced during stress in both seasons, with more pronounced differences at 6 months after planting (Table 2). Differences among cultivars were also significant. The storage roots in cassava start to form 2 months after planting and from this trial it appears that early stress adversely affected storage roots formation. However, during the recovery phase from stress, remarkable increases in root yield occurred, particularly at final harvest (Table 2). Reductions in root yield in final harvest due to stress were significant only in M Col 1684 in both seasons and in CM 507-37 in 1991/92 season. Noteworthy, stressed crop of CMC 40 outyielded the control at final harvest in 1991/92 season. These results imply that early stress, after crop establishment, may not adversely affect the overall root production provided that favorable watering conditions prevail during the rest of the growth cycle. The practical implication of this observation is that cassava could be successfully planted toward the end of a rainy period without large yield losses in regions with bimodal rainfall distribution. This plasticity in crop growth should reflect favourably on spreading planting dates across the season to meet variable market demands for fresh as well as processed cassava.

Nutrient uptake

Table 3 summarizes the total nutrient uptake in roots and top biomass at final harvest (12 months) in the two growing seasons. With the exception of N, nutrient uptake in root biomass was significantly smaller for P, K, Ca and Mg due to water stress in most of the cultivars. The largest amounts of uptake were for K followed by N with less uptake for P, Ca and Mg. There were also significant differences in nutrient uptake among cultivars, irrespective of water treatments in both seasons, particularly in N, P and K. Differences in Ca and Mg uptake were much smaller and insignificant in most of the cases. These results confirm other reports on nutrient uptake of cassava (Howeler and Cadavid, 1983; Howeler, 1985, 1991, 1994; Ghosh et al, 1989; Olasantan et al, 1994; Rhodes, 1995; Pellet and El-Sharkawy, 1997).

With the exception of Ca in 1992/93, water stress significantly reduced nutrient uptake in top biomass with significant differences among cultivars (Table 3). Contrary to roots, the largest amounts of uptake in top biomass occurred with N followed by K. Amounts of P uptake in top biomass were similar to those in roots. On the other hand, much larger amounts of Ca and Mg were accumulated in top biomass as compared to those in roots. Irrespective of water treatment, differences among cultivars were consistently significant for all nutrients, except P which showed the smallest variations. Similar findings were recently reported by Pellet and El-Sharkawy (1997).

Nutrient use efficiency

In 1991/92 season, nutrient use efficiency in terms of root biomass production was significantly greater due to water stress (Table 4). In 1992/93 season, differences due to stress were variable and were significant only for

Table 3. Nutrient uptake in roots and top biomass of cassava at 12 months after planting as affected by early water stress (2-6 months after planting)

Cultivar	Water Stress[a]	1991/1992					1992/1993				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
		Roots (kg nutrient ha^{-1})					Roots (kg nutrient ha^{-1})				
CM 507-37	-	56	13	74	5	8	24	10	70	6	7
CM 507-37	+	48	7	56	5	6	31	7	60	6	7
CM 523-7	-	49	12	75	7	9	30	12	69	12	8
CM 523-7	+	59	9	58	3	8	42	9	72	6	6
CMC 40	-	31	8	75	5	8	17	8	94	8	9
CMC 40	+	47	7	55	4	8	20	5	65	4	5
M Col 1684	-	46	8	77	6	8	23	8	77	9	7
M Col 1684	+	41	8	48	3	6	26	6	52	6	5
LSD 5% (Duncan)		7.7	2.7	15.8	1.8	1.9	11.4	2.4	17.9	4.0	2.4
		Top biomass (kg nutrient ha^{-1})					Top biomass (kg nutrient ha^{-1})				
CM 507-37	-	125	15	55	46	28	51	7	26	23	15
CM 507-37	+	44	5	16	23	11	28	4	13	26	8
CM 523-7	-	89	10	46	37	22	55	7	41	24	12
CM 523-7	+	70	7	23	30	15	45	5	25	25	9
CMC 40	-	101	12	43	46	34	43	8	30	26	16
CMC 40	+	53	5	20	29	16	31	4	20	22	9
M Col 1684	-	93	12	44	54	30	47	5	23	27	14
M Col 1684	+	37	3	11	24	10	19	2	9	25	6
LSD 5% (Duncan)		23.6	2.9	10.4	9.5	8.0	12.5	1.6	6.9	4.7	2.3

[a] (-) Without stress; (+) With stress. Water was excluded during 4 months period starting at 2 months after planting by covering the soil with plastic sheets.

Table 4. Nutrient use efficiency for roots and total biomass production of cassava at 12 months after planting as affected by early water stress (2-6 months after planting)

Cultivar	Water Stress[a]	1991/1992 N	1991/1992 P	1991/1992 K	1991/1992 Ca	1991/1992 Mg	1992/1993 N	1992/1993 P	1992/1993 K	1992/1993 Ca	1992/1993 Mg
		Roots (kg dry wt kg^{-1} total nutrient uptake)					Roots (kg dry wt kg^{-1} total nutrient uptake)				
CM 507-37	-	89	578	126	317	450	160	705	125	413	545
CM 507-37	+	130	999	167	428	631	171	918	138	316	673
CM 523-7	-	104	653	119	326	463	154	689	119	364	655
CM 523-7	+	107	859	170	417	598	135	837	121	378	651
CMC 40	-	75	498	84	195	237	164	614	79	289	393
CMC 40	+	122	1013	162	368	506	168	954	101	330	614
M Col 1684	-	103	717	118	239	377	185	995	129	359	616
M Col 1684	+	150	1062	198	433	730	196	1101	144	284	801
LSD 5% (Duncan)		22	147	24	91	98	44	158	23	115	103
		Total biomass (kg dry wt kg^{-1} total nutrient uptake)					Total biomass (kg dry wt kg^{-1} total nutrient uptake)				
CM 507-37	-	133	862	187	473	670	215	946	168	555	731
CM 507-37	+	161	1233	205	528	778	214	1149	173	395	843
CM 523-7	-	149	932	169	466	661	207	927	160	489	881
CM 523-7	+	140	1129	223	547	785	180	1121	162	506	872
CMC 40	-	144	949	161	372	452	278	1044	135	491	668
CMC 40	+	167	1388	222	505	694	231	1311	139	454	843
M Col 1684	-	148	1027	170	342	540	237	1275	166	461	790
M Col 1684	+	180	1275	238	519	876	241	1354	178	349	985
LSD 5% (Duncan)		22	161	23	97	101	53	195	25	125	107

[a] (-) Without stress; (+) With stress. Water was excluded during 4 months period starting at 2 months after planting by covering the soil with plastic sheets.

P and Mg. The differences among cultivars were also significant, irrespective of water treatment. The increase in nutrient use efficiency under stress was mainly due to the larger reduction in top biomass, and hence less nutrient uptake, as compared to roots (Tables 2 and 3). In most of the cases, root production at final harvest did not vary significantly with water treatment (Table 2). Thus, with less total nutrient uptake under stress, cassava was capable of producing comparable yields regardless of water treatment. This finding is of paramount importance for cassava production systems where resource-limited farmers rarely apply fertilizer and where most of cassava production occurs in low-fertility soils (El-Sharkawy, 1993).

As with roots in 1991/92 season, nutrient use efficiency in terms of total biomass production was significantly greater due to stress (Table 4). There were also significant differences among cultivars. In 1992/93 season, differences due to stress were variable and were significant only for P and Mg. The apparent enhancement in total biomass nutrient use efficiency under stress were due mainly to larger reductions in top biomass, as compared to roots, and hence to lower nutrient uptake.

Response to mid-season water stress

Leaf area index (LAI) and biomass production

Mid-season water stress significantly reduced LAI in all cultivars in both seasons (Table 5, harvests at 6 and 8 months). Differences among cultivars were significant with CM 505-37 and CM 523-7 maintaining larger LAI than CMC 40 and M Col 1684. At final harvest in 1991/92 season (12 months) and after 4 months recovery period from stress, LAI of all cultivars was higher than in the controls. This indicates that cassava can recover from a prolonged water stress imposed in the middle of the growth cycle when normally peak LAI occurs. However, in 1992/93 season LAI of previously stressed plants was not significantly different from the controls except M Col 1684 with lower LAI. Similar findings were reported for various cassava cultivars with different growth habits (Connor et al, 1981; El-Sharkawy and Cock 1987; El-Sharkawy et al, 1992).

Table 5. Response of cassava root yield, top biomass and leaf area index (LAI) to mid-season water stress (4-8 months after planting). Harvests at 2, 4, 6, 8 and 12 months after planting

Cultivar	Water	1991/1992					1992/1993				
	Stress[a]	2	4	6[b]	8[b]	12	2	4	6[b]	8[b]	12
		Root yield (t ha^{-1} dry wt)					Root yield (t ha^{-1} dry wt)				
CM 507-37	-	0.01	1.4	6.8	12.1	16.2	0.01	1.0	5.6	8.7	12.0
CM 507-37	+	0.02	2.1	7.6	7.5	12.4	0.01	1.0	3.1	4.1	10.2
CM 523-7	-	0.01	1.6	7.0	10.9	14.4	0.01	1.4	6.7	10.1	13.1
CM 523-7	+	0.01	1.9	5.9	9.0	13.9	0.01	1.8	3.3	5.5	10.3
CMC 40	-	0.01	2.2	8.6	9.0	10.0	0.01	2.1	6.5	7.7	9.8
CMC 40	+	0.01	3.1	7.2	7.5	11.9	0.01	2.5	4.7	6.6	12.2
M Col 1684	-	0.01	1.5	7.9	12.7	14.3	0.01	1.2	5.5	9.4	12.9
M Col 1684	+	0.02	2.4	7.6	8.0	13.6	0.01	1.2	3.4	5.8	11.4
LSD 5% (Duncan)		0.01	0.4	1.8	2.1	2.8	NS[c]	0.4	1.0	1.4	2.6
		Top biomass (t ha^{-1} dry wt)					Top biomass (t ha^{-1} dry wt)				
CM 507-37	-	0.36	2.8	6.9	5.9	7.9	0.24	2.5	4.7	3.8	4.1
CM 507-37	+	0.41	3.4	4.4	3.7	5.6	0.28	2.6	3.5	2.8	5.5
CM 523-7	-	0.40	2.5	5.9	6.4	6.1	0.42	2.4	5.1	4.4	4.5
CM 523-7	+	0.46	2.5	3.9	3.4	6.0	0.46	2.8	2.9	2.5	4.4
CMC 40	-	0.43	2.6	7.1	6.6	9.0	0.34	2.6	4.9	4.5	6.9
CMC 40	+	0.47	2.9	3.6	3.8	6.2	0.30	2.4	2.3	2.5	5.1
M Col 1684	-	0.42	2.3	5.7	5.8	6.2	0.15	2.3	3.3	3.4	3.7
M Col 1684	+	0.46	2.5	3.4	2.8	4.6	0.24	2.2	2.2	2.1	3.4
LSD 5% (Duncan)		0.12	0.6	0.9	0.9	1.8	0.09	0.5	0.7	0.9	0.8
		LAI					LAI				
CM 507-37	-	0.6	3.3	4.4	1.3	3.0	0.4	2.4	3.3	0.7	2.0
CM 507-37	+	0.7	3.6	2.1	0.2	3.4	0.4	2.6	1.7	0.6	1.8
CM 523-7	-	0.9	2.4	4.6	2.0	1.8	0.7	2.2	3.3	1.3	1.8
CM 523-7	+	0.7	2.3	1.5	0.4	2.6	0.7	2.1	0.8	0.5	1.4
CMC 40	-	0.6	1.9	3.5	0.7	1.8	0.5	2.3	2.5	0.5	1.1
CMC 40	+	0.7	2.0	1.1	0.2	2.3	0.4	2.0	0.8	0.5	0.8
M Col 1684	-	0.6	1.9	3.5	1.7	1.7	0.3	2.1	2.2	0.8	1.5
M Col 1684	+	0.7	2.1	1.5	0.2	2.6	0.4	2.2	0.9	0.6	0.9
LSD 5% (Duncan)		0.2	0.9	0.7	0.5	0.7	0.15	0.5	0.3	0.5	0.4

[a] (-) Without stress; (+) With stress. Water was excluded during 4 months period starting at 4 months after planting by covering the soil with plastic sheets.

[b] Harvests during water stress.

[c] NS = Not significant at 5%

Top biomass (excluding fallen leaves) was also significantly smaller under stress in both seasons, with significant differences among cultivars (Table 5). The largest top biomass without stress occurred in CMC 40 in both seasons, as compared to other cultivars. It is noteworthy that such high top biomass did not coincide with larger LAI in CMC 40. In 1991/92 season, top biomass remained significantly smaller at final harvest in previously stressed crops as compared with the controls. With the exception of CMC 40, differences in final top biomass due to stress in 1992/93 were not significant. The cultivar CM 507-37, however, showed significantly greater final top biomass in previously stressed plants in 1992/93. El-Sharkawy et al (1992), reported similar increases in final top biomass of plants of CM 507-37 that were previously stressed for 105 days initiated at 4 months after planting.

With the exception of CMC 40, dry root yield was significantly reduced under stress in both seasons (Table 5). There were significant differences among cultivars in the unstressed crops at 8 months with CMC 40 showing the smallest yield. CM 507-37 had the smallest yield under stress at 8 months in 1992/93 season. At final harvest, and after a period of 4 months recovery, the previously stressed crops had yields similar to the controls in both seasons, the exception was CM 507-37 in 1991/92 as it showed an extremely high yield in the unstressed crop. Thus, as in early water stress, prolonged mid-season water stress did not adversely affect final root production due to the ability of cassava plant to recover and compensate for yield losses during stress. Yield compensation in previously stressed cassava can be explained, partially, by the enhancement of leaf canopy development after recovery from stress as well as by the higher photosynthetic rates observed in newly developed leaves of previously stressed crops as compared to those in the controls (El-Sharkawy, 1993; Cayón et al, 1997). The new leaves developed after recovery from stress usually have higher nutrient contents, particularly N, as compared to those in unstressed plants (Cayon et al, 1997). Moreover, greater root-sink demand for photoassymilates in previously stressed plants, as compared to the controls, may also partly underlie yield compensation (Connor et al, 1981; El-Sharkawy and Cock, 1987; Cayón et al, 1997).

Nutrient uptake

Only K uptake in final root biomass was significantly lower due to stress in all cultivars in both seasons with significant differences among cultivars in 1992/93 (Table 6). However, CM 507-37 had significantly lower root P uptake due to stress in both seasons. These findings have some practical implications for cassava production systems where soil fertility is usually low in absence of fertilizer application. The removal of large quantities of K (> 60% of total K uptake) in harvested roots would lead to the depletion of this element under continuous cassava cultivation (Howeler, 1985, 1991; Pellet and El-Sharkawy, 1997; Cadavid et al., 1998). Thus, intermittent water stress appears to be beneficial in reducing soil K export without adverse effect on root production.

Nutrients uptake in top biomass tended to vary from year to year under stress with consistently lower uptake of P and K in all cultivars only in 1991/92 (Table 6). It appears therefore, that mid-season stress had less effect, as compared to early stress (Table 3), on nutrient uptake

Table 6. Nutrient uptake in roots and top biomass of cassava at 12 months after planting as affected by mid-season water stress (4-8 months after planting)

Cultivar	Water Stress[a]	1991/1992					1992/1993				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
		Roots (kg nutrient ha^{-1})					Roots (kg nutrient ha^{-1})				
CM 507-37	-	56	13	74	5	8	24	10	70	6	7
CM 507-37	+	41	9	51	3	8	21	6	52	5	5
CM 523-7	-	49	12	75	7	9	30	12	69	12	8
CM 523-7	+	60	10	55	5	7	25	6	56	8	6
CMC 40	-	31	8	75	5	8	17	8	94	8	9
CMC 40	+	37	7	54	3	6	23	7	70	7	7
M Col 1684	-	46	8	77	6	8	23	8	77	9	7
M Col 1684	+	46	8	61	6	7	29	7	60	6	6
LSD 5% (Duncan)		10.8	2.7	16.5	2.1	1.7	8.7	1.9	16.6	4.1	2.5
		Top biomass (kg nutrient ha^{-1})					Top biomass (kg nutrient ha^{-1})				
CM 507-37	-	125	15	55	46	28	51	7	26	23	15
CM 507-37	+	94	8	33	39	20	54	7	23	27	14
CM 523-7	-	89	10	46	37	22	55	7	41	24	12
CM 523-7	+	96	7	37	37	17	46	6	30	23	12
CMC 40	-	101	12	43	46	34	43	8	30	26	16
CMC 40	+	80	7	31	35	19	39	5	22	19	13
M Col 1684	-	93	12	44	54	30	47	5	23	27	14
M Col 1684	+	83	7	32	46	19	39	4	20	25	11
LSD 5% (Duncan)		23.4	2.8	9.6	9.6	8.0	9.9	1.2	6.6	3.8	2.0

[a] (-) Without stress; (+) With stress. Water was excluded during 4 months period starting at 4 months after planting by covering the soil with plastic sheets.

in top biomass. It is known that the major portion of nutrient accumulation occurs at 3-4 months after planting (Howeler and Cadavid, 1983); thus, water stress beyond this plant age would be less effective in reducing nutrient uptake.

Nutrient use efficiency

Only P and K use efficiency in terms of root biomass production was significantly greater due to stress in most of the cultivars in both seasons (Table 7). Differences among cultivars were also significant, irrespective of water treatment. The highest P use efficiency under stress in both seasons was found in CMC 40 and M Col 1684. With regard to changes in K use efficiency for root biomass production under stress, CMC 40 had also the highest increase. This cultivar consistently had higher root yield under stress, as compared to the control, in both seasons (Table 5). Because of its extremely low K use efficiency in absence of water stress, as compared to the other cultivars, it would be advantageous to grow CMC 40 in regions where intermittent stress prevails. Under unstressed conditions, however, other cultivars would be more beneficial in terms of K use efficiency.

As with root, P and K use efficiency for total biomass production was consistently enhanced under water stress in all cultivars in both seasons (Table 7). Differences among cultivars were also significant, regardless of water treatment. Changes in use efficiency of other nutrients were inconsistent among cultivars and among seasons for both root and total biomass production (Table 7).

Response to terminal water stress

Leaf area index (LAI) and biomass production

Prolonged terminal water stress imposed at 6 months after planting, when LAI already had reached its peak, did not significantly affect LAI in most of the cases in both seasons (Table 8). Without stress, LAI decreased rapidly after reaching its peak at 6 months after planting. At this stage of growth, few new leaves are formed and leaf fall increases (Connor and Cock, 1981). Water

Table 7. Nutrient use efficiency for roots and total biomass production of cassava at 12 months after planting as affected by mid-season water stress (4-8 months after planting)

Cultivar	Water Stress[a]	1991/1992					1992/1993				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
		Roots (kg dry wt kg^{-1} total nutrient uptake)					Roots (kg dry wt kg^{-1} total nutrient uptake)				
CM 507-37	-	89	578	126	317	450	160	705	125	413	545
CM 507-37	+	92	729	148	295	443	136	783	136	318	536
CM 523-7	-	104	653	119	326	463	154	689	119	364	655
CM 523-7	+	89	816	151	330	578	145	861	120	333	574
CMC 40	-	75	498	84	195	237	164	614	79	289	393
CMC 40	+	102	851	140	313	476	196	1013	132	468	608
M Col 1684	-	103	717	118	239	377	185	995	129	359	616
M Col 1684	+	105	904	146	261	522	167	1034	142	367	669
LSD 5% (Duncan)		24	149	26	88	97	32	115	25	89	105
		Total biomass (kg dry wt kg^{-1} total nutrient uptake)					Total biomass (kg dry wt kg^{-1} total nutrient uptake)				
CM 507-37	-	133	862	187	473	670	215	946	168	555	731
CM 507-37	+	134	1061	215	429	644	209	1204	209	489	824
CM 523-7	-	149	932	169	466	661	207	927	160	489	881
CM 523-7	+	127	1166	216	472	826	209	1230	172	476	820
CMC 40	-	144	949	161	372	452	278	1044	135	491	668
CMC 40	+	155	1295	213	477	725	279	1439	188	664	864
M Col 1684	-	148	1027	170	342	540	237	1275	166	461	790
M Col 1684	+	141	1211	195	349	699	217	1341	184	476	868
LSD 5% (Duncan)		23	147	20	88	89	35	122	27	91	105

[a] (-) Without stress; (+) With stress. Water was excluded during 4 months period starting at 4 months after planting by covering the soil with plastic sheets.

Table 8. Response of cassava root yield, top biomass and leaf area index (LAI) to early water stress (6-12 months after planting). Harvests at 2, 4, 6, 8 and 12 months after planting

Cultivar	Water	1991/1992					1992/1993				
	Stress[a]	2	4	6[b]	8[b]	12[b]	2	4	6	8[b]	12[b]
		Root yield (t ha^{-1} dry wt)					Root yield (t ha^{-1} dry wt)				
CM 507-37	-	**0.01**	**1.4**	**6.8**	**12.1**	**16.2**	**0.01**	**1.0**	**5.6**	**8.7**	12.0
CM 507-37	+	0.01	2.0	6.7	10.0	11.4	0.01	0.8	5.0	8.6	10.7
CM 523-7	-	0.01	1.6	7.0	10.9	14.4	0.01	1.4	6.7	10.0	13.1
CM 523-7	+	0.01	2.0	8.4	9.8	9.8	0.01	1.2	5.9	8.9	9.6
CMC 40	-	0.01	2.2	8.6	9.0	10.0	0.01	2.1	6.5	7.7	9.8
CMC 40	+	0.01	2.8	11.4	12.5	15.4	0.01	2.6	9.1	10.4	13.7
M Col 1684	-	0.01	1.5	7.9	12.7	14.3	0.01	1.2	5.5	9.4	12.9
M Col 1684	+	0.01	2.1	7.7	11.3	12.2	0.01	1.3	6.5	9.0	10.8
LSD 5% (Duncan)		NS[c]	0.4	1.6	2.4	2.6	NS[c]	0.3	1.1	1.2	3.2
		Top biomass (t ha^{-1} dry wt)					Top biomass (t ha^{-1} dry wt)				
CM 507-37	-	0.36	2.8	6.9	5.9	7.9	0.24	2.5	4.7	3.8	4.1
CM 507-37	+	0.48	3.7	7.9	6.3	6.4	0.14	2.6	4.6	3.2	4.2
CM 523-7	-	0.40	2.5	5.9	6.4	6.1	0.42	2.4	5.1	4.4	4.5
CM 523-7	+	0.52	2.8	6.0	5.8	5.6	0.34	2.1	3.9	3.6	3.4
CMC 40	-	0.43	2.6	7.1	6.6	9.0	0.34	2.6	4.9	4.5	6.9
CMC 40	+	0.48	3.1	6.0	5.9	7.1	0.41	2.7	5.0	4.2	6.3
M Col 1684	-	0.42	2.3	5.7	5.8	6.2	0.15	2.3	3.3	3.4	3.7
M Col 1684	+	0.46	2.4	5.8	5.1	5.3	0.22	2.4	3.9	3.0	3.2
LSD 5% (Duncan)		0.16	0.5	1.1	0.9	1.9	0.09	0.4	0.8	1.0	1.1
		LAI					LAI				
CM 507-37	-	0.6	3.3	4.4	1.3	3.0	0.4	2.4	3.3	0.7	2.0
CM 507-37	+	0.8	3.8	4.5	1.0	1.8	0.3	2.6	3.4	0.7	1.7
CM 523-7	-	0.9	2.4	4.6	2.0	1.8	0.7	2.2	3.3	1.3	1.8
CM 523-7	+	1.0	2.6	3.9	1.6	1.3	0.6	2.2	2.7	0.7	1.0
CMC 40	-	0.6	1.9	3.5	0.7	1.8	0.5	2.3	2.5	0.5	1.1
CMC 40	+	0.7	2.5	3.2	0.8	1.5	0.6	2.3	2.5	0.4	0.9
M Col 1684	-	0.6	1.9	3.5	1.7	1.7	0.3	2.1	2.2	0.8	1.5
M Col 1684	+	0.7	1.9	3.6	1.4	1.4	0.4	2.3	2.7	0.8	1.0
LSD 5% (Duncan)		0.3	0.6	0.7	0.6	0.6	0.14	0.4	0.5	0.5	0.4

[a] (-) Without stress; (+) With stress. Water was excluded during 6 months period starting at 6 months after planting by covering the soil with plastic sheets.

[b] Harvests during water stress.

[c] NS = Not significant at 5%

stress may had enhanced leaf fall and further reduced LAI in cultivars CM 507-37 and CM 523-7. Differences among cultivars in LAI were apparent at this stage of growth, irrespective of water treatment. De Tafur et al (1997a) reported significant differences in seasonal average LAI between CM 507-37 and M Col 1684 under terminal water stress, with the highest values in the former cultivar.

Little changes occurred in top biomass due to stress in all cultivars in both seasons, but differences among cultivars were significant (Table 8). In both seasons, the highest final top biomass occurred in CMC 40, irrespective of water treatment.

With the exception of CMC 40, final root yield was significantly smaller for the other cultivars during water stress in the 1991/92 season. In the 1992/93 season, however, the only significant yield reduction was observed with CM 523-7. Yields of the other cultivars were not significantly affected by stress. In both seasons, CMC 40 had significantly greater final yield under stress, as compared to the control. This finding indicates that water stress, whether terminal or intermittent, was advantageous in terms of root biomass production in CMC 40. It is also known that this cultivar has high leaf photosynthetic rates under both humid (El-Sharkawy et al, 1992) and seasonally dry environments (El-Sharkawy et al, 1990). Because of this important trait and of its remarkable performance under stress, it would be beneficial to use CMC 40 as a genetic source in cassava breeding programs for stressful environments.

Nutrient uptake

With the exception of CM 523-7, N uptake in root biomass was significantly greater during terminal stress in all cultivars in both seasons (Table 9). This may indicate that N allocation within different plant parts was shifted toward the storage roots under stress. Such pattern neither existed under early nor mid-season stress (Tables 3, 6).

For other nutrients, no consistent patterns of uptake in root biomass were observed neither among cultivars nor between water treatments. There were, however, significant differences in P root uptake among cultivars in absence of water stress (Table 9).

Contrary to root, N uptake in top biomass tended to decrease under stress in most cultivars in both seasons, indicating changes in patterns of N allocation (Table 9). In both seasons, P and K uptake also tended to decrease during stress with significant differences only among cultivars. Uptake of Ca and Mg in top biomass were variable, although in some cases there were significant reductions due to stress.

Nutrient use efficiency

Although N use efficiency in root biomass tended to decrease during stress in both seasons, differences were significant only among cultivars (Table 10). Only in CMC 40 in both seasons, P, K, Ca and Mg use efficiency in root biomass was significantly greater under terminal stress. This was apparently due to a higher root production (Table 8) rather than to a lower nutrient uptake (Table 9) under water stress. Thus, for this cultivar water stress was obviously beneficial for root production as well as for nutrient use efficiency.

Table 9. Nutrient uptake in roots and top biomass of cassava at 12 months after planting as affected by terminal water stress (6-12 months after planting)

Cultivar	Water Stress[a]	1991/1992					1992/1993				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
		Roots (kg nutrient ha^{-1})					Roots (kg nutrient ha^{-1})				
CM 507-37	-	56	13	74	5	8	24	10	70	6	7
CM 507-37	+	68	12	59	6	8	36	11	75	8	6
CM 523-7	-	49	12	75	7	9	30	12	69	12	8
CM 523-7	+	51	10	55	4	5	30	7	59	6	4
CMC 40	-	31	8	75	5	8	17	8	94	8	9
CMC 40	+	56	11	84	7	9	32	10	105	10	7
M Col 1684	-	46	8	77	6	8	23	8	77	9	7
M Col 1684	+	66	10	84	8	7	36	8	72	12	6
LSD 5% (Duncan)		12.8	3.0	20.2	2.0	1.9	8.3	2.4	20.1	4.4	2.5
		Top biomass (kg nutrient ha^{-1})					Top biomass (kg nutrient ha^{-1})				
CM 507-37	-	125	15	55	46	28	51	7	26	23	15
CM 507-37	+	97	9	39	35	18	47	6	19	28	13
CM 523-7	-	89	10	46	37	22	55	7	41	24	12
CM 523-7	+	86	8	37	37	16	38	5	20	21	9
CMC 40	-	101	12	43	46	34	43	8	30	26	16
CMC 40	+	82	8	30	41	23	45	6	18	26	15
M Col 1684	-	93	12	44	54	30	47	5	23	27	14
M Col 1684	+	79	7	33	39	18	36	4	17	25	11
LSD 5% (Duncan)		26.1	3.2	11.0	11.5	8.6	11.7	1.5	6.4	5.2	2.9

[a] (-) Without stress; (+) With stress. Water was excluded during 6 months period starting at 6 months after planting by covering the soil with plastic sheets.

Table 10. Nutrient use efficiency for roots and total biomass production of cassava at 12 months after planting as affected by terminal water stress (6-12 months after planting)

Cultivar	Water Stress[a]	1991/1992					1992/1993				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
		Roots (kg dry wt kg^{-1} total nutrient uptake)					Roots (kg dry wt kg^{-1} total nutrient uptake)				
CM 507-37	-	89	578	126	317	450	160	705	125	413	545
CM 507-37	+	69	542	116	278	438	141	688	124	325	616
CM 523-7	-	104	653	119	326	463	154	689	119	364	655
CM 523-7	+	71	543	106	238	465	141	801	122	356	739
CMC 40	-	75	498	84	195	237	164	614	79	289	393
CMC 40	+	111	809	135	320	481	178	856	111	381	623
M Col 1684	-	103	717	118	239	377	185	995	129	359	616
M Col 1684	+	84	715	104	259	486	149	894	121	290	631
LSD 5% (Duncan)		20	122	20	83	77	34	104	23	78	121
		Total biomass (kg dry wt kg^{-1} total nutrient uptake)					Total biomass (kg dry wt kg^{-1} total nutrient uptake)				
CM 507-37	-	133	862	187	473	670	215	946	168	555	731
CM 507-37	+	108	849	182	435	685	192	938	170	443	839
CM 523-7	-	149	932	169	466	661	207	927	160	489	881
CM 523-7	+	112	851	167	374	730	191	1083	164	481	999
CMC 40	-	144	949	161	372	452	278	1044	135	491	668
CMC 40	+	163	1182	197	468	702	260	1250	163	556	909
M Col 1684	-	148	1027	170	342	540	237	1275	166	461	790
M Col 1684	+	120	1025	149	371	697	193	1160	156	376	819
LSD 5% (Duncan)		21	136	20	93	85	37	106	26	82	128

[a] (-) Without stress, (+) With stress. Water was excluded during 6 months period starting at 6 months after planting by covering the soil with plastic sheets.

Nitrogen use efficiency for total biomass production was significantly lower in most of the cases under terminal stress in both seasons (Table 10). As with root, CMC 40 consistently had higher use efficiency under stress in both seasons for P, K, Ca and Mg. In the other cultivars, there were no consistent patterns in P, K, Ca and Mg use efficiency as influenced by terminal water stress, although there were significant differences among cultivars.

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