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CASSAVA VARIETAL RESPONSE TO FERTILIZATION: GROWTH DYNAMICS AND IMPLICATIONS FOR CROPPING SUSTAINABILITY

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SUMMARY

Four contrasting varieties of cassava (*Manihot esculenta* Crantz) were grown for ten months over two consecutive seasons in hillside Colombia with or without nitrogen, phosphorus and potassium fertilization. Sequential harvests were every two months. The two varieties well adapted to acid soils (CM 489-1 and CM 523-7) had higher yields and exhibited the strongest response to fertilization, highest solar radiation use efficiency, earlier canopy ground cover and higher leaf litter accumulation. The export of potassium, however, was no higher than in the other genotypes, mainly as a consequence of higher potassium use efficiency in the adapted varieties. Significant amounts of total calcium, magnesium and nitrogen accumulated in the whole plant were recycled in the leaf litter during growth. High-yielding varieties adapted to acid soils did not exacerbate soil fertility problems of cassava crops; rather, they were beneficial. Certain growth parameters could be used to select for varieties with low impact on soil fertility.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is well known for yielding reasonably well in low-fertility and acid soils where other crops would fail. Even so, in acid soils, cassava yield is limited by deficient phosphorus (P) supply (Howeler, 1985). Lack of potassium (K) can also limit growth, especially after several cassava crops, as a consequence of large export of K in the harvested roots (Howeler, 1991). To improve adaptation of cassava to low-P soils, CIAT began screening cassava germplasm, finding a wide range of variability (CIAT, 1992). Pellet and El-Sharkawy (1993a; b) analysed physiological mechanisms affecting varietal adaptation to low-P soils and response to P fertilization. They pointed out the importance of biomass partitioning in improving root yield response to fertilization. However, there is a lack of information on the implications of fertilization for the sustainability of cassava-based cropping systems.

Concerns about the sustainability of cassava-based cropping systems arise as a consequence of the common practice of planting cassava in fragile and degraded

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soils. Cassava's ability to produce secure yields where other crops such as maize and beans would fail makes it a favorite with resource-poor farmers (CIAT, 1993).

A study, which simulated soil loss by removing different depths of soil artificially, confirmed that cassava storage root yield does decrease with increasing depth of soil removed, but not as drastically as in maize (Lal, 1987). Some cassava genotypes are better than others in partially and temporarily off-setting the detrimental effects of soil erosion on soil productivity (Howeler, 1991). The presence of cassava on eroded hillsides is thus a consequence and, at the same time, a cause of hillside erosion (CIAT, 1993). Cassava itself can cause dramatic soil loss if grown without adequate soil management practices. In a study that quantified soil erosion in cassava-based cropping systems, Reining (1992) found that soil management practices such as planting cassava on contour ridges or contour strips markedly reduced soil loss while producing optimal cassava yields. However, differential varietal effects on soil erosion were not studied. In other trials, Howeler (1991) observed that fertilization greatly reduced soil loss and increased yield, but no information about the interaction between varieties and fertilization was reported.

Another environmental concern is the reduction in soil fertility after a number of cassava crops, principally because of heavy K exports from the soil to the storage roots (CIAT, 1992; Howeler, 1991). This raises the question as to whether selecting varieties which are adapted to low soil fertility and are more responsive to moderate fertilization would exacerbate soil fertility problems, due to greater biomass production and more nutrient uptake. Little information is available about the potential differential effects of varieties adapted to low-fertility soils on system sustainability. Cassava germplasm is characterized by a wide genetic diversity, which is used by breeders to improve cassava yield, quality and adaptability to biotic and abiotic stresses (El-Sharkawy, 1993; Hershey and Jennings, 1992). This diversity could also be used to select for varieties with low impact on soil fertility, if the effect of growth parameters on cropping sustainability were better understood.

A major objective of this study was to determine if physiological and morphological traits associated with cassava growth dynamics in response to fertilization in acid soils could help improve the sustainability of cassava-based cropping systems. The effect of fertilization on growth dynamics in varieties adapted to acid soils was studied specifically and then the growth parameters that, potentially, would affect soil erosion and soil fertility were determined.

MATERIALS AND METHODS

Plant materials, experimental site, experimental design and treatments

Details of the materials and methods used in this series of experiments have been reported by Pellet and El-Sharkawy (1993a; b). The cassava varieties CM 523-7, CM 489-1 and M Col 1684 were grown in a two-year field trial from October 1988

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to July 1990 and, since then, CM 523-7 has been released as a cultivar (ICA Catumare) adapted to acid soils.

The trials were on a farm near the CIAT-Quilichao Research Station, Cauca, Colombia (lat 3°06′N, long 76°31′W, altitude 990 m, mean annual temperature 24°C). The soil was an Inceptisol with low pH (4.3), 65% Al saturation, low P (2.4 μg P g^{-1}), high organic matter (7.3%) and low K (0.16 meq K (100 g soil)$^{-1}$). Average annual rainfall was 1800 mm, with a major peak in December–January and a smaller peak in April–June. In both years, rainfall was lower than potential evaporation in the last six to eight weeks of growth.

The experiment was laid out as a split-plot design with three replications. The first cycle was planted on 6 October 1988, the second cycle on 20 September 1989. Both crops were either unfertilized or given 100 kg N, 100 kg P and 100 kg K ha^{-1} as urea, triple superphosphate and potassium chloride respectively.

Cassava stakes, 15–20 cm in length, were planted vertically at spacings of 1 × 1 m on flat ground. Five sequential harvests of eight protected plants per plot were made every two months. Harvested plants were separated into leaf blades, petioles, stems, storage roots and swollen plant pieces. Leaf litter (fallen leaves) were also collected from the designated eight plants for each harvest and were included in calculations of both aerial and total biomass. Samples of these plant parts were chopped into small pieces and then, to determine dry matter, were oven-dried at 70°C to a constant weight. The nutrient content of samples was determined according to Salinas and García (1985).

Leaf area index, light extinction coefficient and radiation use efficiency

Leaf area index (LAI) was determined at each harvest, using a 20-leaf sample, together with the total dry weight of harvested leaf blades (Veltkamp, 1985). Measurements of light interception by the canopy were carried out during the first crop cycle, before each harvest. A LI-COR Quantum Meter (LI-COR Inc., Lincoln, NE, USA), Model LI-170, with a line sensing length of 1 m was used. The relationship between intercepted light and LAI was calculated according to Veltkamp (1985):

$$\ln(I/I_0) = -K \times LAI$$

where I = light received beneath the canopy (four positions per plot)

I_0 = incoming light just above the crop canopy (one measurement per plot)

K = extinction coefficient.

Average values for K (for each variety and fertilizer treatment) over the growing season were calculated as the slope of a regression line of ln (light absorption) as a function of LAI, according to Veltkamp (1985). These average K values were used to calculate the relative ground cover by the canopy expressed as a percentage (Adams and Arkin, 1977) for each variety and treatment during the two growing seasons.

Manrique *et al.* (1991) calculated solar radiation use efficiency (RUE) by

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assuming that 45% of total solar radiation was photosynthetically active radiation (PAR). In this study RUE was calculated as the slope of the linear regression of total biomass production *versus* cumulative intercepted PAR (IPAR) over time.

RESULTS AND DISCUSSION

Leaf area index

For each variety and growing season, LAI development (Fig. 1) was slow, taking from four to six months to reach maximum values, parallel with the first rain peak between December and January. Then LAI decreased rapidly. This corresponded to a drier period of the year and plants reacted by reducing top growth, thus limiting plant transpiration. In the second growing season particularly between six and eight months after planting, some leaf regrowth making use of the second short rainy period was observed, mainly in fertilized plants of CM 523-7 and CM 489-1. Although unfertilized cassava plants developed a smaller LAI than did fertilized plants, particularly in the second growing season, they had a similar pattern of canopy growth with a high value after a few months

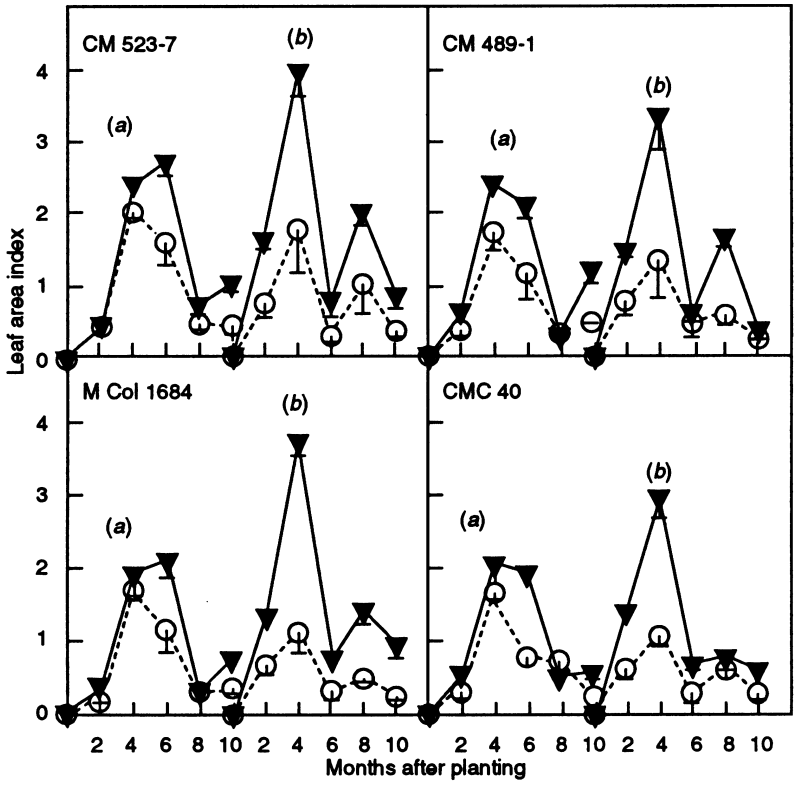


Fig. 1. Leaf area index (LAI) development and evolution over time in response to fertilization (no fertilizer, -○-; 100 kg NPK ha^{-1}, -▼-) in four cassava varieties, CM 523-7, CM 489-1, M Col 1684 and CMC 40. Vertical bars = — s.e. (n = 3); (*a*) = first crop cycle; (*b*) = second crop cycle.

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of growth, a sharp decrease and final regrowth. This finding corresponded with the general pattern described by Cock (1985), and also confirmed the well known tendency for high soil fertility to enhance LAI (Cock and El-Sharkawy, 1988a). In cassava, the importance of the canopy for yield formation has been underscored by many authors (Cock *et al*., 1979; Cock and El-Sharkawy, 1988b; Pellet and El-Sharkawy, 1993a). LAI values observed in the present studies remained sub-optimal for reaching cassava yield potential (Cock *et al*., 1979), even in the fertilized plots. No dramatic varietal differences in LAI development were found.

Storage root yield

In contrast to canopy development, storage root biomass was almost nonexistent in the first two months after planting, and root growth was limited to the fibrous root system (Fig. 2). Four months after planting, when canopy development had almost reached its maximum, the dry weight of the storage root was only about 20–30% of the final yield in fertilized plants. Effects of fertilization

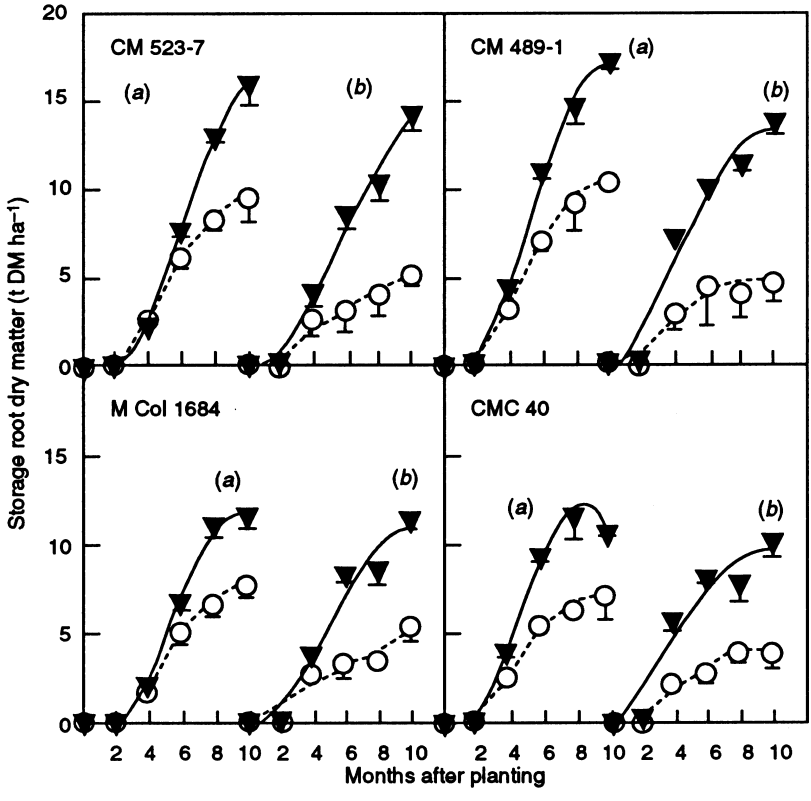


Fig. 2. Storage root dry matter yield evolution over time in four cassava varieties, CM 523-7, CM 489-1, M Col 1684 and CMC 40, in response to fertilization (no fertilizer, -○-; 100 kg NPK ha^{-1}, -▼-). Vertical bars = — s.e. (n = 3) (*a*) = first crop cycle; (*b*) = second crop cycle.

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were obvious at six months after planting in the first growth cycle and at four months after planting in the second cycle.

With fertilization, CM 523-7 and CM 489-1 produced significantly higher final root yields than M Col 1684 and CMC 40 (Pellet and El-Sharkawy, 1993a). These two varieties also had the strongest response to NPK fertilization, differences being almost three-fold between fertilized and non-fertilized plants of the second crop. Over the two years, fertilized plants of each variety produced comparable final yields, but the yield of unfertilized plants decreased from the first to the second year, probably because the soil K was being depleted. Moderate fertilization is believed to be necessary to maintain soil fertility and yield in cassava-based cropping systems (Howeler, 1991).

Light extinction coefficient and solar radiation use efficiency

Only in CM 523-7 and M Col 1684 did fertilization significantly increase the value of the light extinction coefficient in the first crop cycle (Table 1). This indicated higher light interception for the same LAI because of better leaf positioning, possibly as a result of differences in leaf curving and leaf angles among genotypes.

These differential varietal responses for K values were not reflected in variations of radiation use efficiency (RUE), an indication of how plants transform light energy into plant biomass. Biomass formation is a more complex process which involves not only light interception through the canopy but also net carbon fixation through photosynthesis. All genotypes showed a significant increase in RUE in response to fertilization (Table 1), as a direct effect of increased LAI with fertilization. Fertilized plants of CM 489-1 and CM 523-7 showed the highest RUE values, compared with CMC 40 and M Col 1684. As observed by Pellet and El-Sharkawy (1993a), CM 489-1 had the highest single-leaf photosynthesis compared with the other three genotypes, and also responded positively to

Table 1. *Effect of fertilization on the extinction coefficient of light interception (K) and solar radiation use efficiency (RUE) in four cassava varieties*

Variety	Fertilizer treatment (kg NPK ha^{-1})	RUE† (g MJ^{-1})	K
CM 523-7	0:0:0	1.32 (0.17)‡	0.58 (0.07)
	100:100:100	1.84 (0.10)**	0.78 (0.06)*
CM 489-1	0:0:0	1.48 (0.08)	0.59 (0.11)
	100:100:100	2.30 (0.08)***	0.67 (0.06)ns
M Col 1684	0:0:0	1.20 (0.13)	0.54 (0.08)
	100:100:100	1.58 (0.08)**	0.71 (0.06)*
CMC 40	0:0:0	1.15 (0.16)	0.50 (0.10)
	100:100:100	1.56 (0.15)**	0.63 (0.09)ns

†RUE represents the slope of total biomass production over cumulative intercepted photosynthetically active radiation; ‡ s.e. in parentheses; ns, *, **, *** Significance level of t test (pairwise comparison of fertilization effect for each variety), non-significant, significant at $p < 0.05$, 0.01 and 0.001 respectively.

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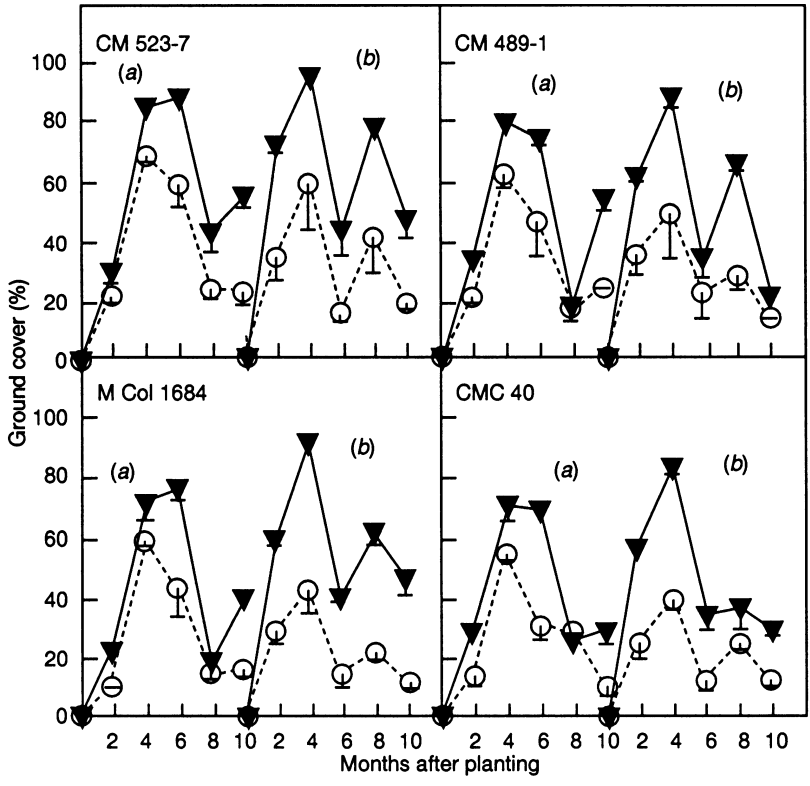


Fig. 3. Effect of fertilization (no fertilizer, -○-; 100 kg NPK ha^{-1}, -▼-) on the evolution of ground cover by the crop canopy over time in four cassava varieties, CM 523-7, CM 489-1, M Col 1684 and CMC 40, and two growing seasons. Vertical bars = — s.e. (n = 3); (*a*) = first crop cycle; (*b*) = second crop cycle.

fertilization. This could explain why CM 489-1 could offset its relatively low light extinction coefficient and have high radiation use efficiency.

Ground cover

Values of LAI over time were combined with the light extinction coefficients from Table 1 to estimate according to Adams and Arkin (1977) the varietal effect of fertilization on the ground cover provided by the canopy (Fig. 3).

Depending on the year and the genotype, fertilized plants covered the ground faster than unfertilized plants and provided 50% of the ground cover after two to three months. No dramatic genotypic differences were observed. With unfertilized plants, however, the varietal effect was greater. In the second cropping cycle, CM 523-7 reached 50% ground cover after about 100 days; CM 489-1 needed about 120 days and M Col 1684 and CMC 40 never reached that level of ground cover provided by the canopy of unfertilized plants. The importance of canopy effect as a sub-factor of 'C' (cropping factor in the Universal Soil Loss Equation) to protect and reduce potential soil erosion has been underscored by Wishmeier and Smith (1978). Although the canopy effect of plants 1 m in height was not as

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effective as mulch ground cover, the estimated canopy effects are important, especially in a crop like cassava which does not compete well with weeds or other potential cover crops. Cassava is planted in the rainy season when the soil is more susceptible to erosion (Reining, 1992) and so the dynamics of ground cover formation after planting become significant. Fast canopy development will provide a better and earlier ground cover. Varietal differences were observed, CM 523-7 having the earliest ground cover when unfertilized. Also important is that NPK fertilization off-set this varietal effect observed in the absence of fertilization, proving that moderate fertilization can contribute to the sustainability of the cassava cropping system as observed by Howeler (1991).

Leaf litter

Up to 3 t ha^{-1} of leaf litter accumulated mostly in the second half of each cropping cycle, when LAI decreased (Fig. 4). Fertilization had a dramatic effect on leaf litter collected, showing no specific interaction with varieties. Again, CM 523-7 recorded the highest values in any treatment over the two cropping

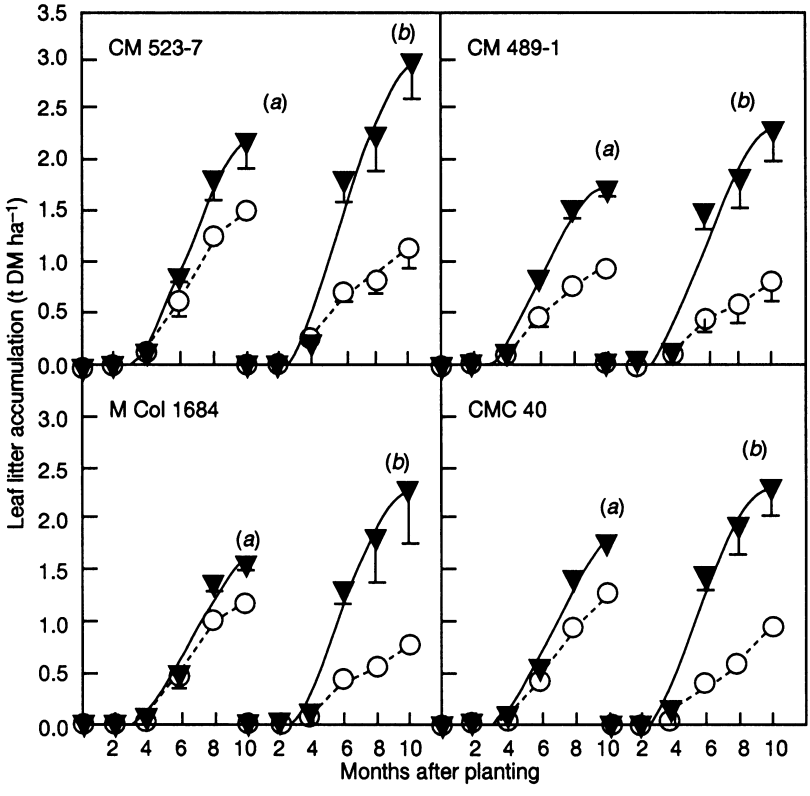


Fig. 4. Effect of fertilization (no fertilizer, -○-; 100 kg NPK ha^{-1}, -▼-) on leaf litter accumulation in four cassava varieties, CM 523-7, CM 489-1, M Col 1684 and CMC 40, during two growing seasons. Vertical bars = — s.e. (n = 3); (*a*) = first crop cycle; (*b*) = second crop cycle.

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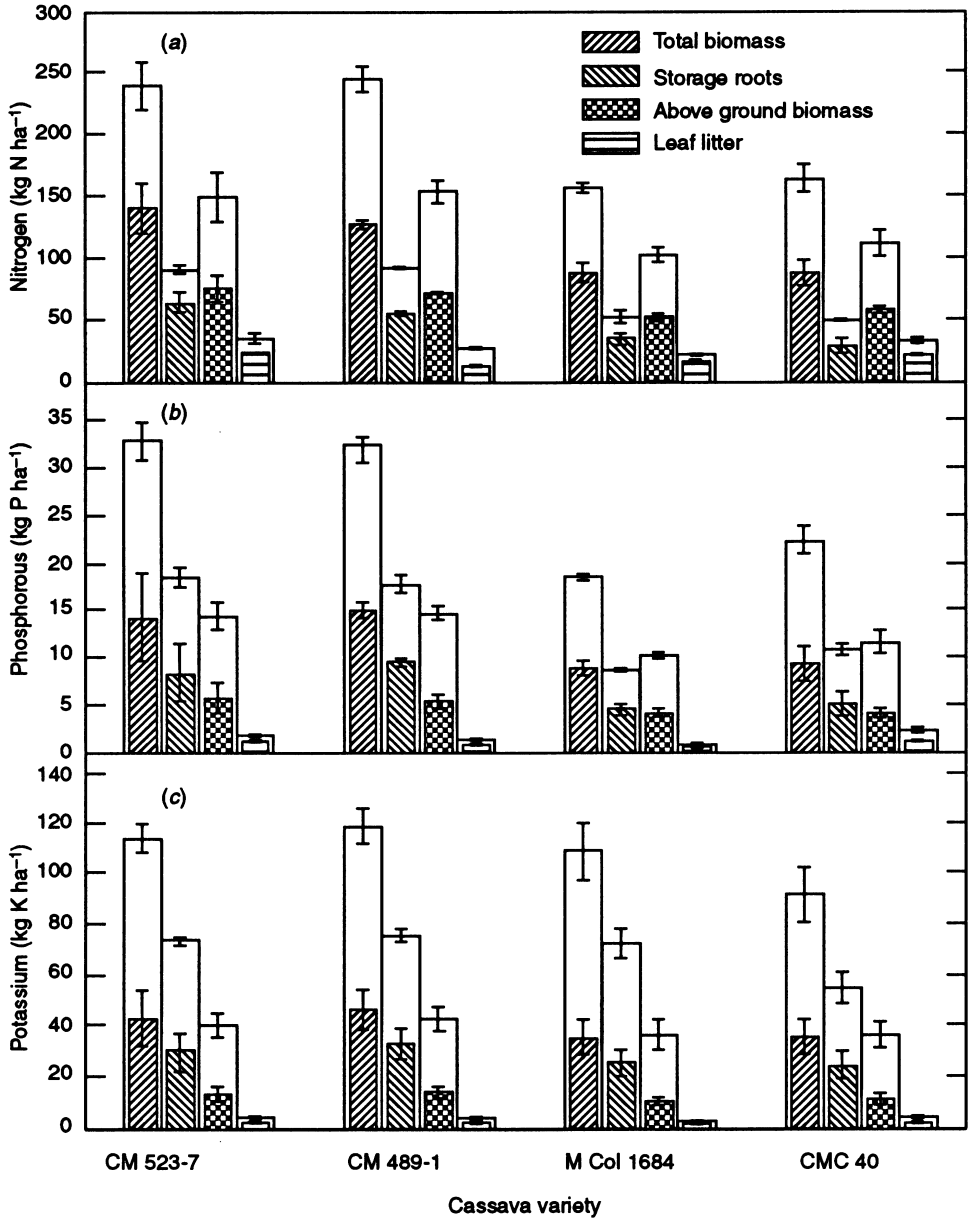


Fig. 5. Distribution of nitrogen (*a*), phosphorus (*b*) and potassium (*c*) accumulation in fertilized (empty bars) and unfertilized (filled bars) ten-month-old cassava crops. Vertical bars (lines) = ± s.e. (n = 3). Hatchings legends are detailed in the figure and fertilizer treatments are given in Fig. 4.

seasons. After leaf area, leaf litter was the second significant plant component contributing to soil cover. Leaf deposition replaces canopy cover and offers a mulch soil-cover when the second rainy period begins. Although leaf litter forms a protective mulch only late in the cassava growing season, its role must not be

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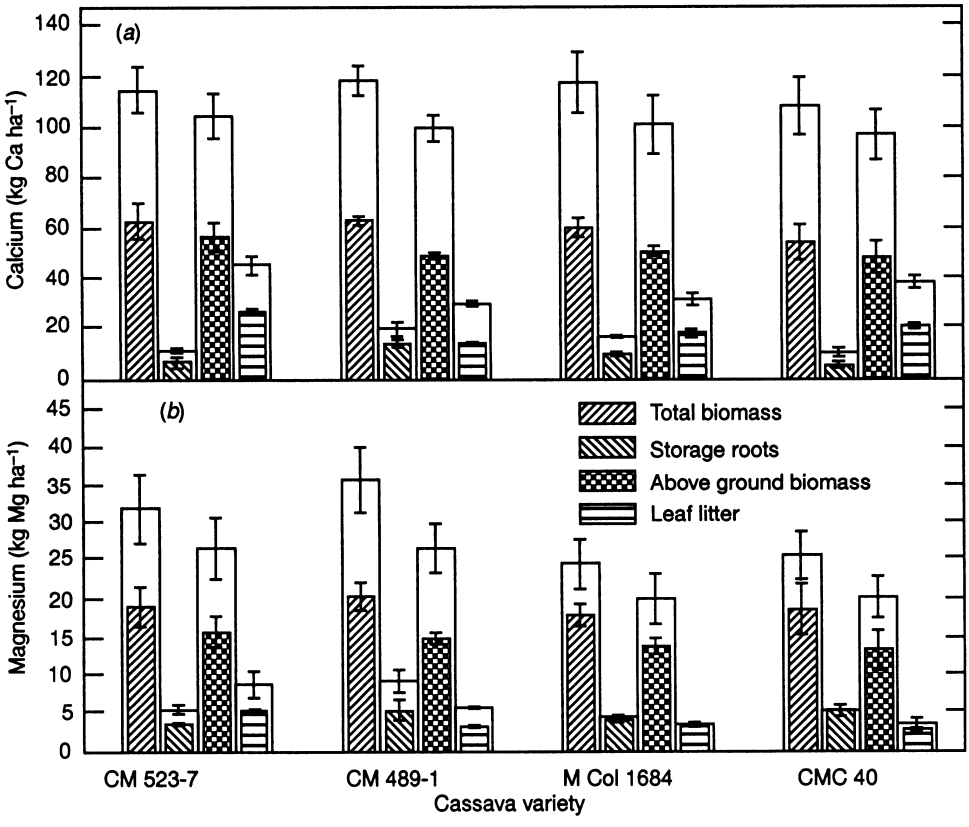


Fig. 6. Distribution of calcium (*a*) and magnesium (*b*) accumulation in fertilized (empty bars) and unfertilized (filled bars) ten-month-old cassava crops. Vertical bars = ± s.e. (n = 3). Hatchings legends are detailed in the figure and fertilizer treatments are given in Fig. 4.

underestimated. Its presence (along with weeds) may contribute to reduction in soil loss during the second half of the growing season (Reining, 1992).

Nutrient accumulation

Figures 5 and 6 show that, for certain nutrients, leaf litter does contribute to the recycling of a significant amount of their total accumulation in the plant biomass. Irrespective of fertilizer treatment, the mean proportion of total nutrient uptake in total biomass concentrated in the leaf litter was highest for Ca (32%) and Mg (19%) (Fig. 6a and b), followed by N (16%) (Fig. 5a). The mean percentages of total P and K accumulated in the biomass and recycled in the leaf litter were low, 6% and 3% respectively (Fig. 5b and c). Inversely, the proportion of total nutrient uptake exported in storage roots was highest for K (67%), followed by P (45%), N (39%), Mg (23%) and Ca (14%). These figures on nutrient export and recycling are influenced by the mobility and partitioning of nutrients in the plant, and by the different physiological functions of nutrients. Low contents of P and K

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in the leaf litter mean that the plants have translocated these nutrients efficiently from aging leaves before leaf abscission.

In response to NPK fertilization, yield increased significantly (Fig. 2), as did the total uptake of these nutrients (Fig. 5a, b, and c). Nutrients added to the system by fertilization were used differently among varieties. In CM 523-7 and CM 489-1, fertilizer P was distributed in equal amounts to the top organs and to the storage roots, demonstrating an efficient use of P. In contrast, M Col 1684 and CMC 40 allocated relatively more fertilizer P to the top organs than to the storage roots. The imbalance between aerial organs and root growth in fertilized plants was the reason for the moderate response, in terms of root yield, to P fertilization in these two varieties (Pellet and El-Sharkawy, 1993a; b). No varietal differences were observed for other nutrients.

Cassava's ability to remove large amounts of K from soils has been well documented (Howeler, 1991). Fig. 5c shows that whole plants of any of the four varieties, when unfertilized, could accumulate more than 40 kg K ha^{-1} and, when fertilized, would accumulate 100–120 kg K ha^{-1}, exceeding the actual input through fertilization (100 kg ha^{-1}). In CM 523-7, CM 489-1 and M Col 1684, exports of K^+ in the roots were similar in treatments with and without fertilization. However, storage root yields were different among the three genotypes, particularly in the fertilized treatments. This means that the concentration of K^+ in the roots of the high-yielding varieties CM 523-7 and CM 489-1 was lower than in M Col 1684. Thus, CM 523-7 and CM 489-1 used K^+ in the storage roots more efficiently than did M Col 1684. The K use efficiency ratio in storage roots (root dry matter mass divided by K accumulation in storage roots) was 42% higher in CM 489-1 than in M Col 1684 in fertilized treatments (228 $\pm$ 11 kg DM per kg K^+ in CM 489-1, compared with 160 $\pm$ 19 in M Col 1684). Nonetheless, K exports were reflected in soil analysis (Fig. 7) and indicated that plant-available soil K concentration decreased from the first to the second growing season, irrespective of the fertilization treatment. However, K fertilization resulted in increased levels of nutrient, compared with unfertilized plots. Results of other studies in a similar environment showed that the K content of the soil and root yield could be maintained over eight consecutive cassava cropping cycles, using a yearly application of at least 125 kg K ha^{-1} (Howeler, 1991).

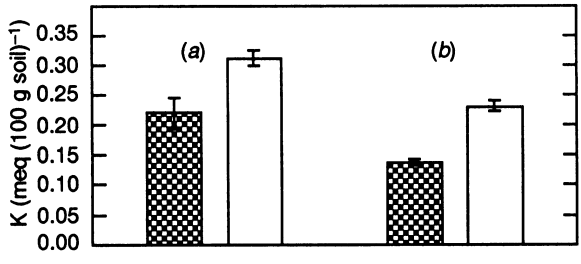


Fig. 7. Soil potassium (K) analysis two months after planting and fertilizer application (no fertilizer, solid bars; 100 kg NPK ha^{-1}, empty bars) over two cassava growing seasons. Vertical bars = $\pm$ s.e. (n = 12); (*a*) = first crop cycle; (*b*) = second crop cycle.

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CONCLUSIONS

Cassava-based cropping systems can affect soil fertility through erosion and heavy nutrient export. The present study illustrates how varieties well adapted to acid soils and with an improved response to fertilization (CM 523-7 and CM 489-1) out-yielded the traditional varieties (M Col 1684 and CMC 40). Parameters related to aerial growth showed that in improved varieties, differences in canopy growth were reflected in soil cover by canopy and leaf litter accumulation. To reduce soil erosion, the establishment of early ground cover is highly desirable, showing the importance of rapid canopy growth in improved varieties. Furthermore, differences in K use efficiency showed that varieties bred for high yield in poor acid soils would not necessarily accelerate K soil mining compared with traditional varieties. The indirect benefits of varieties adapted to acid soils (greater canopy ground cover, leaf litter and K use efficiency) showed that these varieties do not exacerbate pressures on the environment and that, in cassava, genetic variability should be used to select for varieties with low negative environmental impact. In the future, the use of such varieties may help to complement and enhance the effect of soil conservation management measures.

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