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GENETIC VARIATION WITHIN CASSAVA GERMPLASM IN RESPONSE TO POTASSIUM

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SUMMARY

As cassava is grown mostly by small resource-limited farmers throughout the tropics on low-fertility soils with little fertilization and, due to the large potassium (K) export in harvested roots, genotypes that tolerate low-K soils and respond to K fertilization are warranted. The objective of this study was to evaluate cassava germplasm and identify such genotypes.

Fourteen cultivars of cassava (*Manihot esculenta*) selected from the core germplasm at CIAT were grown under rainfed conditions for ten months over five consecutive seasons in Inceptisols either with no K application or with 50, 100 or 200 kg K ha^{-1} applied annually together with adequate nitrogen and phosphorus. All cultivars responded to K application both in terms of root and shoot biomass with the highest yields obtained by CM 507-37 and M Ven 25 in the absence of K application and at high K levels. These cultivars had the highest adaptation indices to low K and the highest K use efficiency for total biomass production. CM 507-37 had the highest K use efficiency for root production at all K levels. Thus, it is desirable to use this material for breeding cassava which is adapted to low-K soils and is able to respond to fertilizer application. However, because of the high hydrocyanic acid (HCN) content in their roots, these cultivars should be crossed with genotypes that are low in HCN, such as HMC-1 and M Cub 74, in order to select lines with both high K use efficiency and low HCN for fresh cassava consumption. Root HCN contents were significantly reduced by application of K across all cultivars. Application of K fertilizer to low-K soils is warranted to minimize health hazards when fresh cassava is used for human consumption.

INTRODUCTION

Cassava (*Manihot esculenta*) is a very efficient tropical root crop in terms of the amount of energy produced per unit of land (Cock, 1982; De Vries *et al.*, 1967), and in the absence of production constraints it compares favourably with other major staple food and energy crops grown in the tropics (El-Sharkawy, 1993). However, under stressful environments (low-fertility soils and prolonged water stress), cassava still produces reasonable yields where other food crops such as maize (*Zea mays*) and sorghum (*Sorghum bicolor*) would probably fail (Cock and Howeler, 1978). Because of its potential to produce under adverse edaphic and climatic conditions, increasingly more marginal land is being used for its production in Africa, Asia and Latin America (El-Sharkawy, 1993).

Cassava is produced by resource-limited small farmers on low-fertility acid soils

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(mainly Oxisols and Ultisols) with virtually no agrochemical inputs (Howeler, 1985). Moreover, due to pressure on land, farmers tend to grow cassava on the same plot for several years without fallow, rotation or fertilization. Under these management practices, both soil fertility and yield decline over time (Cadavid *et al.*, 1998; Howeler, 1991). To maintain soil fertility and hence sustain productivity, application of chemical fertilizer, organic manure and plant residues are desirable practices in these situations (Cadavid *et al.*, 1998; Howeler, 1994; Pellet and El-Sharkawy, 1993a; b). Cassava removes substantial amounts of nutrients, particularly potassium (K), in the harvested roots (Pellet and El-Sharkawy, 1997; Howeler, 1985) and without application of fertilizer under continuous production, soil K would be depleted. Several reports have shown significant responses to K fertilizer in different soils, particularly when cassava was grown continuously for several years in the same plots (CIAT, 1995; Thampatti and Padmaja, 1995; Howeler, 1991; 1985; Kumar *et al.*, 1991; Obigbesan, 1977a; b). Moreover, Pellet and El-Sharkawy (1997) reported genetic differences in K use efficiency among four cultivars, which implied that genetic diversity in response to K exists within cassava germplasm. It was warranted, therefore, to identify cassava genotypes that tolerate low-K soils and at the same time respond to application of K fertilizer. Such materials should be used as genetic sources in cassava breeding programmes designed to improve yield and to sustain productivity without increasing pressure on limited natural resources (Hershey and Jennings, 1992).

The main objectives of this study were to (1) evaluate the response to K application in a group of genotypes selected from the cassava core germplasm at CIAT and (2) identify those genotypes that tolerate low-K soils while responding to K fertilization.

MATERIALS AND METHODS

Plant materials, experimental site, experimental design and treatments

Fourteen cultivars from the core cassava germplasm at CIAT were grown in a five-year field trial on a farm adjacent to the CIAT–Quilichao Research Station, Cauca, Colombia (lat 3°06′N, long 76°31′W, altitude 990 m asl). Composite soil samples taken at 0–20 cm soil depth from the experimental site before the first planting were analysed according to Salinas and García (1985). Soil organic carbon was determined by the Walkely and Black method and soil pH was measured in water at a soil-to-solution ratio of 1:1. Available phosphorus (P) and K in soil were determined by colorimetry and atomic absorption spectrometry respectively in Bray-II extracts. Soil exchangeable Ca and Mg were extracted with 1 M ammonium acetate at a pH of 7.0. Exchangeable Al was extracted using potassium chloride (1 N), and determined by colorimetry. The soil was an Inceptisol with low pH (4.8), high organic carbon (4.8%), low P (2.0 mg kg^{-1} dry soil), low K (0.18 cmol kg^{-1}), high calcium (Ca), magnesium (Mg) and aluminium (Al) (2.04, 0.40 and 2.90 cmol kg^{-1} respectively). It had a clayey texture with 45% clay, 16% silt and 39% sand. Mean annual meteorological data

Table 1. Mean annual meteorological data (based on means of daily readings) at Santander de Quilichao during the 1989–94 seasons.

Season	Rainfall (mm)	Evaporation (mm)	Solar radiation (MJ m^{-2})	Temperature (°C)			Mean relative humidity (%)
				Max.	Min.	Overall mean	
1989–1990	1579	1410	5999	29.6	18.5	24.1	75
1990–1991	1349	1409	6130	30.3	19.1	24.5	73
1991–1992	1271	1431	5326	30.1	18.4	24.5	75
1992–1993	1471	1651	6339	29.9	18.3	24.0	75
1993–1994	2058	1379	5073	30.2	18.3	23.7	77

(based on the means of daily readings) are presented in Table 1. Average annual rainfall varied from 1271 mm to 2058 mm with a major peak in October–December and a smaller peak in March–May. In all years, rainfall was lower than potential evaporation in June–September and January–February. No irrigation was applied in any year.

The experiment was laid out as a split-plot design with four replications where the main plots were assigned to K levels and the subplots to cultivars. The size of the subplot was 30 m^2. Before planting, the land was prepared by disc ploughing in two directions each year. One month after planting, all plots received annually 50 kg nitrogen (N) ha^{-1} (urea, 46% N) and 50 kg P ha^{-1} (triple superphosphate, 20% P) band-applied. The K treatments were 0, 50, 100 or 200 kg K ha^{-1} (KCl, 50% K) band-applied at 30 d after planting in each year.

Healthy stem cuttings, 20 cm in length, were selected every year from fertilized mother plants of all cultivars and planted vertically in flat land in a 1 × 1 m arrangement to give 10 000 plants per hectare. Planting dates coincided with the start of the rainy period (anywhere between mid-October and mid-November), depending on the growing season. The trial was kept weed-free during the first five months with manual weeding.

Yield, biomass, nutrient uptake and root hydrocyanic acid (HCN) determination

At 10 months after planting the 12 central plants from each subplot were harvested to determine yield and biomass production. Five kilograms each of fresh storage roots and of aerial parts (stems and remaining leaves) were chopped into small pieces and oven-dried at 70 °C to a constant weight to determine dry matter concentration. Subsamples were taken from fresh roots to determine the content of HCN in the root parenchyma, using the enzymatic assays developed by Cooke (1978) and O'Brien *et al.* (1991) in the second, third, fourth and fifth year harvests. Subsamples of the dry matter from different plant parts (roots, stems, petioles and leaves) were ground through a 40-mesh screen Wiley laboratory mill. The K concentration of samples was determined by atomic absorption according to Salinas and García (1985) in the second and third growing seasons.

RESULTS AND DISCUSSION

Root yield and biomass production

Table 2 presents data on dry root yield at 10 months after planting for the first and fifth growing cycles and the overall 5-year average. Although the soil-K of this site was at the critical level for cassava (0.18 cmol kg^{-1} dry soil), there was a significant response in the first year to K application at 50 kg ha^{-1} across all cultivars. Above that K level, there was no response across cultivars. However, in some cultivars, the highest K level of 200 kg ha^{-1} depressed root yield (for example CM 523-7, HMC-2). On the other hand, there was a positive response to the highest K level in cultivars CM 91-3 and M Col 1684. Differences among cultivars were significant at all K levels. These findings corroborate earlier reports on cassava response to K by other workers (Howeler, 1991; 1985; Obigbesan, 1977a).

In the fifth cycle yields were substantially lower at zero K than in the first cycle. Thus, the overall positive response to K fertilizer was more pronounced in all cultivars at the 50 and 100 kg ha^{-1} levels (Table 2). There was no apparent response across cultivars to 200 kg K ha^{-1}. Differences among cultivars were significant at all K levels with the highest yields observed in CM 507-37 and M Ven 25. The lowest yields were found in CMC 40, HMC-2 and CM 91-3. Other cultivars showed intermediate yields. However, yields of all cultivars at all K levels were much lower in the fifth cycle compared with the first. In general, yields

Table 2. Effect of potassium (K) fertilization on dry root yield (t ha^{-1}) at the final harvest for 14 cassava cultivars grown at Cauca, Colombia in 1989–94.

	Potassium fertilization (kg ha^{-1})											
	First year				Fifth year				Five-year average			
Cultivar	0	50	100	200	0	50	100	200	0	50	100	200
M Col 1505	12.6	17.0	14.4	14.9	4.5	8.5	9.0	9.1	7.9	11.6	12.1	13.1
CM 91-3	11.6	15.5	15.0	17.6	3.3	7.7	5.2	7.4	7.7	11.3	11.4	12.3
CM 489-1	12.5	17.2	15.3	16.1	5.7	8.0	10.4	11.3	8.2	13.2	13.6	14.4
CM 507-37	14.6	18.3	17.1	16.0	5.8	10.8	12.7	14.1	9.9	14.7	16.4	16.0
CM 523-7	12.4	15.7	16.9	13.0	6.4	9.7	12.2	11.9	7.6	12.5	13.9	12.6
CM 1585-13	14.5	15.4	14.6	14.4	5.9	7.2	11.4	11.1	9.2	11.2	12.3	12.3
HMC-1	16.2	19.2	18.5	19.5	8.3	9.0	10.8	9.1	10.1	12.6	13.2	13.8
HMC-2	15.0	14.5	15.4	13.2	4.2	5.4	7.2	5.8	8.3	11.5	11.7	12.0
CMC 40	10.1	13.4	12.5	11.6	3.2	4.9	4.2	3.8	6.8	9.2	9.5	10.0
M Col 1684	14.0	13.9	14.3	16.2	4.4	10.0	10.5	9.5	8.6	11.5	13.0	12.8
M Cub 74	13.1	14.1	14.2	14.9	4.8	7.9	8.8	10.5	9.5	12.0	11.5	13.4
M Pan 70	14.9	16.6	16.4	16.1	5.6	9.9	10.9	9.2	10.0	12.6	12.7	13.0
M Ven 25	14.3	15.3	15.7	14.2	8.5	10.7	12.2	12.4	11.5	14.3	15.3	13.9
SG 105-35	14.9	15.8	16.2	15.4	3.9	9.1	11.8	10.7	8.7	12.2	13.5	12.7
Average	13.6	15.9	15.5	15.2	5.3	8.5	9.8	9.7	8.9	12.2	12.9	13.0
L.s.d. 5% for cultivars	2.6	2.8	3.9	2.8	2.2	2.2	2.3	2.7	1.4	1.4	1.6	1.9
L.s.d. 5% for K levels	1.2				0.6				0.2			

tended to decrease after the second cropping cycle at all K levels (data not shown). Although the very high rainfall that occurred during the fifth cycle (Table 1) might have had a depressing effect on cassava productivity, the decreasing trend observed in preceding years indicates that consecutive cassava cultivation was probably the main cause in this case. Since N and P were adequately supplied in each year, other elements (Ca and Mg) probably became limiting in view of the high cassava productivity observed in this trial.

Across years, the response to K fertilizer was significant, particularly at the 50-kg ha^{-1} level; above this level the response was much less (Table 2). There were large and significant differences among cultivars at all K levels with the highest yields in CM 507-37 and M Ven 25. The lowest average yields were again observed with CMC 40 at all K levels. Under prolonged water stress (4 to 6 months) at different stages of growth, yields of CMC 40 were significantly greater compared with unstressed crops (El-Sharkawy *et al.*, 1998). Thus, it appears that this cultivar is more adapted to water-deficit environments than to wet ones. Nevertheless, the relatively high cassava productivity that was observed at 10 months with this group of cultivars agrees with earlier findings in similar environments (Pellet and El-Sharkawy, 1997; Pellet and El-Sharkawy, 1993a; b; El-Sharkawy *et al.*, 1992a; El-Sharkawy *et al.*, 1990) and indicates that cassava compares favourably with other warm climate food crops such as maize, sorghum and rice (*Oryza sativa*) (El-Sharkawy, 1993). High leaf photosynthetic rates of field grown cassava (>35 μmol CO_2 m^{-2} s^{-1}, El-Sharkawy *et al.*, 1992b) and high harvest index (Kawano *et al.*, 1978) may underlie such high productivity. Root yield of cassava was found to be positively and significantly correlated with leaf photosynthesis, as measured in the field under humid and seasonally dry environments (De Tafur *et al.*, 1997; El-Sharkawy *et al.*, 1990).

Dry root yields at 50 kg K ha^{-1} were significantly correlated with root yields at zero K application across years ($r = 0.75$, $p < 0.01$). The cultivars CM 507-37 and M Ven 25 had the highest yields at all K levels, whereas CMC 40 had the lowest yield. Other cultivars were intermediate. The calculated adaptation index to low K (adaptation index = (dry root yield at zero K)(dry root yield at 50 kg K ha^{-1})/(mean dry root yield at zero K)(mean dry root yield at 50 kg K ha^{-1}) was also highest for M Ven 25 and CM 507-37 and lowest for CMC 40 (Table 3). Adaptation indices for other cultivars ranged from low to moderate.

These findings indicated that the cultivars M Ven 25 and CM 507-37 were the most productive at low K as well as at high K among this group of cultivars. Such materials should be used as genetic sources for the improvement of cassava productivity under favourable as well as stressful environments. Major advances have been made in breeding and selection under favourable environments (Hahn *et al.*, 1979; Kawano *et al.*, 1978). Due to the expansion in cassava cultivation in marginal soils and in stressful environments in the tropics (Howeler, 1994; El-Sharkawy, 1993; Romanoff and Lynam, 1992), genotypes adapted to low-fertility soils would be advantageous in this case (Hershey and Jennings, 1992).

Table 3. Adaptation index to low K for 14 cassava cultivars (average of five years) grown at Cauca, Colombia in 1989–94.

Cultivar	Low-K adaptation index†	Cultivar	Low-K adaptation index	Cultivar	Low-K adaptation index
M Ven 25	1.51 HA‡	CM 489-1	1.00 MA‡	HMC-2	0.88 LA‡
CM 507-37	1.34 HA	SG 105-35	0.98 MA	CM 523-7	0.87 LA
HMC-1	1.17 HA	CM 1585-13	0.95 MA	M Col 1505	0.84 LA
M Pan 70	1.16 HA	M Col 1684	0.91 MA	CM 91-3	0.80 LA
M Cub 74	1.05 HA			CMC 40	0.58 LA

†Low-K adaptation index $= \dfrac{(\text{Dry root yield at zero K})\ (\text{Dry root yield at 50 kg K ha}^{-1})}{(\text{Mean dry root yield at zero K})\ (\text{Mean dry root yield at 50 kg K ha}^{-1})}$

‡HA = High adaptation (>1.00), MA = Moderate adaptation (1.00–0.90), LA = Low adaptation (<0.90).

In contrast with root biomass, application of K up to 100 kg ha^{-1} did not affect shoot biomass across cultivars in the first year (Table 4). However, shoot biomass was significantly greater at 200 kg K ha^{-1}. Differences among cultivars were significant at all K levels. In the fifth year, response to K was more pronounced with significant differences across cultivars at all K levels. As with roots, shoot biomass was smaller compared with the first year crop at all K levels. Nevertheless, reduction in shoot biomass over the years was less pronounced than

Table 4. Effect of potassium (K) fertilization on dry shoot biomass (t ha^{-1}) at final harvest for 14 cassava cultivars grown at Cauca, Colombia in 1989–94.

	Potassium fertilization (kg ha^{-1})											
	First year				Fifth year				Five-year average			
Cultivar	0	50	100	200	0	50	100	200	0	50	100	200
M Col 1505	4.5	6.2	6.7	6.9	1.8	4.4	7.1	6.9	2.9	4.5	6.1	6.2
CM 91-3	5.2	6.3	4.6	8.4	2.3	4.4	3.7	4.1	3.7	5.1	4.8	6.4
CM 489-1	5.1	6.2	5.9	7.9	3.7	5.0	5.7	7.6	4.2	5.4	5.8	7.5
CM 507-37	5.5	6.4	5.5	7.7	3.9	5.8	7.4	9.4	4.7	7.1	7.7	8.5
CM 523-7	4.1	4.0	5.7	6.0	3.6	4.5	5.2	6.5	3.9	5.2	6.1	7.0
CM 1585-13	6.4	5.7	4.5	6.4	3.0	3.3	5.5	5.1	3.7	4.2	4.8	5.1
HMC-1	6.3	6.9	6.8	8.4	4.1	5.1	6.3	6.1	4.5	6.0	7.2	7.8
HMC-2	7.2	6.8	7.7	8.6	2.4	3.2	4.5	4.4	4.8	6.3	7.1	7.4
CMC 40	5.5	6.4	7.7	7.7	3.2	4.4	4.0	3.6	4.2	5.7	6.3	6.0
M Col 1684	4.7	5.1	4.6	6.3	1.8	5.1	6.3	6.1	3.0	4.3	5.4	5.4
M Cub 74	5.0	4.5	4.9	5.7	2.7	3.6	4.9	4.6	3.8	4.3	4.7	5.2
M Pan 70	7.7	6.8	6.2	7.4	2.9	5.0	5.6	5.3	4.2	5.7	5.1	6.0
M Ven 25	8.7	8.6	8.2	6.5	5.3	7.0	6.7	8.4	6.4	8.2	8.9	7.3
SG 105-35	5.8	5.4	4.8	6.2	1.6	3.8	4.1	4.6	3.5	4.6	5.1	5.7
Average	5.8	6.1	6.0	7.2	3.0	4.6	5.5	5.9	4.1	5.5	6.1	6.5
L.s.d. 5% for cultivars	1.6	1.4	1.7	2.2	1.1	1.3	1.2	2.0	0.9	1.0	1.2	1.4
L.s.d. 5% for K levels	0.4				0.3				0.3			

reduction in root yield (Tables 2 and 4). Differences among cultivars were also significant in the fifth year with the highest biomass in CM 507-37 and M Ven 25 and the lowest in CM 91-3, CMC 40 and SG 105-35. The overall cultivar average across years showed a positive and significant response to K application up to 200 kg K ha^{-1}. At all K levels average shoot biomass differed significantly among cultivars. The highest average shoot biomass was in CM 507-37 and M Ven 25. In contrast to root production in CMC 40, its average shoot biomass was moderate, compared with other cultivars (Tables 2 and 4).

Root HCN content

In the second year, K application significantly reduced root HCN up to 200 kg K ha^{-1} across all cultivars (Table 5). Cultivars differed significantly in their HCN content at all K levels with the highest content in M Ven 25 and the lowest in HMC-2. By the fifth year the HCN content had increased compared with the second year at all K levels, across all cultivars, with the highest content at zero K and the lowest at 100 kg K ha^{-1}. This pattern was also observed in the third and fourth year (data not shown). Reasons for the increase in HCN with consecutive years of cassava cultivation are not known. The largest increase in HCN was in M Ven 25 at all K levels followed by CM 507-37. In contrast, the HCN content of CMC 40 was lower at all K levels in the fifth year compared with those in the second year crop.

Table 5. Effect of potassium (K) fertilization on hydrocyanic acid (HCN) content in root parenchyma (mg kg^{-1} dry weight) of 14 cassava cultivars grown at Cauca, Colombia in 1989–94.

	Potassium fertilization (kg ha^{-1})											
	Second year				Fifth year				Four-year average			
Cultivar	0	50	100	200	0	50	100	200	0	50	100	200
M Col 1505	297	183	171	216	329	259	243	210	384	299	279	242
CM 91-3	217	173	157	140	264	263	225	179	292	278	256	189
CM 489-1	308	190	160	158	334	201	133	161	483	239	210	188
CM 507-37	671	401	406	401	1169	1049	674	780	1127	874	667	632
CM 523-7	281	163	142	134	331	313	370	265	367	288	281	230
CM 1585-13	201	148	168	148	219	205	153	178	254	232	228	184
HMC-1	206	187	163	141	202	173	193	188	258	257	227	189
HMC-2	307	149	134	112	449	423	370	353	404	296	308	255
CMC 40	185	140	177	182	124	163	147	103	259	268	238	200
M Col 1684	765	570	523	647	986	1074	996	754	972	981	868	835
M Cub 74	297	177	124	127	282	221	246	273	346	264	266	233
M Pan 70	271	236	182	208	216	256	206	181	338	288	256	244
M Ven 25	1034	955	812	926	1969	1625	1462	1403	1572	1357	1293	1326
SG 105-35	417	203	241	214	281	209	190	647	382	267	264	351
Average	390	277	254	268	511	460	401	405	531	442	403	378
L.s.d. 5% for cultivars	255	141	143	105	207	208	227	651	126	77	77	137
L.s.d. 5% for K levels	75				48				23			

The 4-year average of HCN content across all cultivars was significantly lower with applications of K up to 200 kg ha^{-1}. Again, the highest average HCN content was observed in M Ven 25 followed by CM 507-37. Other workers (Kumar *et al.*, 1991; Howeler, 1985; Obigbeson, 1977b) reported reductions in root HCN in various cassava cultivars with application of K fertilizer. These findings point to the importance of K in controlling HCN in cassava roots in order to minimize health hazards, particularly when fresh cassava is used for human consumption (Essers, 1995). Plant mulch rich in K was found to be as effective as K fertilizer in reducing root HCN in a long-term trial on sandy soils in northern Colombia (Cadavid *et al.*, 1998).

K uptake and use efficiency

Across all cultivars, K application significantly increased the uptake of K by roots, with the largest uptake at 200 kg K ha^{-1} (Table 6). Differences among cultivars were also significant at all K levels. In the absence of K application, CM 523-7 had the smallest uptake, while M Pan 70 had the largest uptake. With 200 kg K ha^{-1}, CM 489-1 had the largest uptake, whereas CM 523-7 had the smallest uptake again. Differences in root biomass in the second and third year (data not shown) may partly explain differences in K uptake among cultivars.

The uptake of K by the shoot biomass was significantly increased with K application across cultivars, with the largest uptake at 200 kg K ha^{-1} (Table 6).

Table 6. Average potassium (K) uptake (second and third year) in root and shoot biomass (kg ha^{-1}) for 14 cassava cultivars grown with potassium fertilization at Cauca, Colombia in 1989–94.

	Roots (kg K ha^{-1})				Shoot biomass (kg K ha^{-1})			
Cultivar	0	50	100	200	0	50	100	200
M Col 1505	19	44	60	100	8	20	31	43
CM 91-3	17	41	63	81	9	21	31	48
CM 489-1	21	54	73	113	9	20	28	41
CM 507-37	24	53	82	103	9	25	31	44
CM 523-7	12	45	61	70	11	27	38	63
CM 1585-13	16	48	61	79	8	14	21	36
HMC-1	18	36	63	75	10	28	38	58
HMC-2	14	47	62	100	12	31	49	69
CMC 40	14	37	61	77	8	21	25	41
M Col 1684	25	51	86	95	7	13	24	32
M Cub 74	21	44	49	89	8	13	20	37
M Pan 70	25	45	55	79	9	24	24	38
M Ven 25	21	44	58	71	22	42	57	66
SG 105-35	22	47	63	80	8	18	29	49
Average	19	46	64	87	10	23	32	47
L.s.d. 5% for cultivars	9	13	19	22	5	8	10	13
L.s.d. 5% for K levels	4.6				5			

Differences among cultivars were also significant at all K levels. In the absence of K application, M Ven 25 had the largest uptake, whereas M Col 1684 had the smallest uptake. With 200 kg K ha^{-1}, HMC-2 had the largest uptake, while M Col 1684 had the smallest uptake. In the second and third years, M Col 1684 had the lowest shoot biomass in the absence of K fertilizer as well as at 200 kg K ha^{-1}, whereas M Ven 25 had the highest shoot biomass in both years in the absence of K application. Thus, differences in K uptake among cultivars might be due partly to differences in shoot biomass production.

At all K levels and across cultivars, K uptake into roots was nearly twice that into the shoot biomass, indicating the substantial K export through harvested roots. These findings confirm the previous reports on K uptake and removal by cassava (Pellet and El-Sharkawy, 1997; Howeler, 1991; 1985; Obigbesan, 1977b). In the light of this fact, replenishing soil K is necessary for maintaining soil fertility as well as for sustaining cassava productivity, especially when cassava is cultivated continuously on the same site for several years (CIAT, 1995; Howeler, 1991; 1985). Moreover, application of K to low-K soils would be beneficial in reducing root HCN and thus reducing health hazards when fresh cassava is used for human consumption (Essers, 1995).

Potassium use efficiency for root production was significantly lower across all cultivars with increasing applications of K (Table 7). Differences among cultivars were significant at all K levels, with the lowest efficiency in CM 523-7

Table 7. Average potassium (K) use efficiency (second and third year) for root and total biomass (kg dry weight kg^{-1} total potassium uptake) for 14 cassava cultivars grown with potassium fertilization at Cauca, Colombia in 1989–94.

	Roots (kg K ha^{-1})				Total biomass (kg K ha^{-1})			
Cultivar	0	50	100	200	0	50	100	200
M Col 1505	256	177	134	100	355	245	198	145
CM 91-3	264	173	133	97	385	252	191	144
CM 489-1	253	183	143	103	407	267	206	155
CM 507-37	289	205	162	112	413	301	237	165
CM 523-7	203	150	124	79	373	243	195	135
CM 1585-13	293	186	150	101	417	260	215	148
HMC-1	279	164	117	91	411	265	199	149
HMC-2	225	159	104	82	394	252	170	130
CMC 40	247	143	111	94	431	255	193	147
M Col 1684	247	175	122	102	328	232	167	141
M Cub 74	292	194	147	99	416	268	215	141
M Pan 70	273	164	147	111	370	242	207	166
M Ven 25	262	179	142	108	406	286	226	167
SG 105-35	260	186	131	89	362	260	190	136
Average	260	174	133	98	391	259	201	148
L.s.d. 5% for cultivars	54	32	18	15	73	45	24	19
L.s.d. 5% for K levels	15				22			

and the highest in CM 507-37. It is noteworthy that CM 507-37 had a very high yield in the absence of K as well as with K application (Table 2). Moreover, with the exception of M Ven 25, CM 507-37 had the highest low-K adaptation index compared with other cultivars (Table 3). This cultivar was also found to be tolerant of prolonged water stress due to better leaf retention and an extensive fine roots system (El-Sharkawy *et al.*, 1992a; El-Sharkawy and Cock, 1987). Because of these traits, it would be beneficial to use CM 507-37 as a genetic source for breeding cassava for stressful environments and partially to alleviate pressure on limited natural resources through genetic solutions. However, because CM 507-37 and M Ven 25 contain high HCN in their roots, it is desirable in a breeding programme to cross these cultivars with genotypes low in HCN, such as HMC-1 and M Cub 74, when fresh cassava is used for human consumption.

As with roots, K use efficiency for total biomass production was significantly lower across all cultivars with increasing K application (Table 7). Also, differences among cultivars were significant at all K levels, with the highest efficiency in M Ven 25 and CM 507-37 and the lowest in M Col 1684. These observations again support the high level of adaptation to low K and the moderate response to K application found in both CM 507-37 and M Ven 25 (Table 3).

CONCLUSIONS

Development of improved technology for sustainable agriculture is highly desirable for both the conservation of dwindling natural resources and increasing food production. Cassava exports more than 60% of total K uptake through the harvested roots, thus depleting soil K. Moreover, most cassava production occurs in low-fertility soils with little fertilization. Due to the limited economic resources available to cassava producers (mainly small farmers), cassava cultivars that tolerate low-K soils and at the same time respond to K fertilizer are advantageous. The present study showed that within cassava germplasm, genetic diversity exists in response to low-K soils as well as to K fertilization. Cultivars such as CM 507-37 and M Ven 25 had high root yields in low-K soils and at the same time responded reasonably to K application. Both cultivars had high adaptation indices to low-K soils and high K use efficiency for total biomass production. CM 507-37 had the highest K use efficiency for root production at all levels of K compared with other cultivars tested. These materials should be used to breed improved cultivars with low negative impact under marginal production systems and for improving productivity under favourable environments. However, because CM 507-37 and M Ven 25 contain high HCN concentrations in their roots, they should be crossed with genotypes low in HCN, such as HMC-1 and M Cub 74, in order to select lines for fresh cassava consumption. As root HCN decreases with higher levels of K, it is warranted to apply fertilizer to low-K soils to minimize health hazards, particularly when fresh cassava is used for human consumption.

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