ISSN 0120-2340
CIAT Series No. 02EC1-79
June 1980

1979 Cassava Program Annual Report

Centro Internacional de Agricultura Tropical
Apartado Aéreo 67-13
Cali, Colombia

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Apartado 6713
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ISSN 0120-2340
CIAT Series No. 02EC1-79
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Correct citation:

Centro Internacional de Agricultura Tropical. Cassava Program 1979 Annual Report. Cali, Colombia. 1980. 93 p.
Also available in Spanish.

Manihot esculenta/Research/Physiology/Plant physiological processes/Nutritional requirements (Plant)/Composition/Pests/Pest control/Insect biology/Biological control/Diseases and pathogens/Bacterioses/Mycoses/Deterioration/Plant breeding/Germplasm/Cultivars/Selection/Harvest index/Resistance/Technology/Technology evaluation/Cultivation/Propagation materials/Cultural practices/Cultivation systems/Intercropping/Soil requirements/Fertilizers/Tissue culture/*Erinnyis ello*/*Trichogramma* spp./*Telenomus* spp./*Anagyrus* sp./*Calosoma* sp./*Kalodiplosis coccidarum*/*Anastrepha* spp./*Phenacoccus* sp./*Coptotermes* sp./*Aleurotrachelus socialis*/ *Mononychellus* sp. / *Tetranychus* sp. / *Xanthomonas manihotis* /*Sphaceloma manihoticola*/*Glomerella* sp./*Gloeosporium* sp./*Phoma* sp./Transfer of technology/

Print order: 1500 copies.

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HIGHLIGHTS

When CIAT's Cassava Program initiated its activities, scientific information about this major carbohydrate source for human food and animal feeding was scarce. Thus efforts have focused on basic research on the cassava plant and its environment, and the simultaneous development of improved production technology, while better defining the process for its transfer to national institutions and eventually to its ultimate user, the farmers. Within this context and following CIAT's overall minimum input philosophy, research is aimed at: (a) improved technology for areas in Latin America and Asia where cassava is presently grown and (b) technology for expanding cassava production into the vast, under-utilized areas of Latin America and Asia characterized by the acid, infertile oxisols and ultisols.

This year a better understanding was achieved on interactions between the cassava plant and stress environments. Physiological studies of the cassava plant under stress conditions were given increased emphasis; a major study was initiated on the water requirements of cassava. Evaluation of cassava cultivars for adaptation to acid, infertile oxisols and ultisols confirms the existence of genotypes highly tolerant to low pH and high Al levels, producing 90% of maximum yield in a soil with pH 4.0 and 77% exchangeable Al. Cassava's recognized adaptation to low fertility soils has in the past been inconsistent with nutrient solution studies which had demonstrated cassava has very inefficient root system, particularly for P uptake. Mycorrhizal inoculation of cassava resulted in a marked increase in dry matter production and P uptake where P supply was limiting but did not have a beneficial effect where P was not limiting. This showed cassava adaptation to infertile soils depends on an effective mycorrhizal association.

In a high disease pressure environment it was demonstrated that cassava bacterial blight (CBB) and superelongation are controlled by independent genetic mechanisms. This finding indicates the continuous nature of field resistance of cassava to these two diseases. Moreover, disease evaluation of crosses demonstrated the existence of higher levels of disease resistance in some progeny than in either parent.

A long term study on genotype ecosystem interactions was initiated. A standardized system for identification and evaluation of potential biotic problems in a given ecosystem was developed. Regional cultivars showed the highest level of resistance to the range of negative production factors existing in each ecosystem. Germplasm screening was reorganized on an ecosystem basis. The frequency of genotypes with tolerance to the broad range of climatic, biotic and edaphic conditions in any particular ecosystem was found to be low. Work was initiated on the development of germplasm resource pools to increase gene frequencies for adaptation to specific ecosystem characteristics.

A hybrid line this year reached a new maximum yield of 82.2 t/ha in a replicated yield trial at CIAT. Evaluation of promising hybrid lines suggests that four principal classifications are emerging: (a) lines with moderately high yield potential across different environments and with moderate resistance to CBB and superelongation; (b) lines adapted to the stress conditions of oxisols producing high dry matter content and showing tolerance to CBB and superelongation; (c) lines adapted to the hot, humid lowland tropics which have disease but no edaphic constraints; and (d) very high yielding lines grown under favorable agricultural conditions and no pathogen stress. The second year of testing of hybrids in the Colombian regional trials identified six lines that gave average yields of 25-27 t/ha across all sites. Only two selections from the CIAT germplasm bank achieved higher yields.

Weeds are also a primary constraint to cassava production. A new pre-emergent herbicide, oxyfluorfen, has given better weed control than previous products tested, even for controlling purple nutsedge (*Cyperus rotundus* L). Mulching and intercropping were shown to be other effective weed control practices, the optimal control depending on capital and labor resources of the farm. Potential intercropping systems were also identified for oxisol/ultisol regions where cowpea and peanut gave the best results in association.

The Cassava Program has placed greater emphasis on technology transfer and strengthening of national programs through training, germplasm exchange, technical publications and close collaboration with colleagues in national programs. This transfer process has been significantly aided this year with the development of cassava tissue culture technique which permits the international shipment of pathogen-free cassava germplasm. The first training course on cassava meristem handling was held this year for scientists in cooperating countries. A germplasm exchange program was initiated with Brazil.

PHYSIOLOGY

Fertilizer Response

M Mex 59 is a very leafy type and last year (CIAT Annual Report, 1978) was shown to vary its leaf area greatly as fertility level was changed. M Mex 59 was planted at high and low fertility levels at five different plant populations in CIAT-Quilichao. At the low fertility level leaf area index (LAI) increased by about 60% as population was increased from 0.5 to 2.8 plants/m², while at high fertility the increase was 120% (Figure 1). These data support the hypothesis proposed last year that cassava restricts leaf growth at low fertility maintaining a high nutrient content in the leaves.

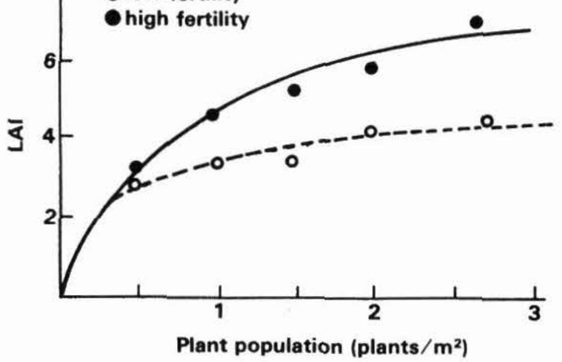

Figure 1. Leaf area index of cassava five months after planting at low and high fertility at various plant populations.

Five months after planting, the dry root yield (average of 4.5 t/ha) of the low fertility treatment was not significantly different over the range of plant populations. At high fertility, yield was significantly affected by plant populations with lower yields at the higher plant populations (Figure 2). The highest yields at high fertility were equal to the average yield at low fertility.

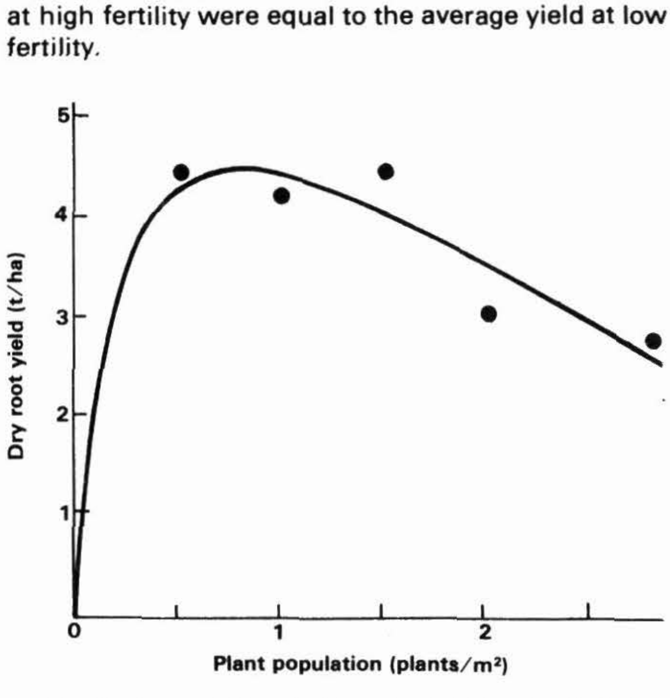

Figure 2. Relation between cassava root yield at five months after planting and plant population at high fertility.

A trial at CIAT-Palmira showed that the interception of photosynthetically active radiation (PAR) was closely related to LAI (Figure 3) and that there is a varietal difference in the relation between light interception and LAI. In general, these data show that a cassava crop intercepts 90% of the PAR at LAI 3 and as LAI doubles to 6 it will intercept only 9% more. This suggests that large increments over a LAI of 3 will have relatively little effect on crop growth. Furthermore, as LAI increases, the proportion of new dry matter produced in the roots (distribution index) decreased markedly. In both relations — crop growth rate vs. LAI and distribution index vs. LAI — there is no indication that plants grown at low fertility are less efficient per unit LAI than plants grown at high fertility. Plants grown at low fertility had restricted leaf area but maintained leaf efficiency.

Because very little if any extra biomass is produced above LAI 3, there appears to be no advantage to the crop of increasing LAI above that level. In terms of root production, increasing LAI above 3 is disadvantageous as the production and maintenance of higher LAIs leads to lower distribution indices, which result in lower root yield. At high fertility, LAI can be changed markedly by different plant populations, hence yield is very sensitive to plant population. At low fertility, however, LAI varies less as plant population changes; therefore yield is more stable over a wide range of plant populations under low fertility. Furthermore, low fertility plots (no N, P or K applied) in CIAT-Quilichao gave a reasonable dry root yield of 4.5 t/ha after only five months, while high fertility plots yielded less. These data clearly demonstrate that it is possible to overfertilize cassava, making it exccessively leafy, particularily at high plant populations.

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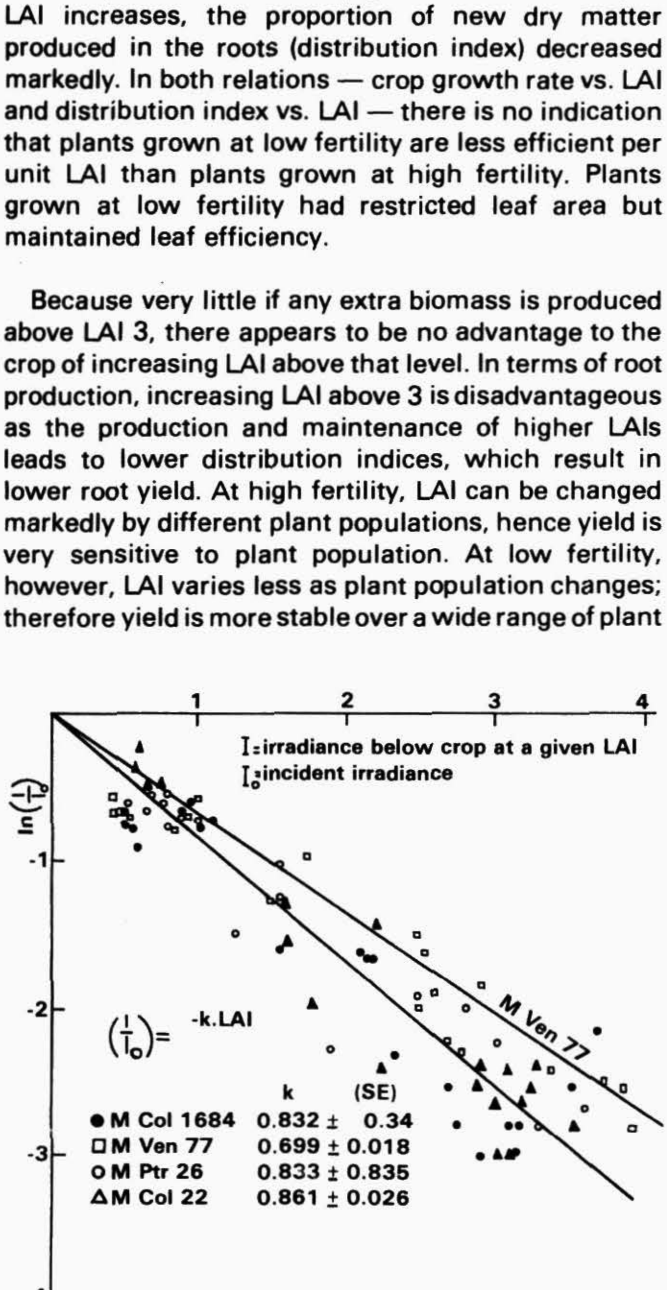


Figure 3. Penetration of phytosynthetically active radiation into canopies of four cassava cultivars.

Photosynthesis

Simulation experiments suggest that small increases in the photosynthetic rate of leaves will give proportionately larger increases in root yields. Screening of large numbers of plants was attempted using plants grown in small pots and results were extremely variable. Many clones showed a marked decrease in the photosynthetic rate of individual leaves as plants aged. However last year's results showed that for plants in very large pots high rates of photosynthesis could be obtained with plants nearly four months old. It is not convenient to use very large pots for screening purposes and so other ways to maintain a stable photosynthetic rate over time were sought. Reduction of the total photosynthetic area of the plants in pots by removing 3 out of 4 leaves eight weeks after planting rapidly restored photosynthetic rate to its initial value and it could be maintained by removing 3 of every 4 new leaves formed (Figure 4).

Six varieties with similar morphological characteristics but with differences in photosynthetic rate (28 - 30 mg CO_2 $dm^{-2}hr^{-1}$ at 1000 μE m^{-2} sec^{-1}) were grown in the field and harvested at 2,4,6,8, and 12 months. Leaf area duration (LAD), total biomass

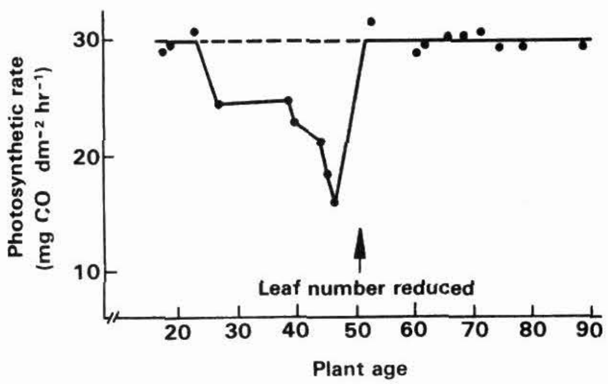


Figure 4. Changes in photosynthetic rate of the first fully expanded leaf at 1500 $\mu E\ m^{-2}\ sec^{-1}$ with age of pot grown cassava plants before and after reducing leaf number. (Mean of seven varieties.)

(including fallen leaves) and root dry weight were recorded. Root dry weight was only slightly correlated with photosynthetic rate and no relation between total biomass per unit LAD and yield was obtained. It is probable that the range of photosynthetic rate was too small in these trials to detect any relationship; however, the technique is promising as the variability of total dry matter per unit LAD was very low.

Dry Matter Content of Roots

The percentage dry matter or starch content of the root is an important quality criterion either for the fresh market or for processing. Large differences in dry matter content between varieties and sites have been observed (CIAT Annual Report, 1978). Analysis of the results of temperature genotype trials (CIAT Annual Report, 1977) showed a marked increase in dry matter content after 16 months at lower temperatures (Figure 5). At the lowest temperature (20°C) dry matter content increased with time after planting. At 24°C, dry matter content was greatest at 12 months and then decreased, the decrease being most marked in the cultivar Popayan wich lodged. At 28°C, dry matter content of the higher biomass clones declined from eight months onwards. These data suggest that maximum dry matter content is reached earlier at higher than at lower temperatures with maximum dry matter content at 8, 12, and 16 or more months at 28,24, and 20°C, respectively. There was very little varietal difference in starch content at low temperature, and at the 12 month harvest differences were more marked at 28°C. Hence screening for dry matter content can most readily be done at high temperature sites.

Under the high fertility conditions of CIAT-Palmira the mean dry matter content of the roots of seven varieties increased markedly from 2-6 months after planting and then showed a slight increase up to 12 months. In another trial at CIAT-Palmira two varieties increased dry matter content up to 15 months after planting while a third showed a decrease from 12-15 months after planting.

At the low fertility site of CIAT-Quilichao with intermediate temperatures root dry matter content of three varieties increased markedly from 4 to 9 months after planting. Nine months after planting, root dry matter content was greater at the high fertility level and was maintained until the final harvest at 12 months, whereas it declined at the lower fertility level (Figure 6).

The effects of various stress factors on root dry matter content were observed. A moderate water

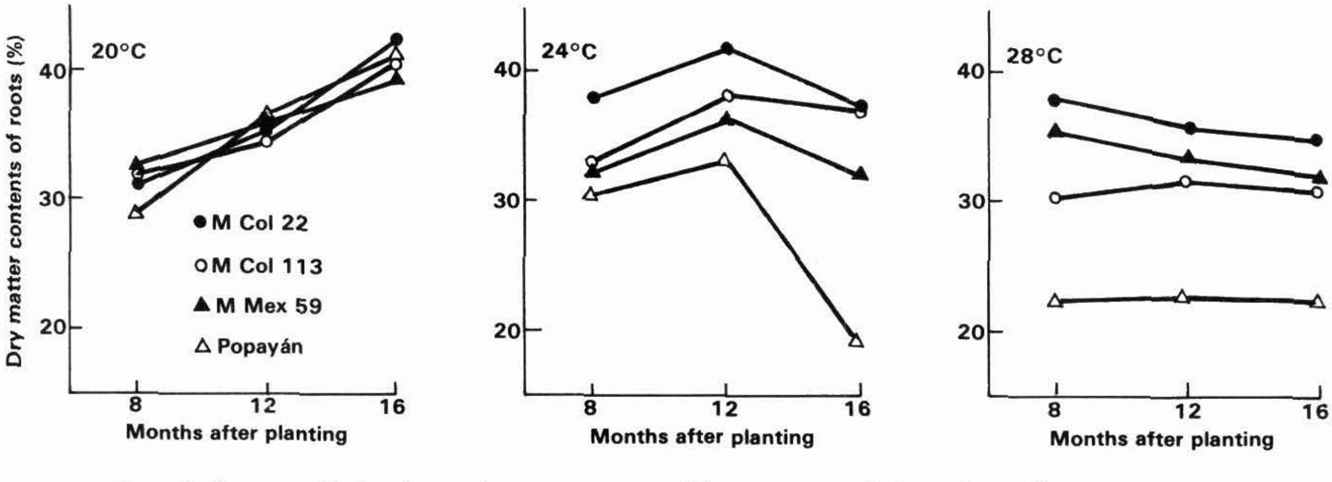


Figure 5. Changes with time in root dry matter contents of four cassava varieties at three different temperatures.

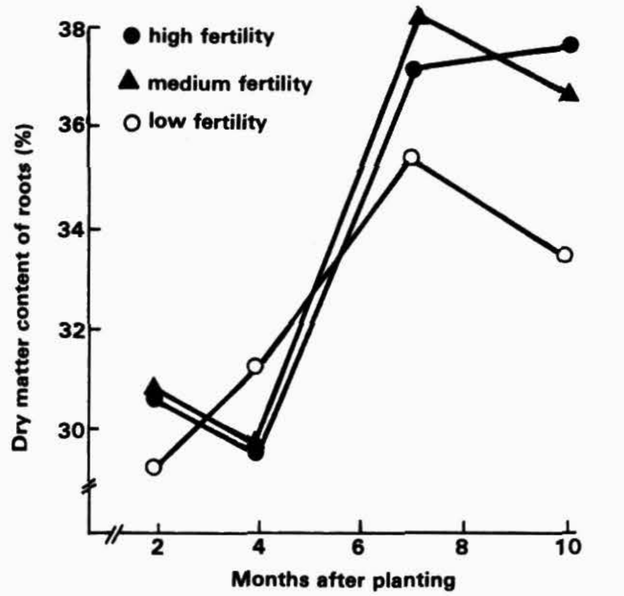


Figure 6. The effect of fertilizer level on the dry matter content of roots at different ages at CIAT-Quilichao.

stress for four months at CIAT-Palmira had no effect on root yield, however root dry matter content was significantly reduced; the control plot showed a dry matter content in roots of 35.8%, while stress periods from 4-8 and 8-11 months after planting decreased dry matter content to 34.2 and 32.7%, respectively. When plants were shaded (50%) during the first three months after planting, root yield was substantially reduced but the dry matter content was not affected when plants were harvested 8.5 months after planting. On the other hand, 50% shading for two months during the root bulking period reduced root dry matter content from 39.3 to 37.6% but reduced root growth rate by 37%. Root clipping at three months reduced thick root number, increasing the carbohydrate supply to the remaining roots. This treatment had no significant effect on either root yield or root dry matter content at 6, 9, or 12 months after planting. However, two months after blocking the carbohydrate supply to the roots by ring barking, root dry matter content was reduced from 37.1 to 22.0%.

These data suggest that varietal differences in dry matter content are greater at higher temperatures; root dry matter content increases with plant age and then declines; the maximum dry matter content is reached at an earlier age when temperatures are higher; stress conditions (e.g., water stress, low fertility or weed competition) that reduce carbohydrate supply to the roots during the bulking will decrease root dry matter content.

Water Stress

A preliminary trial with 50 clones showed large differences in yield reduction resulting from a period of rain exclusion maintained from 4 to 7 months after sowing. Trials are now established in the field to follow in more detail the responses of selected clones in an attempt to define the mechanisms of response to water stress and, hence, to identify the factors associated with the maintenance of yield under conditions of water shortage. Results for M Col 22 and M Mex 59 (early and late bulking types, respectively) indicate a highly developed capacity to maintain internal water status within a close range despite a rapidly deteriorating water supply. This is achieved by a combination of reduction in production and expansion of leaves, morphological and physiological modifications to the stomatal system, and the capacity of the fibrous root system to penetrate deep into the soil. Data presented in Figure 7 for M Col 22 show that after the exclusion of rainfall for two months, when below the treated plots the soil water potential was at -15 bars to a depth of 1 m, the combined effect of reduced leaf area and decreased leaf diffusive conductance was able to maintain water potential values in the stressed plants almost equal to those in the control. Under these conditions the plants in the stressed plots had water consumption rates at least 25% less than the controls and were still able to maintain a slight leaf production and apparently, a slight root growth also. It is necessary to elucidate the independent as well as the dependent effects of water stress on the processes of leaf production and of leaf carbon fixation to extend the theories of the control of root growth by carbohydrate production that have already been established for non-stressed conditions.

The response of pot-grown plants to periods of water shortage is also being studied. In these experiments measurement of leaf photosynthesis and transpiration show that a close relationship exists between photosynthetic rate and leaf water potential which is dominated by stomatal closure. The relatively low residual conductance to CO_2 transfer within the leaf, previously defined for cassava under well watered conditions, is further depressed under even short term stress. The applicability of these responses of pot grown plants must be evaluated by comparison with measurements of plant status and response in the

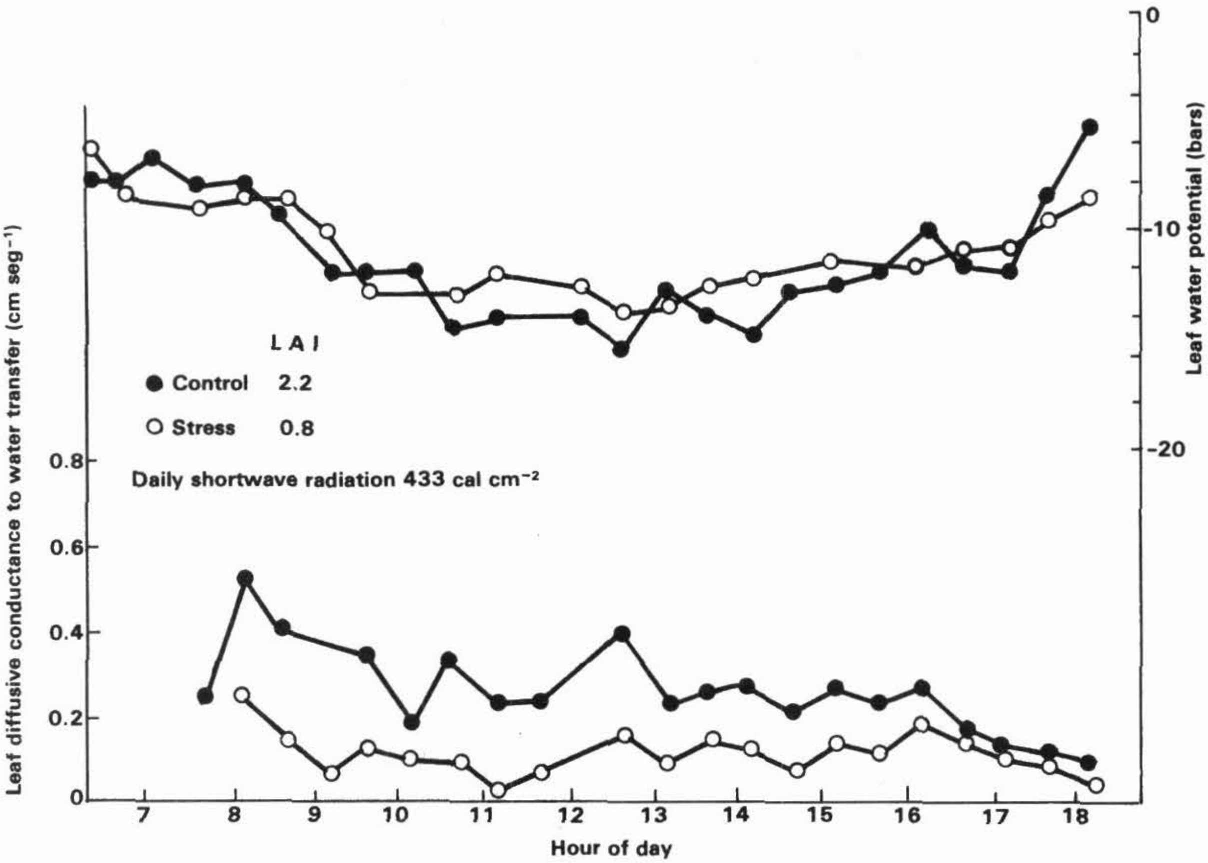


Figure 7. Leaf water potential and leaf diffusive conductance of cassava variety M Col 22 after two months of rainfall exclusion.

field. The water potential of well-watered plants commonly falls to -15 bars during the day but a these levels stomata are considerably more open (Figure 7) than was recorded in the stressed, potted plants. There remains, however, the possibility that internal effects of water stress may restrict photosynthetic carbon assimilation under these as well as under stressed conditions.

ENTOMOLOGY

During 1979 research continued to accumulate necessary information to develop a pest management program for cassava based on varietal resistance, biological control, and cultural practices.

Cassava Hornworm

Studies were continued on *Trichogramma* and *Telenomus,* two important egg parasites in the regulation of *Erinnyis ello* populations. Results show that one *Trichogramma* female can produce a maximum of 133 adults (average of 42.3). One *Telenomus* female can produce up to 228 adults (average of 98.9). One *Telenomus* female parasitized an average of 32.5 eggs of *E. ello,* while the *Trichogramma* female only parasitized an average of 2.5 eggs.

In the cassava areas of Armenia and Caicedonia, Colombia, during the rainy season, a high percentage of pupae of *E. ello* was destroyed by a fungus classified as *Cordyceps* sp. Under laboratory conditions at CIAT the fungus was cultured on oats-agar. *E. ello* larvae, ready to pupate, were placed in sterilized sawdust and inoculated with the fungus. More than 80% of the resulting pupae were destroyed. Research with this fungus will continue.

Light traps

Black-light traps permit the study of population fluctuations of the hornworm; determining periods of greatest or lowest abundance allows for better planning of the application of different pest management techniques. Light traps (bulb F20T 12/BL) placed 5-6 m above ground level captured a maximum of 3094 adults, with the greatest capture between 24:00 and 02:00 hours.

Daily counts in light traps were recorded at CIAT and Risaralda from March to October. Generally more females were captured. Peak months of capture at CIAT were March and April while at Risaralda they were May and August. Captured females continued to oviposit.

Beneficial Insect Bank

During 1979, techniques were developed for maintaining small permanent colonies of the following beneficial insects: *Trichogramma* spp., *Telenomus* sp., *Anagyrus* sp., two species of *Podisus*, four species of Reduviidae, *Kalodiplosis coccidarum*, and the carabid *Calosoma* sp. These beneficial insects, plus instructions for their rearing and release are now available to national programs.

Cassava Fruit Fly

The cassava fruit flies (*Anastrepha manihoti* and *A. pickeli*) can reduce the quality of planting material (CIAT Annual Report, 1977). Studies on damage severity and production of clean planting material were continued in Armenia and Caicedonia. As determined by using McPhail traps with hydrolyzed maize as an attractant,fruit fly populations are greatest when plant age is from 60-150 days; 6-7 months after planting, adult populations are reduced considerably. These results coincide with findings that show that the greatest percentage (97%) of cassava terminals attacked by *Anastrepha* ocurred between 90-120 days.

Bi-weekly applications of insecticides to cassava plants (dimethoate or fenthion) resulted in a high percentage (95.5%) of planting material free of the *Anastrepha/Erwinia* caratovora complex (Table 1) as compared to the control (17.5% clean stakes). Applications at 30, 45, and 60 days did not give adequate control.

Mealybugs

Studies on the biology of mealybugs, yield losses, varietal resistance, and natural enemies were continued during 1979. Until 1978, only *Phenacoccus gossypii* had been identified in Colombia; recently *P. manihoti* was identified in the Llanos Orientales. All studies herein reported refer to *P. gossypii.*

Life cycle

The life cycle of *P. gossypii* was studied on five cassava cultivars (M Mex 59, M Col 655, M Col 1890, M Col 1185 and M Col 1065). Significant differences between cultivars were found in the average duration of the life cycle and in the duration of each instar (Table 2). The life cycle was shortest on M Col 1185 and M Col 655. This indicates that populations could build up faster on these two cultivars. Significant differences

Table 1. Damage caused by fruit flies (Anastrepha spp.) to stakes from cassava (variety Chiroza) plantations treated every 15, 30, 45 or 60 days.

	Undamaged stakes (%)			
Treatment*	15 days	30 days	45 days	60 days
Dimethoate	95.9	35.9	22.1	24.9
Fenthion	92.7	34.4	21.9	26.1
Control	17.5	-	-	-

*At a rate of 0.5 cc i.a./liter of water.

Table 2. Duration of each *P. gossypii* larval instar on 2-month old plants of five cassava varieties under field conditions (mean 72% R.H.; 23.5°C).

Variety	No. of observations	Mean duration of instar (days): 1st	2nd	3rd	4th	5th
M Mex 59	42	9.9	6.2	7.0	6.8	7.56b[1]
M Col 655	15	9.2	5.7	5.5	8.2	7.35bc
M Col 1890	45	11.0	6.0	6.0	8.2	7.70b
M Col 1185	40	8.0	8.0	7.0	7.0	7.20c
M Col 1065	35	10.0	9.0	7.0	6.0	8.02a

1 Mean values followed by the same letter are not significantly different at a 0.05 level.

were also found in the size of females during the different instars, with the greatest increase in size during the last instar.

Distribution and development of populations

Nine cultivars of cassava were infested at 45 days with six *P. gossypii* egg masses and protected in screened cages to prevent attack by natural enemies. Counts showed that 44.9, 41.0, and 14.1% biological stages (nymphs accounted for 95%) were found on the basal, middle and upper third of the plant respectively. Some cultivars presented similar grades of damage but significant differences in populations; M Mex 20 had 2081 mealybugs in different instars, while M Col 22, only had 941.

These differences in duration of life cycle and population development indicate possible differences in susceptibility of the cultivar.

Natural enemies

In Africa, where the mealybug is causing serious crop losses in cassava, only *Spalgis lemoles,* Druce (Lepidoptera: Lycaenidae) is reported as an important natural enemy of *P. manihoti.* In Colombia numerous natural enemies have been reported (CIAT Annual Reports, 1977 and 1978), and during 1979 an additional complex of parasites and predators have been identified (Table 3). Larvae of *Kalodiplosis coccidarum* feed on eggs of *Phenacoccus,* occasionally reaching 100% predation in mealybug colonies. The parasite *Anagyrus* sp. (CIAT Annual Report, 1978) was also abundant and attacked nymphs and female adults.

Termites

The best treatment to prevent termite attack up to 150 days has been with a combination of captan, carbendazin, and aldrin (CIAT Annual Report, 1978). Results in 1979 indicate that termites only attack those parts of the plant that are dying or rotting due to pathogens or physiological processes.

Eighty-one percent of all treated plants were attacked by termites around the initial cutting; however, only 1.73% of the roots were affected by termites.

Slugs

During 1979, frequent attacks of slugs identified as *Vaginulus (Sarasinula) plebeius* (Veronicellidae), were recorded at CIAT-Palmira. Slugs preferably attack stakes and young plants, consuming bark, buds, and leaves. A maximum of 52 slugs were observed on one plant during the night. Excellent control was achieved using methaldehyde mixed with a food attractant and applied around the base of the plant.

Phoenicorprocta sanguinea: This species is a defoliator found in nearly all cassava growing regions of Colombia. As many as four eggs per leaf have been found; however, it is not of economic importance at this time due primarily to its natural enemies. *Phoenicoprocta* has five larval instars with a total life

Table 3. Parasites and predators of *P. gossypii* identified at CIAT-Palmira, 1978-79.

Order	Family	Species	Association
Parasites			
Hymenoptera	Encyrtidae	*Acerophagus* sp.	All are parasites of
		Hexacnemus sp.	nymphs and adult
		Eusemion sp.	females
	Eulophidae	*Prospaltella* sp.	
	Signiphoridae	*Signiphora* sp.	
	Pteromalidae	Unknown genera	
Predators			
Diptera	Cecidomyiidae	*Kalodiplosis coccidarum*	Egg predator
Coleoptera	Coccinellidae	*Coccidophilus* sp.	Egg and nymph predator

cycle from egg to adult of 39 days. Its larvae were parasitized by *Apanteles* sp. that emerged from the prepupal stage. An average of 23.4 (max., 33; min., 12) *Apanteles* adults emerged from each larva.

Whiteflies

Samples of whiteflies on cassava were collected in Nataima (Tolima, Colombia), CIAT-Palmira, and CIAT-Quilichao.

Three species of whiteflies were found attacking cassava at the same time; 92% were identified as *Aleurotrachelus socialis,* Bondar, 4.6% as *Trialeurodes variabilis,* and 2.8% as *Bemisia tuberculata* Bondar.

Studies to determine yield loss and frequency of insecticide applications for controlling whiteflies (*Aleurotrachelus socialis*) were carried out in Espinal, Tolima, with cassava cultivars CMC 40, M Ven 218, and CMC 57. These cultivars were treated every 15, 30, and 45 days with monocrotophos (0.6 cc. a.i./l of water), dimethoate (0.4 cc. ai.i./l of water), and fenthion (0.75 cc. ai.i./l of water).

Applications of monocrotophos and dimethoate were equally effective in decreasing whitefly populations and increasing yield. The best yields were obtained when monocrotophos was applied every 15 days (Table 4). Results of this trial confirm that yield reductions by whiteflies can be severe, as a maximum of 68% reduction was observed for M Ven 218 (Table 5). Nevertheless frequent applications of insecticides not only reduce beneficial insect populations but also increase production costs; therefore, utilization of resistant cultivars and biological control appear to be the best method for supressing whitefly populations.

Mites

Evaluations for resistance

Cultivar evaluations for resistance to mites (*Mononychellus* sp.) carried out over the last two years (greenhouse evaluations, two field evaluations in CIAT and two in Guajira, Colombia) were analyzed. Correlations between blocks within experiments (range $r^2 = 0.64 - 0.32$) and between experiments (range $r^2 = 0.50 - 0.26$) were similar. This indicates that the variety by site interaction is less important than the

Table 4. Effect of insecticides on the average yield of cassava cultivars CMC 40, M Ven 218, and CMC 57 at ICA-Nataima (Espinal, Tolima), 1979.

Treatment	Yield (t/ha) with insecticides applied every: 15 days	30 days		45 days	
Monocrotophos	18.5	15.2	(17.8)[1]	13.6	(26.5)
Dimethoate	15.1	14.4	(4.6)	14.0	(7.3)
Fenthion	10.0	9.6	(4.0)	7.8	(22.0)
Control	7.0				

1 Figures in parenthesis are yield reduction percentages as compared to yield obtained with insecticide applications every 15 days.

varietal effects. Thus the resistance to *Mononychellus* sp. is relatively stable across environments. The average selection efficiency (number of cultivars that were selected in both blocks over total number of cultivars) was about 75%. Data from these and other evaluations have been combined to select 43 promising cultivars for resistance.

Effect of Mononychellus sp. attack on cassava yield

Two yield trials were carried out to study the differential effect of mites (*Mononychellus* sp.) on susceptible and resistant cassava cultivars. A split plot design was used with insecticide-treated (protected with bi-weekly applications of 1-2 cc monocrotophos/l of water) and untreated as main plots and cultivars as subplots. In Guanabanal, Valle del Cauca (Colombia), the four cultivars (M Col 638, M Col 113, M Bra 12, and Enanita) suffered a moderate mite attack during the third month and a heavy attack during months 7 - 9, but no differences in yield between the protected and the unprotected plots were detected. This was expected because of the almost complete defoliation which occurred due to drought and independent of the mite attack in the seventh to ninth month period. The moderate attack in the third month was not enough to decrease yields although differences in mite damage evaluations and leaf size reduction existed between the four cultivars.

Eight cassava cultivars were planted in protected and unprotected plots in Fonseca, Colombia. These plots received irrigation. There was a mite attack from the third month to the seventh month of crop age (Figure 8).

Table 5. Yield of cassava cultivars CMC 40, M Ven 218, and CMC 57 receiving bi-weekly applications of insecticides (monocrotophos, dimethoate, and fenthion) to control whiteflies.

Variety	Yield (t/ha) Monocrotophos		Dimethoate		Fention		Control
M Ven 218	10.12	(68.3)	8.80	(63.5)	5.33	(39.8)	3.21
CMC 57	17.27	(64.8)	13.96	(56.5)	8.70	(30.2)	6.07
CMC 40	28.04	(57.7)	22.55	(46.6)	15.88	(25.2)	11.87

1 Figures in parenthesis are yield reduction percentages as compared to yield obtained with insecticide applications.

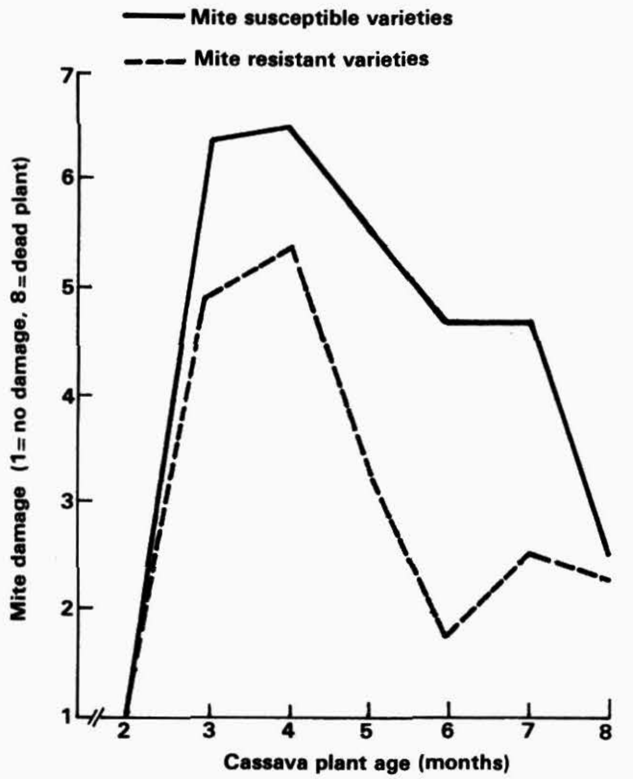


Figure 8. Fluctuation of mite (*Mononychellus* sp.) damage on resistant and susceptible cassava varieties in Fonseca, Colombia (December 1978-June 1979).

According to mite damage evaluations and mite counts the cultivars were separated into a susceptible and a resistant group for analysis. Susceptible cultivars as a whole had significant losses in fresh root yield, number of roots, weight, total plant weight, harvest index, number of planting stakes obtainable, leaf size, leaf formation rate, and plant height, whereas the resistant varieties did not (Table 6). Without insecticide protection both the resistant and susceptible cultivars lost significantly more foliage than with protection but the susceptible cultivars were relatively more affected than resistant cultivars. With respect to root quality, mite attack did not alter dry matter or HCN contents in any cultivars.

Biology of M. tanajoa

The biology of *M. tanajoa* was studied using resistant and susceptible cultivars. Fecundity and two-way preference tests were carried out in growth chambers (28°C night, 30°C day; 12-hour day; 40-70% RH.) using leaf discs on moist cotton in petri dishes (Table 7). Mites on the resistant and tolerant cultivars generally showed a lower fecundity and preference than on the susceptible cultivars. The only exception was M Bra 12. Mite counts in the field on M Bra 12 were comparable to other resistant cultivars. Therefore, there must be some other parameter of M Bra 12 which limits mite reproduction.

Table 6. The effect of a mite (Mononchellus sp.) attack on different parameters of resistant varieties at Fonseca, Colombia (October 1978-June 1979).

Parameter	Change in parameter compared to protected plots (%)[1] Resistant	Susceptible
Yield (kg fresh root weight)	-17.9 ns[2]	-69.4 *[2]
Number of roots per plot	-11.9 ns	-43.0 *
Weight per root (kg/root)	- 9.6 ns	-48.7 *
Weight commercial roots to total root weight	- 5.7 ns	-45.0 *
Branch weight (kg/plot)	+ 0.4 ns	-47.4 *
Total weight (kg/plot)	- 7.8 ns	-60.9 *
Harvest index	-11.1 ns	-26.3 *
Planting stakes obtainable	-19.1 *	-67.3 *
Leaf size (cm^2/leaf)	- 4.9 ns	-34.3 *
Leaf formation rate (leaves/day)	0.0 ns	-13.3 *
Foliage (cm shoot with foliage)	-27.3 *	-42.1 *
Defoliation (%)	+18.5 *	+23.8 *
Plant height (cm)	- 7.7 *	-21.7 *

1 1- (unprotected plot/protected plot).

2 ns = not significant; * = significant at a 0.05 level.

Table 7. Mite (M. tanajoa) fecundity and preference on seven cassava varieties compared to field damage ratings.

Variety	Fecundity (eggs/♀/2 days)	Preference (% of M Col 22)	Damage rating[1]
M Col 22	6.77a[2]	100a[3]	S
M Col 1438	6.05a	98a	S
M Bra 12	5.95a	73b	R
M Ven 125	4.73b	47c	R
M Col 113	4.67b	-	I
M Col 282	4.42b	38cd	R
M Col 1434	3.25c	36d	R

1 Damage rating: R = resistant; I = intermediate; S = susceptible.
2 Figures within columns followed by the same letter are not significantly different at a 0.05 level.
3 Analysis done on two-day mite counts for data from all combination of the varieties.

Studies on the development of *M. tanajoa* under growth chamber conditions on a resistant (M Col 1434) and a susceptible (M Col 22) cultivars were carried out using detached leaves (lobes and discs). Results showed that mites developed slower, had shorter adult lives and had higher nymph mortality on the resistant cultivar. These studies indicate that there are both non-preference and antibiotic resistance mechanisms against mites in cassava.

Tetranychus sp.

Studies on preferences and fecundity were done under growth chamber conditions with *Tetranychus urticae*. Cultivars tested were the resistant M Col 282, M Col 1434, M Ven 125, and M Bra 12 and the susceptible M Col 1438, M Col 22, and M Ven 173. The leaf-disc technique, which consists in cutting 1.8 cm diameter leaf discs, placed on moist cotton in petri dishes was the standard method used.

All possible combinations of the resistant and susceptible cultivars were tested. Ten adult female mites were placed on each disc, which slightly overlapped with a disc of a different cultivar thereby testing two cultivars with each repetition in incubators (12 hours light; 30°C day 27°C night; 50-70% RH).

Results after three days showed that 70% of the mites were feeding on susceptible cultivars. The highest oviposition also occurred on the susceptible cultivars. These results indicate both a feeding and an ovipositional preference for the susceptible cultivars. Among resistant cultivars there was no significant difference in preference for feeding nor oviposition. Under growth chamber conditions (12 hours light; day temperature 30°C; night temperature 27°C; and 40-70% RH) females of *T. urticae* from two distinct sources (susceptible variety, M Col 22 and resistant variety M Col 1434), were placed on a range of resistant and susceptible cultivars.

Fecundity, in general, was less on resistant cultivars (M Col 1434, M Col 282, M Bra 12, and M Ven 125) than on susceptible ones (M Col 22, M Ven 173, and M Col 1438). The source influenced the fecundity of the female. Females developed on susceptible cultivars oviposited more than those from resistant cultivars regardless of whether they were placed on resistant or susceptible cultivars (Table 8).

During nine continuous months the cultivar M Col 22 was submitted to an attack of the mite *M. tanajoa* at an average damage grade of 2.9 (scale of 0-5). During this time the same cultivar was treated every 15 days

Table 8. Mite (*M. tanajoa*) development and mortality on detached leaves under growth chamber conditions (28°C night, 30°C day, 40-70% R.H.).

	Damage rating[1]	Time to adult (days)	Adult life (days)	Nymphal mortality 1	Nymphal mortality 2
M Col 22	S	9.2b[2]	5.6a	55%	34%
M Col 1434	R	9.9a	3.6b	74%	52%

1 Damage rating: S = susceptible; R = resistant.
2 Figures within columns followed by the same letter are not significantly different at a 0.05 level.

with monocrotophos (1 cc/l of water). Observations showed that leaf area on the unprotected plants was 25.7% less than on the insecticide-treated plants due to the reduction in leaf size caused by the mite attack.

Wide Type Resistance

In collaboration with the Cassava Pathology Section a five-year study was initiated to identify sources of resistance to several diseases and insect pests under diverse ecological conditions (CIAT Annual Report, 1978).

Between the five ecosystems that are being studied CIAT-Palmira presented the greatest number of insect and mite pests while Media Luna and Popayán showed the least number of pests (see Pathology section).

PLANT PATHOLOGY

The relationships between *Xanthomonas manihotis* and *X. cassavae,* two bacterial pathogens of cassava which induce similar symptoms at the angular leaf spot phase, were investigated. Factors influencing the severity of *X. manihotis* and its pathogenic variability under greenhouse and field conditions were also examined.

Studies on survival of *X. manihotis* were undertaken by the techniques of direct immunofluorescence (IF) and the enzyme-linked immunosorbent assay (ELISA).

The variability of *Sphaceloma manihoticola,* the causal agent of the superelongation disease, was tested by inoculating isolates from the same ecosystem but from varieties having different levels of susceptibility and also from the same variety but with different cultural characteristics. In cooperation with Cornell University, Department of Plant Pathology, characterization studies of the growth regulator that induces elongation were undertaken.

Studies on inter-relationships and interactions between cassava, its ecosystem, and biotic problems and their influence on crop improvement programs were carried out in five contrasting ecosystems. The identification of biotic problems in each ecosystem as well as their incidence and severity and the environmental interactions of their occurrence on different genotypes will be recorded over a five-year period. Preliminary results are presented here.

Cassava Bacterial Blight

Taxonomy

Taxonomical studies showed that *X. manihotis* and *X. cassavae,* the causal agents of cassava bacterial blight (CBB) and cassava bacterial leaf spot, respectively, are physiologically and biochemically related. However, mineral analysis of hydrolyzed and non-hydrolyzed polysaccharides of these two organisms showed some differences (Table 9). Serological tests

Table 9. Mineral analysis of non-hydrolyzed polysaccharides (0.04% dilution) of Xanthomonas manihotis, X. cassavae, and a Colombian yellowish isolate.

Element (ppm)	X. manihotis	X. cassavae	Colombian yellowish isolate
N	123.2	145.6	179.2
P	17.5	32.3	17.3
K	8.5	10.0	6.8
Ca	15.0	22.5	10.0
Mg	3.8	5.0	2.5
Na	72.5	70.0	62.5
Mn	0.25	0.25	0.25
Zn	1.50	1.75	0.75
Cu	0.63	0.86	0.63
B	-	0.04	0.08
S	8.0	8.0	10.6

did not show relationships between *X. manihotis* and *X. cassavae,* but the latter was serologically related with some Colombian yellowish isolates. Similarly, differences were found in the symptoms induced by these two organisms under control conditions, up to the angular leaf spot phase. Those induced by *X. cassavae* were slower to develop (12 days) than those of *X. manihotis* (5 days); only *X. cassavae* showed the angular spot phase while *X. manihotis* invaded the inoculated tissues producing leaf spots, blight, and gum exudation along petiols and the stem. It was concluded that *X. manihotis* and *X cassavae* are taxonomically different entities.

Epidemiology

CBB severity was affected by day/night temperature fluctuations under control conditions; constant temperatures reduced disease severity while fluctuating ones increased it (Figure 9). The relationships between percentage of available water in the soil and CBB severity, however, were not significantly correlated when cassava plants were grown on sandy and clay soils with similar nutrient levels.

It had been previously reported that rainfall duration, quantity, and distribution also appear to be important factors affecting the development of CBB epidemics (CIAT Annual Reports, 1973, 1977 and 1978). Data on rainfall accumulation and distribution taken from the Carimagua and Caribia ecosystems (Table 10) during 1978 and 1979 showed that; CBB epidemics in Carimagua during these two years reached the same peak, but during 1979 the most severe epidemics appeared four weeks later than in 1978, possibly because rainfall accumulation (April-July) was less in 1979 than in 1978, and also rainfall during 1978 was more intense following planting in April and May. Similarly, the development of the epidemics at the

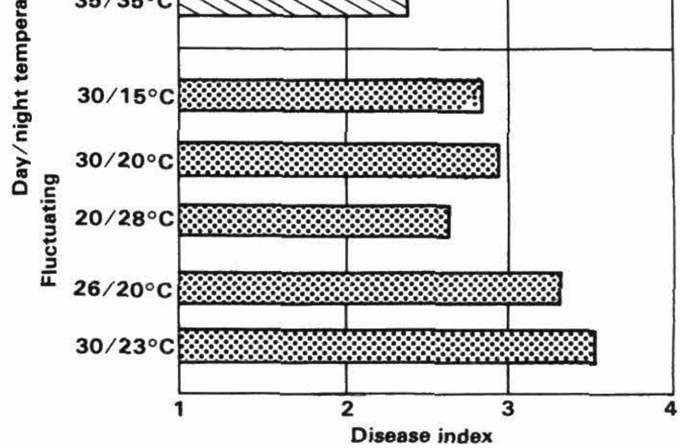


Figure 9. Effects of constant and fluctuating day/night temperatures on cassava bacterial blight severity.

Table 10. Negative production factors (NPFs) that could reduce yields in five different ecosystems in Colombia.

Negative production factors	Locations: Caribia	Media Luna	Carimagua	CIAT-Palmira	Popayán
Climatic conditions					
Mean temperature (°C)	26.0 (ND)[1]	27.2 (ND)	26.1 (ND)	24.0 (ND)	18.0 (S)
Rainfall (mm/year)	1308 (ND)	1326 (ND)	2031 (ND)	1000 (S)	2500 (ND)
Rainfall duration (months)[2]	9 (ND)	9 (ND)	8 (S)	5 (ND)	5 (ND)
Dry period (months)	3 (ND)	3 (S)	4 (S)	5 (ND)	6 (ND)
Edaphic conditions					
pH	6.2 (ND)	6.0 (ND)	4.7 (S)	6 (ND)	4.5 (S)
Al concentration	Low (ND)	Low (ND)	High (S)	Low (ND)	High (S)
Fertility	Good (ND)	Low (ND)	Low (S)	Good (ND)	Low (ND)
Texture	Sandy-clay (ND)	Sandy (ND)	Clay loam (ND)	Clay (M)	Clay loam (ND)

1 (ND) = no damage; (M) = moderate damage; (S) = severe damage.
2 For CIAT-Palmira and Popayán rainfall duration occurs in two seasons during the year while for the rest of the sites it occurs in one season.

exponential phase on susceptible cultivars was higher in 1978 than in 1979. In contrast, CBB severity and epidemic development in Caribia was higher during 1979 than in 1978 due to variation in rainfall accumulation and distribution. Generally, disease severity in Caribia was lower than in Carimagua, possibly due to fluctuating temperatures over a wider range at Carimagua.

Pathogen survival and seed transmission

The epiphitic survival of *X. manihotis* on cassava leaves was reported last year by IITA. Our investigations this year, following direct immunofluorescence (IF) and the enzyme-linked immunosorbent assay (ELISA) tecniques, have reinforced this finding and show that this pathogen can live epiphitically on weeds growing in affected plantations at Carimagua where CBB is endemic (Table 11). It appears that the population of this bacterium living on weed and cassava leaves increases during the rainy season, possibly due to increases in inoculum potential as better dissemination by rain-splash and windflow occur. This finding has implications for the control of CBB by crop rotation or fallowing; the elimination of weeds during these periods is necessary for good control of CBB.

Transmission of *X. manihotis* in sexual seeds of cassava was also studied by direct IF and ELISA assays (Figure 10). The pathogen was detected in seed embryos but not in other tissues. Using similar methods it was also detected in pollen. While both healthy and infected seeds showed no signs of damage due to *X. manihotis,* a concentration of approximately 10^4 cells/ml was encountered in infected embryos. Seed transmission in these tests varied from 0 to 40% and germination of infected seeds was much lower than healthy ones (Table 12). The percentage of embryo infection for ungerminated seeds was 40-60%.

The presence of *X. manihotis* in seed tissues and its low survival have implications for plant quarantine regulations which are generally less strict for true seed than vegetative materials. Care must be taken to deliver true seeds only from disease-free cassava plantations.

Pathogen variability

Possible pathogen/host interactions were studied by the controlled inoculation of 51 isolates from different regions to eight cassava cultivars with a range of susceptibility levels. The virulence of the isolates and the tolerance of the cultivars to them

Table 11. Epiphytic survival of Xanthomonas manihotis on weed leaves determined by both immunofluorescence (IF) and enzyme-linked immunosorbent (ELISA) assays.

Species	Reaction to assay:[1] IF	ELISA
Solanum nigrum americanum	+	+
Sida dictyocarpa	-	+
Emilia sagittata	+	+
Hyptis mutabilis	+	+
Amaranthus dubius	++	++
Melothria sp.	+	+
Euphorbia hirta	-	-
Conyza canadiense	+	+
Centrosema macrocarpum	-	-
Cascaria nitida	-	-
Cissampelos sp.	+	+
Elencina indica	-	-
Digitaria sanguinalis	-	-
Cyperus rotundus	±	-

1 ++ = strongly positive reaction; + = positive reaction; ± = weakly positive; - = negative reaction.

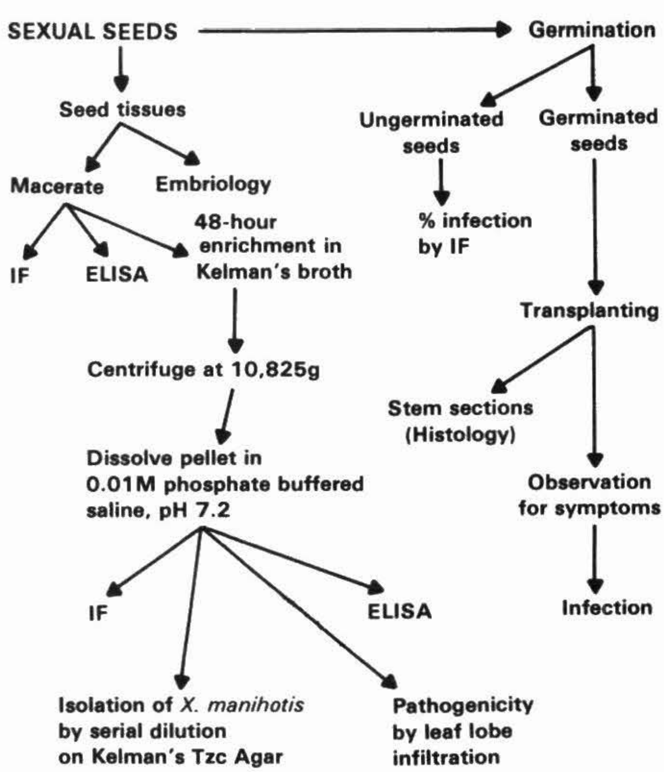


Figure 10. Scheme used for the detection of *X. manihotis* in true seeds by immunofluorescence (IF) and enzyme-linked immunosorbent (ELISA) assays.

varied, but there was no interaction between isolates and cultivars (P = 0.05 level), which implies the absence of races. The reaction of these cultivars under field conditions at Carimagua, Media Luna, and Caribia showed the same levels of tolerance, even though disease severity was higher in Carimagua than in the other ecosystems.

Superelongation

Etiology

Studies carried on by Ziegler, Powell and Thurston (Department of Plant Pathology and Pomology, Cornell University) with five CIAT-isolates of *Sphaceloma manihoticola* have demonstrated that this pathogen produces a plant regulator *in vitro* that was identified as GA_4 gibberellic acid (GA_4). It is interesting to note that no fungus other than *Gibberella fujikuroi*, the causal agent of the so-called bakanae disease of rice, has been unequivocally shown to produce gibberellic acids.

Epidemiology

The development of a superelongation epidemic on susceptible cultivars planted at Carimagua in 1978 and 1979 showed different rates than those observed for

Table 12. Germination and embryo infection of cassava sexual seeds collected from CBB-infected and uninfected fields.

Month of sampling (weather conditions)	Seeds from infected fields[1] Germination[2] (%)	Embryo infection[3] (%)	Seeds from uninfected fields Germination (%)	Embryo infection (%)
January (dry)	-	10	-	0
February (dry)	-	3	-	0
March (dry)	12	5	84	0
April (wet)	6	2	66	0
May (wet)	20	0	74	0
June (wet)	-	40	-	0
Average	13	10	70	0

1 Data taken on an average of 24 seeds/sample.

2 Germination of seeds was under control conditions (28°C; 80% R.H.) on water-soaked paper towels.

3 Positive ELISA reactions were obtained in March and April samples; negative reactions in May samples. Percentage of embryo infection was obtained by the immunofluorescence method.

CBB. In 1979 the disease developed faster than in 1978, but the epidemic of 1978 was more severe than that of 1979. As reported last year (CIAT Annual Report, 1978), this situation implies large disease/environment interactions.

Similarly, as reported in 1978 (CIAT Annual Report, 1978), the disease rating distribution of the 237 cultivars tested during superelongation epidemics at Carimagua in 1979, also showed a bimodal arrangement in June, one group formed by those rated 4-5 (susceptible) and the second group by those rated 1-2 (resistant). As the epidemic increased with time, the distribution became unimodal. However, the initial bimodal distribution was not as striking as in 1978 possibly due to the limited number of cultivars evaluated during 1979 (237) compared to that of 1978 (1348) and to the fact that most cultivars evaluated this year came from ecosystems where superelongation has not been reported. The distribution of CBB epidemics was, as last year, unimodal.

Anthracnose and Phoma Leaf Spot

The development of a combined epidemic of both anthracnose (*Colletotrichum* spp. and *Gloeosporium* spp.) and Phoma leaf spot (*Phoma* sp.) in the Popayan ecosystem on 67 genotypes was examined during a seven-month period in relation to rainfall. Data indicate that in this ecosystem it is necessary to evaluate for resistance after a six-month cycle if planting is carried out at the beginning of the rainy season. The evaluation for resistance to other NPFs existing in Popayan may require longer evaluation periods (15 months) due to the effect of low temperature on cassava growth.

Frog Skin Disease

The transmission of frog skin to several plant-virus differentials and to healthy cassava plants has been attempted with negative results. Preliminary purification assays have also proved negative.

Leaf-symptomless frog skin-infected plants grown under field conditions at CIAT-Palmira have shown severe mosaic symptoms under growth chamber conditions (12 h at 20 and 25°C, 80-140 foot-candle and 80% RH). When these plants were incubated at 600-1000 foot-candle, 80% RH, and 25-30°C, leaf symptoms in new leaves disappeared. However, several frog skin-infected cultivars did not show leaf symptoms under low temperature conditions. This suggests that there are other viral diseases affecting cultivars infected with frog skin of which symptoms are severely developed under low temperature conditions. This was confirmed in Popayan (cool region) and Media Luna (warm region) by planting cuttings from plants of several cassava varieties showing symptomless leaves. Severe mosaic symptoms were observed in Popayan but only moderate symptoms in Media Luna. However, when stakes from plants showing severe mosaic symptoms at Popayan were planted in Media Luna, symptoms remained as severe.

Fifty days after planting the height of plants infected by frog skin was generally greater than that of healthy plants, occasionally double (e.g., cultivar Quilcace). However, frog skin-infected stakes produced fewer shoots. Symptoms of the disease were readily observed in some cultivars as early as three months after planting.

Cassava/Ecosystem Relationships

The relationship between cassava cultivars and ecosystems is being investigated by planting regional and introduced genotypes in five ecosystems (Table 10) and evaluating the most important parameters. Although these studies have been planned over a five-year period, the following results have been obtained so far:

- Several unrecorded biotic problems (diseases, insects and mites) have been identified in each ecosystem affecting introduced cultivars, and their importance has been evaluated based on damage caused on susceptible cultivars (Table 13). It appears that the incidence and severity of biotic problems in cassava are related to the ecological characteristics of a given region. Their identification and the evaluation of their potential importance is better observed on introduced non-adapted cultivars than on the regionally adapted materials.

- Resistance to the main NPFs of a given ecosystem is much higher in cultivars from ecosystems similar to the testing site than in those from ecosystems with a different set of NPFs (Figure 11). When CIAT's germplasm collection (representative of most Latin American countries) was evaluated for its resistance to the NPFs existing in Carimagua and Popayán (Table 10), the resistance to the NPFs of each of these ecosystems was 1.7 and 1.5%, respectively, while the resistance recorded on groups of cultivars collected from these or similar ecosystems was 10.3 and 26.3%, respectively. Similar percentages of resistance were obtained at Carimagua for CBB and superelongation, two biotic problems endemic in this ecosystem (Figure 12). None of the resistant cultivars at Popayan was resistant at Carimagua and viceversa.

This indicates the presence of strong cultivar/ecosystem interactions, at least among ecosystems with different sets of NPFs.

For better evaluation of resistance to the biotic NPFs in a given ecosystem and to obtain a high and uniform stress from the existing biotic problems, cultivars susceptible to biotic NPFs were planted in rows every 10 m with testing material planted in 1m rows of 10 plants and with 2-3 replications (Figure 13). The selected resistant material was planted in a second-cycle trial of 30 plants/cultivars/replication (total of 3 replications). In the Carimagua and Popayan ecosystems the resistance of the first selected material (first cycle) had the same rating for the second cycle and the percentage of resistance for each ecosystem of the first selected material was 85 and 80%, respectively.

- Mean reactions of groups of native cultivars, of germplasm from contrasting ecosystems and of materials from the other three ecosystems, showed that native cultivars of each environment had the highest levels of resistance to the NPFs existing in each ecosystem (Figure 14). No cultivars were resistant to the biotic NPFs of more than two ecosystems.

After six months, mean plant heights of all cultivars varied in relation to each ecosystem indicating that factors other than temperature (possibly edaphic factors) also appear to have a strong influence on plant development (Figure 15).

Two cultivars, one tolerant to an ecosystem with severe NPFs (Carimagua) and the other to an ecosystem with relatively moderate NPFs (Valle del Cauca at CIAT-Palmira), were planted every three months during a 15 month period in another ecosystem with moderate NPFs (Caribia, where most of the NPFs are common to those of Carimagua, but different to those of CIAT). The yield of cultivar Llanera (native to Carimagua) decreased slightly and the rating of NPF resistance was almost constant. In contrast, cultivar M Col 113 (native to CIAT-Palmira), showed a considerable yield decrease from 18.2 to 2 t/ha and striking susceptibility to the NPFs present in Caribia (Figure 16).

Table 13. Biotic negative production factors (BNPFs) to cassava identified and evaluated in five different ecosystems in Colombia.

BNPFs	Location				
	Caribia	Media Luna	Carimagua	CIAT-Palmira	Popayán
Diseases					
Bacterial blight	M[1]	L	S	NP	NP
Superelongation	L	L	S	NP	NP
Concentric-ring leaf spot	NP	NP	NP	NP	S
Anthracnose	M	L	S	S	S
Brown leaf spot	M	S	M	L	NP
Blight leaf spot	M	L	M	L	NP
White leaf spot	M	M	NP	NP	NP
Bacterial stem rot	L	L	L	M	NP
Cassava ash	NP	NP	NP	L	M
Cassava common mosaic	L	L	NP	M	S
Insects					
Hornworm	L	L	S	L	L
Whiteflies	M	M	L	L	L
Thrips	M	L	M	S	L
Lacebugs	L	L	M	M	L
Shoot flies	L	L	L	M	NP
Fruit flies	L	NP	L	L	L
Leaf beatles	NP	NP	NP	M	NP
Gallmidges	L	L	M	L	NP
Termites	L	M	L	NP	NP
Stemborers	NP	NP	M	NP	NP
Leaf cutter ants	NP	NP	M	NP	NP
Mites					
Mononychellus sp.	L	M	L	M	L
Tetranychus sp.	L	L	L	L	NP
Oligonychus sp.	L	L	M	M	M

1 S = severe damage; M = moderate damage; L = light damage; NP = not present.

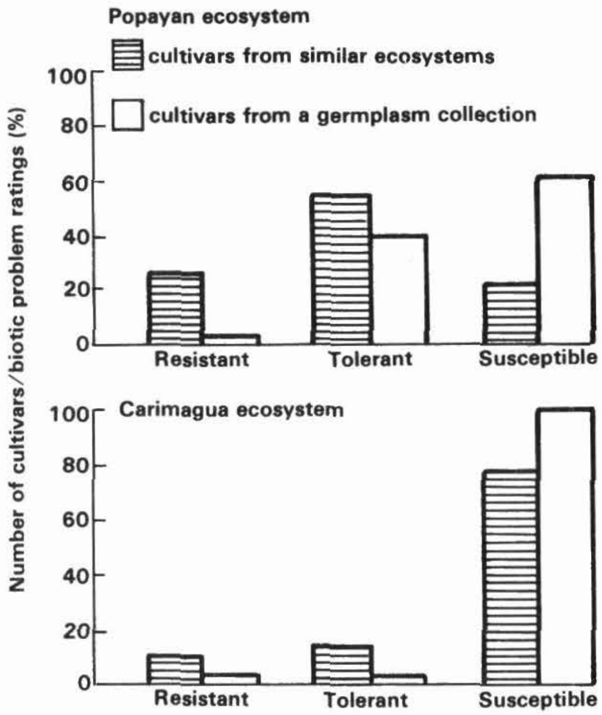


Figure 11. Distribution of cassava cultivars from a germplasm collection and from those collected at similar ecosystems per NPF rating at Popayan and Carimagua.

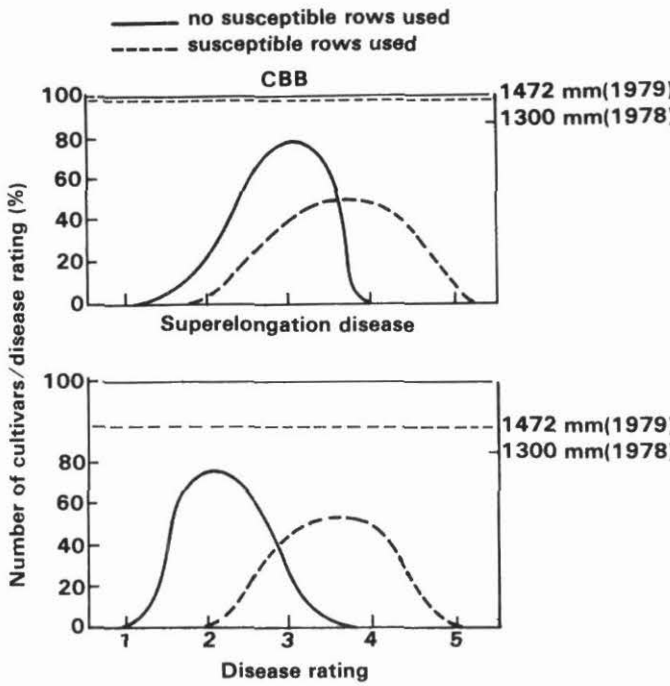


Figure 13. Distribution of cassava cultivars per CBB and superelongation ratings at the highest epidemics when susceptible *plant-rows were planted each 10 m, in relation to controls* (without susceptible plant-rows).

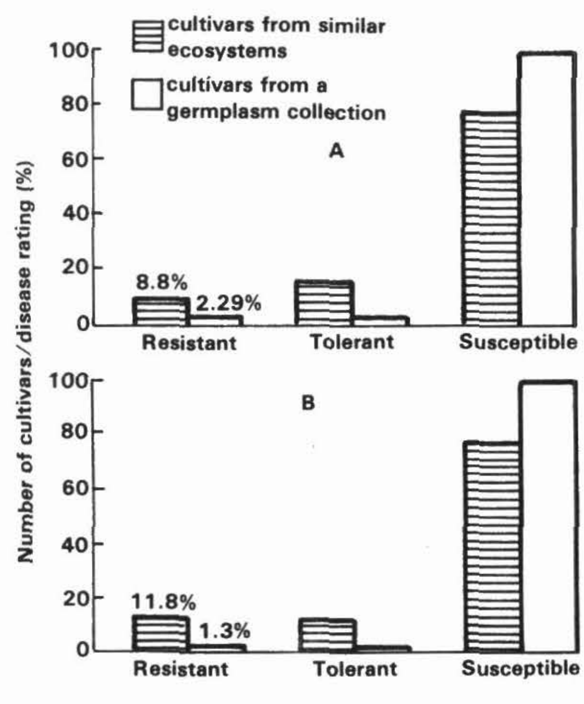


Figure 12. Distribution of cultivars from both a germplasm collection and from cultivars selected at similar ecosystems per CBB and superelongation ratings at the peak of the epidemic of both diseases in Carimagua.

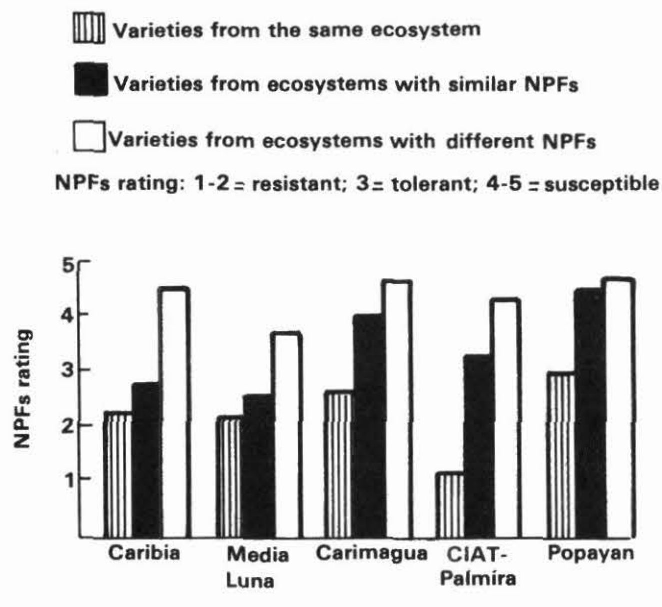


Figure 14. Mean reaction of 25 varieties collected or selected in five different ecosystems to the negative production factors (NPFs) present in each ecosystem.

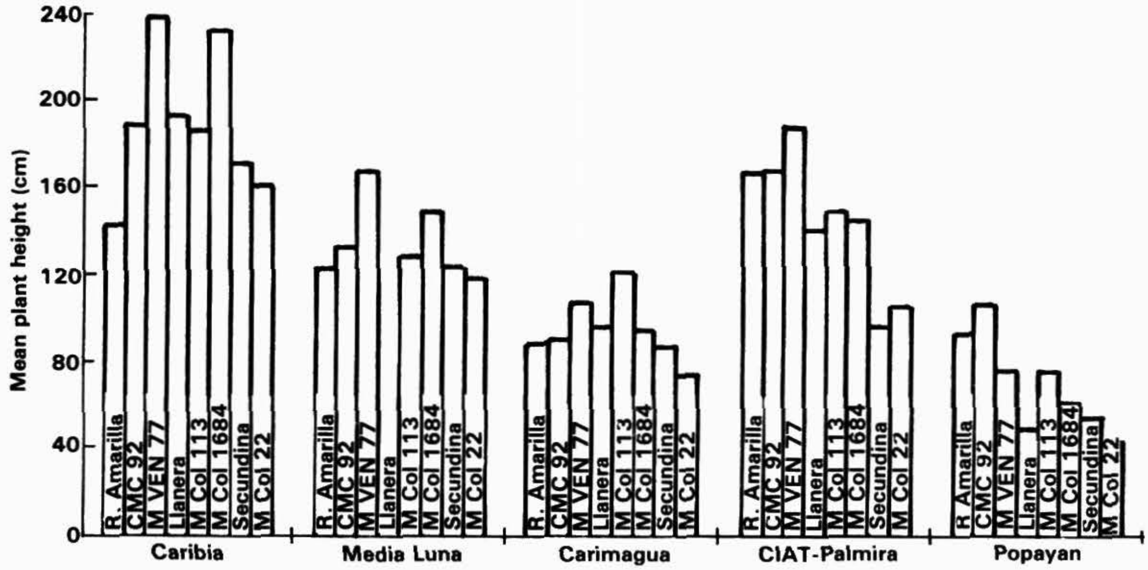
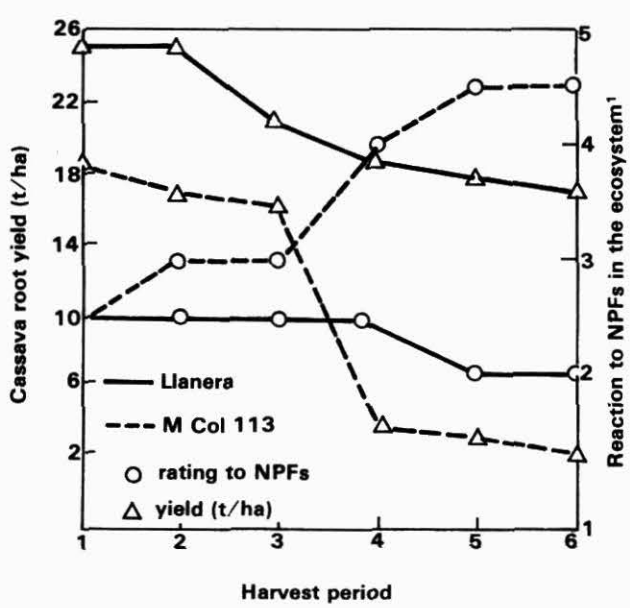


Figure 15. Plant height of eight cultivars, (two from each of four ecosytems) planted in the same ecosystem and at CIAT-Palmira. (Data taken when varieties were six months old.)

This may indicate that at least for diseases and pests, the selected material in ecosystems with severe biotic problems could perform well in other ecosystems with similar but moderate problems. However, if edaphic and climatic factors are constrasting, the performance of the selected material may not be as expected. In contrast, material selected from ecosystems with moderate biotic problems may be severely affected by biotic problems of ecosystems with more severe NPFs or by moderate but different biotic NPFs.



1 NPFs rating: 1-2 = resistant; 3 = tolerant; 4-5 = susceptible.

Figure 16. Effect of negative production factors (NPFs) of the Caribia ecosystem on yield and reaction of cassava cultivars Llanera and Valluna (M Col 113) from eccsystems with different NPFs, planted every three months during a 15-month period.

● Germination, production, and yield of stakes from cultivars susceptible to NPFs present in each of four ecosystems were reduced when replanted in the same ecosystem. However, they were not even slightly reduced when stakes were taken from resistant cultivars grown in the same ecosystem. Germination of stakes from resistant and susceptible cultivars from CIAT-Palmira (an ecosystem with moderate NPFs) was slightly reduced (Table 14). This may indicate that the quality of the planting material produced by a given cultivar is related to biotic (diseases, pests, etc.) and abiotic (climatic and soil factors) pressures on the cultivar during its growing cycle and the genetic capability of such cultivar to overcome such pressures.

Physiological Post-Harvest Deterioration of Cassava

Evaluation of deterioration

A refined version of the method of Marriott (1977) was used for deterioration evaluations in whole roots. Deterioration was allowed to progress from the

Table 14. Ecosystem/cultivar effects on germination, stake production, and yield of susceptible and resistant cultivars to the negative production factors (NPFs) existing in each of four ecosystems.

Ecosystem	Origin of stakes	Germination (%)		Number of stakes		Yield (t/ha)	
		Susceptible	Resistant	Susceptible	Resistant	Susceptible	Resistant
Carimagua	CIAT-Palmira	99	100	3	4	0.9	14.3
	Carimagua	50	99	-	-	-	-
Popayán	CIAT-Palmira	92	97	-	-	2.4	20.0
	Popayán	83	84	1	3	2.0	18.0
Caribia	CIAT-Palmira	97	93	8	13	18.2	25.3
	Caribia	42	86	4	15	1.7	16.8
Media Luna	CIAT-Palmira	73	98	5	10	9.5	25.6
	Media Luna	56	96	-	-	-	-

proximal end only through a 15 cm undamaged section by covering the distal end with PVC film. Transverse cuts made after three days at 2 cm intervals and scored on a 0-10 area-based scale produced a profile of deterioration down the root. This system was used to assess variation in susceptibility to deterioration both within and between cultivars. It was determined that each cultivar has a large variation in susceptibility perhaps depending on chemical root parameters or environment conditions.

Auxin effects

Roots vacuum-infiltrated with auxins showed an increase in their deterioration level; 200 ppm 1 indol acetic acid (IAA) increased deterioration levels by an average of 53.8% and 100 ppm, by 27.0%.

However, intact and pruned plants treated with naphtalene acetic acid (NAA) in lanolin paste at 200 and 500 ppm concentration (the effective concentration reaching the root would have been considerably less than this level) showed decreases in susceptibility to deterioration (Table 15). Even unpruned plants showed large decreases when the pruning-harvest interval was three weeks. It would appear that auxin concentration is a key factor in the response to deterioration.

Correlations with chemical parameters of the root

Plants of four cultivars (M Col 22, Llanera, M Ven 218, and CMC 40) were harvested at each of five ages (7, 9, 11, 13, and 15 months) and data was obtained on starch, cyanide (total and free), dry matter, and deterioration levels for each cultivar/age. A further harvest two months later provided similar data.

Table 15. Percentage change in deterioration produced by NAA at 200 and 500 ppm on pruned and intact M Col 22 plants for 2- and 3-week pruning-harvest intervals.

Auxin concentration	Pruned plants		Unpruned plants	
	2 weeks	3 weeks	2 weeks	3 weeks
NAA 200 ppm	-43.5	+1.4	-0.7	-31.6
NAA 500 ppm	-37.3	+84	-5.1	-45.3

Table 16. Correlations between various root parameters obtained for M Col 22, Llanera, CMC 40, and M Ven 218 at two harvest dates at a two-month interval.[1]

	Deterioration	Starch	HCN total	HCN free	HCN free/total	Dry matter	Age
Deterioration	-	+0.698**	+0.209	+0.120	-0.074	+0.317	+0.029
Starch	+0.633**[2]	-	-0.070	-0.076	-0.013	+0.519*	-0.269
HCN total	-0.164	-0.293	-	+0.789**	-0.040	+0.066	+0.274
HCN free	-0.332	+0.011	+0.541*	-	+0.546	+0.029	+0.398
HCN free/total	-0.183	+0.035	-0.440	+0.460*	-	+0.189	+0.323
Dry matter	+0.372	+0.470*	-0.390	-0.297	+0.196	-	+0.132
Age	-0.217	+0.183	+0.159	+0.400	+0.296	+0.166	-

1 Numbers above diagonal are from August harvest; numbers below diagonal are from October harvest.
2 * = significant at P = 0.05; ** = significant at P = 0.01.

The results show a large variability of almost all parameters for each cultivar over the range of ages harvested. In M Col 22, the August harvest gave total cyanide levels varying from 81 ppm to 44 ppm, deterioration levels from 87 to 60% and starch content from 32 to 36%. However, starch levels were more stable in Llanera (30%) and M VEN 218 (32%).

Inter-and intra-harvest correlations show several relationships existing between the various parameters (Table 16). Overall, deterioration was found to correlate positively with root starch content ($r = 0.627$, $P = 0.01$ for both harvests combined) and not with any other parameter. It is especially interesting that there is no deterioration/age relationship.

Table 17. Correlations of the same parameter between the two harvests, both for plot/plot and age/age.

	Correlation coefficient	
Parameter	Between plots	Between ages of plants
Deterioration	+0.728*[1]	+0.849**
Starch	+0.465	+0.608**
HCN total	+0.628**	+0.568**
HCN free	+0.493*	+0.367
HCN free/total	+0.289	+0.049
Dry matter	+0.362	+0.456*

1 * = significant at P =0.05; ** = significant at P = 0.01.

There is some indication of a negative correlation between total root cyanide content and deterioration within each cultivar. Experiments in which these analyses were carried out on individual roots showed a positive correlation between deterioration and root free cyanide content ($r=0.738$, $P=0.05$). Further research on cyanide content will continue.

The various parameters demonstrate a good correlation between the two harvest both for the same plot at each harvest and, even more, for plants of the same ages but of different plots (Table 17).

Induction of deterioration

Vascular streaking was induced in fresh root slices when placed in contact with pre-deteriorated tissue in sterile conditions for 24 hours. Streaking consistently appears only below the contact area. In one experiment of 20 replications, the number of deteriorated vessels in fresh tissue controls was minimal ($3.6\ cm^{-2}$), while deteriorated tissue produced $47.0\ cm^{-2}$ below the contact area, and only with $0.3\ cm^{-2}$ on the same slices outside the contact zone. This is further evidence of the presence of a translocatable initiating factor.

GERMPLASM DEVELOPMENT

During late 1978, the Germplasm Development section was created as a new unit within the CIAT cassava program. This new section has responsibilities in collection, maintenance, evaluation and distribution of cassava germplasm, and genetic improvement toward several broadly defined goals. Since this is the first review of this section in a CIAT Annual Report, the specific objectives and methodology will be given in some detail.

During 1979 principal activities were in the areas of compilation and computerization of data on cassava germplasm, the development of an improved system for germplasm maintenance in the field, evaluation of germplasm accessions in several high stress sites (Carimagua, Popayan and the Guajira), and initiation of a breeding program to develop source populations for adaptation to moderate and high stress cassava growing areas.

Germplasm Collection and Maintenance

The present status of CIAT's cassava germplasm collection is presented in Table 18.

Although Colombia has been relatively well collected, there still remain areas from which few or no genotypes have been obtained. Examples are parts of the Llanos Orientales, Amazonas, Choco, and the southwestern part of Colombia. Future collections within Colombia will concentrate in these areas.

Table 18. Present status of CIAT's cassava germplasm collection.

Country of origin	No. of accessions
Colombia	1707
Venezuela	205
Ecuador	131
Perú	99
Cuba	67
Mexico	67
Brazil	53
Panama	21
Puerto Rico	16
Costa Rica	15
Dominican Republic	5
Paraguay	4
Bolivia	3
Total	2393

Three collections were made within Colombia during 1978-79. The first was in Huila at altitudes of over 1500 m, with the purpose of increasing the frequency of accessions adapted to cool climates and tolerance to *Phoma* leaf spot. The 27 clones collected are being evaluated in Popayan and several show promise of good adaptation. A second collection was made in the Llanos Orientales, near Yopal, Casanare, where 34 varieties were collected. They are being evaluated at Carimagua as sources of resistance to bacteriosis, superelongation, and adaptation to acid infertile soils. Near the end of 1979 an expedition was made to Amazonas near Leticia, Colombia, and 150 cultivars were collected. Very little material has been previously collected in this area, although one of CIAT's most consistently high yielding genotypes across several locations, M Col 1684, was collected at Leticia. Eighty four Cuban varieties were introduced into CIAT this year and are under evaluation at CIAT-Palmira.

A standardized collection form has been developed to maximize the information available on each new accession.

The number of accessions brought to CIAT from national program collections will increase in the future as the Instituto Colombiano Agropecuario, ICA, has approved meristem culture introduction of material from other countries. This methodology will facilitate quarantine procedures and assure the introduction of clean material to CIAT. The first collection introduced to CIAT by this method was from northern Peru. High priority will be given to receiving the Brazilian cassava germplasm, since that collection represents one of the world's greatest resources of variability. Meristem culture also increases the possibilities for sending CIAT material to national programs for testing and incorporation into breeding programs.

Cleaning of the germplasm bank by passing each accession through meristem culture is under way by the Genetic Resources Unit. Eventually all accessions will be passed through meristem culture, both as a means of laboratory storage in test tubes, and to eliminate possible accumulation of virus and other diseases within clones that have been propagated vegetatively for many generations (see section on Cassava Tissue Culture).

Sexual seeds of 13 wild species of *Manihot* were introduced into CIAT from the collection of Dr. N.M.A. Nassar working at the Universidade Federal de Paraiba, Areia, Brazil. These will be evaluated for potential contributions to cassava breeding, and crossability with cultivated cassava.

Germplasm Evaluation

Nearly all the cassava germplasm accessions have been evaluated at CIAT-Palmira in a preliminary evaluation for yield, root form and quality, plant growth habit and other traits (CIAT Annual Reports, 1973-1975). After this initial evaluation emphasis is being placed on performance in four moderate to high stress environments in Colombia: Carimagua (low pH, low P, bacteriosis, anthracnose, superelongation); the north coast (drought, mites, *Cercospora* sp.); Popayan (low temperatures, *Phoma* leaf spot, anthracnose); and CIAT-Quilichao (low pH, low P, drought, thrips). These sites represent combinations of several of the major stress factors which occur in a large percentage of the world's present and potential cassava growing areas.

The primary goal is to identify genotypes with moderate to high tolerance/resistance to a combination of all production limiting factors rather than narrow attention on individual traits by specific disciplines. Emphasis in all environments is given to final yield as the integrating measure of tolerance to all stress factors and yield potential. In all sites cultivars have been found having wide resistance.

Carimagua

During the 78/79 growing season, 1370 germplasm accessions were evaluated for adaptation to Carimagua conditions. The majority were highly susceptible to both bacteriosis and superelongation (CIAT Annual Report, 1978). One hundred-three accessions were selected based on root yields, harvest index, and disease resistance. These were planted in large plots for re-evaluation. Most of the remaining materials in the germplasm bank not previously evaluated in Carimagua have been replicated in single row plots. As in previous evaluations, only a small percentage showed moderate to high levels of resistance to CBB and superelongation.

Popayan

The preliminary screening trials planted last year in Popayan have been harvested and re-selected. Three germplasm accessions (M Col 741, M Col 862, and M

Col 1292) and two hybrids (CM 35-36, and CM 327-55) were selected as promising and planted in a replicated yield trial. Few hybridizations have been made specifically for adaptation to this environment; consequently significant gains could be expected from crosses among the best germplasm accessions.

Media Luna

Last year the Pathology section initiated an evaluation of 392 germplasm accessions at Media Luna in the North Coast of Colombia. The trials are intended to determine whether there exists a broader germplasm base with good adaptation to the North Coast conditions than the one presently known. One hundred-one accessions were selected at harvest based on root yield, harvest index, and resistance to the adverse factors of the area, and replanted in a replicated yield trial.

Fonseca

Trials were first begun last year in Fonseca, Guajira by the Entomology section for study of mite (*Mononychellus*) population dynamics and host plant resistance. This site provides a very effective environment for screening for mite resistance and drought tolerance, and this year a more extensive screening of germplasm has been initiated. At present 314 germplasm accessions and 12 hybrids are being evaluated in single row trials with two replications. One replication will be irrigated so that the only major stress is from mite attack, and the other replication will be subject to both water stress and mite attack. It should be possible to get an indication of severity of mite attack as related to water stress of the plant.

Development of Resource Pools

Although the CIAT germplasm collection covers an extensive range of genetic variability, further definition and improvement are desirable to make this resource more readily utilizable by breeders in national programs. The breeding activities of the Germplasm Development section are not aimed at producing a finished product, but rather sources of variability that can be further adapted and refined by national programs and by the Varietal Improvement section. Basic sets of environmental conditions should be defined, and for each of those environments a separate gene pool developed with a broad genetic base to leave ample opportunity for local selection. The definition of selection environments follows from characteristics of major present and potential cassava growing regions. Resource pools will be based on a diverse germplasm base of genotypes with the necessary adaptation/resistance characteristics, with subsequent selection for high yield potential and root quality.

Three germplasm pools are under development. The selection environments of Carimagua, Guajira, and Popayan were chosen as being representative of various combinations of stress factors that occur over extensive cassava-growing areas. It is expected that a few cycles of selection and recombination will be required to develop a well-adapted population for each area, after which more emphasis can be placed on yield and quality characteristics.

In addition to formation of the basic pools described above, studies are in progress on variability within the CIAT cassava germplasm for maturity, root HCN content, and post-harvest deterioration.

Rapid Screening for Root Starch Content

Root starch content is of critical importance to quality and market acceptability of cassava (CIAT Annual Report, 1978). A breeding program could benefit from a rapid screening method in the early stages of selection in order to maximize progress in combining high starch content with yield and adap-

Table 19. NaCl concentration and specific gravity of solutions used in rapid screening for cassava root starch content.

NaCl concentration (g/l)	Specific gravity (24°C)	Root starch content (%)
50.5	1.0350	20
99.3	1.0675	25
150.5	1.1005	30
203.5	1.1330	35
256.1	1.1660	40

Table 20. Change in specific gravity of NaCl solution after passing different numbers of cassava root samples.

Initial NaCl concentration (g/l)	No. of samples passed 50	100	150	250
50.5	2.8[1]	6.3	6.3	8.7
99.3	3.4	4.7	4.7	7.2
150.5	1.5	4.9	4.7	6.3
203.5	3.1	3.1	4.6	7.5
256.1	1.9	1.9	1.9	3.0

1 Percentage decrease from specific gravity of original solution.

tability characteristics. The method based on the relationship between specific gravity and starch content has been simplified for more rapid screening. Roots are sampled with a cork borer, and the samples passed through a series of NaCl solutions of varying specific gravities (Tables 19 and 20). Starch content can be rated by the specific gravity of the solution in which the sample first floats, going from lowest to highest specific gravity.

The principle is the same as the traditionally used method of determining specific gravity by weight in air and weight in water, but sampling is considerably faster. The two methods were compared and a highly significant correlation exists between them (Figure 17). In addition to usefulness as a rapid screening method, this technique could be used as a simple evaluation method where the facilities are not available for a more accurate determination.

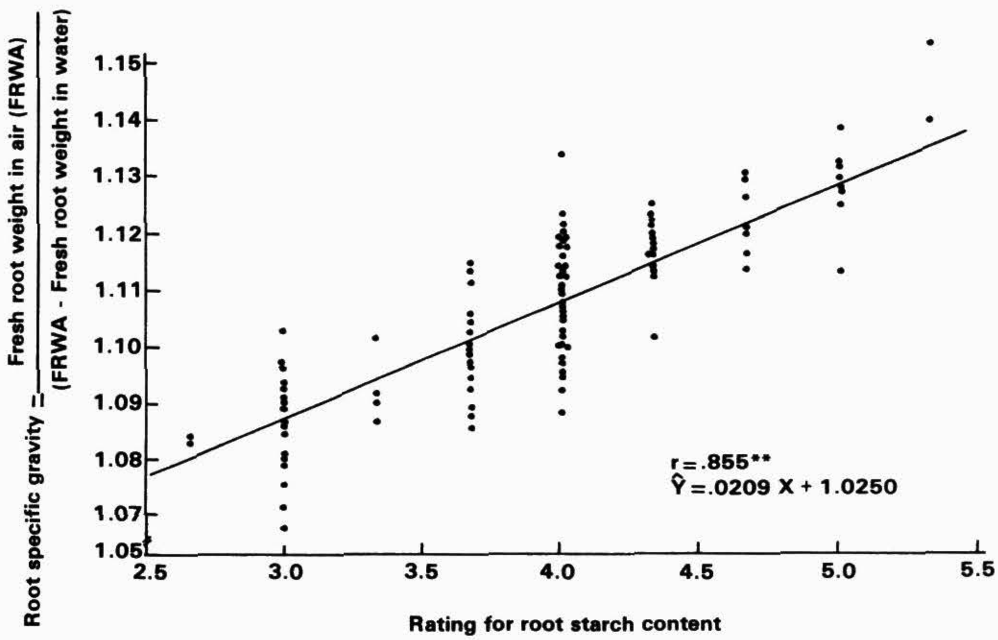


Figure 17. Linear relation between rapid screening method for starch content and traditional root specific gravity method. (Data for specific gravity were taken from trials carried out in the Cassava Varietal Improvement Section.)

VARIETAL IMPROVEMENT

Yield Trials

Hybridizations, selection of F_1 seedlings, observational yield trials (single-row trials), and replicated yield trials were continued at CIAT, Caribia and Carimagua.

At CIAT, 46 lines (25% of all entries) yielded more than 50 t/ha/year and the maximum yield was 82.2 t/ha/year (Figure 18). These lines considerably outyielded the best germplasm accessions (M Ven 218 and M Col 1684) and the local cultivar (M Col 113 or Valluna). Root dry matter content was generally high with an average of 0.335.

A similar result was obtained at Caribia (Figure 19). Several lines yielded more than 50 t/ha/year and the maximum yield of 66.4 t/ha was obtained by CM 323-403 which was harvested nine months after planting. The best germplasm accession, M Col 1684, was as good as the best hybrid lines.

Low root dry matter content has been the general characteristic of the Caribia harvest. High temperature is believed to be a major cause of low dry matter content. In Caribia a harvest done eight months after planting gave an average yield for all genotypes of 27.3 t/ha and an average dry matter content of 0.322. For the 12-month harvest, the average yield was 34.9 t/ha and the dry matter content, 0.280. Several lines such as CM 91-3, CM 342-170, CM 430-9, and CM 440-5 gave average yields of 40 t/ha and a dry matter content of 0.34 at the 8-month harvest. The majority of the genotypes had good eating quality at the 8-month harvest while few remained with acceptable eating quality at the 12-month harvest.

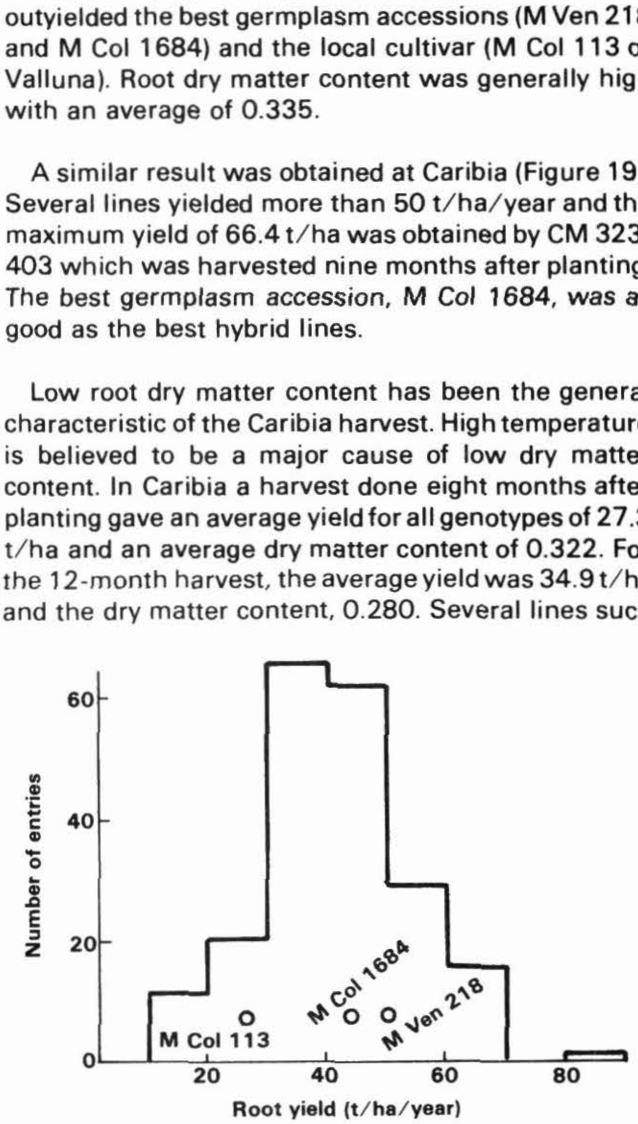


Figure 18. Frequency distribution of CIAT cassava lines at different yield levels in replicated yield trials carried out at CIAT-Palmira, 1979.

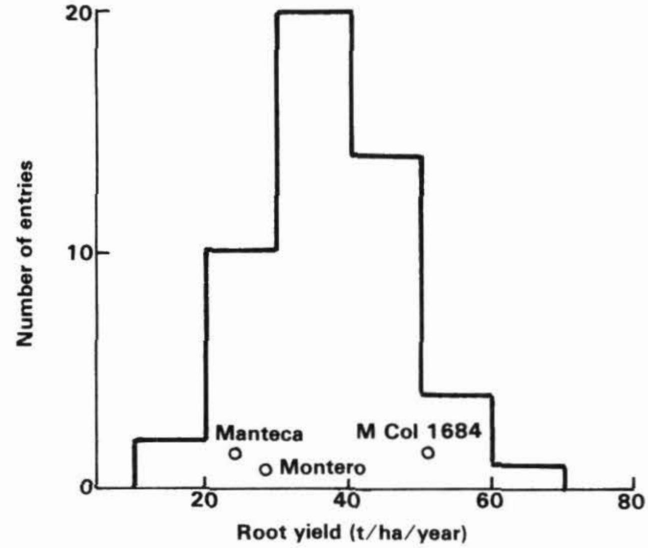


Figure 19. Frequency distribution of CIAT cassava lines at different yield levels in replicated yield trials carried out at Caribia, 1979.

While low root dry matter content is a general characteristic of cassava in high temperature climates, early harvesting may solve the problem to some extent. Results also suggest that selection for early production should be considered.

In Carimagua, resistance to CBB and superelongation has been a major concern. Other causes of low yields are low soil fertility and insect pests. Average yields in Carimagua were much lower than those obtained at CIAT-Palmira and Caribia. In a trial planted in May, five lines outyielded the best local cultivar, M Col 638 (Figure 20). In the October trial about 50% of lines outyielded M Col 638 and eight genotypes, including the best germplasm accession M Col 1684, yielded more than 25 t/ha/year (Figure 21).

CBB and superelongation ratings of the most recent populations (those of replicated yield trials planted June 1979) were compared with those of the original germplasm population planted in 1974 (Figures 22 and

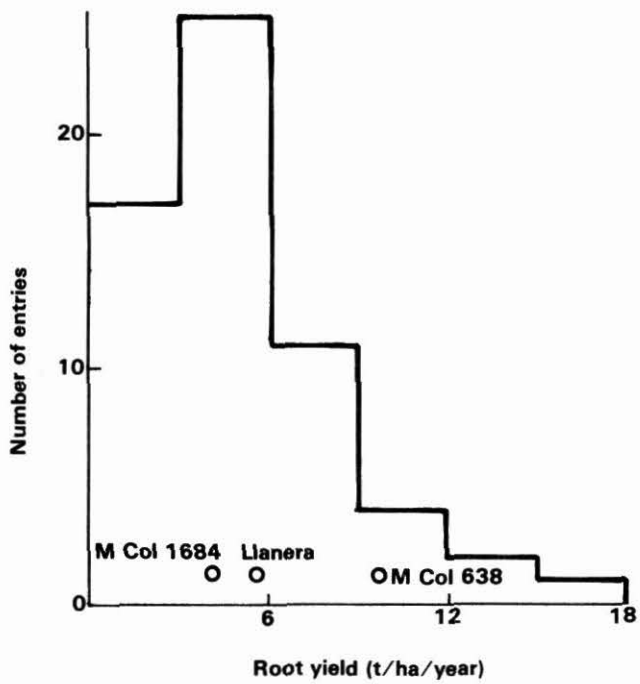


Figure 20. Frequency distribution of CIAT cassava lines at different yield levels in the May replicated yield trial at Carimagua, 1979.

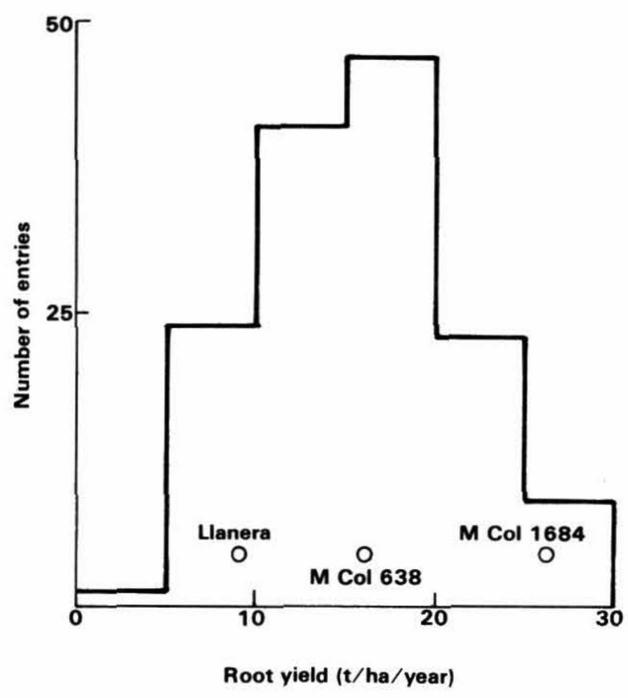


Figure 21. Frequency distribution of CIAT cassava lines at different yield levels in the October replicated yield trial at Carimagua, 1979.

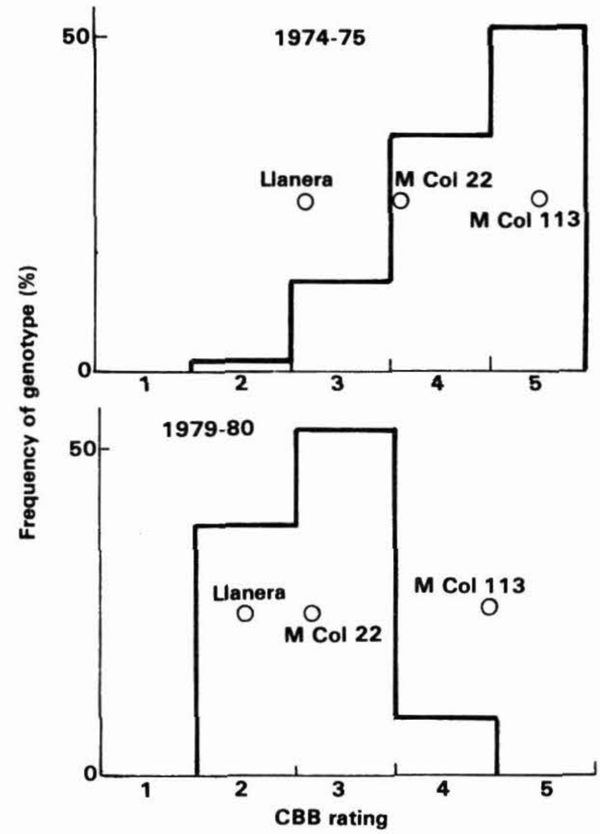


Figure 22. CBB reaction comparisons between unselected (original germplasm accession of 1974-75 and selected CIAT lines of 1979-80) populations in Carimagua.

23). The effect of selection in Carimagua for resistance to CBB and superelongation has been highly significant.

Outstanding Germplasm Accessions

Through several years of repeated evaluation in and outside CIAT's headquarters in Palmira, the following germplasm accessions have been confirmed to be outstanding and thus merit special description (Table 21).

M Col 1684

In terms of yield and wide adaptability, M Col 1684 is clearly the best among all the germplasm accessions. It is moderately resistant to CBB and superelongation and is particularly well adapted to the Caribia and Carimagua environments. Its high yield is mainly due to its extremely high harvest index. Its shortcomings include high HCN content, high susceptibility to thrips and difficulty of harvest. Roots are bitter and not acceptable for fresh consumption. High susceptibility

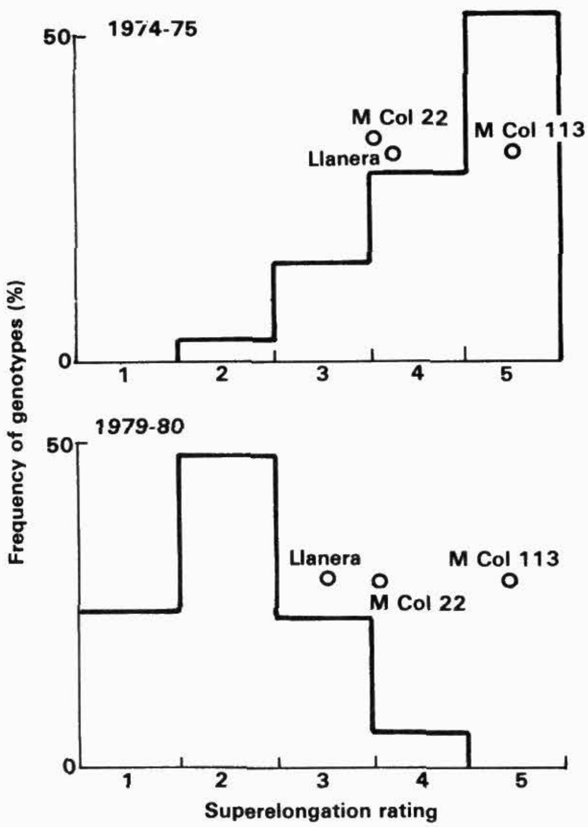


Figure 23. Superelongation reaction comparisons between unselected (original germplasm accession of 1974-75) and selected (CIAT lines of 1979-80) populations in Carimagua.

to thrips may be the cause of relatively unstable yields in certain locations, such as CIAT-Palmira.

M Col 1684 was originally collected by ICA from the Leticia area of Colombia and registered as CMC 163 in ICA's cassava germplasm collection. M Col 1684 received much attention in 1974 when it showed a very high harvest index in a germplasm evaluation at CIAT-Palmira, ranking ninth among 230 selected germplasm accessions evaluated in a replicated yield trial in 1975. Special recognition was given to M Col 1684 when it significantly outyielded all other germplasm accessions at Caribia and Carimagua in 1976.

Since 1975, 21,000 hybrid seeds have been produced with M Col 1684 of which about 5000 have been distributed to national programs in America and Asia. Some 18,000 open-pollinated seeds which include M Col 1684 in their genealogy have been sown at Carimagua for seedling selection. In addition 4500 open-pollinated seeds have been sent to national programs. Some selections from the earliest crosses with M Col 1684 such as CM 507-34 and CM 507-37 (Llanera x M Col 1684) are showing promising results both at CIAT and Carimagua.

M Col 1468

M Col 1468 is widely known as Mantequeira in Brazil. It was developed by the Instituto Agronomico de Campinas in Brazil and registered as CMC 40 in ICA's collection in Colombia. Although it is not as high yielding nor as widely adapted as M Col 1684 it gives reasonably high yields under varying conditions. Its drawbacks are low root dry matter content, susceptibility to thrips, susceptibility to root rotting before harvest, and lodging. About a thousand hybrid seeds were produced and several selections such as CM 342-52 and CM 342-170 (M Col 22 x M Col 1468) are being intensively evaluated.

M Ven 218

M Ven 218 was first included in the yield trial with selected germplasm at CIAT-Palmira in 1975; under these conditions it has yielded 30-60 t/ha/year and has ocassionally yielded well at Caribia. Root starch content is high and roots are highly preferred for fresh consumption. High susceptibility to CBB and difficulty of harvest are its major drawbacks. Some other accessions show similar characteristics to M Ven 218. Approximately 6500 hybrid seeds have included M Ven 218 or similar types as parents. Crosses with CBB resistant types have given favorable results in the Carimagua environment.

Promising Lines

Six to 10 lines per year are passed to the Agronomy section for multiplication and planting in the regional trial network. These promising lines can be grouped into the following classifications (Table 21).

Lines with stable performance

CM 430-37 has demonstrated fairly good yield stability over different locations (64 t/ha/year at CIAT-Palmira, 36 at Caribia, 27 at Villavicencio, and 23 at Carimagua) although its yield has never been exceptionally high in any location. CM 430-37 is one of the best selections from a cross between Llanera and M Col 647, both from the Llanos Orientales. It is

Table 21. Characteristics of promising cassava lines and germplasm accessions which have performed well both in and outside CIAT-Palmira environment.

Genotype	Cross (year)	Fresh root yield (t/ha/year)				Root starch content	Eating quality	Ease of harvest	Disease reactions[1]	
		CIAT	Caribia	Villavicencio	Carimagua				CBB	Superelongation
Promising lines										
CM 430-37	Llanera x M Col 647 (1974)	64	36	27	14-23	Medium	Good	Average	MR	MR
CM 91-3	M Col 688 x Llanera (1973)	43-49	42	-	10-22	Medium	Good	Average	MR	MR
CM 430-9	Llanera x M Col 647 (1974)	40-52	43	-	10-20	Medium	Good	Average	MR	MR
CM 440-5	Llanera x M Col 647 (1974)	43-54	49	-	10-25	Medium	Good	Average	MR	MR
CM 523-7	M Col 655A x M Col 1515 (1975)	46	-	-	15-28	High	Good	Average	R	R
CM 321-188	M Col 22 x M Ven 270 (1973)	61-67	42-52	24	5-14	High	Good	Easy	S	S
CM 489-1	M Col 822 x M Ven 270 (1975)	79	41	33	-	Medium	Acceptable	Easy	S	S
CM 323-403	M Col 22 x M Mex 59 (1973)	-	48-66	-	-	Low	Poor	Easy	S	S
CM 342-170	M Col 22 x M Col 1468 (1973)	14-28	42-51	-	-	Medium	Good	Easy	S	S
Outstanding germplasm accessions										
M Col 1684		25-51	23-50	31	10-26	Low	Unacceptable	Difficult	MR	MR
M Col 1468		31-46	25-40	24	12-22	Low	Acceptable	Easy	MR	S
M Ven 218		32-60	21-37	-	5-15	High	Good	Difficult	S	MR
Controls										
Llanera		20-29	9-30	14	5-15	Low	Good	Difficult	MR	MR
M Col 22		13-31	21-44	18	4-19	High	Good	Easy	S	S

1 Ratings for cassava bacterial blight (CBB) and superelongation: S = susceptible; MR = moderately resistant; R = resistant.

significantly better than Llanera regarding harvest index, ease of harvest, root dry matter content, and CBB resistance. CM 91-3, CM 391-2, CM 430-9, and CM 440-5 are similar lines.

Lines with resistance to CBB and superelongation

CM 523-7 has ranked first in two yield trials at Carimagua (15 t/ha/year in the May planting and 28 t/ha/year in the October planting) although its yield at CIAT-Palmira was poor. It is resistant to CBB and superelongation and high in root dry matter content (37 and 38% at Carimagua and 39% at CIAT-Palmira). This combined resistance in one line with high root dry matter content is new, as previous types adapted to the Llanos Orientales such as Llanera, M Col 647, M Col 638, M Col 1684 or M Ven 77 have low dry matter content. Although other lines show even higher levels of resistance than CM 523-7, their yields have not been impressive.

High-yielding lines under good conditions

CM 489-1 yields very well at CIAT (79 t/ha/year), Caribia (41 t/ha/year), and Villavicencio (33 t/ha/year). CM 321-188 has repeatedly given a high yield at CIAT (61 and 67 t/ha/year) and Caribia (42 and 52 t/ha/year). However, their high susceptibility to CBB and superelongation restricts their use in disease-infested areas.

Lines adapted to hot lowland climates

CM 323-403 ranked second (48 t/ha/year) at Caribia in the 1977 trial and first in 1978 (52 t/ha/year) and 1979 (66 t/ha/9 months). The second and third plantings of this line were made using locally grown stem cuttings. This indicates good adaptation of this line to Caribia conditions. Its performance has not been impressive under CIAT-Palmira conditions. CM 342-170 has demonstrated a similar tendency in performance.

Harvest Index for Selecting Across Environments

Selection for higher harvest index has been the major tool for obtaining high yielding genotypes. To test whether harvest index is a valid selection criterion over a wide range of environmental conditions, the relative importance of harvest index and total weight to root yield was analyzed at different yield levels in different locations using data from six replicated yield trials carried out at CIAT, three at Caribia and three at Carimagua over the past three years (Table 22). Although genotypes used were not the same throughout the trials, many common genotypes were included. Thus the average yield of all genotypes in each trial could be regarded as an indicator of the environmental productivity level. A trial of early season planting at Carimagua offered an analysis at the lowest yield environment with an average yield of 4.9 t/ha/year while one trial at CIAT offered the highest yield environment with an average yield of 42.1 t/ha/year.

Under both very high and very low yielding environments, harvest index was highly correlated to root yields (Figure 24). The relative importance of harvest index was high across all the locations and yield levels. The relative importance of total plant weight tended to be greater under low than under high yield environments. Hence total plant weight was less important than harvest index at CIAT-Palmira, while it was equally important at Caribia. At Carimagua, it seemed to be slightly more important than harvest index.

From variance analysis in a series of genotype x environment experiments, heritability of root yield, harvest index, and total plant weight was calculated (Table 23). In this case, heritability can be used as an indicator of stability of each yield character over different environments. The actual value of heritability was given as follows:

$$\frac{V_G}{V_G + V_{G \times E} + V_E}$$

Where V = variance, G = genotype, G x E = genotype x environment interaction, and E = error.

Heritability of harvest index was much higher than that of root yield and total plant weight in any of four genotype x environment combinations (Table 23). This indicates that harvest index is a highly stable character over a wide range of environments while yield and total plant weight are not as stable.

Table 22. Relationship between harvest index and total plant weight with root yield under diverse environmental conditions. (Data from replicated yield trials, 1977-79.)

Location	Average yield of trial (t/ha)	r_{YA}	$\sqrt{V_A/V_Y}$ [1]	r_{YB}	$\sqrt{V_B/V_Y}$ [1]
Carimagua	4.9	0.813**	0.615	0.840**	0.530
Carimagua	15.3	0.691**	0.406	0.932**	0.748
Carimagua	19.1	0.773**	0.640	0.889**	0.712
Caribia	24.1	0.582**	0.710	0.789**	0.738
Caribia	27.3	0.852**	0.690	0.807**	0.436
Caribia	29.8	0.711**	0.499	0.821**	0.760
CIAT-Palmira	26.3	0.840**	0.956	0.242	0.042
CIAT-Palmira	27.8	0.817**	0.907	0.409	0.321
CIAT-Palmira	28.6	0.918**	1.040	0.542	0.254
CIAT-Palmira	30.4	0.763**	0.823	0.551**	0.476
CIAT-Palmira	37.2	0.668**	0.708	0.767**	0.670
CIAT-Palmira	42.1	0.776**	0.767	0.525*	0.404

1 $\sqrt{V/V}$: Relative size of variance of harvest index or total plant weight to that of root yield (variables are converted into logarithmic scale). A refers to harvest index; B to total plant weight; and Y to root yield.

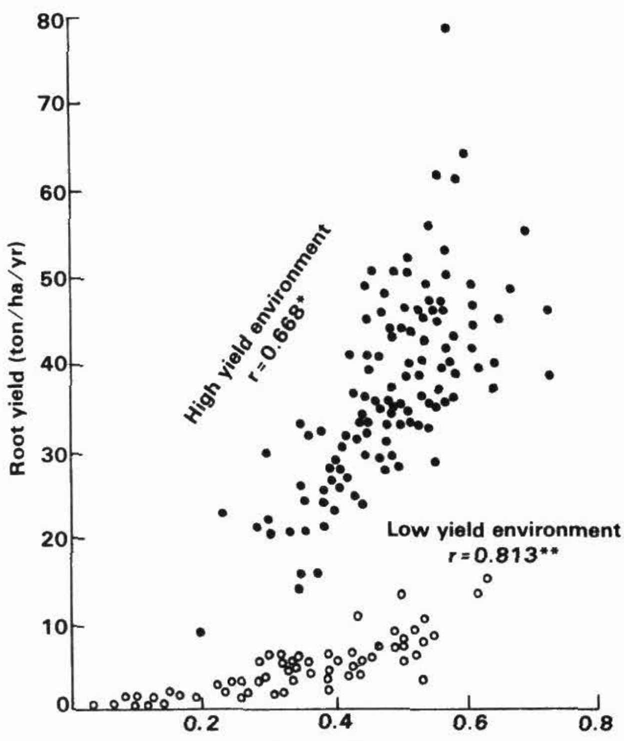


Figure 24. Correlation between harvest index and root yield of cassava under high (CIAT-Palmira) and low (Carimagua) yield environments.

Cassava is a unique crop in that harvest index is a decisive factor influencing yield from low to high yielding environments. This suggests that common physiological factors for high yield exist for a wide range of environments. The use of the harvest index in selection is thus justified for a wide range of environments and good progress in crop improvement may be expected not only in high yielding or low stress environments but also in low yielding or high stress environments for cassava.

Breeding Methodology for CBB and Superelongation Resistance

Assessment of yield loss

An assessment of yield loss due to simultaneous infections of CBB and superelongation revealed that both diseases reduce root yield in an additive manner although the effect of CBB was much greater than that of superelongation in any situation (Table 24). There seems to be no interaction effects between the two diseases.

Effect of field selection

Three populations — *unselected lines from CIAT*, lines selected in an observational yield trial at Carimagua (single-row trial, planted April 1978), and lines selected in a seedling trial at Carimagua (planted April 1978) — were planted as single-row trials at Carimagua April 1979 to study the effect of field selection for CBB and superelongation. There was a significant difference between the unselected and selected populations while no appreciable difference existed between the line-selected and seedling-selected populations (Table 25).

Table 23. **Heritability of cassava yield characters** calculated from genotype x environment experiments.

Type of experiment	Root yield	Harvest index	Total plant weight
Genotype x location[1]	0.350	0.648	0.170
Genotype x year[2]	0.681	0.852	0.341
Genotype x spacing[3]	0.390	0.948	0.522
Pure vs. mixed populations[4]	0.542	0.967	0.472

1 Thirty-two genotypes x 3 locations (CIAT-Palmira, Caribia, and Carimagua).
2 Twenty genotypes x 4 years at CIAT-Palmira.
3 Twenty genotypes x 2 spacings (1 x 1 m and 2 x 2 m) at CIAT-Palmira.
4 Twenty genotypes in pure populations and mix-planting with M Col 638 at CIAT-Palmira.

Table 24. Cassava fresh root yield at different levels of CBB and superelongation resistance at Carimagua. (Data from replicated yield trials.)

		Fresh root yield (t/ha/year)				
		CBB rating[1]				Average at each
		2	3	4	5	superelongation rating
Early planting (n = 59)						
	2	-	-	5.7	3.7	4.7
	3	12.4	7.5	4.4	-	8.8
Superelongation rating	4	5.9	5.5	3.8	-	5.1
	5	6.1	4.1	2.4	1.3	3.0
Average at each CBB rating		9.2	5.6	3.3	1.8	4.9
Late planting (n = 148)						
	2	22.3	17.1	14.3	-	18.5
	3	20.6	18.8	16.9	17.0	18.3
Superelongation rating	4	-	17.3	14.9	12.2	15.3
	5	-	18.4	13.8	12.4	13.1
Average at each CBB rating		21.3	17.8	14.9	12.5	15.4

1 CBB rating: 2 = disease symptoms only on leaves; 3 = infected leaves and stems; 4 = dieback in more than 50% of plants; 5 = death or dieback in 50% of plants.

2 Superelongation rating: 2 = disease symptoms only on leaves; 3 = disease symptoms on leaves of all plants and occacional stem elongation; 4 = 50% of plants show stem elongation; 5 = leaves dying of disease infection.

This confirms the high effectiveness of field selection for CBB and superelongation at Carimagua. Single-row trials (observational yield trial) are the most efficient selection method when a considerable number of genotypes are to be evaluated simultaneaously for yield and disease resistance. Seedling selection is the best method when a vast number of genotypes are to be evaluated primarily for disease resistance.

Genetic basis of continuous variation in field resistance

A total of 36 genotypes were planted in a trial at Carimagua to study initial disease infection and spreading within the host plants. In the case of CBB, the number of CBB-infected leaves was not closely correlated with the number of stems showing dieback M Col 638, for example, is generally regarded as a CBB resistant type and performed as such in terms of number of leaves infected among all genotypes studied; however, there were a number of genotypes which showed higher resistance than M Col 638 in terms of number of stems showing dieback. This suggests that for CBB different genetic systems correspond to initial infection and disease spreading within the host plant.

In the case of superelongation, the initial infection, measured by number (%) of infected stems, was

Table 25. Efficiency of field selection for CBB and superelongation at Carimagua (1978-79).

Superelongation rating[1]	No. of lines: CBB rating[2] 1	2	3	4	5	% of lines at each superelongation rating
No selection[3]						
1	2	4	11	3	8	3.3
2	-	7	4	3	3	2.0
3	3	47	66	47	11	20.5
4	-	36	130	137	49	41.4
5	-	4	80	125	70	32.8
% of lines at each CBB rating	0.6	11.5	34.2	36.5	16.6	100.0
Single-row selection[4]						
1	5	6	5	3	-	9.6
2	10	8	8	2	-	14.1
3	19	42	18	9	2	45.5
4	16	28	8	6	2	30.3
5	-	-	-	-	-	0.5
% of lines at each CBB rating	25.3	42.4	20.2	10.1	2.0	100.0
Seedling selection[5]						
1	17	14	12	2	-	14.4
2	24	21	5	-	-	16.0
3	35	58	23	2	1	38.0
4	25	34	24	2	-	27.1
5	3	3	5	3	-	4.5
% of lines at each CBB rating	33.2	41.5	22.0	2.9	0.3	100.0

1 *See footnote on* Table 24 for superelongation rating.
2 See footnote on Table 24 for CBB rating.
3 Unselected lines from CIAT.
4 Lines selected from a single-row trial at Carimagua (18.4% selection).
5 Lines selected from a seedling trial at Carimagua (3.7% selection).

generally correlated with disease spreading, measured by the degree of stem elongation. However, M Col 1684 appeared to be highly susceptible to initial infection but moderately resistant to disease spreading.

To further study this point, 13 crosses of M Col 113 and 11 of M Col 22 were compared. Each cross contained several lines, each represented by 20 plants. Although there was no difference in number of infected stems between the two populations, there was a clear difference in regression axes of stem elongation on number of infected stems between the two populations. This is an indication that independent genetic systems of cassava correspond to initial infection and disease spreading. The results obtained this year suggest that field resistances to CBB and superelongation under Carimagua conditions are continuous genetic characters.

The results also offer a possibility of selecting for higher resistance from crosses between moderately resistant parents. A cross between a genotype resistant to initial infection but susceptible to disease spreading and the other genotype susceptible to initial infection but resistant to disease spreading should produce resistance to both processes by recombination. Results obtained this year support that present CBB and superelongation resistance might be durable.

Relationship between disease resistance and yield characters

It often occurs in improved crop species that a negative correlation exists between multigenic disease resistance and agronomically desirable characters because resistance genes come from wild relatives or primitive cultivars.

To study whether this is the case with cassava, disease reaction of genotypes at Carimagua was compared with yield characters at CIAT where the cassava plants are free from CBB and practically free from superelongation infections (Table 26). CBB and superelongation ratings at Carimagua were not correlated with root yield, harvest index, and root dry matter content at CIAT. It can be concluded that selection for higher disease resistance is not being done at the expense of higher yields.

Selection of parental genotypes for disease resistance

Evaluation of phenotypic resistance at Carimagua is easy and there is a good correlation between parents and progeny (CIAT Annual Report, 1978). However, the possibility of a specific combining effect having a role in the genetics of disease resistance should not be discarded. Several parental genotypes were evaluated during a two-year period through the frequency of resistant offspring. The following genotypes were identified as good parental materials: 1) For both CBB and superelongation, M Col 638 and M Col 1684; 2) for CBB, M Col 647 and CM 309-56; and 3) for superelongation, M Ven 307, M Mex 24, M Mex 17, M Pan 70, M Pan 114, M Ven 218 and, CM 208-10.

Table 26. Relationship between disease resistance and yield characters.

		No. of genotypes							
		Disease rating at Carimagua[1]							
		CBB				Superelongation			
Data at CIAT		2	3	4	5	2	3	4	5
	20	-	1	1	-	-	-	1	1
	30	1	3	2	1	-	1	3	3
Yield (t/ha)	40	1	10	11	1	2	7	5	9
	50	2	8	6	1	-	3	8	6
	>50	1	5	-	2	-	2	2	4
	30	-	3	-	1	-	2	1	1
	32	-	7	3	-	-	2	5	3
Dry matter contents (%)	34	-	8	8	1	2	3	5	7
	36	3	7	3	2	-	3	5	7
	38	1	2	4	1	-	2	2	4
	>38	1	1	1	-	-	1	1	1
	0.40	1	4	3	1	-	1	4	4
	0.45	1	5	2	-	-	1	4	3
	0.50	-	4	4	2	1	3	4	2
Harvest index	0.55	3	5	4	1	-	3	1	8
	0.60	-	5	5	1	1	3	3	4
	0.65	-	3	-	-	-	1	1	1
	>0.65	-	-	-	-	-	-	-	-

1 See footnote in Table 24 for CBB and superelongation ratings.

AGRONOMY

This section continued validating cultural practices and testing germplasm emerging from the breeding program through the Colombian Regional Trial Network.

Regional Trials

The fifth consecutive testing cycle was completed this year with the eight trials harvested in Colombia. Table 27 shows the main ecological and edaphic characteristics of the testing locations which cover a wide range in altitude, temperature, rainfall, soil texture and fertility conditions. The technology used is based on low input levels (*CIAT Annual Report*, 1974) principally based on improved germplasm and simple agronomic practices. Fertilizer was used only at Carimagua and CIAT-Quilichao. At Carimagua, the standard fertilizer rates of 0.5 t/ha of lime, 1 t/ha of 10-20-20, 20 kg S/ha and 5 kg Zn/ha were applied. At CIAT-Quilichao planting is done in the same field year after year and only 100 kg N/ha and 115 kg P_2O_5/ha were applied. Zinc was included in the stake treatment.

A heavy outbreak of CBB and superelongation occurred at Carimagua this year. At CIAT-Quilichao, moderate attack of superelongation as well as thrips and mites were the main problems. Table 28 shows the yields of all germplasm selections and hybrids tested. At 7 of the 8 locations, a CIAT germplasm selection or hybrid again outyielded the local cultivar. In 5 of the 8 sites M Col 1684 gave the highest yield averaging 33.1 t/ha across locations. After testing M Col 1684 in 19 trials planted in 10 Colombian locations for three years and 10 trials in other eight countries for two years, its overall mean has been 31.4 t/ha which is outstanding. These results confirm that this selection is probably the

Table 27. Main climatological and edaphic characteristics of the 1978-79 Colombian Regional Trials sites.

Site	Altitude (masl)	Mean temperature (°C)	Rainfall (mm)[1]	Days to harvest	Soil texture	pH	Organic matter (%)	P Bray II (ppm)	K (meq/100g)
Media Luna	10	27.2	1120	330	Sandy loam	6.3	1.10	43.5	0.06
Carimagua	200	26.2	1870	347	Silty clay	4.7	3.42	3.0	0.18
Rionegro	250	27.0	2358	318	Clay loam	4.2	1.85	3.9	0.15
Nataima	430	27.8	895	252	Sandy loam	6.0	0.93	47.9	0.29
CIAT-Palmira	1000	23.8	810	308	Clay	6.1	4.28	42.8	0.41
CIAT-Quilichao	1070	23.0	1291	255	Silty clay	4.1	7.22	3.2	0.22
Caicedonia	1200	22.2	1902	347	Silty loam	5.6	4.18	27.0	0.90
Pereira	1480	19.0	2653	357	Silty loam	4.7	8.01	6.8	0.11

1 Total rainfall during the cassava growing cycle.

Table 28. Yields of promising ICA-CIAT cassava varieties and hybrids at eight locations in Colombia, 1978-79 testing cycle.

Varieties and hybrids	Yield (t/ha) Media Luna	Carimagua	Rionegro	Nataima	CIAT-Palmira	CIAT-Quilichao	Caicedonia	Pereira	Average yield (t/ha)
Best local[1]	8.8	12.6	18.3	10.6	15.7	17.1	45.2	39.5	21.0
M Col 1684	40.7	14.5	40.9	29.0	24.7	24.5	57.1	-	33.1
M Mex 59	28.1	2.8	27.8	24.1	-	-	28.9	13.3	20.8
CMC 40 (M Col 1468)	26.0	13.5	24.8	24.0	29.6	-	58.4	19.0	27.9
CM 323-37	25.4	-	22.1	23.1	-	-	-	-	23.5
CM 323-375	23.3	7.3	25.2	25.3	30.0	18.9	43.3	17.1	23.8
CM 309-41	22.5	11.9	26.4	-	30.6	13.4	55.5	22.5	26.1
CM 326-407	21.2	7.9	24.5	20.8	22.7	17.1	48.3	-	23.2
CM 321-188	21.2	5.6	24.1	26.2	40.3	20.9	54.2	-	27.5
CM 309-211	20.7	12.6	24.5	-	31.5	17.4	-	-	21.3
CM 308-197	19.9	3.2	32.8	32.1	34.8	21.3	48.5	-	27.5
M Col 22	19.8	3.7	-	-	25.4	-	42.4	8.7	20.0
ICA-HMC-2	19.6	13.9	-	-	24.9	-	-	37.2	23.9
CM 305-120	19.0	10.5	23.2	29.3	24.9	21.5	50.3	-	25.5
CM 340-30	18.8	-	26.4	24.4	25.4	20.5	42.8	-	26.3
M Ven 156	18.8	-	20.6	-	22.0	-	-	-	20.5
M Ven 218	17.4	-	-	21.4	27.9	-	36.5	19.1	24.5
CMC 84 (M Col 1513)	16.4	5.2	28.0	20.1	-	-	41.5	30.3	23.6
CM 344-27	14.4	5.0	22.4	20.9	32.3	17.6	49.9	-	23.2
CM 311-69	13.6	14.5	24.7	-	-	23.6	-	-	19.1
CM 344-71	13.0	4.9	19.4	27.6	29.0	26.0	42.4	-	23.2
CM 305-41	12.1	1.2	15.3	26.6	37.7	25.4	49.7	30.9	24.9
M Ven 77	-	13.2	22.3	-	-	-	-	-	17.8
SM 1-150	-	9.3	-	-	-	-	-	-	9.3
CM 192-1	-	7.4	-	24.6	25.9	20.1	49.2	-	25.4
CMC 99 (M Col 1529)	-	-	25.3	-	-	-	-	-	25.3
Colombiana (R)	-	-	17.0	-	-	-	-	-	17.0
MPTR-26	-	-	-	25.5	23.8	-	-	-	24.7
M Mex 17	-	-	-	23.5	20.7	-	-	-	22.1
M Pan 70	-	-	-	17.1	28.8	-	33.3	-	26.4
ICA-HMC-7	-	-	-	-	37.7	24.7	-	-	31.2
ICA-HMC-1	-	-	-	-	30.9	-	58.4	38.1	42.5
CM 430-51	-	-	-	-	-	-	46.1	-	46.1
M Ven 168	-	-	-	-	-	-	-	32.2	32.2
CMC 76 (M Col 1505)	-	-	-	-	-	-	-	28.4	28.4
M Col 1292	-	-	-	-	-	-	35.7	-	35.7
CMC 59 (M Col 1488)	-	-	-	-	-	-	-	36.1	36.1
Average, including local varieties	20.0	8.2	24.4	23.8	28.2	20.4	46.3	26.6	25.7
Best promising variety or hybrid	40.7	14.5	40.9	32.1	40.3	26.0	58.4	38.1	

1 Best local for Media Luna, cultivar Secundina; for Carimagua, Llanera; for Rionegro, Venezolana; for Nataima, Venezolana 2; for CIAT-Palmira, Valluna; for CIAT-Quilichao, Valluna; for Caicedonia, Chiroza Gallinaza; and for Pereira, Chiroza Gallinaza.

best among all the germplasm accessions and indicates its high yield potential across locations.

Cultivar CMC 40 (M Col 1468) ranked second this year with an average yield of 27.9 t/ha across seven locations (Table 28). It is important to note that this Brazilian cultivar, has given an overall mean yield of 25.5 t/ha in 39 trials at 14 Colombian locations for five years. This cultivar can also be considered to have high yield potential across environments, having been planted from Argentina to Mexico. CMC 40 can be grouped with six hybrids with average yields across locations ranging from 25.4 to 27.5 t/ha. These results are more impressive when considering that yields at Media Luna, Carimagua, and CIAT-Quilichao, locations with the most adverse factors to cassava production, are included in the average. Three of 6 top ranked hybrids (CM 192-1, CM 305-120, CM 308-197, CM 309-41, CM 321-188, and CM 340-30) have CBB-resistant parents which indicates that the incorporation of disease resistance is a principal means to obtain wide adaptability.

Five-year results

After five years of regional trials, cultivar M Col 1684 and CMC 40 (M Col 1468) can be considered as the benchmark selections for measuring the yield potential of hybrids. The first generation of hybrids has completed two years of testing. The results suggest that the highest yielding hybrids have yields comparable to those of the two benchmark germplasm selections. In considering only those hybrids planted in more than 10 locations, a group of six can be identified as promising; this group is composed of CM 308-197 (27.5 t/ha), CM 192-1(25.9 t/ha), ICA-HMC 2(25.9 t/ha), CM 323-375 (25.7 t/ha), CM 309-41 (25.1 t/ha), and CM 323-87 (24.0 t/ha).

It is of interest to note that the Colombian national average cassava yield has increased from 8.0 to 9.7 t/ha according to estimates of the National Planning Office of the Ministry of Agriculture (OPSA). This might be explained by the fact that a greater share of the cassava market is produced by farmers using improved technology in zones of high yield potential.

Table 29 shows the average fresh and dry root yield of the three most promising cultivars compared with that of the local cultivars during five cropping cycles. An average fresh root yield of 32.8 t/ha was obtained for the three most promising cultivars, compared with 21.6 t/ha for the local cultivars. This result represents a 238% yield increase over the national average and a 52% increase over the average of the best local cultivars. It is interesting to point out that the dry matter yields obtained with cassava are higher than the national average of any of the grain crops in Colombia. It must be stressed again that in the case of cassava, minimum purchased inputs are used. Results indicate that progress has been made towards stabilization of target yields with improved genetic material specially at locations with severe limitations for cassava production.

Consequently, after five years of regional trials in Colombia, it can be reaffirmed that simple improved technology based on better agronomic practices (CIAT Annual Report, 1974) and improved germplasm is effective in increasing farmer's yields.

International Yield Trials

Table 30 shows some climatological characteristics of the sites in eight countries where cooperative international trials were harvested this year. With the exception of Venezuela, CIAT selections again yielded higher than local cultivars. If only those cultivars or hybrids that were harvested in five or more locations are considered, hybrid CM 323-375 with 28.3 t/ha ranked first across locations, followed by M Col 1684 with 26.7 t/ha (Table 31). The low yield in Argentina was due to a heavy CBB attack. Data also suggests that for both Argentina and Bolivia, no selections are available with resistance to low winter temperatures and high yield potential. It must be pointed out that international trials are mainly sent to countries where these are conducted by agronomists that have previously participated in cassava training courses at CIAT. For this reason, all international trials are reported back. Tremendous progress has been achieved in establishing an increased number of national regional trials networks. Although Brazil does not plant a CIAT international yield trial due to quarantine regulations, they have the largest national trial network followed by Colombia and Honduras.

This year, a total of 122 national trials were planted in 10 Latin American countries (Table 32). This increased interest can be traced back to the number of agronomists that have received training in cassava at CIAT.

In relation to international yield trials a total of 21 testing cycles have been completed by 1979 in 11

Table 29. Average fresh and dry root yields of the three best promising varieties, compared with the best local variety during the five testing cycles.

	Yields (t/ha) in testing cycle											
	1974-75				1975-76				1976-77			
	Promising		Local		Promising		Local		Promising		Local	
Site	FRW[1]	DM[1]	FRW	DM	FRW	DM	FRW	DM	FRW	DM	FRW	DM
Media Luna	26.7	7.9	17.7	7.0	17.6	5.2	4.0	1.4	17.1	5.1	5.7	2.1
Carimagua	6.2	2.1	3.8	1.3	25.6	9.4	22.9	8.3	23.9	8.5	17.3	5.5
Nataima	41.1	13.3	33.6	7.2	28.4	7.7	16.3	5.0	33.6	9.9	8.0	2.3
Rionegro	29.7	7.5	15.7	4.0	21.9	8.3	11.7	3.7	45.2	14.0	16.1	5.4
CIAT-Palmira	40.6	14.7	26.8	9.6	30.9	11.4	22.1	7.4	42.6	15.0	22.5	8.0
CIAT-Quilichao	-	-	-	-	-	-	-	-	-	-	-	-
Caicedonia	37.3	15.0	32.3	11.5	25.0	8.8	15.8	5.3	51.2	19.8	41.2	14.1
Pereira	19.8	7.7	16.9	6.3	44.5	17.4	45.8	16.4	--[2]	--	--	--
Average/cycle	28.8	9.7	21.0	6.7	27.7	9.7	19.8	6.8	35.6	12.0	18.5	6.3

(continuation)

	Yields (t/ha) in testing cycle											
	1977-78				1978-79				Average			
	Promising		Local		Promising		Local		Promising		Local	
Site	FRW	DM	FRW	DM	FRW	DM	FRW	DM	FRW	DM	FRW	DM
Media Luna	23.9	6.3	5.6	1.5	31.6	9.0	8.8	2.8	23.4	6.7	8.3	3.0
Carimagua	32.2	10.3	10.1	2.9	14.3	3.4	12.6	3.1	20.4	6.7	13.3	4.2
Nataima	33.2	9.8	22.0	7.2	30.1	9.2	10.6	3.6	33.3	10.0	18.0	5.1
Rionegro	35.2	10.5	12.9	4.2	33.9	9.5	18.3	5.8	33.2	9.9	14.9	4.6
CIAT-Palmira	31.1	10.5	24.2	8.6	38.6	13.5	15.7	5.0	36.8	13.0	22.3	7.7
CIAT-Quilichao	50.3	15.7	45.7	14.5	25.3	8.2	17.1	5.3	37.8	12.0	31.4	9.9
Caicedonia	38.0	11.2	12.1	3.5	57.9	19.7	45.2	15.3	41.9	14.9	29.2	9.9
Pereira	41.5	15.3	40.1	15.0	37.1	13.3	39.5	15.0	35.7	13.4	35.2	13.2
Average/cycle	35.7	11.2	21.6	7.2	33.6	10.7	21.0	6.9	32.8	10.8	21.6	7.2

1 FRW = Fresh root yield; DM = dry root yield.

2 Due to long cropping cycle, a cycle was lost by accumulation.

Table 30. Climatological characteristics of cassava International Regional Trial Sites during 1978-79 testing cycle.

Countries	Altitude (masl)	Mean temperature (°C)	Rainfall (mm)	Days to harvest
Mexico (Chetumal)[2]	10	26.0	1500	365
Honduras (San Pedro Sula)	60	25.5	2000	375
Argentina (Formosa-El Colorado)	78	20.2	522	205
Ecuador (Pichilingue)	100	25.0	1405	335
Venezuela (Valencia)[3]	120	25.0	1300	335
Dominican Republic (San Cristóbal)	120	25.0	1532	363
Costa Rica (Santa Clara)	180	22.0	3779	345
Bolivia (Santa Cruz)	437	20.0	1100	380

1 Total rainfall during growing cycle.
2 Harvested in September 1978.
3 Harvested in June 1978.

countries of Latin America. Although the figure seems low, it should be kept in mind that except for Colombia, international trials started three years ago only after some experience had been gained with the Colombian trials.

Table 32 shows that the average fresh root weight of the best ICA-CIAT cultivars was 39.4 t/ha as compared to 29.2 t/ha for the best local variety of the different countries. This represents a 35% increase. Results obtained indicate that these countries have local cultivars that are good enough to increase productivity if the simple, inexpensive technology recommended is used, but a stronger contribution of national extension services to implement this technology in farmer's fields is required.

Uniform Yield Trials

Uniform yield trials reported last year (CIAT Annual Report, 1978) demonstrated a significantly higher yield of the exterior ring (border rows) of cassava plots, suggesting the need to eliminate it for yield data calculation. This year, four varieties were planted in a systematic (nonrandomized) latin square design at each of three locations — CIAT-Palmira, ICA-Caribia and Carimagua. The objective of the trial was to study the effect of varietal competition and non-planted spaces on the yield of the four cassava varieties used at each location. The effect of competition was measured by calculating root yield of the exterior and successive inner rings. Root yield is shown in Figure 25. There is no border effect on root yield at Carimagua. At CIAT-Palmira and Caribia only the more vigorous varieties M Mex 11 at CIAT and M Mex 59 both at CIAT-Palmira and Carimagua, showed a significant border effect. Tables 33, 34 and 35 summarize the yield data of the exterior ring and average yield of the second, third and fourth inner rings. Root yield of the exterior ring is higher than the inner area yields, except for M Col 22 at CIAT and CM 309-41 at Carimagua, which are both the less vigorous varieties, and consequently compete

Table 31. Yields of promising ICA-CIAT cassava varieties harvested in International Regional Trials during the 1978-79 testing cycle.

	Fresh root yield (t/ha)								
Varieties	Bolivia I[1]	Honduras I	Dominican Republic I	Venezuela I	Argentina II	Costa Rica II	Mexico II	Ecuador III	Average
Best local[2]	19.8	19.6	24.6	39.0	-	19.7	5.0	18.0	20.8
M Ven 77	-	-	-	-	6.0	-	-	-	6.0
CMC-40 (M Col 1468)	16.2	13.5	47.0	25.3	8.0	19.8	14.9	36.6	22.6
ICA-HMC-2	-	-	42.4	-	-	-	17.3	-	29.8
CM-323-375	20.1	23.7	40.0	-	-	24.6	-	33.1	28.3
CM 305-41	-	-	39.4	-	-	-	-	34.3	36.8
CM 308-197	-	-	36.9	37.1	10.5	-	13.9	31.2	25.9
M Col 1684	21.9	31.3	39.9	25.2	3.2	35.0	15.4	42.4	26.7
ICA-HMC-1	16.5	-	32.6	-	-	-	11.7	31.9	23.1
CM 305-38	16.5	-	31.5	-	-	21.9	-	29.6	24.8
CMC 84 (M Col 1513)	10.1	17.5	31.3	11.1	-	25.3	6.4	29.5	18.7
ICA-HMC-7	-	-	33.0	-	-	-	9.1	41.8	27.9
M Ven 218	11.5	14.1	28.9	30.0	-	14.8	11.6	-	18.4
CM 309-211	-	-	25.3	-	-	-	-	27.9	26.6
M Mex 59	-	29.5	21.5	13.8	2.5	31.3	-	31.7	21.7
M Col 22	17.1	12.4	23.5	12.4	-	9.1	9.5	26.2	15.7
ICA-HMC-4	-	-	28.4	26.3	-	-	7.5	27.5	22.4
CM 305-145A	-	-	20.9	-	-	-	-	31.4	26.1
Local[2]	14.0	19.1	22.7	12.0	-	11.7	-	-	15.9
SM-1-150	-	-	-	29.1	-	-	10.2	-	19.6
CM 337-7	-	-	-	-	-	-	10.0	-	10.0
CM 309-41	-	-	-	-	-	-	9.0	-	9.0
CM 192-1	-	-	-	33.5	-	-	8.5	-	21.0
CM 333-19	-	-	-	-	-	-	7.1	-	7.1
CM 314-58	-	-	-	-	-	-	3.6	-	3.6
M Mex 17	9.2	-	-	-	-	-	3.0	25.2	12.4
CM 309-163	-	12.6	-	-	9.8	18.0	-	-	13.4
CMC 76 (M Col 1506)	-	-	-	16.5	-	-	-	-	16.5
CM 314-66	-	-	-	20.6	-	-	-	-	20.6
M Col 677	-	-	-	6.5	-	-	-	-	6.5
MPTR 26	-	15.7	-	-	-	16.1	-	33.3	21.7
CM 323-87	-	-	-	-	-	-	12.9	-	12.9
M Pan 70	16.3	-	-	-	-	-	-	-	16.3
M Col 638	12.7	-	-	-	-	-	-	-	12.7
M Ven 156	11.1	-	-	-	-	-	-	-	11.1
Average, including local varieties	15.2	19.0	31.7	22.6	6.7	20.6	9.8	31.3	19.9
Best promising variety or hybrid	21.9	31.3	47.0	37.1	10.5	35.0	17.3	42.4	-

1 Testing cycle I, II or III.

2 Best local in Bolivia, Gancho; Honduras, Criolla de San Andrés; Dominican Republic, Zenón; Venezuela, Branca; Costa Rica, Valencia; Mexico, M Mex 59; Ecuador, Yema de Huevo. Other local cultivars in Bolivia, Colla; Honduras, Itú; Dominican Republic, Cogollo Morado; Venezuela, Burrera; Costa Rica, MAG-2.

Table 32. Yield data of best ICA-CIAT and local varieties in International Trials and number of National Regional Trials planted during 1979.

Country	Cycles harvested by 1979	No. testing sites 1979	Fresh root yield (t/ha) Local	Best ICA-CIAT material	No. of ICA-CIAT varieties with 25% more than the local
Argentina	2	-	-	10.5	-
Bolivia	1	7	19.8	21.9	0
Brazil	-	62	-	-	-
Colombia	5	18	19.1[1]	37.3	11
Costa Rica	2	6	19.7	35.0	4
Cuba	1	3	-	-	-
Dominican Republic	1	6	24.6	47.1	10
Ecuador	3	6	18.0	42.4	16
Guyana	2	-	16.4	30.5	1
Honduras	1	10	19.6	31.3	2
Mexico	2	5	5.0	17.3	15
Venezuela	1	1	39.0	37.1	0
Total	21	124			
Average yield			29.2	39.4	

1 Includes five locations in cooperation with ICA.
2 Corresponds to 1975 and 1976 data.

negatively with the other varieties. Standard deviations but mostly variances of the exterior rings are considerably higher than those of the inner rings, corroborating last year's results that one border row should be eliminated for estimating yield data.

Cultural Practices

Planting systems

Optimum planting density, stake treatment and selection (to protect the stake against soil borne pests and during storage) are recommended agronomic practices to secure good cassava yields and the farmer's income.

At La Idea farm, in Media Luna, the local variety Secundina and the introduced cultivar M Col 22 were planted under three systems to evaluate the effect of planting density and management of planting material. Stakes were freshly cut and planted in the rainy season. The systems used were: (1) local planting system at 8000 plants/ha; (2) local planting system but with selected and chemically treated stakes as recommended by CIAT; and (3) CIAT-planting system at 10,000 plants/ha, with selected and treated stakes.

Table 33. Mean root yields by exterior ring 1 and average yield of inner rings 2, 3, and 4 of several cassava varieties grown at Carimagua, 1979.

Variety	Ring	Root yield (t/ha)	SD (t/ha)	Var.
CMC 9	Exterior 1	5.05	0.80	0.64
	2-3-4	5.61	1.51	2.45
CM 309-41	Exterior 1	11.55	1.47	2.16
	2-3-4	13.29	2.88	8.47
CM 309-196	Exterior 1	6.31	0.89	0.80
	2-3-4	5.12	1.27	1.91
M Col 638	Exterior 1	14.76	3.21	10.35
	2-3-4	13.51	2.93	8.69
Mean 1		9.41	1.59	3.48
2-3-4		9.38	2.14	5.38

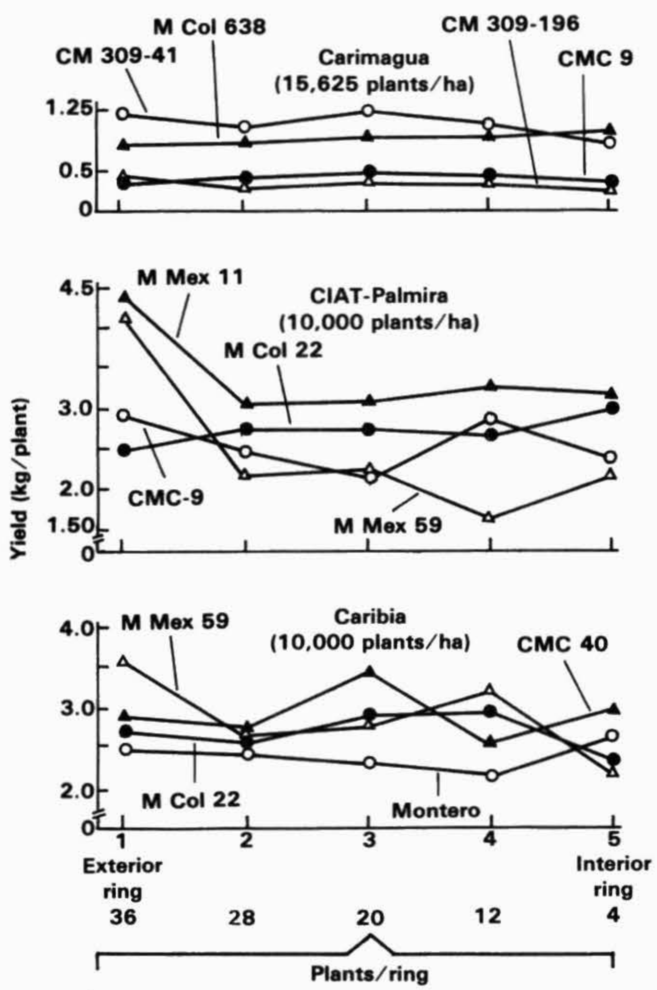


Figure 25. Effect of ring position in the experimental plot (exterior, interior) on root yield of four varieties at each of three locations.

Table 34. Mean root yields by exterior ring 1 and average yield of inner rings 2, 3, and 4 of several cassava varieties grown at CIAT-Palmira, 1979.

Variety	Ring	Root yield (t/ha)	SD (t/ha)	Var.
CMC 9	Exterior 1	29.09	11.77	138.56
	2-3-4	25.21	5.34	31.90
M Col 22	Exterior 1	25.03	8.79	77.28
	2-3-4	27.36	3.52	15.04
M Mex 11	Exterior 1	43.55	9.68	93.76
	2-3-4	31.03	5.93	36.03
M Mex 59	Exterior 1	41.04	9.15	83.76
	2-3-4	19.74	3.58	13.31
Mean 1		34.67	9.84	98.34
2-3-4		25.83	4.59	24.07

Stand losses varied from 6 to 11% for all treatments. Non significant (P = 0.05) yield increases of 12 to 15% were achieved by stake selection and treatment (Table 36), but higher planting density did not increase yields beyond stake management alone. The additional cost for stake selection and treatment is about US$20/ha. Using freshly cut planting material may not require chemical treatment of stakes, but when delay occurs

Table 35. Mean root yields by exterior ring 1 and average yield of inner rings 2, 3, and 4 of several cassava varieties grown at Caribia, 1979.

Variety	Ring	Root yield (t/ha)	SD (t/ha)	Var.
CMC 40	Exterior 1	24.85	6.40	41.03
	2-3-4	21.75	4.97	26.61
M Col 22	Exterior 1	23.25	7.94	63.15
	2-3-4	24.39	5.24	28.09
M Mex 59	Exterior 1	31.74	9.06	82.14
	2-3-4	23.18	2.15	5.03
Montero	Exterior 1	23.07	7.23	52.28
	2-3-4	20.07	8.22	67.86
Mean 1				59.65
2-3-4				31.89

Table 36. Effect of planting methods on commercial root yield of cassava varieties Secundina and M Col 22 at Media Luna, 1979.

Planting system	Root yield (t/ha)	Yield increase (%)
Secundina		
Local	20.5a[1]	-
Local + stake selection and treatment[2]	23.0a	12.2
Stake selection and treatment + 10,000 plants/ha[2]	22.3a	8.7
M Col 22		
Local planting	21.8a	6.3
Local + stake selection and treatment	23.6a	15.1
Stake selection and treatment + 10,000 plants/ha	23.2a	13.1
CV (%) = 12.51		

1 Mean values followed by the same letter are not significantly different at a 0.05 level.
2 Additional cost of chemicals + labor = US$20/ha; price of cassava = US$60/t fresh roots.

between cutting and planting, stake treatment is highly effective (CIAT Annual Report, 1978). Consequently this is a recommended practice to secure high yields.

Replacement of non-germinated stakes

The replacement of non-germinated stakes is a common practice, especially in research activities in which a complete plant population is desired if not essential. The latter is especially true in systematic designs where each plant represents a treatment. Ideally, the replaced plants have the same vigor and yielding capacity as their non-replaced neighbors, but actually replaced plants are often weaker, therefore, not being able to compete with surrounding plants. In order to determine the best way of replacing ungerminated stakes, two separate trials were planned in CIAT-Palmira.

In the first trial, the low-vigor, high germinating cultivar M Col 22 was used and the treatments consisted of three replacement methods compared to the normal planting (check treatment) as shown in Table 37. All of the 36 plants in each plot were affected by the given treatment and yield data was taken from the 16 central plants of each plot.

Commercial root yield was not affected by the replacement method, but root number was significantly smaller in the check treatment (Table 37). Root shape was altered by the use of plastic bags and by the use of a shovel for transplanting on day 25.

Table 38 shows the relative root yield for the different replacement methods used in the second trial with cultivar M Col 1684. Fifteen days after planting (except treatments 11 and 12 in Table 38), five randomly selected plants in each plot were removed and replaced. After 12 months, replaced plants were harvested separately from the non-replaced plants, excluding plot borders. Table 38 shows the yield of the replaced plants calculated as a percentage of the yield of the non-replaced neighboring plants.

There was no significant difference between the various methods, except that replanting with shovel after 30 days (a practice commonly used) was inferior to other methods. Replanting is recommended to be done as early as possible, preferably between 15 and 20 days after planting. The use of paper bags is cheaper than plastic bags and has the advantage of not having to remove the bag at replanting and thus, reduces root damage. The planting of additional stakes directly in the plots is less time consuming than planting in bags; however, the transplanting of these with the shovel is more time consuming and more

Table 37. The effect of method of stake replacement on yield of cassava cultivar M Col 22 in CIAT-Palmira.

Treatment	Method of stake replacement	Commercial root yield (t/ha)	Relative root yield (%)	No. of Commercial roots/plant
1	Normal planting; complete germination (planted day 1)	21.5a[1]	100	1.6b
2	Stakes in plastic bags, planting on day 25	20.1a	93	4.2a
3	Stakes in ridges; transplanting by shovel on day 25	24.2a	112	4.8a
4	Replacement with new 30 cm stakes on day 25	21.1a	98	4.5a

1 Mean values within a column followed by the same letter are not significantly different at a 0.05 level.

Table 38. Effect of the stake replacement method used on the relative yield of cassava cultivar M Col 1684 in CIAT-Palmira.

Treatment No.	Replacement method	Relative root yield[1] (%)
1	Complete germination	100
2	Stakes in plastic bags, planted after 15 days	102
3	Stakes in plastic bags without bottom, planted after 15 days	98
4	Stakes in cardboard boxes, planted after 15 days	84
5	Stakes in peat plots, planted after 15 days	87
6	Stakes in paper bags, planted after 15 days	98
7	Stakes in ridges, transplanted after 15 days at 10:00	108
8	Stakes in ridges, transplanted after 15 days at 16:00	95
9	Stakes in ridges, transplanted after 20 days at 16:00	100
10	Stakes in ridges, transplanted after 30 days at 16:00	70
11	Replacement with new 20 cm stakes after 15 days	84
12	Replacement with new 35 cm stakes after 15 days	118

1 Yield of replaced stakes as percentage of yield of unreplaced neighboring plants.

damaging to the roots than is the planting of bagged plants. The planting of additional stakes in paper bags appears a good alternative to the use of plastic bags or the transplanting method, as long as replanting is done timely before bags decompose.

Weed control

Weed control is the major single cost factor in cassava production. With rising labor costs large cassava producers will shift more to chemical weed control, replacing the traditional labor-intensive hand weeding. The small cassava producer in marginal areas, however, can only rely upon family labor. Thus cultural weed control practices such as the use of well adapted varieties with high early vigor and adequate planting densities, the utilization of mulches or green covers, and multiple cropping systems may provide adequate solutions to weed control problems for small cassava producers. Research reported here emphasizes both chemical and cultural approaches trying to identify better products and practices for weed control in cassava.

Chemical weed control

Evaluation of the promising preemergent herbicide oxyfluorfen was continued at CIAT-Palmira and was extended to Caribia, ICA's experimental station on the North Coast of Colombia where weed pressure is extremely high and the presence of purple nutsedge (*Cyperus rotundus* L.) allows evaluation of herbicides for its control.

At CIAT-Palmira, the long lasting control of both broad- and narrow-leaved weeds provided by oxyfluorfen at a rate of 1 kg a.i./ha was confirmed. However, similar control levels were achieved with a mixture of oxyfluorfen at half that rate (0.5 kg a.i./ha) plus alachlor at 1.4 kg a.i./ha, which reduced the cost 25%.

At Caribia it was found that the oxyfluorfen/alachlor mix was also efficient in depressing purple nutsedge development more than other products during the first five weeks of observation. While the standard diuron/alachlor treatment did not provide nutsedge control and many other products or mixtures showed controls below 20% at 36 days after application, the oxyfluorfen/alachlor mixture still gave 50% nutsedge control under very heavy pressure from this weed (Figure 26).

At CIAT-Palmira, a yield trial using cassava variety CMC 40 planted in ridges at 1 x 1 m spacing was conducted to investigate the effect of different rates of oxyfluorfen on cassava root yield and dry matter content. Treated plots were left untouched allowing weed development for three months (with the exception of the manually cleaned plots) after which a weeding of all treatments was carried out, excluding the weedy check plots. Cassava was harvested 10

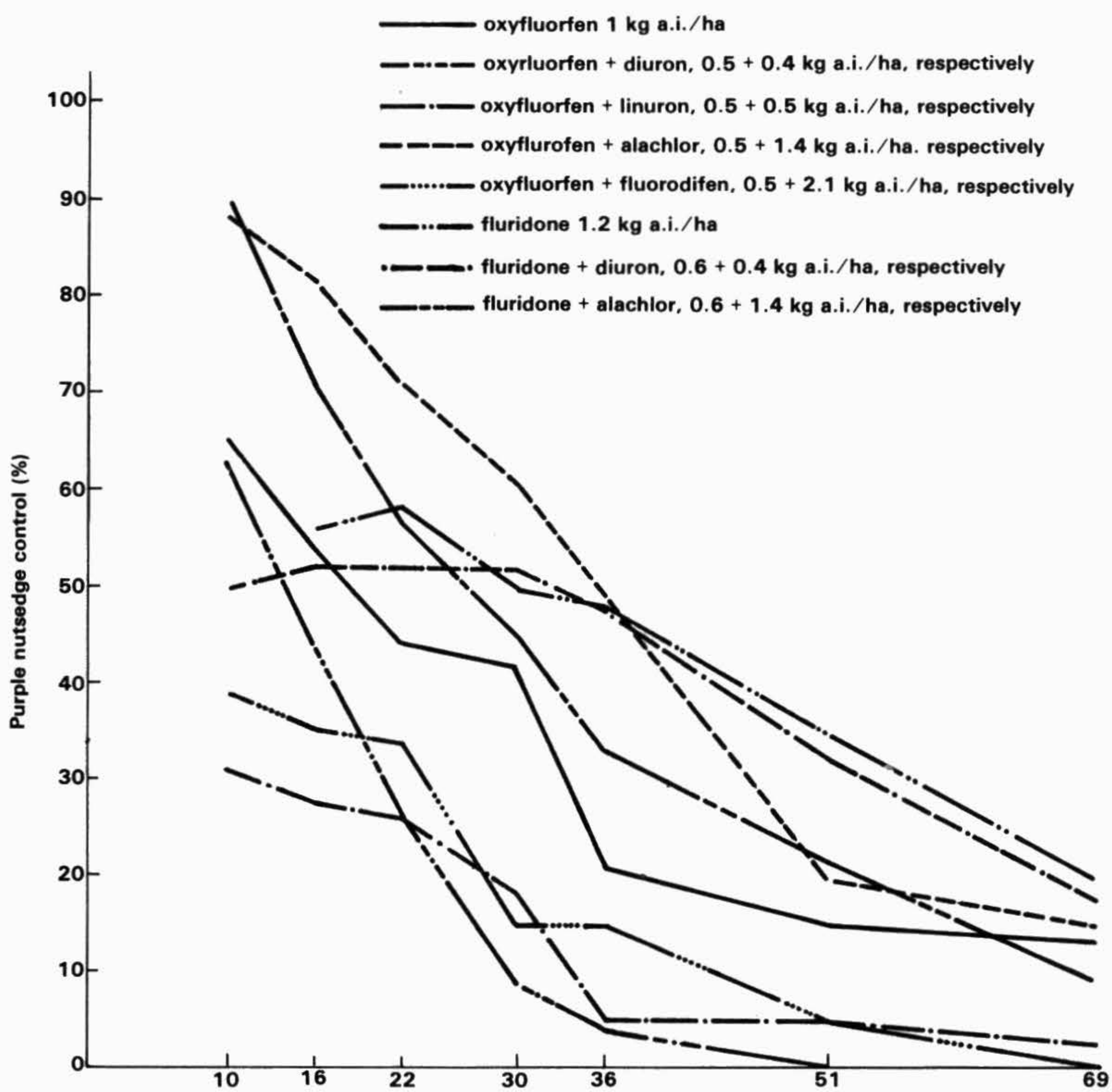


Figure 26. Control of purple nutsedge (*Cyperus rotundus* L.) with new preemergent herbicides applied alone or in mixtures, at Caribia, 1979.

months after planting. Total root yield was considerably reduced without weed control but was not significantly affected by different rates of the herbicide. Rates of oxyfluorfen between 0.5 and 1.0 kg a.i./ha appeared to be the most efficient. Dry matter content in roots was more depressed by weed competition in the weedy check and low herbicide treatments than in those with rates of the chemical. There was no significant difference in root dry matter content between the manual weeding check plots, the diuron/alachlor and the 0.5 kg a.i./ha treatment with oxyfluorfen (Table 39).

Cultural weed control

Variety and planting density

Cultural control of weeds is achieved by any practice which can give a competitive advantage to the crop. A first step in this direction may be the correct management of the variety and spacing factors. A trial was conducted at Caribia experimental station using cassava varieties M Mex 59, a vigorously branching, leafy type and M Col 22, a non-vigorous, non-leafy type, at populations of 7500 and 15,000 plants/ha. Yield results (Figure 27) indicate that vigorous varieties are less sensitive to deficient weed control than non-vigorous varieties due to their genotypically determined greater competing ability. With good weed control (and other cultural practices), yield appears to be largely determined by the yielding ability of a genotype, hence yield differences due to planting density are small. Under these favorable conditions,

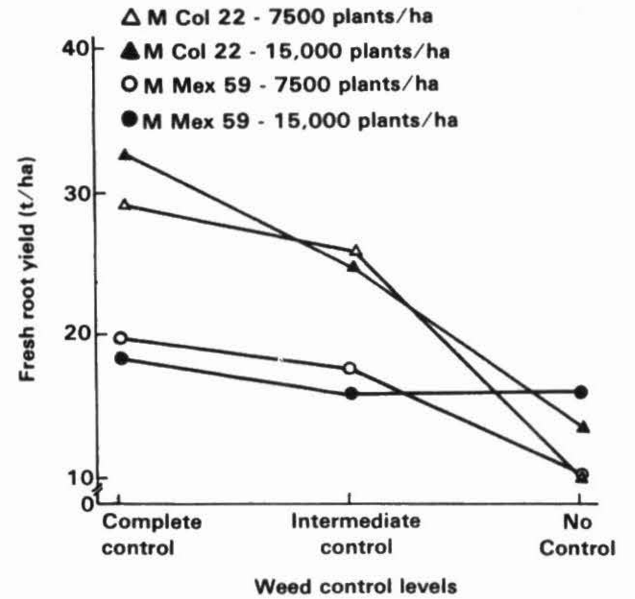


Figure 27. Effect of a non-vigorous (M Col 22) and a vigorous (M Mex 59) plant type and plant population on cassava root yield at different weed control levels, ICA-Caribia, 1978-79.

Table 39. Comparison of the effect of oxyfluorfen and diuron/alachlor treatments on fresh root yields and dry matter content of cassava cultivar CMC 40, CIAT-Palmira, 1979.

Treatment	Application rate (kg a.i./ha)	Fresh root yield (t/ha)	Root dry matter content (%)
Oxyfluorfen	0.25	18.4a[1]	33.1ab
Oxyfluorfen	0.50	19.5a	33.7a
Oxyfluorfen	1.00	21.3a	33.6ab
Oxyfluorfen	2.00	19.1a	33.5ab
Diuron + alachlor	1.2 + 1.4	21.1a	34.0a
Hand-weeded check	-	24.1a	34.1a
Unweeded check	-	11.2b	32.3b

1 Figures within columns followed by the same letter are not significantly different at the 0.05 level.

the yielding ability of the non-vigorous variety M Col 22 was not fully expressed at the low planting density, thus its yield response to a higher density was positive. In contrast, the yielding ability of the vigorous cultivar M Mex 59 was already expressed at the low planting density, thus its response to increased density was negative. A similar density/plant type interaction was observed at the intermediate weed control level, however, the situation was different when weed control became deficient. Under the latter conditions, genotypic differences lost their influence on yield and higher plant populations as a means of cultural weed control gained importance; from low to high planting density yield increases were up to 60%. If deficient weed control is anticipated, yield losses can be reduced by increasing planting density. A change of variety to a more competitive genotype should be considered as the second alternative.

Mulching and green covers

Mulching is a practice often recommended to control weeds, reduce erosion, maintain soil moisture, and reduce soil temperature. Several mulching practices were tested at Carimagua and CIAT-Palmira with cassava varieties M Ven 168 and M Mex 59, respectively. The effect of treatments on yield, weed growth and soil temperature are shown in Table 40. In Carimagua yields were low due to CBB, stemborers and lodging during a wind storm. In CIAT-Palmira yields were affected by stemborers and root rot due to poor drainage. Excess water was the cause of very low yields in the irrigated check. In both trials, the highest cassava yields were obtained with a maize straw mulch. This mulching practice provided a good control of weeds and a lasting soil cover. Puntero grass (*Hyparrhenia rufa*), sugarcane leaves and

Table 40. Effect of mulching practices on cassava root yield, soil temperature and weed control at harvest in Carimagua (cultivar M Ven 168) and CIAT (cultivar M Mex 59).

	Carimagua			CIAT-Palmira	
Type of mulch	Root yield (t/ha)	Soil temperature (°C)	Weeds (t/ha)	Root yield (t/ha)	Soil temperature (°C)
Check with weed control	10.3ab[1]	25	-	24.9ab	23
Check without weed control	8.7b	28	31.2	23.1abc	23
Loosened soil	8.7b	27	-	22.3abc	23
Plantain leaves	10.4ab	28	27.0	-	-
Maize plants	12.8a	26	17.0	27.3a	22
Hyparrhenia rufa	12.5a	27	23.5	-	-
Kudzu	12.4a	27	27.5	-	-
Check with irrigation	10.1ab	29	-	17.9c	23
Rice straw				22.9abc	23
Cassava leaves/stems				19.1bc	24
Sugarcane leaves				26.1a	23
Stylosanthes				25.8a	23

1 Figures within columns followed by the same letter are not significantly different at the 0.05 level.

Stylosanthes straw also proved good for mulching due to their persistence. Plantain leaves, kudzu straw and cassava leaves were less effective as they decomposed rapidly within the first three months, leaving the soil exposed for weed growth. Soil mulching by loosening the soil surface during the dry season to break capillarity flow of water was not effective in either location.

In another trial conducted at CIAT-Palmira, the green cover established with *Desmodium heterophyllum* and with intercropped beans gave a similar control to that achieved with continous manual weeding. On the other hand, a sugarcane bagasse mulch showed initially very high control but later lost its effectiveness; a similar situation was observed with the preemergent herbicide treatment (Figure 28). Cassava gave the greatest yields when four manual weedings were carried out at 22, 40, 60 and 115 days after planting. However, this was also the most expensive weed control system in terms of labor input (Table 41). Chemical weed control requires less investment in labor but increased expenses in capital. Cassava yields could be doubled with the use of the preemergent herbicide mixture as compared to no weed control but they were still 30% lower than those of the manually weeded check due to weed competition after the initial effect of the herbicide was lost. The use of legume green covers required high inputs of both labor and capital. The high seed value of both legumes explains the capital cost of these weed control systems. Both legumes reduced cassava yield by about 20%, a yield reduction which was offset by the additional production of dry beans in the cassava bean system. The two types of legume green covers provided very effective weed control over several months (Figure 28) but they still required some initial hand weeding for establishment. Since cassava yield in the two green cover treatments was not much different from that obtained with mulching it may be concluded that competition for water and nutrients was minimal. Thus, the green cover weed control is another alternative considering the possibility of producing the seed material locally to reduce capital cost and obtaining additional income from beans and long lasting cover, erosion control, N fixation and

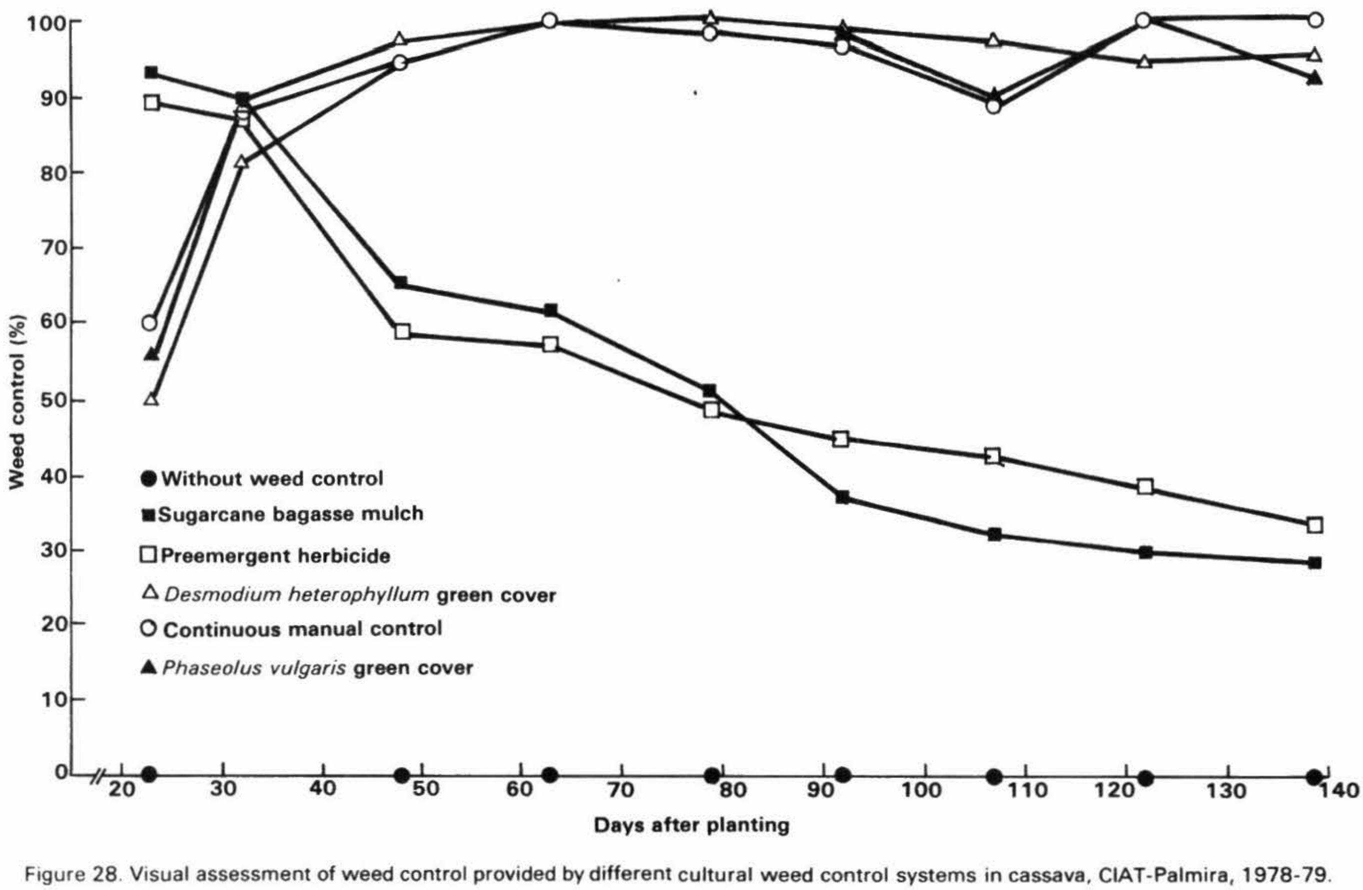


Figure 28. Visual assessment of weed control provided by different cultural weed control systems in cassava, CIAT-Palmira, 1978-79.

Table 41. Effect of weed control systems on weeding cost and yields of cassava variety CMC 40, CIAT, 1979.

Weed control system	No. of hand weedings	Costs (Col. $/ha) Labor	Capital	Fresh root yield (t/ha)
No weed control	-	-	-	12.9
Preemergent herbicide[1]	-	200	2100	23.4
Sugarcane bagasse mulch[2]	-	1200	340	27.6
Green cover of *Phaseolus vulgaris*[3]	2	5000	6600	26.8
Green cover of *Desmodium heterophyllum*[4]	2	5800	2400	26.9
Manual weeding[5]	4	9600	-	33.2
CV %				13.6
SD				2.97

1 Linnuron (1 kg commercial product/ha) + fluorodifen (7 l commercial product/ha); 1 man-day/ha for application.

2 Sugarcane bagasse at 17 t/ha, Col. $20/t (transportation cost not included); 6 man-days/ha for application.

3 Black beans, cultivar Porrillo Sintético, intercropped at a seed rate of 120 kg/ha, Col. $55/kg; 25 man-days for initial weeding. Dry bean yield obtained was 1.94 t/ha.

4 *Desmodium heterophyllum* intersown at a seed rate of 4 kg/ha, Col. $600/kg seed; 29 man-days for initial weeding.

5 Fourty-eight man-days for manual weeding.

forage material from *D. heterophyllum*. The weed control system using a sugarcane bagasse mulch was an interesting alternative requiring a low level of labor and capital. Even if a reasonable charge was made for transportation of the sugarcane bagasse (during 1979, CIAT bought bagasse at Col. $150/t, including $20 for the raw material and $130 for transportation), the total cost for weed control would not be much greater than that of the herbicide mixture. Besides, mulching gave an 18% greater cassava yield and it is an ecologically harmless cultural practice.

The results demonstrate that a variety of effective and economic alternatives for cultural weed control in cassava can be chosen by the farmer according to his particular labor and capital situation.

Storage of Planting Material

Cassava planting often follows the pluviometric cycles of the year causing considerable time intervals between harvesting and the subsequent planting. During these periods, stored planting material is exposed to physical damage, dehydration, diseases and insect pests. All these factors together cause losses in viability of stakes and ultimately in root yield. Earlier research efforts (CIAT Annual Reports, 1977 and 1978) have shown the importance of preventing dehydration by proper storage and protecting stakes chemically against fungal agents. To test longer storage intervals and different storage conditions, a field trial was conducted using cassava variety CMC-76. Storage duration was 0, 30, 60 and 90 days at dry room environmental conditions, in a shaded site in the field or in an earth silo. All material was treated before storage with BCM and captan at 3000 ppm each. After storage, the 1 m long stakes were cut into 20 cm pieces, dip-treated with the recommended fungicide-insecticide-micronutrient mixture and planted at 1 x 1 m on ridges. The field was previously irrigated to secure optimum moisture conditions at planting.

When storage conditions were adequate (dry room or open air shade conditions), germination rate was higher in the stored than in the fresh planting material independent of storage duration (Figure 29). Even with inadequate storage (earth silo) the 30-day stored material initially showed a higher germination rate as compared to fresh material. Final germination percentage was almost unaffected by storage duration when conditions were adequate, reaching 95-100% at all intervals. In contrast, final germination percentage was strongly reduced by longer storage periods when storage conditions were inappropriate.

Root yield

Root yield was influenced by both duration and condition of storage (Table 42). Yield declined at the longer storage intervals under all storage conditions but yield reduction was more drastic under non-adequate storage conditions. The effects of both duration and condition of storage were highly signficant ($P = 0.001$). Also, a highly significant storage duration/storage condition interaction was found indicating that as storage duration increases, conditions under which planting material is stored gain more importance. The best treatment was storing 1 m stakes vertically under the shade of a bambu canopy. Rooting of the stakes in the soil and some sprouting of the apical buds was not detrimental to preservation. Stakes wrapped in plastic and buried in 80 cm-deep earth silos produced excess moisture through transpiration and suffered severe premature sprouting and poor germination. Under these conditions, variation in root yield was explained by final germination percentage, i.e. percent stand at harvest ($R^2 = 0.90^{***}$). However, under adequate storage conditions (shaded field site, on soil, in vertical position), a large portion of root yield variation was not explained by stand at harvest ($R^2 = 0.42$) indicating that other factors related to storage duration also influenced yield (Figure 30).

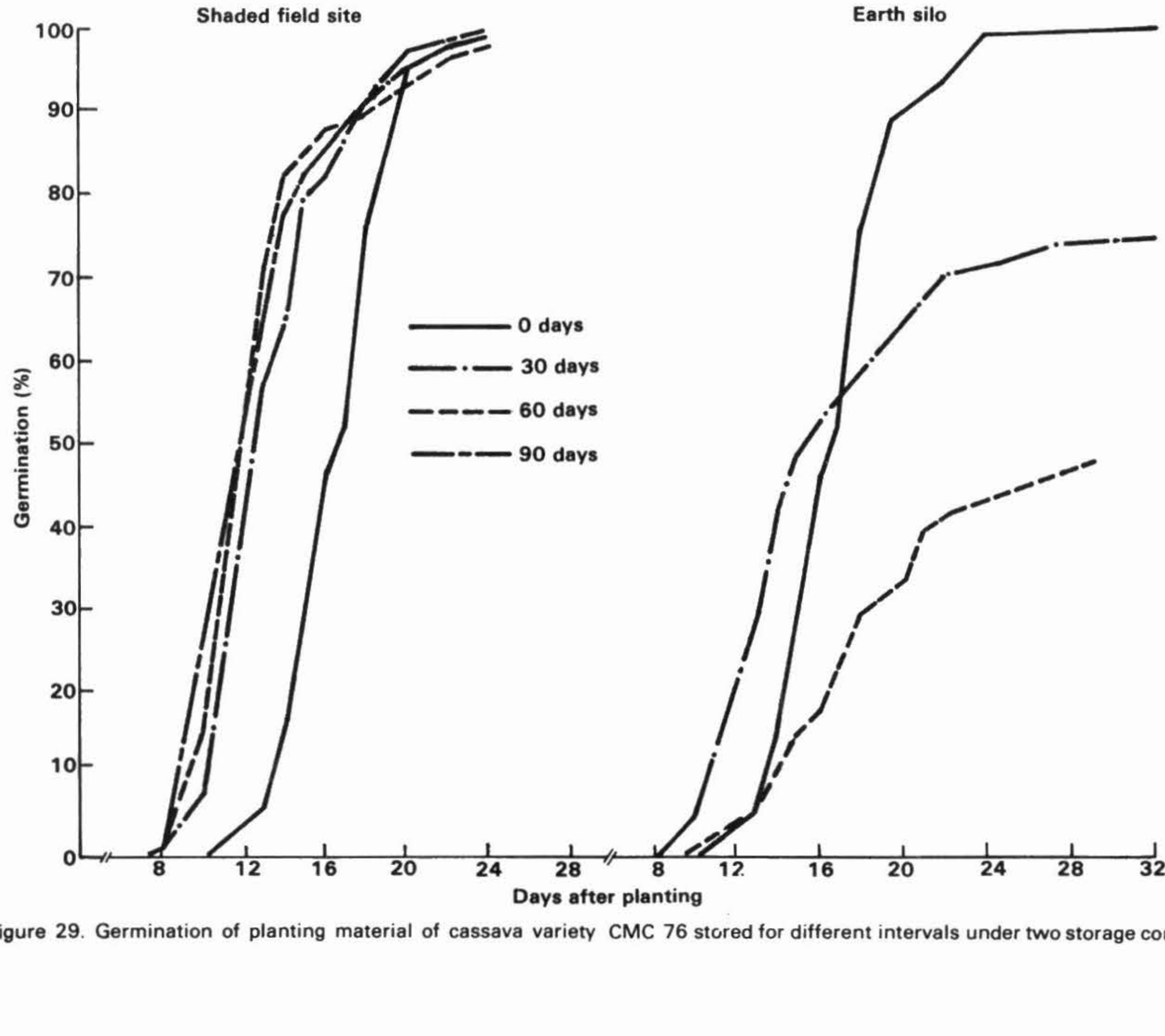


Figure 29. Germination of planting material of cassava variety CMC 76 stored for different intervals under two storage conditions.

Table 42. Fresh root yield of cassava variety CMC 76 as influenced by condition and time of storage of planting material.

Storage conditions	Storage duration (days)	Stand at harvest (%)	Cassava root yield (t/ha)
Dry room, 1 m stakes, vertical position	0	100	35.5
	30	100	29.7
	60	98	26.9
	90	98	24.0
Shaded field site, 1 m stakes, on wooden base, horizontal position	0	100	35.5
	30	100	24.5
	60	100	24.0
	90	94	25.5
Shaded field site, 1 m stakes on soil, vertical position	0	100	35.5
	30	100	31.9
	60	100	27.8
	90	96	23.9
Earth silo, 1 m stakes, plastic wrap, horizontal position	0	100	35.5
	30	73	20.3
	60	65	19.6
	90	0	0.0
Earth silo, 20 cm stakes, plastic wrap, horizontal position	0	100	35.5
	30	96	31.5
	60	79	21.8
	90	0	0.0
CV %		8.7	16.0
SD		7.26	3.9

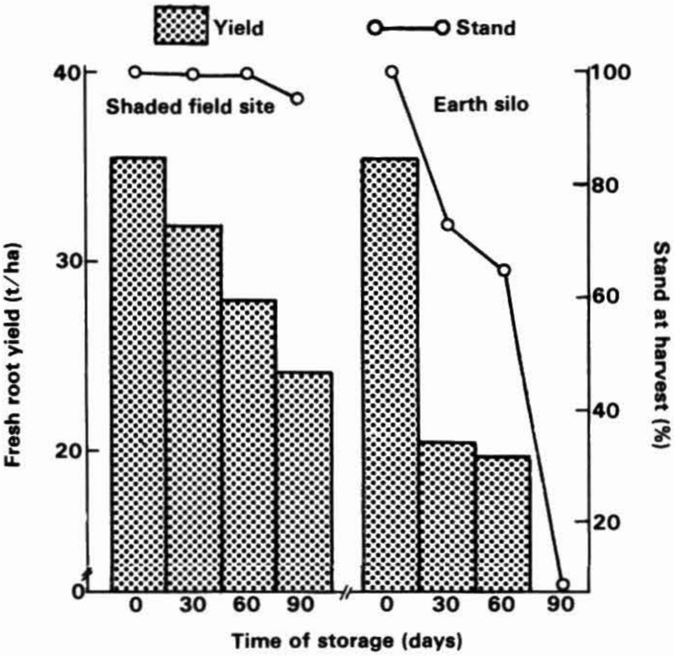


Figure 30. Effect of storage duration and storage conditions of cassava planting material on fresh root yield and stand at harvest.

Root number and size

Plants from stored planting material showed lower total roots and marketable roots/plant than did those from fresh planting material even if storage conditions were adequate (Table 43).

Plants with a lower root number had increasing root size, but root size did not increase sufficiently to stabilize root yield. The decline in total and marketable root numbers was clear and may account for some of the yield depression at the longer storage periods ($R^2 = 0.80^{***}$).

Conclusions

(1) With chemical treatment and appropriate storage conditions, cassava planting material can be preserved and germination secured for several months.

(2) In tropical climates, no costly construction is necessary for storage if a shaded site under field conditions is available.

Table 43. Effect of storage duration of planting material on root characteristics of cassava variety CMC 76 harvested 11 months after planting.

Storage duration (days)	Total number of roots/plant	No. of marketable roots/plant	Mean root size Length (cm)	Mean root size Perimeter (cm)
0	12.2a[1]	7.5a	26.3a	19.8ab
30	11.5a	6.2ab	26.1a	19.3b
60	9.4b	5.1b	27.2a	21.1a
90	10.7ab	5.8b	26.7a	21.0a

1 Figures within columns followed by the same letter are not significantly different at the 0.05 level.

(3) As duration of storage increases, the conditions under which planting material is stored become more critical.

(4) With the complete germination achieved by chemical treatment and proper storage, yield reduction due to duration of storage is not adequately explained by stand at harvest. Under these conditions, other factors affecting root system and top growth as a consequence of storage duration are responsible for the observed variation in yield.

Multiple Cropping

Research with beans allowed the establishment of some of the physiological and agronomic principles of cassava/legume intercropping. However, field beans are not adapted to the low humid tropics and perform poorly on acid, inferile soils where cassava has the potential to yield well. Therefore, identification of legume species and genotypes with potential to be intercropped with cassava was initiated by screening bean collections for adaptation and tolerance to poor, acid soil conditions, growth habit, growth duration, yield and competitive effect on cassava. For simultaneous planting with cassava, legumes should have a non-aggressive growth habit (erect or prostrate, but not climbing), cover the ground rapidly, and mature in less than 100 days. Earliness is essential for the legumes to reach the pod filling stage before cassava starts to close rows and shading gets serious. Work also initiated to determine optimum agronomic practices such as legume planting density and spacial arrangements for its association with cassava.

Soil conditions

Most trials were conducted on an ultisol (Ortoxic Palehumult) at CIAT-Quilichao. Screening of legumes was also done at CIAT-Palmira and Caribia.

The potential of cowpeas and peanuts as companion crops for cassava in associated systems in poor soils is shown by the reasonable grain yields obtained with low fertilizer applications.

Screening of species and cultivars

Collections of 61 cowpea varieties (*Vigna unguiculata*), 66 mungbeans (*Vigna radiata*), 14 pigeon peas (*Cajanus cajan*), 9 winged beans (*Psophocarpus tetragonolobus*), 8 soybeans (*Glycine max* L.), 3 lime beans (*Phaseolus lunatus*) velvet beans (*Stizolobium derringianum*) and 1 cultivar each of jack beans (*Canavalia ensiformis*), sword beans (*Canavalia gladiata*), and peanuts (*Arachis hypogea*) were tested at CIAT-Quilichao, Caribia, and CIAT-Palmira, for growth habit, growth duration, and yield in monoculture and association with cassava. A basal dressing of 0.5 t/ha of dolomitic lime and 50, 100, 75, and 10 kg/ha of N, P_2O_5, K_2O, and Zn, respectively, were applied to the collections at CIAT-Quilichao while no fertilizer was used at the medium and high fertility sites of Caribia and CIAT-Palmira. At CIAT-Palmira, however, legumes received rhizobial inoculation and three foliar sprayings providing N, Zn, and B.

In the screening trials the species showing highest productivity at CIAT-Quilichao and adaptation to conditions at the other two sites was *V. unguiculata* (Table 44). Outstanding cultivars such as TVX 1193-059D, TVU 1977-OD, and TVX 1836-9E yielded over 2000 kg/ha of grain in monoculture and also gave the greatest intercrop yields. The local groundnut variety ICA-Tatui 76 grown at CIAT-Quilichao in monoculture and with cassava also showed adaptation to infertile and acid soils, a short growth cycle, and an adequate growth habit for intercropping with cassava. Mungbeans did not adapt to soil conditions at CIAT-Quilichao but proved to be highly productive at CIAT-Palmira and in Caribia where they appear to be an excellent companion crop for cassava due to their low competitive effect. The other legumes tested at CIAT-Quilichao were either low yielding, too late maturing or otherwise unsuitable for cassava intercropping.

Effect of legume/cassava intercropping on yields

Legumes competed with cassava in different ways, according to their vegetative development. In general, when vigorous vegetative and reproductive growth was exhibited by legumes, cassava yields were depressed to a greater extent (Table 45). Jack beans and sword beans depressed cassava yield most,

Table 44. Grain yield and growth duration of legume species tested in monoculture for adaptation at three locations, 1979.

	Location					
	CIAT-Quilichao		Caribia		CIAT-Palmira	
Species	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity
Vigna unguiculata						
Mean of 61 cultivars	1179	82	799	62	2522	79
Vigna radiata						
Mean of 66 cultivars	31	79[1]	1245	58	1620	66[1]
Arachis hypogea						
1 cultivar	1822[2]	106[3]	-	-	3080[2]	114[3]
Stizolobium derringianum						
Mean of 2 cultivars	948	143	-	-	-	-
Psophocarpus						
Mean of 9 cultivars	11	113[1]	-	-	3151	64[4]
Phaseolus lunatus						
Mean of 3 cultivars	5	-	-	-	3480	80
Cajanus cajan						
Mean of 14 cultivars	0	-	-	-	3359	96
Canavalia ensiformis						
1 cultivar	0	-	-	-	-	-
Canavalia gladiata						
1 cultivar	0	-	-	-	-	-

1 Days to first harvest of mature pods.
2 Yield of unshelled groundnuts.
3 Days to physiological maturity.
4 Days to pod setting.

Table 45. Competitive effect between different legume species and cassava at CIAT-Quilichao and Caribia, 1978.

Intercropping system	Legume grain yield			Cassava root yield		
	Monoculture (kg/ha)	Intercropped (kg/ha)	Reduction (%)	Monoculture (t/ha)	Intercropped (t/ha)	Reduction (%)
Cowpea/cassava[1] Yield trial (CIAT-Quilichao)	2156	1944	10	40.8	26.3	36
Cowpea/cassava[2] Screening trial (CIAT-Quilichao; mean of 61 cowpea cultivars)	1179	459	61	19.3	14.3	26
Mungbean/cassava[3] Yield trial (Caribia)	1359	847	38	34.6	34.4	1
Mungbean/cassava[2] Screening trial (CIAT-Quilichao; mean of 66 cultivars)	31	6	81	19.3	19.2	1
Pigeonpeas/cassava[2] Screening trial (CIAT-Quilichao; mean of 24 cultivars)	0	0	-	19.3	16.6	14
Jack beans/cassava[2] Screening trial (CIAT-Quilichao; 1 cultivar)	0	765	-	19.3	10.8	44
Sword beans/cassava[2] Screening trial (CIAT-Quilichao; 1 cultivar)	0	0	-	19.3	6.3	68
Groundnuts/cassava[4] Yield trial (CIAT-Quilichao)	1822	1543	15	34.1	28.0	18

1 Cassava cultivar CMC 40 with cowpea TVU-201-ID.
2 Cassava cultivar CMC 84.
3 Cassava cultivar M Col 22 with mungbean 1380 Mg 50-10A.
4 Cassava cultivar CMC 40 with groundnut ICA-Tatui 76. Yield figures are given for unshelled groundnuts.

possibly due to their vigorous vegetative growth, but low or no grain production was obtained. Cowpeas reduced cassava root production less and suffered greater grain yield reduction in the screening trial than in the yield trial, where soil fertility was higher. Mungbeans which performed poorly even in monoculture suffered an extreme yield reduction in association with cassava at CIAT-Quilichao while cassava yields were not affected. At Caribia, however, they performed well both in monoculture and in association. A consistent balanced performance was shown by groundnuts, suffering little yield reduction when intercropped and competing much less with cassava than other species.

These results indicate that cassava has more competitive advantage over other crops under low soil fertility. While differences in competition with cassava were large between species, it appeared that variation in growth habit (very erect, semierect or prostrate) within one species was of minor influence on cassava yield.

Planting density and spatial arrangement

Research on cassava/beans association at CIAT showed that by simultaneously planting normal monoculture densities of both crops the highest land equivalent ratios and the greatest total yields were obtained. To validate this practice with cowpeas and groundnuts under acid, infertile soil conditions, trials were established at CIAT-Quilichao using legume densities of 110,000, 220,000 and 550,000 plants/ha. Cassava density was kept constant at 9259 plants/ha at 1.8 x 0.6 m spacings. At the same time, different spatial arrangements of legumes between cassava rows were tested (Figure 31).

Yield results of intercropped cowpeas showed that greatest yields were obtained with 110,000 plants/ha, a density which is currently used for cowpea monoculture plantings (Figure 32).

Cassava yield data showed that 110,000 plants/ha of cowpea gives the least competition on cassava

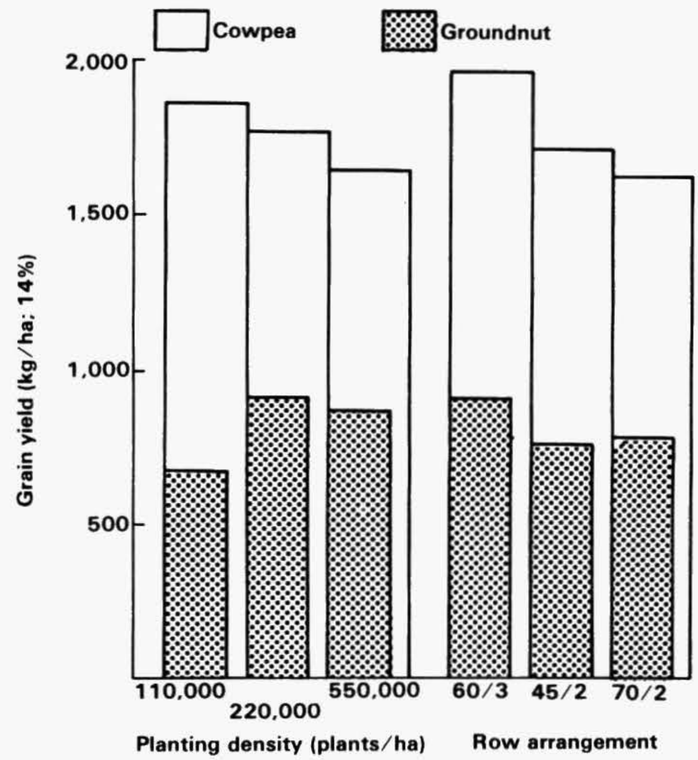


Figure 32. Grain yield of cowpea variety TVU 354-1B and unshelled groundnut yield of variety ICA-Tatui 76 as influenced by legume planting density and row arrangement in association with cassava, CIAT-Quilichao, 1979.

(Figure 33). In an additional cassava/cowpea trial, densities of 70,000, 100,000, and 150,000 plants/ha were tested showing little difference between cowpea yields at the first two densities but a yield decline at the highest plant population. It was thus confirmed that a planting density around 100,000 plants/ha can be safely used for cowpeas intercropped with cassava. Groundnut yields were also affected by planting density, giving greatest yields at 220,000

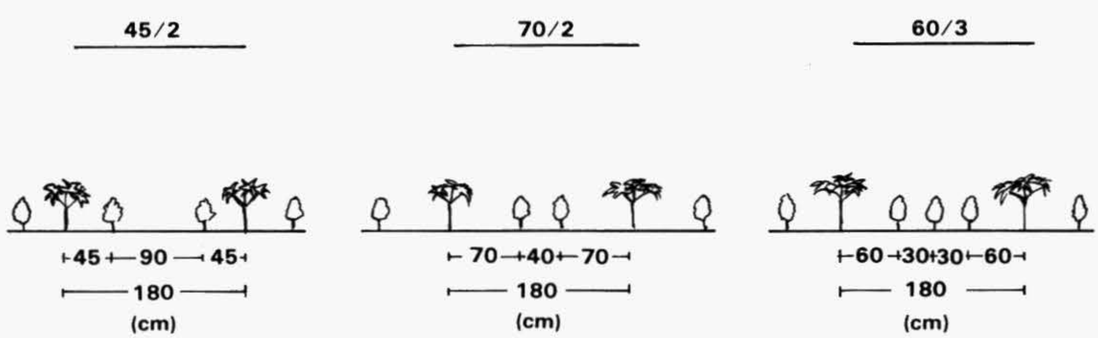


Figure 31. Row arrangements tested for legume/cassava associations.

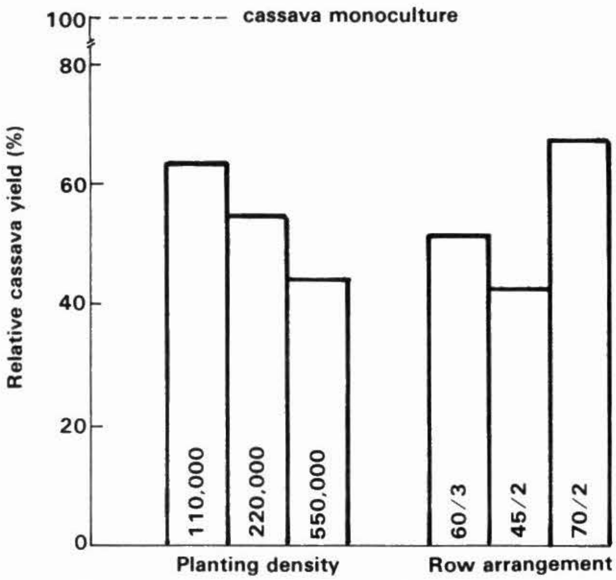


Figure 33. Effect of cowpea planting density and row arrangement on fresh root yield of cassava variety CMC 40, CIAT-Quilichao, 1979.

plants/ha (Figure 32). Cassava in this trial is still to be harvested.

Grain yields of both cowpeas and groundnuts showed a distinct advantage of the 60/3 spatial arragement system (Figure 32). With cowpea, the 70/2 system yielded lowest, possibly due to an increased intraspecific competition in this arrangement. Groundnuts yielded lowest in the 45/2 system which may be due to greater competition from cassava. Cassava root yields in the cowpea trial were least affected by the 70/2 arrangement and most by the 45/2 arrangement as could be expected (Figure 33). As a result, the 60/3 arrangement appears to be a reasonable alternative combining an intermediate cassava yield reduction with highest legume yields. However, if emphasis is on cassava production, the 70/2 arrangement would be preferable.

SOILS AND PLANT NUTRITION

A major objective of CIAT's Cassava Program is to develop technology for cassava production on acid infertile soils. The strategy to attain this objective follows a two-pronged approach:

(1) The development of cassava germplasm that will be well adapted to grow on acid, low fertility soils; and, (2) the development of diagnostic criteria to determine the type and amount of fertilizer to be applied, and to determine the most effective way of applying these fertilizers.

To develop germplasm adapted to acid, infertile soils it is necessary to evaluate the existing germplasm for adaptation to specific factors that limit cassava production on these soils. Low levels of available P and high levels of exchangeable Al had been previously identified as factors seriously limiting yields. Thus, large numbers of cultivars from the germplasm bank are being screened for tolerance to low levels of P and high levels of Al in nutrient solution or in soil.

Nutrient Solution Screening for Low-P Tolerance

During 1979 a total of 270 cultivars were screened in nutrient solutions. Four rooted plantlets of each cultivar were grown for three weeks in two nutrient solutions at 0 and 16 ppm added P. At the end of this period a P-tolerance index was calculated by dividing dry matter production at 0 ppm P by that at 16 ppm P. Although 32% of the material was found to be highly tolerant (tolerance index 80%), the consistency of the results was not very good due to large variations among single plants. Using more replications and a longer growth period would improve the methodology but at the expense of the main advantage of speed and simplicity of the nutrient solution screening. Improvements in the methodology, including a low but non-zero P-check, are presently under investigation.

Field Screening for Low-P Tolerance

A field screening trial for low-P tolerance in CIAT-Quilichao was planted with 32 cultivars in plots which received 0 and 100 kg P_2O_5/ha (the same plots had received 0 and 200 kg P_2O_5/ha the previous year).

Half of the P-plots were harvested at five months and the other half at 12 months. As in 1978, a P tolerance index was calculated for each cultivar as follows:

$$\frac{\text{Yield at O P}}{\text{Yield at 100 } P_2O_5} \times \frac{\text{Yield at O P}}{\text{Highest yield at O P}} \times 100\%$$

A regression analysis of P tolerance indices determined at five months using total fresh weight production, with those determined at 12 months for root production gave a low correlation coefficient of 0.27. A similar analysis using root yield at five months to calculate the P tolerance indices given an R-value of only 0.22. The lack of correlation between P response at five months and at 12 months indicates that it will be necessary to wait a full year to determine a cultivar's tolerance level to low-P soils.

The P tolerance index varied from 4.2 to 81.5 with an average of 31.7. The best cultivars were: M Col 1292, M Mex 59, M Col 1684, M Ven 156, and CMC 84, which had tolerance indices above 50.

Field Screening for Acid Soil Tolerance

In 1977 lime blocks had been established in CIAT-Quilichao by the application of 0, 0.5, 2, and 6 t calcitic lime/ha. These blocks were used in 1978 for the screening of 30 cassava cultivars for tolerance to acid soils. Liming increased soil pH, Ca and Mg and decreased exchangeable Al and available Mn as shown in Table 46.

At harvest there was a small but highly significant response to liming, which increased average root yields from 2.09 to 2.15, 2.22, and 2.34 kg/m^2 with the application of 0.5, 2 and 6 t lime/ha, respectively. Average root yields without lime were 90% of those with 6 t/ha applied lime. Comparing root yields at 0 and 6 t lime/ha, acid soil tolerance indices were calculated according to the formula:

$$\frac{\text{Yield at O lime}}{\text{Yield at 6 t lime}} + \frac{\text{Yield at O lime}}{\text{Highest yield at O lime}} \times 100\%$$

These indices ranged from 3.3 to 103.3 and the best cultivars were: M Col 706, M Col 1787 A, M Ecu 56, M Ecu 69, and M Ecu 154, which all had a tolerance index above 50. M Col 706 produced a single-row yield of 61 t/ha without lime, and significantly higher yields than any other cultivar at all lime levels, with the exception of M Ven 87 which produced the highest yield with 6 t lime/ha.

Although cassava is extremely tolerant to low pH and high exchangeable Al, and shows little response to liming, it is expected that with time the lime response will become more significant on this soil. Residual acidity of fertilizers and mineralization of the organic matter (7-9%) decreased pH in some fields from 4.7 to 4.0 during one year despite the fact that 0.5 t/ha of lime had been applied. This gradual pH decline not only increased exchangeable Al but greatly increased Mn solubility; in some areas soil Mn concentration was above 200 ppm and over 1000 ppm in upper cassava leaves. These levels are far above the critical level (approximately 200 ppm in leaves) and may cause serious yield declines.

P Requirements and Fertilization

In 1977 the external P requirement of cassava was determined by planting cultivar Llanera in CIAT-Quilichao and Carimagua in plots which received various levels of incorporated triple superphosphate (TSP) corresponding to P concentrations in the soil solution from 0.005 to 0.2 ppm, as determined from P-sorption isotherms. The first planting in CIAT-Quilichao resulted in an external P-requirement of approximately 0.02 ppm (CIAT Annual Report, 1978). Replanting of the same plots without additional P applications resulted in only a minor response to P,

Table 46. Effect of liming on the chemical characteristics of a CIAT-Quilichao soil.

Lime	pH	Al	Ca	Mg	K	Al sat	Mn	P
(t/ha)		(meq/100 g)				(%)	(ppm)	
0	4.05	3.90	0.69	0.23	0.15	77	49	21.8
0.5	4.17	3.57	1.13	0.25	0.15	69	51	20.9
2	4.55	2.07	3.01	0.28	0.15	37	35	17.1
6	5.30	0.20	7.09	0.28	0.16	2	19	17.1

with yields increasing from 19.7 to 25.3 t/ha with the initial application of 322 kg P_2O_5/ha (0.01 ppm in the soil solution). Yields declined to 21-22 t/ha at higher P application rates. These low yields, compared to 48 t/ha in 1978, are attributed to a general decline in yielding ability of this cultivar in all trials. It may also be due to increased fixation of P with time as indicated by a decline in Bray II-extractable P. A slow release of mineralized organic P may also have decreased the response, although the soil P level and the yield of the check plot were not significantly different from those of last year.

In Carimagua, growth response to applied P was good with plants showing typical symptoms of P deficiency in the check plots and very vigorous growth at high levels of applied P. Although Llanera is tolerant to CBB, its vigorous growth favored severe attack by this disease which seriously affected root yields. Yields increased from 5.8 to 14.2 t/ha with the application of 42 kg P_2O_5/ha (0.02 ppm P in the soil solution). Above this rate yields declined to about 9-10 t/ha. Although response to P was highly significant, high rates of applied P decreased the harvest index from 0.51 to 0.35, possibly due to excessive top growth. The low harvest index contrasts sharply with indices of 0.72-0.77 reported for Llanera in previous years (CIAT Annual Reports, 1977 and 1978).

Application of 42 kg P_2O_5/ha not only increased root yield but also increased starch content from 28.7 to 31.8%, resulting in a starch yield increase from 1.7 to 4.5 t/ha.

P Sources and Application Method

Phosphorous sources and method of application may affect yields as much as the rate of application. Different P sources such as TSP, Huila rock phosphate, fused magnesium phosphate, granulated or non-granulated partially acidulated rock phosphates, and several combinations of rock phosphate with TSP were tested in band or broadcast applications to cassava cultivar Llanera in two trials at CIAT-Quilichao in cooperation with the CIAT/IFDC Phosphorous Project. Although this cultivar had responded markedly to P applications at this site in 1978 there was no response in terms of root yield in either of the two trials this year; however, foliage yields were markedly increased by P applications. The lack of response to applied P was thought to be due to an inadequate translocation of carbohydrates from tops to roots in this cultivar (harvest index of only 0.3-0.4) and high rate of mineralization of organic P.

Another trial was planted in Carimagua using cultivar Llanera to determine the best method of application of TSP, simple superphosphate (SSP), basic slag, and Huila rock phosphate at rates of 100, 200 and 400 kg P_2O_5/ha. Plants had low vigor and were seriously affected by CBB. Yields were low ranging from 6.0 to 8.5 t/ha (Figure 34). There was a highly significant response to rates of applied P but there was no significant difference between sources. Concentrating TSP in a band near the plant tended to increase yields, while broadcast application of SSP, basic slag, and Huila RP tended to be superior to banding.

The same trial was planted in CIAT-Quilichao with cultivar M Ven 168 and TSP, basic slag, and Huila rock phosphate. Although the cultivar suffered from a severe thrip attack, plant growth was vigorous and root yields ranged from 31 to 38 t/ha. Figure 35 shows that application of all P sources resulted in a significant yield increase up to 400 kg P_2O_5/ha. TSP and basic slag were equally good sources except at 100 kg P_2O_5/ha, where TSP was more effective. Huila rock

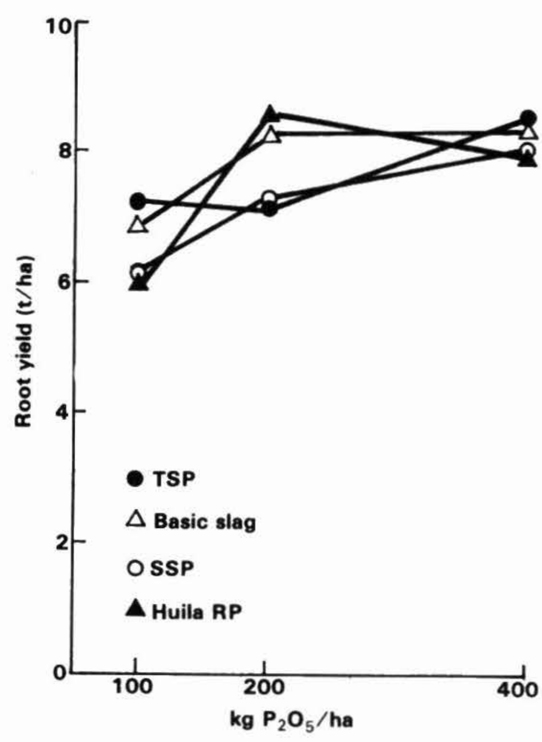


Figure 34. Yield response of cassava cultivar Llanera to the application of various levels and sources of phosphorous in Carimagua, 1977B.

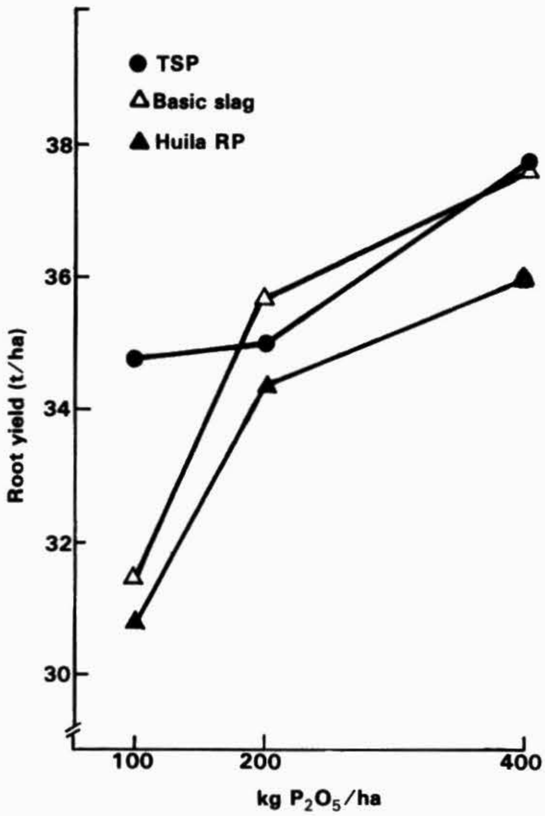


Figure 35. Yield response of cassava cultivar M Ven 168 to the application of various levels and sources of phosphorous in CIAT-Quilichao, 1977B.

phosphate was slightly inferior to the other two sources. Methods of application ranging from continuous bands under the stake to strip and broadcast applications, were not significantly different, which is rather surprising for this highly P-fixing soil.

Effect of Mycorrhiza on P Uptake and Plant Growth

Two trials were conducted at University of Queensland, Australia, to study the effect of mycorrhiza inoculation on P uptake and growth of cassava, one in a P deficient soil, and another in a flowing nutrient solution culture.

Inoculated and non-inoculated cassava plants were grown in a highly P fixing Oxisol to which eight levels of P were applied, ranging from 0 to 16 t P/ha. Half of the pots were sterilized to eliminate the native mycorrhizal population.

Table 47 shows the effect of sterilization and P applications on the P concentration in soil solution extracted by centrifugation, as well as the effect of inoculation on dry matter yields and total P uptake. In the unsterilized soil, inoculation had a marked effect on dry matter yield and P uptake at the intermediate P levels of 0.1, 0.5, 1 and 2 t/ha (equivalent to 0.23, 1.14, 2.3 and 4.58 t P_2O_5/ha). However, the effect was much more pronounced in the sterilized soil, where inoculation increased dry matter yield three fold and total P uptake seven fold (Figure 36).

In the sterilized soil with uninoculated plants the lack of a mycorrhizal association essentially eliminated P uptake until about 4 t P/ha had been applied. Thus, it appears that cassava roots without mycorrhiza are extremenly inefficient in P uptake, and are highly dependent on an effective mycorrhizal association for P uptake in low P soils.

These conclusions were corroborated in a nutrient solution trial where inoculated and non-inoculated plants of eight cassava cultivars and one cultivar each of maize, rice, beans, and cowpea were grown at four constant P concentrations of 0.1, 1, 10, and 100 μM. Inoculation markedly increased dry matter production and P uptake of all cassava cultivars only at the 1 μM P, while it also increased P concentrations in tops and roots at 0.1 μM P. At 10 and 100 μM P cassava plants had reached near maximum yields and inoculation did not result in mycorrhizal infection of roots nor had a beneficial effect on dry matter yield. None of the other species became infected in nutrient solution and all reached their maximum yield at 1 μM P, while cassava required 10 μM P. Figure 37 shows that without mycorrhiza, cassava has a very coarse and inefficient root system, while with mycorrhiza, P uptake is greatly enhanced, resulting in better top and root growth. In nutrient solution, roots of inoculated plants were covered with a slimy substance consisting of masses of mycorrhizal hyphae, which greatly increased the nutrient absorbing surface of the plant.

Long Term Fertility Trial

Since cassava extracts large amounts of nutrients from the soil, especially K, continuous cassava cultivation must lead to nutrient depletion of the soil unless the crop is adequately fertilized. To study the long term effect of cassava cultivation on soil fertility and cassava yields, a N-P-K factorial experiment which will continue for several years was planted in CIAT-

Table 47. Effect of P application, soil sterilization and mycorrhizal inoculation of cassava cultivar M Aus 10 on the P concentration of the soil solution and on total dry matter production and P uptake of plants grown for eight weeks in an oxisol from Maleny, Queensland, Australia.

P applied (t/ha)	P in soil solution (uM)		Total dry matter g/plant				Total P uptake (mg/plant)			
	U[1]	S	UN	UI	SN	SI	UN	UI	SN	SI
0	-	-	11.7	11.8	10.8	9.5	15	17	7	8
0.1	1.9	2.4	22.5	24.4	12.8	15.6	35	40	8	19
0.5	6.6	4.9	27.6	41.1	13.7	30.7	56	85	8	49
1	14.4	16.1	35.3	41.4	11.4	29.1	66	76	8	47
2	-	39.7	41.6	52.8	20.1	54.7	94	94	14	100
4	38.0	52.0	73.9	76.1	67.6	69.1	120	122	82	157
8	196.0	250.0	96.5	88.4	87.8	84.4	161	167	187	206
16	727.0	795.0	96.7	92.3	65.9	68.0	262	249	247	237

1 U = unsterilized soil; S = sterilized soil; UN = unsterilized, non-inoculated; UI = unsterilized, inoculated; SN = sterilized, non-inoculated; and SI = sterilized, inoculated.

Figure 36. The effect of soil sterilization and mycorrhizal inoculation on growth of cassava cultivar M Aus 10 in an oxisol from Maleny, Queensland, Australia, to which 1 t/ha P (equivalent to 2.29 t/ha P_2O_5) had been applied. Note the marked effect of inoculation in the sterilized soil on the left.

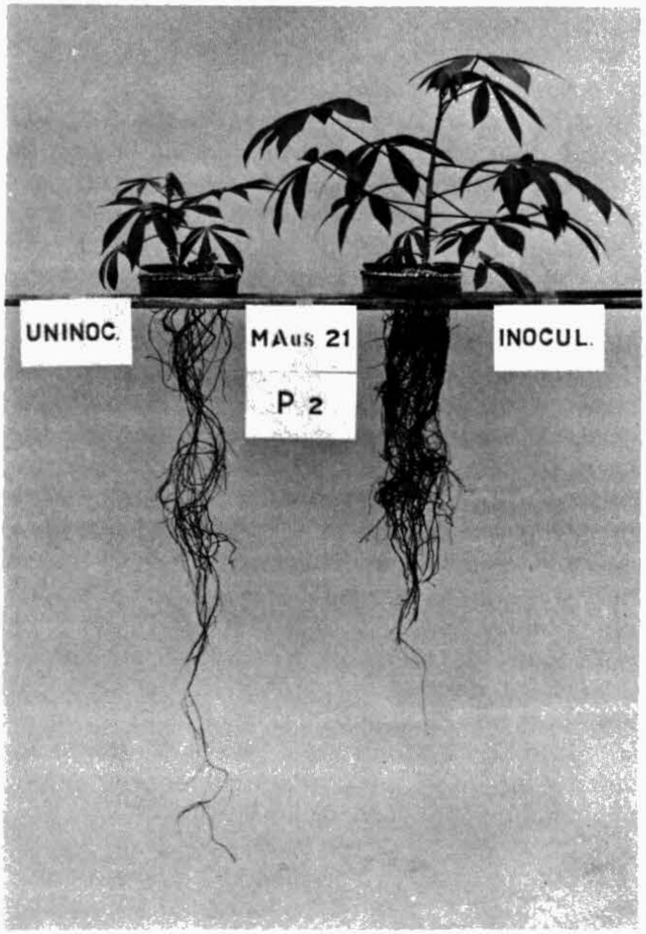


Figure 37. Effect of mycorrhizal inoculation on cassava cultivar M Aus 21 growing in flowing solution culture at constant P concentration of 1 μM. Note the improvement in top and root development due to mycorrhiza.

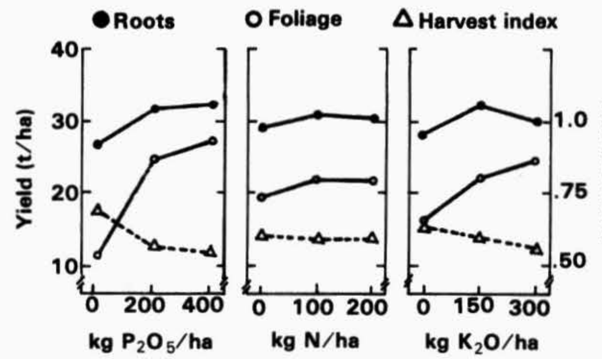


Figure 38. The effect of N, P and K application on the fresh root and foliage yield and on the harvest index of cassava cultivar Llanera at CIAT-Quilichao, 1977B.

Quilichao with cultivar Llanera. Nitrogen was applied as urea at 0, 100, and 200 kg N/ha, phosphorous as TSP at 0, 200, 400 kg P_2O_5/ha, and potassium as KC1 at 0, 150, and 300 kg K O/ha. The experiment received a basal application of 500 kg/ha dolomitic lime, 20 kg S/ha and 10 kg Zn/ha. All fertilizers were broadcast and incorporated before planting. No additional fertilizer applications will be made. Eight additional treatments for comparison were established which receive fertilizer annually.

In the first planting, growth response to applied P was marked, with less response to N and K. At five months, average plant height increased from 118 to 144 cm with the application of P. Figure 38 shows the effect of N-P-K fertilization on root and top yield, and harvest index. Again, the large response of tops to P and K fertilization was not correlated to a good response in root production. There was a significant response in root yield to P and K at levels of 200 kg P_2O_5 and 150 kg K_2O/ha, respectively, but with no additional response to higher rates of application. Response to N was not significant either in terms of root or top yields. Both P and K fertilization drastically decreased the harvest index, while N fertilization had little effect. None of the three elements had a significant effect on starch content.

Soil analyses after harvest indicated no significant change in P and K contents where these elements were not applied. Phosphorous application at the rate of 200 and 400 kg P_2O_5/ha increased the P content from 5.5 to 16.3 and 34.9 ppm, respectively; K applications of 150 and 300 kg K_2O/ha increased exchangeable K from 0.20 to 0.26 and 0.32 meq/100 g, respectively. No significant K response would be expected at these high K levels in the soil, but K application would still be advisable to prevent soil depletion due to crop removal (about 95 kg K_2O/ha in this trial).

K Fertilization

In the Carimagua soil (mean K content of approximately 0.06 meq/100 g), cassava is expected to respond to K fertilization. On light soils, especially under high rainfall conditions, K leaches readily and a fractionated application may be advisable. A trial was established with cassava cultivar Llanera to determine the best time of application of varying K levels (0, 50, 100, and 200 kg K_2O/ha).

At harvest there was no significant overall response to K application although a fractionated application —

1/3 at planting, 1/3 at 30 days and 1/3 at 90 days — was better than any other method or time of application. The rather light texture of the soil (clay loam) and the low effective exchange capacity (2.3 meq/100 g) may require a fractionated application of N and K to prevent losses through leaching.

However, although root yields were not significantly increased by K applications, starch content did increase from 26.7 to 34.2% with 50 kg K_2O/ha (Figure 39). Starch yield increased linearly with increasing amounts of applied K up to 200 kg K_2O/ha. The highest starch yield was obtained with fractionated applications of 100 kg K_2O/ha.

Fertilization with Mg and Ca

The soils in CIAT-Quilichao are rather high in K and low in Mg and symptoms of Mg deficiency have been observed in some cultivars. On the other hand, Carimagua soils are low in K, Ca, and Mg. A trial was planted in both sites using cassava cultivars CMC 40 and Llanera for CIAT-Quilichao and Carimagua, respectively to determine the best level, source and method of application of Mg. Sources were $MgSO_4$ $7H_2O$, MgO, and dolomitic lime, each applied at 20, 40, and 60 kg Mg/ha. The MgSO was either applied in bands or broadcast; in addition, $MgSO_4$ was applied as three foliar sprays at 0.5, 1.0, and 2.0%. The plots were uniformly limed with 800 kg/ha calcitic lime with a

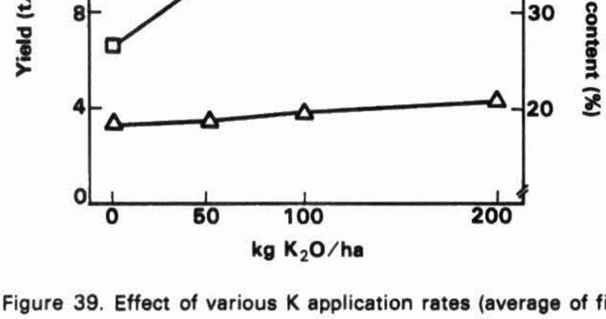


Figure 39. Effect of various K application rates (average of five application times) on the starch content of roots and root yields starch of cassava cultivar Llanera planted at Carimagua.

correction used for the lime equivalent of the MgO and dolomitic lime sources.

In CIAT-Quilichao, plant growth of CMC 40 was vigorous but with little response to Mg and no Mg deficiency symptoms were observed. Table 48 shows that there was a good consistent response to band application of 60 kg Mg/ha as $MgSO_4$. However, the response to other sources was more erratic with a maximum yield reached at either 20 or 40 kg Mg/ha. There was a significant response to application of 20 or 40 kg Mg/ha, but there were no significant differences among sources or methods of application. Foliar application was most effective at a concentration of 1% $MgSO_4$ applied at 30, 60, and 90 days.

In Carimagua, overall Llanera yields were low and there was no response to Mg except at 60 kg Mg/ha. There was no response to foliar application of $MgSO_4$. Fertilization with Mg increased starch content from 26.9% to about 30%, resulting in a significant increase in total starch yield. There were no significant differences among sources. However, considering the cost of fertilizers and transport, the most economical source of Mg would be dolomitic lime, followed by MgO in combination with calcitic lime.

In another trial at Carimagua, Llanera yields increased from 12.9 to 16.0 t/ha with the application of 800 kg Ca/ha applied as gypsum. This source of Ca gave higher yields and higher Ca contents in the leaves than the same amount of Ca applied as calcitic lime. However, the latter source resulted in a higher pH and Ca content and a lower percent Al saturation in the soil. Applying 500 and 2000 kg $CaCO_3$ equivalent/ha as mixtures of calcitic and dolomitic lime with Ca/Mg ratios varying from 20 to 1.83, it was found that 500 kg/ha with a 1.83 Ca/Mg ratio, corresponding to pure dolomitic lime, gave the highest root and starch yield. A similar yield was obtained with the application of 800 kg Ca/ha as gypsum (4.6 t/ha), but its high cost and transportation makes it an expensive source of Ca. Thus, it may be concluded that the application of 500 kg/ha of dolomitic lime, which has been a standard practice in Carimagua for several years is both agronomically and economically the best source of Mg and Ca for cassava.

Figure 40 shows the relation between root yield and the Ca and Mg contents in the youngest fully expanded leaf blades of plants three months old. A critical Ca content, corresponding to 95% of maximum yield, was estimated to be 0.80%, while the critical Mg content

Table 48. Effect of levels, sources and methods of application of mangesium on root yield and starch content of cassava cultivars CMC 40 and Llanera planted at CIAT-Quilichao and Carimagua, respectively.

Mg rates (kg/ha)	Method of application	CIAT-Quilichao Root yield (t/ha)	Carimagua Root yield (t/ha)	Carimagua Starch content (%)
0		29.9b[1]	10.8b	26.9
20 as $MgSO_4$	Bands	31.3ab	11.5b	31.4
40 as $MgSO_4$	Bands	34.4ab	10.3b	30.0
60 as $MgSO_4$	Bands	36.0a	12.6ab	31.4
20 as $MgSO_4$	Broadcast	35.2ab	10.4b	33.1
40 as $MgSO_4$	Broadcast	34.4ab	10.6b	31.4
60 as $MgSO_4$	Broadcast	31.9ab	13.4ab	30.0
20 as MgO	Broadcast	29.9b	13.1ab	30.0
40 as MgO	Broadcast	34.8ab	10.9b	30.0
60 as MgO	Broadcast	33.3ab	11.6b	30.0
20 as dolomitic lime	Broadcast	34.0ab	9.6b	31.4
40 as dolomitic lime	Broadcast	32.3ab	11.0b	28.4
60 as dolomitic lime	Broadcast	31.1ab	16.7a	30.0
0.5% $MgSO_4$	Foliar	29.3b	9.7b	26.9
1.0% $MgSO_4$	Foliar	34.4ab	9.9b	30.0
2.0% $MgSO_4$	Foliar	33.8ab	9.0b	31.5

1 Mean values within columns followed by the same letter are not significantly different at the 0.05 level.

was estimated to be above 0.29%. A critical Mg content of 0.29% was obtained in 1977 for CMC 40. The Ca and Mg contents of upper petioles were much higher (1.08-1.70% Ca and 0.23-0.34% Mg) but less correlated with yields than those of upper leaf blades. For diagnosis of Ca and Mg deficiency it is therefore recommended to sample the youngest fully expanded leaf blades.

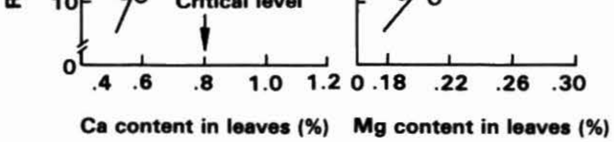


Figure 40. Fresh root yield of cassava cultivar Llanera in relation to Ca and Mg contents in the youngest fully expanded leaf blades at three months after planting.

P x K Interaction

On the poor sandy soils of Media Luna, near the Colombian north coast, the vigorous cassava cultivar M Mex 59 showed some response to application of high and moderate levels of P and K last year (CIAT Annual Report, 1978). During 1979, further P x K fertilization studies on these soils showed no response to P or K fertilization by either M Col 22 or Secundina (Figure 41), although previous soil analyses indicated P and K far below the critical levels established. The lack of response to fertilization this year might have been due to a less intense total rainfall as compared to the previous year. The cultivars used are also less vigorous than M Mex 59 and thus more susceptible to unfavorable weather conditions. Other possible causes, such as leaching of applied fertilizers and presence of additional limiting factors, will be studied.

Fertilization with S, Zn, Cu and B

CIAT-Quilichao soils are considered very low in S and B and intermediate in Zn. Because of the high

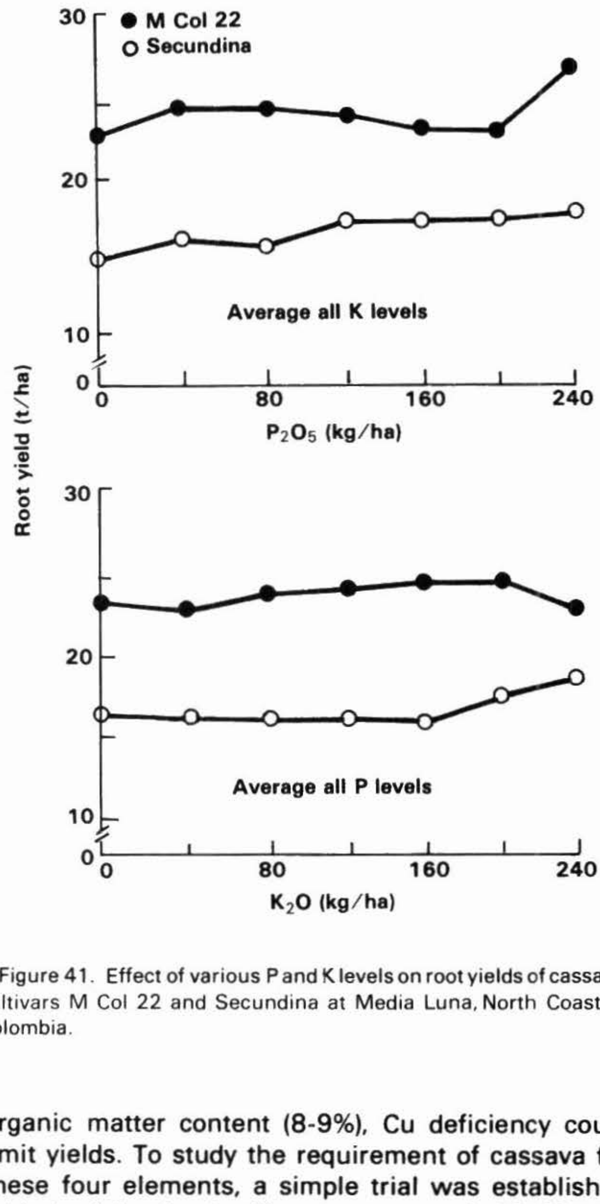


Figure 41. Effect of various P and K levels on root yields of cassava cultivars M Col 22 and Secundina at Media Luna, North Coast of Colombia.

organic matter content (8-9%), Cu deficiency could limit yields. To study the requirement of cassava for these four elements, a simple trial was established with the following fertilizer treatments: 0, 10, 20, and 40 kg S/ha as elemental S; 0, 5, 10, and 20 kg Zn/ha as $ZnSO_4.7H_2O$; 0, 5, 10 and 20 kg Cu/ha as $CuSO_4.5H_2O$; and 0, 1, 2, and 4 kg B/ha as borax. All were band applied at planting except for S which was applied broadcast.

Growth of M Col 1684 was rather vigorous but no nutrient deficiency symptoms or responses to the applied elements could be observed. Table 49 shows the effect of the applied fertilizers on nutrient content of leaf blades and petioles of the top, middle and bottom part of the plant at three months of age, as well as the final root yield obtained.

None of the applied elements had a statistically significant effect on yields which were extremely high, ranging from 52 to 63 t/ha (average 57.5 t/ha). Application of B dramatically increased the B content of leaves; maximum yield was attained with 19.4 ppm B in upper leaves, which is above the critical level of 17 ppm reported for whole tops. The high yield obtained with an extremely low B content of 4.8 ppm in the leaves indicates that cassava may be tolerant to low levels of B. Applications of Zn increased the Zn content of upper leaves from 75 to 100 ppm, but even without applied Zn, the Zn content was above the critical level. Application of Cu had no consistent effect on Cu contents of leaf blades or petioles, which in all cases were above the critical level of 7 ppm. Applications of S actually decreased the S content of upper leaves, which was above the critical level of 0.32%.

From these data it was concluded that sampling of the youngest fully expanded leaf blades is recommended for the determination of B and Zn status and is probably equally efficient for Cu and S status.

Application Method for NPK

Two trials to determine the best method of NPK fertilizer application were planted in Carimagua with cultivar M Col 638, one at the beginning and another at the end of the rainy season (1978A and B, respectively). One t/ha of fertilizer 10-20-20 was applied in different ways as shown in Table 50.

In 1978A, fertilizer application increased yields from 12.3 to 23.3 t/ha, but some methods of application were much more effective than others. Best results were obtained with half of the fertilizer broadcast and incorporated and half band applied at planting. Good yields were also obtained with the application in single short bands at about 5 cm from the stake, the standard practice in Carimagua. Most of the other methods were not significantly different, except that broadcast application before ridging was inferior to other methods. Moreover, broadcast application tends to stimulate weed growth more than band application, especially on very infertile soils.

Fertilization in plantings just before the start of the dry season (1978B) increased yields nearly five fold, from 4.4 to 20.1 t/ha. Yields during the dry season planting were slightly but not significantly lower than those of the wet season planting. In the 1978B planting, the highest yield was obtained broadcasting the fertilizer without ridging. However, there was no

Table 49. Effects of S, Zn, Cu, and B applications at planting on yields and contents of these elements in leaves and petioles of the upper, middle and lower portions of the plant, three months after planting cassava cultivar M Col 1684 at CIAT-Quilichao.

Treatment (kg/ha)		Fresh root yield[1] (t/ha)	Upper		Middle		Lower	
			Leaves	Petioles	Leaves	Petioles	Leaves	Petioles
% S								
S	0	57.3	0.40	0.17	0.34	0.01	0.29	0.07
	10	53.1	0.38	0.13	0.36	0.01	0.29	0.02
	20	59.0	0.34	0.14	0.33	0.03	0.28	0.01
	40	62.0	0.36	0.15	0.34	0.01	0.31	0.01
ppm Zn								
Zn	0	55.8	75.0	85.0	75.0	120.0	100.0	205.0
	5	58.1	85.0	100.0	75.0	120.0	125.0	230.0
	10	58.5	85.0	100.0	75.0	135.0	115.0	225.0
	20	60.3	100.0	115.0	85.0	145.0	110.0	235.0
ppm Cu								
Cu	0	58.5	8.1	8.1	42.5	10.0	16.3	8.1
	5	62.6	8.1	8.1	37.5	10.0	12.5	8.1
	10	53.4	8.1	8.1	35.6	10.0	22.5	8.1
	20	56.7	7.5	10.0	28.8	10.0	22.5	6.9
ppm B								
B	0	53.3	4.8	11.6	4.8	10.4	9.8	17.0
	1	60.3	19.4	15.6	23.6	11.4	31.6	16.4
	2	53.0	26.4	18.8	37.6	14.6	60.0	15.2
	4	58.1	38.6	16.4	50.0	21.4	59.6	21.4

1 Yield figures were not significantly different at the 0.05 level.

significant difference between most methods of application.

Planting Density x Fertilization

The third cycle of long-term planting density x fertilizer trials at CIAT-Palmira and ICA-Caribia were harvested during 1979 and the fourth cycle was planted. Results followed the same trends as those from the two previous years (CIAT Annual Reports, 1977 and 1978). Significant differences (P = 0.05) in yield were found between cultivars at both locations, but fertilizer applications did not significantly affect yields of commercial roots except for M Col 22 at CIAT-Palmira (Table 51).

Figure 42 shows that cultivar CMC 40 yielded significantly less at both locations with 5000 plants/ha than at higher planting densities. The same was true for M Col 22 at CIAT-Palmira. Overall yields were higher in Caribia than at CIAT-Palmira. Yields drastically decreased due to three years of continuous cropping (Figure 43), especially in the case of CMC 40 at CIAT-Palmira. As further cycles are planted in the same plots, loss of initial vigor and growth are evident.

It is interesting to observe that after three years of continuous cropping the yield of cultivar M Mex 59 (vigorous type) has remained relatively stable both at CIAT-Palmira and Caribia, while that of the less vigorous cultivars CMC 40 and M Col 22 decreased

Table 50. Effect of the method of fertilizer (1 t/ha 10-20-20) application on the yield of cassava cultivar M Col 638 planted at the beginning and at the end of the rainy season, (1978A and B, respectively) in Carimagua.

Method of fertilizer application	Root yield (t/ha) 1978A	1979B
Broadcast and incorporated without ridging	15.7bc[1]	20.1a
Broadcast and incorporated before ridging	12.9cd	16.1abcde
Broadcast on top of ridge, light incorporation	16.1bc	15.5abcde
Short single bands near vertical stake	19.0b	16.7abcde
Short single bands under vertical stake	15.5bc	18.3ab
Short double bands near vertical stake	17.8b	14.8bcde
Continuous band under horizontal stake	16.3bc	17.0abcde
Circle application around vertical stake	17.7b	16.0abcde
In hole, 5 cm from vertical stake	18.4b	15.2bcde
In hole, directly under vertical stake	18.6b	18.2abc
1/2 broadcast, 1/2 banded at planting	23.3a	14.9bcde
1/2 broadcast at planting, 1/2 broadcast at 60 days	16.3bc	15.1bcde
1/2 broadcast at planting, 1/2 banded at 60 days	15.9bc	15.4abcde
1/2 banded at planting, 1/2 broadcast at 60 days	17.8b	12.9e
1/2 banded at planting, 1/2 banded at 60 days	18.3b	17.8abcd
Check with no fertilizer	12.3d	4.4f
Mean	17.0	15.5

1 1978A corresponds to the May planting at the beginning of the rainy season; 1979B corresponds to the November planting at the end of the rainy season.
2 Figures within columns followed by the same letter are not significantly different at the 0.05 level.

Table 51. Effects of fertilization on commercial root yields of cassava cultivars CMC 40, M Ccl 22, and M Mex 22 grown at CIAT-Palmira and Caribia.

Treatment	Fresh root yields (t/ha)[1] CMC 40	M Col 22	M Mex 59
CIAT			
Control	11.2a[2]	17.3a	14.1a
Fertilized[3]	12.4a	19.4b	13.8a
CV %	33.97	14.90	27.96
Caribia			
Control	22.9a	22.1a	11.0a
Fertilized[4]	26.4a	26.3a	9.1a
CV %	22.48	20.37	51.28

1 Mean of four planting densities.
2 Means within a column and location followed by the same letter are not significantly different at the 0.05 level.
3 Fertilizer rate: 50, 100, and 100 kg/ha of N, P_2O_5, and K_2O, respectively.
4 Fertilizer rate: 100, 0, 150, and 20 kg/ha of N, P_2O_5, K_2O, and Zn, respectively.

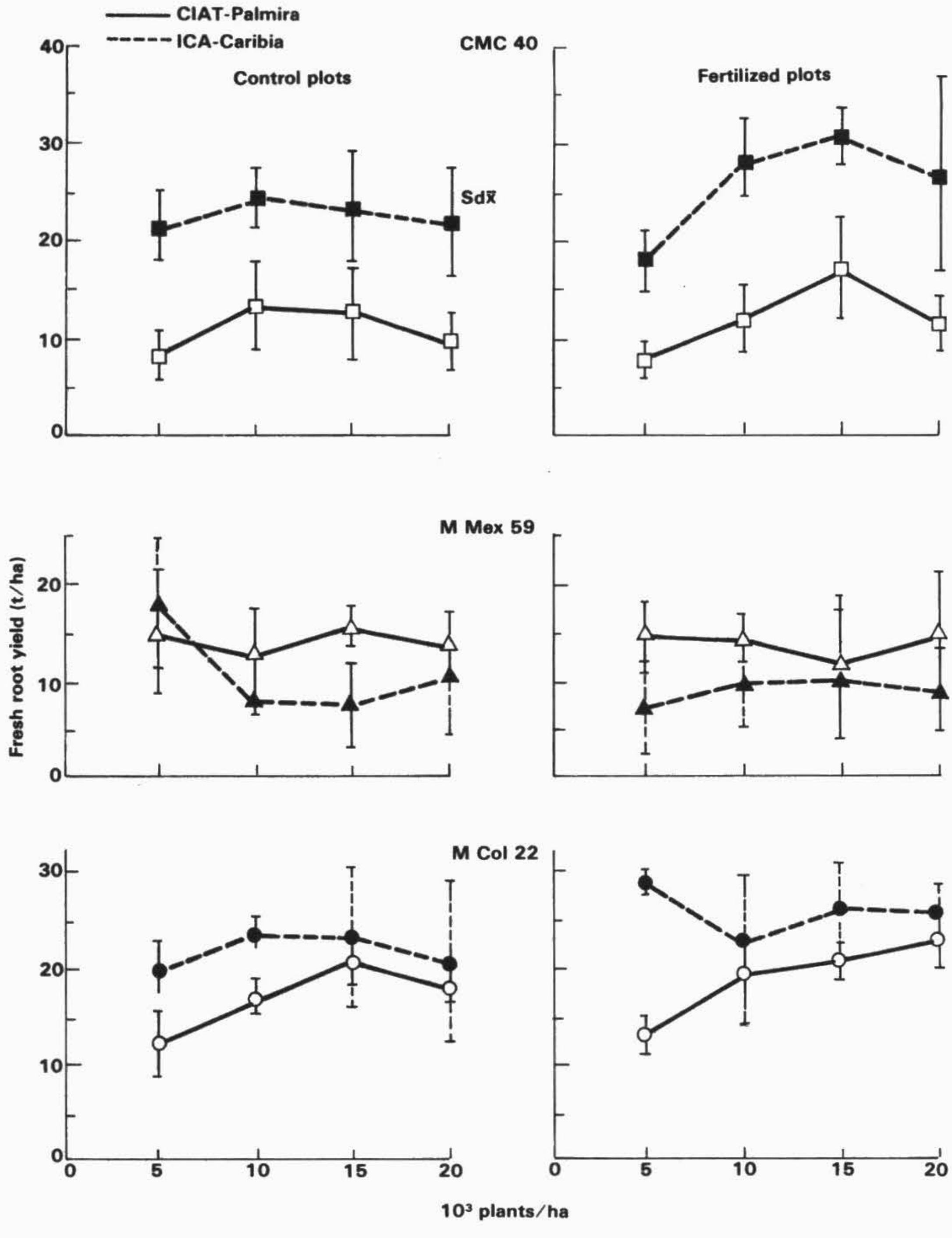


Figure 42. Effects of planting density and fertilization on fresh root yields of cassava cultivars CMC 40, M Mex 59 and M Col 22 grown at CIAT-Palmira and Caribia, 1979.

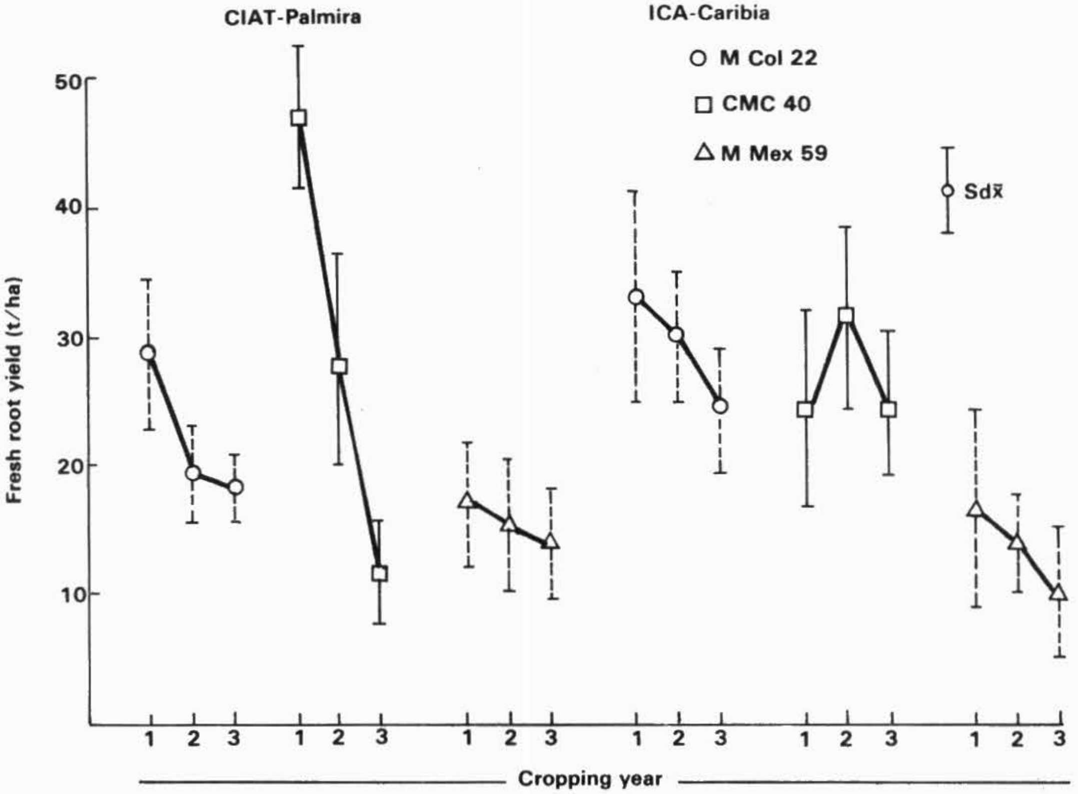


Figure 43. Effect of three years of continuous cassava cropping at CIAT-Palmira and Caribia on fresh root yields of cassava cultivars M Col 22 (non-vigorous plant type), CMC 40 (intermediate vigor), and M Mex 59 (vigorous).

markedly with time, especially at CIAT-Palmira. It might be indicated that on the heavy clay soils at CIAT-Palmira, continuous cropping favored root pathogens while on the lighter soils at Caribia (with higher precipitation and better rainfall distribution during the rainy season, longer dry season and warmer temperature), soil borne diseases are less likely and consequently yields are less affected by continuous cropping.

Soil analyses after each harvest indicate that the P content of the control plots decreased markedly at both locations. In Caribia fertilization with K had no effect on the K content of the soil possibly due to leaching losses on this light textured soil. P is not applied in Caribia due to the high initial P content of the soil. At CIAT-Palmira, fertilization slightly increased the P and K contents of the soil.

Maximum Yield Trial

Several years of experience with cassava in Carimagua have shown that root yields in this adverse ecosystem are generally much lower than those obtained at CIAT-Palmira or other more favorable locations. Limiting factors in Carimagua are diseases and insect pests, low soil fertility and a long dry season. In order to determine the maximum yielding potential of cassava in the Carimagua ecosystem, the eight highest yielding and most disease tolerant cultivars available were used. Although the field has been previously cultivated and fertilized, and considerable residual fertilizer effects could thus be expected, high fertilizer inputs were applied. Also, water stress was eliminated by sprinkle irrigation during four of the months of the dry season. Irrigation resulted in a significant decline in spider mite attack during the dry season. Table 52 shows the root and top yields as well as harvest indices obtained with and without irrigation. The effect of irrigation was non-significant in 7 of the 8 cultivars, indicating cassava's high drought tolerance. However, in M Col 1684, a high-yielding but non-vigorous cultivar, irrigation increased yields 48%. This cultivar, which was the highest yielder in last year's trial (CIAT Annual Report, 1978), produced the record yield of 50.7 t/ha in Carimagua. Other highly

Table 52. Fresh root yields, harvest indices, and disease reaction of eight cassava cultivars grown in Carimagua with and without supplemental irrigation during the dry season.

Cultivar	Apparent reaction to:[1]		Fresh root yield (t/ha)		Harvest index	
	CBB	Superelongation	With irrigation	Without irrigation	With irrigation	Without irrigation
M Col 1684	m	m	50.7a	34.2b	0.77	0.69
M Ven 77	m	m	33.8b	29.5bc	0.59	0.52
CM 430-37	s	s	26.4bcd	26.6bcd	0.64	0.56
CM 309-41	m	m	24.1cde	24.0cde	0.63	0.56
SM 1-150	m	s	23.0cdef	18.7defg	0.59	0.48
CM 309-442	m	m	19.9def	14.8fg	0.50	0.41
M Col 638	m	m	18.8defg	20.0def	0.45	0.45
Llanera	m	s	11.4g	15.9efg	0.38	0.43
Average			26.0	23.0		

LSD irrigation (5%) = 3.20 t/ha

LSD variety (5%) = 5.35 t/ha

LSD irrigation x variety (5%) = 7.56 t/ha

1 Reaction to disease: m = moderate; s = susceptible.
2 Figures followed by the same letter are not significantly different at the 0.05 level.

promising cultivars are M Ven 77 and CM 430-37. These high yields indicate that there is germplasm presently available that has enough disease tolerance so as to obtain high yields even under the adverse conditions of the Llanos Orientales, provided proper management of the crop is followed. However, the cost of fertilizers alone (including transport) used in this trial was about Col. $30.000/ha, which must be paid for by a yield increase of at least 15 t/ha at a price of $2000/t roots. Although this may not be economical, the cost of fertilization can be reduced considerably with time as soil fertility builds up and much lower rates are required.

ECONOMICS

The cassava economics section focused on the expansion of the on-farm trials initiated in 1978. These trials have the objective of assessing the role of cassava within whole farm systems as a means of diagnosing further requirements or refinements in cassava production technology. They also serve to measure and validate the productivity of new cassava technology under actual farm conditions before it is released to national institutions. The trials serve as an information feedback mechanism from the farm level into the technology production program and to feed technology components forward to national institutions. In the initial stages of this research, work has been located within Colombia and the trials are being carried out in collaboration with Colombian institutions.

The Program is currently working in four principal sites, which are described in Table 53. The sites chosen should provide a good understanding of the response of improved technology to variation in agroclimatic stress conditions; the interaction between farming systems and the characteristics cassava technology should have; and, the interaction between cassava farming systems and cassava markets.

It has been hypothesized that the choice of cassava as a principal cropping activity is influenced by three principal factors:

- **Agro-climatic conditions.** Cassava as a species is adapted to a wide range of climatic and edaphic factors; however, its comparative advantage compared to other crops is its yielding ability under stress conditions.

- **Availability of resources to the farmer.** In marginal agricultural zones relative land/labor ratios heavily influence the choice between cropping activities and grazing activities. Since cassava is relatively labor intensive and labor markets are usually not well developed in marginal areas, cassava is principally found on farms where this ratio is low, i.e., on small-scale farms.

- **Output market conditions.** Since cassava is highly perishable after harvest and transport is costly in comparison to the value of the crop, the distance from the market will heavily influence output price; since cassava markets are independent of one another (because of transport costs) and market size is usually small, marketing risk due to season market gluts is high; marketed cassava thus tends to come from farmers having few other alternatives, i.e., small-scale farmers in more marginal agricultural zones.

Results reported here are those for Media Luna in the Colombian northern coast. It is the only site for which a complete year of data is available.

Media Luna On-Farm Trials

Farming systems

In the farm trial site of Media Luna, agricultural stress produced by environmental factors are

Table 53. Locations and characteristics of the zones where on-farm trials are currently being carried out in Colombia.

Location	Altitude (masl)	Rainfall (mm)	Soil characteristics: Bray II-P (ppm)	K (meq/100 g)	pH	Average farm size (ha)	Principal competing crop	Principal market
North coast								
Media Luna	10	1400	3.9	0.08	6.0	5.8	Sesame	Fresh urban and large-scale starch
Cauca								
Mondomo	1450	2402	1.6	0.30	4.3	15.1	Coffee	Small-scale starch
Santander								
Palmas del Socorro	1225	2560	2.5	0.20	4.0	5.9	Sugarcane	Subsistence
Llanos Orientales								
Villavicencio	350	2500	3.1	0.10	4.6	60.0	Coffee	Fresh urban

moderate to severe for most crops. Nevertheless, agroclimatic stress conditions are probably representative for cassava. Soils in the zone are sandy with low fertility (low organic matter and well below critical levels of P and K for maximum cassava production).

Annual rainfall averages approximately 1400 mm, distributed throughout a 7-8 month rainy season (April-November); the dry season covers a 4-5 month period of the year (December-March). The critical cassava planting season from May to June allows the plant the full advantage of the rainy season. The high average temperature of 28°C, the very low water retention capacity of the soil, and the poorly distributed and variable rainfall results in substantial water stress, which cannot be avoided by a crop such as cassava with a long growing season. Soil and water stress conditions existent in the region severely limit the choice of cropping alternatives.

Land use patterns for the farmers in the sample (average farm size, 5.9 ha) are dominated by cassava. It is principally sown in association with maize and to a lesser extent with the relatively more drought resistant crops, sesame and cowpea. Sesame is the only crop that competes for land with cassava.

Even though land/labor ratios among the small-scale farmers in the sample are relatively low, labor availability can be limiting at critical periods in the cropping year, especially since the rainfall distribution defines planting dates. The rainfall distribution heavily influences labor needs, which tend to be concentrated in the May-August period, i.e., during the principal planting season and the period during the first two weedings (Table 54). Production practices are thus conditioned by these environmental factors and resource constraints.

In order to maximize income, the farmer has to plan for alternative planting dates and harvest times, depending upon farm size and labor availability. Moreover, he is further restricted by access to the market; he cannot sell to intermediaries when he would always like to and therefore cannot plan his harvest with any degree of certainty. Harvest is relatively well distributed through a 12-month period, which shows both the storability of standing cassava and the regulation of market supplies.

Yield increasing technology is obviously necessary in this system to increase incomes given the limited land resources of the farmers. However, the market

Table 54. Characteristics of the typical farming systems in Media Luna, Colombia.

Period	Labor distribution during cropping year[1] (%)	Distribution of marketed production (%)[2]	
		Fresh market	Starch market
1st year			
May-June	39	-	-
July-September	32	-	-
October-November	7	-	-
December-April	10	37	-
2nd year			
May-June	6	23	10
July-September	4	7	13
October-November	2	4	3
December-April	-	1	2
Total	100	72	28

1 Of a total of 289.9 man-days.
2 Total of 22.8 tons.

structure puts further restrictions on the characteristics of the technology, which are particularly associated with germplasm requirements. Early maturity is essential in the system to reduce marketing risk and take advantage of surplus labor for harvest in the slack season. Cultivars must be capable of being stored in the ground for long periods with little risk of yield or quality losses. Resistance to root rot pathogens is important. Quality maintenance in the ground through the marketing season, particularly low fiber content and high starch content, becomes important in order to ensure high prices. These requirements thereby provide the necessary background for evaluating the agronomic trials with new technology.

Agronomic field trials

Besides determining the structural components of the cassava farm system, the farm trials also attempt to determine the potential yields of cassava with new technology, to evaluate the introduction of new technology within a whole farm context, and to assess the implications that these results have for the research program. The evaluation of new technology compared to farmers traditional technology precedes the farmer's subjective evaluation of the technology, after which he will decide whether or not to adop it. The trials test those components of a potential technology package that appear to be consistent with the needs of the farming system. Moreover, in those cases in which the farmer can adopt various individual components from the total package, the latter is broken down into factorial trials to evaluate the yield of each component.

Productivity of tradicional technology

Farmers in the region use relatively low plant populations of approximately 6250 plants/ha which do not vary between monoculture and intercropping systems. The length of cuttings is appropriate and planting is done vertically. Cuttings are not selected for disease and insect problems and are stored without protection for as long as two months. Replanting is a rather common practice. No fertilizer is used. Where farm size is large enough the rotation system cassava/*Panicum maximum* (3.0-4.0 and 1.5-3.0 years, respectively) is frequent.

Yields using traditional technology averaged 7.1 t/ha. Factors potentially influencing yield were incorporated into a regression equation and the results are presented in Table 55. Soil color, crop rotation, and to a lesser extent the amount of labor used in weeding made a substantial impact on yield. Surprisingly, intercropping and the time of planting had no apparent effect on yield levels.

Differences in management (or differences in restrictions on whether farmers could rotate their land or use more labor) and soil quality between farms appeared to greatly influence cassava yields under traditional technology. This yield variance between farms occurred in a region that is otherwise homogenous. The question arises as to the extent that recommendations about new technology can be generated without taking these sources of variation into account.

Productivity of improved technology

The agronomic trials tested four technology components: increased plant population (10,000 plants/ha); stake selection and treatment; fertilization (500 kg/ha 10-20-20); and improved germplasm. Plant population and stake selection and treatment were tested as one component in the first set of trials. Cultivars tested included the local cultivar Secundina and CIAT selections M Col 22, a non-vigorous, efficient plant type, and CMC 40, a medium vigorous cultivar. The trials were planted in the main planting season in May and harvested before the beginning of the rainy season in April.

The results of the agronomic trials are presented in Table 56. There was a large increase in the yield of the local cultivar from 7.1 to 12.1 and 13.1 t/ha using improved agronomy and improved agronomy plus fertilizer. There was no statistically significant response to fertilizer for the cultivars tested except in the case of M Col 22 which is an unexpected result given the low fertility status of the soil. There were no significant differences in yields between the CIAT selections and the local cultivar but very significant differences in starch contents were observed. Starch content of the more vigorous cultivars, Secundina and CMC 40, declined with fertilization but increased in the non-vigorous cultivar M Col 22; however, these differences were not significant.

Two principal conclusions can be drawn from the trials. First, the response of the local cultivar to the recommended cultural practices resulted in a 70% yield increase. Given that cultural practices are usually highly location specific, the potential wide applicability

Table 55. Yield variation in local cassava cultivar Secundina due to various production and management factors, Media Luna, 1979.

Regression factor	Yield advantage t/ha	Yield advantage Description
Labor for weeding	.10*[1]	Per additional man-day
Soil color	1.14**	Red over white soils
Cropping system	.34	Monoculture over intercropping
Fallow rotation	1.42*	Fallow over successive cropping
Planting season	.47	Early over late planting
Average yield level traditional technology = 7.13 t/ha		
SD = 2.7 t		
CV = 0.38		
R^2 of regression = 0.24		

1 Level of significance = **(P < 0.1); *(P < 0.2).

Table 56. Yield and starch content of local and CIAT cultivars under improved agronomy and improved agronomy plus fertilizer.

Variety and treatment	Yield (t/ha) Mean	Yield (t/ha) Standard deviation	Starch content (%) Mean	Starch content (%) Standard deviation
Secundina				
Improved agronomy[1]	12.1a[2]	3.9	33.0a	1.1
Agronomy and fertilizer	13.1a	4.6	30.8a	2.9
CMC 40				
Improved agronomy	15.4a	5.7	23.8c	2.5
Agronomy and fertilizer	15.7ab	3.5	19.6c	6.4
M Col 22				
Improved agronomy	13.7a	3.1	27.1b	1.9
Agronomy and fertilizer	17.5b	4.4	29.0b	2.3

1 Includes a plant population of 10,000 plants/ha, and stake selection and treatment.
2 Values within columns followed by the same letter are not significantly different at the 0.05 level.

of these practices is encouraging. On the other hand, in areas where environmental stress is not so severe, the yield response might not be as high. Second, variation across farms in yield and starch content was found to be substantial and could not be readily explained because of the limited number of farms in the first set of trials. However, soil type differences and probably differences in pathogen incidence and in the effect of fallowing account for much of this variation. The design of technology packages for a region must take into account sources of variation as well as mean yield evaluations. Although not represented here, this should include an estimation of temporal as well as spatial variation.

The farm trials raised two issues. First, the characteristic of wide-adaptability as identified in the regional trials was not sufficient to outyield traditional varieties. The question arises why this result as the farm level should differ from the regional trial evaluation. Second, while yield may be a sufficient characteristic for final cultivar evaluation in the regional trials, market value is the principal selection characteristic at the farm level and this depends on other characteristics which consumers will pay for.

The widely adapted selections in the farm trials did not perform as well as the regional trials would have suggested, while the local cultivar responded markedly to good management. This can be explained by the large potential inter-farm variability observed in the on-farm trials, where cultivars were exposed to the full range of yield-constraining factors difficult to capture in regional trials. Besides the stressful climatic conditions, on-farm trials capture the much lower fertility status of soils on small-scale farms that have been continuously cropped as well as the variation in soil type. Moreover, the trials are exposed to a higher probability of pathogen attack characteristic of the region.

Under this particular set of farm-level conditions, there was no statistically significant differences in yield between the local and widely-adapted cultivars. These results do not resolve the issue of wide adaptability *versus* local adaptability but rather help to further focus research and evaluation methodologies. These results also confirm the importance of validation at the farm level as the final step in technology evaluation.

The second issue raised by the farm trials has been that while the yield levels between local and selected cultivars were similar, quality characteristics, particularly starch content, were not the same. Markets are small enough, wholesaler risk so high, and alternative supplies usually so plentiful that inferior quality cassava will not be traded. Also, given that cassava must be able to be stored in the ground for at least an eight-month period after maturity, the cultivar must as well be able to maintain this minimum quality during storage.

Results on varietal starch content indicated a surprisingly high coefficient of variation for the introduced cultivars. This characteristic appeared to respond negatively to stress factors. Evidence from both the regional trials and on-farm trials suggests that it is much more difficult to produce high quality cassava under stress conditions. The characteristic of starch content in the local cultivar appears to be well adapted to conditions in the farm trial site, consistently maintaining starch levels well above 30%. Farmers indicate that the local cultivar can maintain this quality with storage in the ground. The interaction between yields, starch content and harvest date is currently being verified.

CASSAVA TISSUE CULTURE

Meristem-Culture Propagation

Single plantlet cultures

The distinct response of different cassava varieties to meristem culturing is mainly related to their ability to root *in vitro* (CIAT Annual Report, 1978). Shoot differentiation can be readily achieved with cytokinins; however, shoot promoting levels of these hormones generally inhibit rooting. On the other hand, rooting hormones tend to promote callusing when combined with cytokinins.

A simple procedure was deviced for the production of single root plantlets. The method consisted in culturing

0.5-0.6 mm meristem tissues in Murashige-Skoog medium (MS), supplemented with 2% sucrose and 0.05-0.01 mg/l of BAP (6-benzylaminopurine), Ga (gibberellic acid-3) and NAA (α- naphtalene acetid acid). Two weeks later shoots (with or without concomitant callus) had differentiated in most cultures. Then all stem tips measuring at least 0.5 cm were removed from the shoots and planted on a rooting medium containing low concentrations of the MS salts and 4% sucrose. Within one week rooting initiated in cuttings. This technique allows not only quick rooting, irrespective of the cassava variety, but also avoids callus formation at the shoot-root transition zone; this is highly desirable for successful potting. Over 40 cassava genotypes have been processed through the single-plantlet system, successfully and consistently.

Multiple-shoot cultures

Along with improved multiplication rates, a propagation system should secure high genotype stability of the materials. Both requirements are met if cassava shoot-tips are promoted to proliferate axillary shoots in culture.

The strong apical dominance, evident in the uppermost 4-6 primordial nodes of a cassava shoot apex can be broken chemically and thus the otherwise dormant buds could be promoted to grow.

Shoot-tips (Figure 44a) of a range of cassava varieties were cultured under various concentrations of cytokinins. Within 2-3 weeks, near 90% of the cultures in all varieties developed into shortened shoots with axillary buds flushing along the axes (Figure 44b). BAP concentrations up to 0.5 mg/l enhanced the growth of axillary buds; higher levels of BAP did not significantly change the number of buds, but these were less at BAP concentrations above 1.0 mg/l. Conversely, the elongation of shoots linearly decreased with BAP. Once dormancy of axillary buds was broken, further growth into axillary shoots only occurred upon reduction of the BAP concentration and by this means, multiple-shoot cultures formed (Figure 44c). The shoot forming capacity of the cultures allows to harvest 10-20 stem tips/week (Figure 45). However, after the 8-9 weeks of continuous culture, the rate of shoot formation declined to 5-10/week. At this stage, some cultures became old and phenolic-type toxic substances accumulated.

The culture conditions for the induction and proliferation of multiple shoot cultures were: 28 ± 2°C day and 25 + 2°C night temperatures, 2000 lux illumination intensity and a 14-hour photoperiod.

The stem tips harvested weekly (see arrows, Figure 44c) were planted on the rooting medium in order to recover entire plantlets (Figure 44d). The rooted plantlets were then hardened at lower temperature (25°C day and night) and higher illumination (15, 000 lux) conditions. This hardening treatment imparted to the test tube plantlets tolerance to moisture stress (Figure 44e) and hence increased their survival during potting (Figure 44f). The hardening of the test tube plantlets and the watering of the potted plants with a high P fertilizer (10-52-10) permitted to achieve near 100% plant survival.

Thus, once established, one multiple shoot culture has the potential for producing 40-80 plants monthly. Work is underway to further increase the organ-forming capacity of the cultures.

Disease Eradication

Frog-skin disease

The etiology of the frog-skin disease is still unknown, but evidence (CIAT Annual Reports, 1977 and 1978) suggests the presence of a virus-like organism. Therefore, research was designed to develop a means of eradication of a virus-like disease through meristem culture.

Stakes obtained from diseased plants and healthy control plants were subjected to thermotherapy for four weeks. Heat treatment greatly enhanced sprouting and shoot vigor in contrast to the greenhouse-grown stakes. Apical meristems of two sizes were isolated from heat treated, greenhouse-grown sprouts, and cultured in agar medium. Entire plantlets were quickly recovered upon rooting of the cultures. The meristem-derived plants were transplanted to the field; control plants were also grown directly from stakes. To evaluate the effects of the various factors studied on the eradication of the frog skin disease, the plants were harvested after a five-month growth period in the field. Stakes obtained from symptom-free plants were again grown in the field for another five-month cycle. A second evaluation was carried out in order to confirm the results.

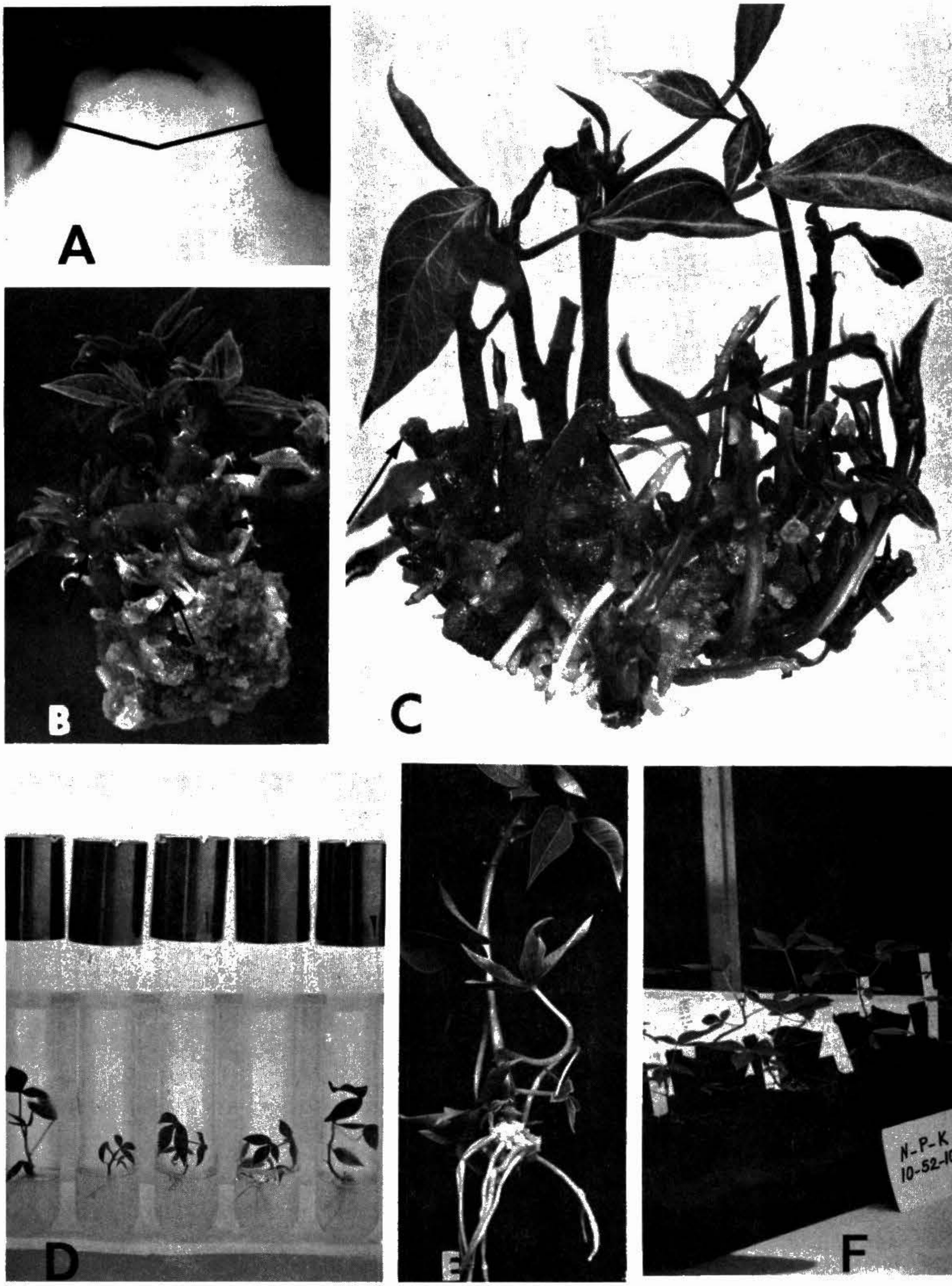


Figure 44. Meristem-culture propagation of cassava: (a) A shoot-tip prior to excision and culture (x40). (b) Initiation of axillary buds (arrows) on shoot-tip cultures (x6). (c) Multiple-shoot culture formation due to the proliferation of axillary shoots (x5). (d) Rooted plantlets recovered from multiple-shoot cultures by means of the "node-bud" cutting technique (x0.5). (e) A well developed plantlet after hardening and before potting (x1.5). (f) Potted plants 9-10 weeks after culturing, ready for field transplanting (x0.15).

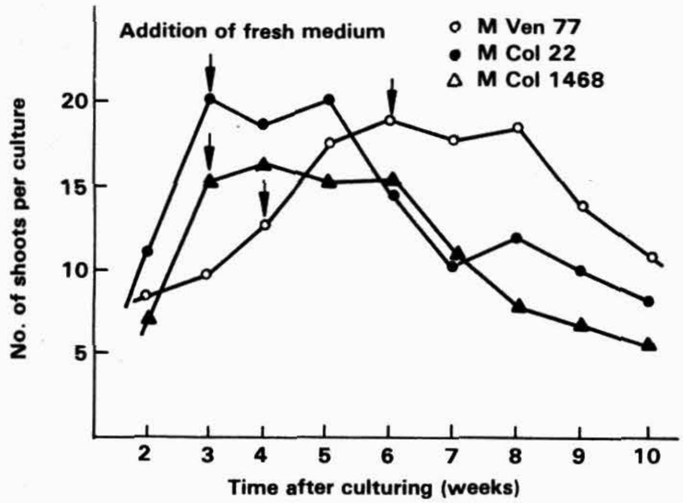


Figure 45. Production of axillary shoots in liquid-shake (Murashige-Skoog salts + 2% sucrose + 0.05 mg/l BAP + 0.02 mg/l NAA), multiple-shoot cultures of cassava cultivars M Ven 77, M Col 22, and M Col 1468. (Average of three cultures.)

Table 57 shows the results of both evaluations. The highest rates of sympton-free plants were obtained by culturing very small meristem tissues of heat-treated sprouts. The results of the second growth cycle confirmed the disease-free status (over 90% disease-free plants) of plants in the first cycle. When small meristems were cultured without the pre-heating treatments of sprouts, the rate of eradication recorded in the first cycle decreased. Also, culturing larger meristems, even after thermotherapy, significantly reduced eradication rates. These results confirm that a viral agent could be causing the frog-skin disease.

Mosaic-type diseases

Sprouted cuttings of cassava materials showing mosaic symptoms were placed under controlled conditions at 35°C. After two weeks new leaves formed without mosaic symptoms. However, these reappeared when plants were transferred to 20°C. This control of mosaic development through high temperature may suggest the presence of a virus-like organism.

The sprouted cuttings were kept under thermotherapy for two weeks; then, 0.4-0.5 mm meristem tissues were excised and cultured *in vitro*. Under greenhouse conditions, no mosaic symptoms were observed in 85% of the meristem-derived plants. The

Table 57. Eradication of cassava frog-skin disease through the meristem culture technique as shown by observations made 5-6 months after planting in the field.

Cultivar	Treatment of stakes	Size of meristem tissue	Symptom-free plants (%) 1st cycle[1]	2nd cycle
M Col 33	No treatment	Small	92	85
		Large	35	6
	High temperature	Small	96	95
		Large	60	15
M Col 2	No treatment	Small	100	95
		Large	86	22
	High temperature	Small	100	100
		Large	79	20
M Brasil 12[2]	-	Large	100	100
M Col 33[3]	-	-	0	0

1 First-cycle plants were derived directly from meristems; stakes obtained from these originated the second-cycle plants.
2 Control: disease-free variety.
3 Control: plants derived from diseased stakes.

average root yield of these plants was 3-4 times higher than comparable plants showing mosaic.

Six out of a group of 10 cassava varieties infected with the frog-skin disease developed mosaic symptoms when grown at 20°-22°C for two months. Thermotherapy of these plants confirmed that new leaves grew without mosaic.

Meristem culture of the heat treated materials gave plants free from both mosaic and frog-skin symptoms. A few plants of cultivar M Col 22, originated from non-heat treated sprouts, were grown in the greenhouse. Only three of these plants developed mosaic symptoms, and two developed both mosaic and frog-skin disease symptoms. Whether the mosaic is related or not to the frog-skin disease is not known.

These results suggest that the frog-skin disease as well as other mosaic-type diseases can be eliminated by meristem culture techniques.

Work is underway to use thermotherapy directly with meristems during the *in vitro* culture. This technique would greatly speed up the eradication process. The use of chemotherapy in conjunction with meristem culture is also being studied.

Germplasm Conservation

Any germplasm storage system should guarantee minimal losses and maximal genetic stability. Meristem cultures meet these requirements and thus constitute a suitable technique for the conservation of disease-free cassava germplasm.

Contrary to the rapid growth required in propagation, research in germplasm conservation aims at developing a means of obtaining a minimum growth rate of meristem cultures for long-term storage.

To date, cassava meristem cultures have been maintained for up to 18 months without having to refill the nutrient media.

Besides the effect of low temperature (20°C) during storage, the composition of the culture media also played a role in reducing the growth rate of the meristem cultures (Table 58). Shoot elongation decreased without a significant change in the number of nodes formed. Sucrose levels over 4% were detrimental to culture survival especially at low temperature. On the other hand, increases in BAP concentrations also delayed growth of cultures, but was detrimental to survival when cultures were kept at high temperature or when the sucrose level was high. In the former case, the cultures grew quickly, depleted the medium and became senescent by the sixth month in storage; in the latter case, however, the growth of cultures was inhibited after the third month in storage. Thus, in order to delay growth of cultures without losses in survival, it appears that the culture medium

Table 58. Effects of temperature, sucrose and cytokinin levels on growth rate and survival of cassava meristem cultures. (Average of three cassava varieties and five cultures per variety.)

Treatment				Growth of cultures		
Day/night storage temperatures (°C)	Sucrose (%)	BAP[1] (mg/l)	Storage period (months)	Shoot elongation (cm/month)	No. nodes formed/month	Survival (%)[2]
30/25	2	0.01	6	2.3	2.2	20
		0.05	6	1.2	1.5	32
	4	0.01	5	1.5	2.4	25
		0.05	4	1.1	1.6	29
20/20	2	0.01	12	1.3	1.0	80
		0.05	15	0.5	0.8	95
	4	0.01	15	0.4	0.8	94
		0.05	3	0.2	0.1	50

1 6-benzylaminopurine added to the MS salts + 0.1 mg/l gibberellic acid.
2 Percent viable cultures retrieved at the end of each storage period.

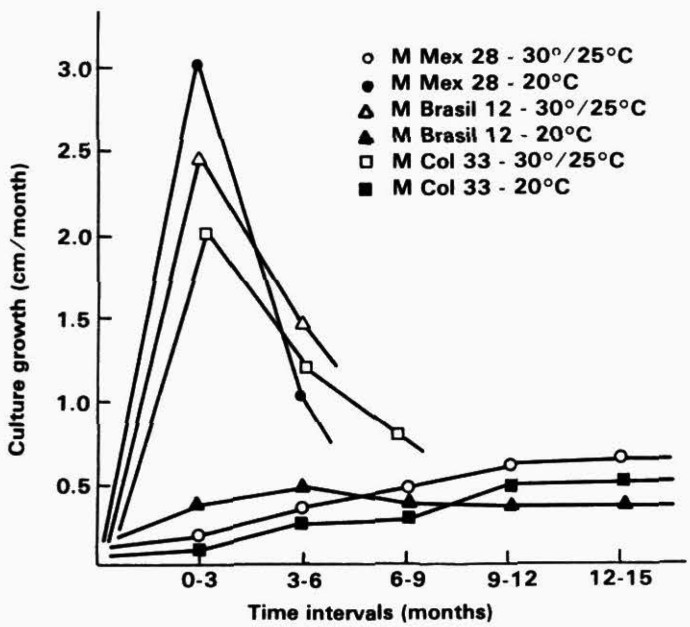


Figure 46. Effect of two temperature regimes (30°/25°C day/night temperatures and 20°C constant) on growth rates of meristem tissues of cassava varieties M Mex 28, M Brasil 12, and M Col 33 stored throughout a 12-15 month period. (Average of 4-5 replicates recorded trimontly.)

should contain either high sucrose and low BAP or conversely, low sucrose and high BAP.

Cultures maintained for 15 months at 20°C were still viable in contrast to those maintained at 30°/25°C day/night temperature regime after six months of storage. Moreover, low temperature during storage promoted axillary shoot growth thus favoring longer duration of the cultures. Storage duration before transferring to fresh media will depend upon the growth rate of the cultures; preferably it should be slow enough without affecting culture survival. The growth of cultures, stored at two temperature regimes, has been monitored every three months during 12 to 15-month storage periods (Figure 46). During the first three months, cultures stored at a 30°/25°C day/night temperature regime grew rapidly, but thereafter the growth rate dropped due to nutrient depletion of the media and phenolic oxidation of the tissues. The growth of cultures at 20°C increased slightly at the befinning and remained rather constant after 12 months of storage. Based on these results, a minimum transfer period of two years was estimated.

In order to test the phenotypic stability of the materials, cultures are being retrieved from storage every six months, propagated *in vitro*, potted, and transplanted to the field. Initial observations indicate plants are true-to-type.

Research continues to further develop the meristem culture storage of cassava. However, the technique will now be used to gradually transform the cassava germplasm into the meristem culture form for storage. Research also continues to study the feasibility of freeze-preserving cassava meristem cultures at the Prarie Regional Laboratory in Saskatoon, Canada, and the University of Birmingham, England.

International Exchange of Germplasm

Meristem culture combined with heat treatment provides an efficient means to eradicate virus-like diseases. Other contaminating organisms sucn as insects, mites, fungi, and bacteria, should also be absent in aseptic meristem cultures. Hence, the international exchange of cassava germplasm in the form of disease-free meristem cultures would greatly reduce the risks of disseminating pests and diseases.

A simple procedure was developed this year in collaboration with the Brazilian Centro Nacional de Recursos Genéticos (CENARGEN), to exchange cassava germplasm in the form of meristem cultures. The overall procedure comprises the following steps: (1) preparation of disease-free cultures; (2) packing and shipment of cultures; (3) handling at the receiving end (recovery of plants and propagation); and (4) testing and release of materials.

Two trial shipments were air mailed to Brazil: one in the form of single rooted plantlets and the other in the form of meristem tips. In spite of the abrupt temperature changes (10°C to 45°C) recorded during shipment, the cultures did not suffer irreversible damage. It was found that both a high agar medium and a constriction made on the lower part of the test tube prevented the agar from being disturbed due to shaking. However, the cultures etiolated because of the protracted (25 day journey) darkness in the package. The cultures grew green again following exposure to diffuse illumination.

A third shipment consisting of 15 advanced breeding lines in the form of meristem tips was sent to Brazil. The cultures arrived safely and are being multiplied prior to re-distribution from CENARGEN to the Centro de Pesquisa de Mandioca y Fruticultura (CNPMF), the Brazilian cassava research center at Cruz Das Almas.

Reciprocally, 12 Brazilian cassava varieties were dispatched to CIAT. Plants have been recovered and multiplied from the meristem cultures to undergo testing in the greenhouse.

In collaboration with the Colombian plant health authorities and the Agrarian Research Center of northern Peru, plans were made to transfer from that country to CIAT duplicates of over 100 cassava accessions in the form of aseptic meristem cultures.

INTERNATIONAL COOPERATION

The generation of improved technology must be closely linked to an effective transfer mechanism to national institutions if the ultimate goal of raising national yield levels is to be achieved. In this respect, CIAT's Cassava Program refined its strategy for improving the flow of cassava techology to national programs.

Latin America

The Cavassa Program's outreach strategies for Latin America vary from one country to another basically depending upon two factors: first, the potential to produce and market cassava in a given country, and second, the degree of development of their national cassava program.

Within this context, CIAT's international cooperation activities in Latin America are designed in relation to needs of major groups of countries:

● Countries with a strong national cassava research program linked to well-developed extension programs. A potential demand for increased cassava production has been identified and thus there is a national policy to expand the production of cassava in the country.

CIAT's Cassava Program assists such countries in the identification of limiting production factors and in the definition of a research strategy. Technology being transferred includes agronomic practices and new cassava genetic material recommended for the specific conditions of the countries. Brazil, Colombia, Cuba and Mexico are examples of countries in this category.

● Countries with capable research programs but not linked to well-defined production and market objectives. National policies favoring cassava production increases, marketing, and utilization are lacking.

These countries receive assistance in the evaluation of national and introduced cultivars to determine production potential and in the analysis of the possible economic benefits of increasing cassava production. Information of this nature can then be used by local planners and decision makers in policy implementation. Examples of countries in this category are the Dominican Republic and Ecuador.

● Countries with limited or no cassava programs and interested in increasing cassava production. These countries, have the potential to increase cassava production, but have not explored marketing and utilization alternatives, nor have they developed a research and production program. Countries in this category are usually grain importers.

The CIAT Cassava Program can assist these countries by providing training to professionals in the evaluation of germplasm and technology generated at CIAT and to obtain base data necessary for evaluating the potential of cassava.

● Countries with carbohydrate deficits not interested, at the national policy level, in increased cassava production or not having a well defined cassava program, although with a potential to produce this root crop.

CIAT attempts to make these countries aware of the potential of cassava by establishing and evaluating international trials with the collaboration of local researchers, and by collecting data on cultural and agronomic practices and making them available to national planners. Within this group Bolivia, Costa Rica, and Honduras have requested CIAT's assistance to improve their national or regional cassava program activities. There, local agronomists have been trained and international trials have been established.

Germplasm exchange

Distribution of selected cultivars has been a major activity linking CIAT's Cassava Program with its cooperators in the cassava network. Cuttings of 13 cultivars and 12 hybrids were sent to 25 national agencies in 17 different countries for a total of 119,582 cuttings delivered (Table 59). The cassava breeding section sent sexual seeds to several countries and the meristem tissue culture section has sent cassava meristems of promising varieties to Brazil on a trial basis to develop and test a system to move materials safely among participating countries (see section on Meristem Tissue Culture on Page 78).

Asia

The low average cassava yield for Asia of 10 t/ha is due, among other reasons, to the lack of improved, low input technology (adapted, high-yielding varieties, improved agronomic practices and efficient processing and storage technology), and trained personnel.

In the last few years many Asian countries have shown interest in this root crop and have structured their own national cassava production programs as in Indonesia, India, Malaysia, the Philippines, Thailand, and Sri Lanka.

Germplasm distribution

The post-quarantine cassava station at Indang, Cavite, Philippines (14°08'N and 120°54'E) as set up in collaboration with the Cassava Program's out-posted staff member in Asia, is now fully operational. Fifteen selections received from the CIAT germplasm bank in March, 1978, are now being propagated as are 10 CIAT hybrids from true seed.

In mid-1979, a set each of 300 cuttings of nine cassava cultivars was distributed to cooperators in India, Indonesia, and Sri Lanka for further propagation and evaluation.

Other Asian regions with which international cooperation links are being developed, through deliveries of planting material of promising CIAT cassava cultivars and hybrids are Cook Island, Laos, Papua New Guinea, the Trust Territories, Samoa, and Vietnam.

Table 59. Planting material (20 cm long cuttings) of 13 varieties and 12 hybrids sent to 18 countries during 1979.

Country	Varieties	Hybrids	Total
Argentina	1280	1420	2700
Barbados	100	400	500
Bolivia	0	512	512
Canada	120	0	120
Costa Rica	0	300	300
Cuba	65300	60	65360
Dominican Republic	580	2320	2900
Ecuador	400	3010	3410
England	16	0	16
Haiti	70	100	170
Holland	28	0	28
Honduras	100	200	300
Mexico	1400	3400	4800
Surinam	196	472	668
United States	403	120	523
Venezuela	300	1500	1800
Windward Islands	60	30	90
Colombia	31490	3895	35385
Total	101843	17739	119582

Regional trials

Regional trials have already been set up in three locations and data on the performance of entries included will be available by 1980. Two additional regional trials in the Philippines will soon be established.

Research

The cassava outreach program has provided *assistance and direct* advice on field research being conducted at experiment stations in national programs in the Philippines (herbicide screening and weed control), Sri Lanka (field testing of cassava varieties intercropped with coconuts), Indonesia (planting methods and plant density), Thailand (long-term fertility trials), and Malaysia (variety trials in peat and mineral soils).

Training

Cassava rapid propagation

The Philippine government has lately emphasized the extensive production of cassava not only for starch production but also to produce alcohol as motor fuel. However, local Philippine varieties are only yielding 6-9 t/ha. Aware of the need to rapidly propagate the CIAT varieties being multiplied at the Cavite Experiment Station, the government has requested through its *National Food and* Agriculture Council, CIAT's assistance in conducting short term training and seminars on rapid propagation of these varieties. To date, three sessions have already been conducted with a total participation of 45 government professionals.

Tissue culture

The cassava outreach program identified seven Asian participants who received training in tissue culture at CIAT's headquarters in Palmira, Colombia, in the four-week course held there. Participants represented national programs of the following Asian countries: Indonesia (1); Malaysia (2); the Philippines (1); Thailand (2) and Sri Lanka (1).

Intensive course on cassava *production*

A total of 42 Asian participants have already been interviewed for the scheduled four-week intensive cassava production/extension course to be held at Leyte, Philippines, in June 1980. From the 42 professionals interviewed some 25-30 participants will be selected for training.

TRAINING AND COMMUNICATION ACTIVITIES

Training

In collaboration with CIAT's Training Office, which has major responsibilities in coordinating all CIAT training efforts, the Cassava Program trained a total of 68 professionals from 25 countries in different areas of specialization (Table 60).

Of special interest this year was the first eight-week course on Meristem Tissue Culture of Cassava in which seven scientists from the Asian countries mentioned above. Such training is intended to facilitate the exchange of pathogen-free germplasm between countries the technique also serves the purpose of rapid multiplication and storage of germplasm.

Audiotutorial Materials

The development of auto-didactic materials (audiovisuals accompanied by study guides) on cassava technical information continued throughout 1979 in collaboration with CIAT's Communication Support Unit. These teaching sets are used by training participants as complementary aids of classroom, laboratory, and field work. During the year efforts were accelerated to disseminate these materials to research, extension and teaching institutions throughout Latin America. These sets have proved to be effective in support of CIAT-sponsored in-country *trianing courses*. Table 61 shows the list of cassava audiotutorial units presently available.

Table 60. Number of professionals trained in cassava at CIAT in 1979 by discipline of specialization and category of training.

Discipline of specialization	Postdoctoral Fellows	Visiting Research Associates	Research Scholars	Postgraduate Research Interns	Postgraduate Production Interns	Special trainees	Short course participants	Total
Agronomy	1 (12.0)[1]	1 (3.0)	-	2 (10.0)	-	1 (1.0)	-	5 (26.0)
Economics	-	-	-	1 (5.0)	-	2 (7.0)	-	3 (12.0)
Entomology	1 (12.0)	2 (19.0)	1 (12.0)	-	-	-	-	4 (43.0)
Germplasm	-	-	-	2 (2.0)	-	3 (2.5)	-	5 (4.5)
Plant breeding	1 (7.0)	-	-	1 (10.0)	-	-	-	2 (17.0)
Plant pathology	-	3 (30.0)	-	2 (9.0)	-	1 (1.0)	-	6 (40.0)
Plant physiology	-	1 (12.0)	2 (14.0)	1 (11.0)	-	2 (4.0)	7 (7.0)	13 (48.0)
Production	-	-	-	-	-	-	39 (39.0)	39 (39.0)
Rural sociology	-	1 (6.0)	-	-	-	1 (4.0)	-	2 (10.0)
Training (Planning of Courses)	-	-	-	1 (0.5)	-	-	-	1 (0.5)
Weed control	-	-	-	1 (3.0)	-	-	-	1 (3.0)
Total	3 (31.0)	8 (70.0)	3 (26.0)	11 (50.5)	-	10 (19.5)	46 (46.0)	81[2] (243.0)

1 Numbers in parenthesis are man-months of training.
2 Countries of origin of professionals trained:

Bolivia	(1)	Dominican Republic	(10)	Honduras	(1)	Holland	(5)	Sri Lanka	(1)
Brazil	(14)	Ecuador	(2)	Mexico	(3)	Indonesia	(1)	Thailand	(2)
Colombia	(16)	El Salvador	(1)	Perú	(1)	Japan	(1)	United Kingdom	(1)
Costa Rica	(2)	Guyana	(1)	Venezuela	(2)	Malaysia	(2)	United States	(3)
Cuba	(13)	Haití	(2)	Cameroon	(1)	Philippines	(1)	West Germany	(4)

Table 61. Cassava audiotutorial units available (only in Spanish).

Series	Title
04SC-02.01	Un tipo ideal de planta de yuca para rendimiento máximo
04SC-02.02	Cultivo de tejidos de yuca y sus aplicaciones
04SC-02.03	Morfología de la planta de yuca
04SC-03.01	Descripción de las enfermedades de la yuca
04SC-03.05	Almacenamiento de raíces frescas de la yuca
04SC-04.01	El control ae Erinnyis ello (gusano cachón de la yuca)
04SC-04.02	Descripción de las plagas que atacan el cultivo de la yuca y características de sus daños
04SC-06.01	Sistema de propagación rápida de la yuca
04SC-06.02	Selección y preparación de estacas de yuca para siembra
04SC-07.01	Bases del mejoramiento genético de la planta de yuca

Table 62. Cassava publications issued in the established CIAT series during 1979.

Code	Title	Language	Pages	Press run
02E1C-78	Annual Report 1978	English	104	1520
02S1C-78	Separata Informe Anual 1978	Spanish	113	1200
08EC-5	Abstracts on Cassava, Vol. V	English	190	1500
08SC-5	Resúmenes sobre yuca, Vol. V	Spanish	211	1500
05EC-6	Enzymatic Assay for Determining the Cyanide Content of Cassava and Cassava Products	English	14	1500
05SC-6	Ensayo Enzimático para Determinar el Contenido de Cianuro en las Raíces y en los Productos de la Yuca	Spanish	19	1500
10SC-7	Una Sembradora Automática de Dos Surcos para Estacas de Yuca: Desarrollo, Diseño y Construcción del Prototipo	Spanish	12	1000
05EEn-3	Cassava Harvesting Aid	English	14	1500
05SEn-3	Un Implemento para Ayudar en la Cosecha de Yuca	Spanish	14	1500
09SC-3	Desórdenes Nutricionales en la Yuca	Spanish		1500
01EC-5	Cassava Newsletter No. 5	English		1280
01SC-5	Boletín Informativo de Yuca No. 5	Spanish		1025
01EC-6	Cassava Newsletter No. 6	English		1250
01SC-6	Boletín Informativo de Yuca No. 6	Spanish		1025
01EC-7	Cassava Newsletter No. 7	English		1250
01SC-7	Boletín Informativo de Yuca No. 7	Spanish		1200

Printed Media

New titles published by CIAT are shown in Table 62. The Cassava *Documentation Center*, as part of the Scientific Information Exchange Unit, developed the majority of the cassava publications this year, reflecting the level of maturity it has now reached.

Numbers 5, 6, and 7 of the Cassava Newsletter were published in English and Spanish. There has been a very favorable response to this newsletter by its audience and numerous contributions from cassava workers were received at the Cassava Documentation Center.

PERSONNEL

Senior staff
Anthony C. Bellotti, PhD, Entomologist (Coordinator)
Abelardo Castro, PhD, Agronomist
James H. Cock, PhD, Physiologist (on sabbatical leave)
Clair Hershey, PhD, Plant Breeder
Reinhardt Howeler, PhD, Soil Scientist
Kazuo Kawano, PhD, Plant Breeder
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J. Carlos Lozano, PhD, Plant Pathologist
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Eitel Adolfo Burckhardt, Biologist, Soils
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* Dario Cárdenas, Econ., Economics
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Carolina Correa, Econ., Economics
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Gustavo Jaramillo, Ing. Agr., Agronomy
Javier López, Ing. Agr., Cultural Practices
Sara Mejía, Ing. Agr., Plant Physiology
Pedro Millán, Ing. Agr., Germplasm
Germán E. Parra, Ing. Agr., Plant Physiology
Edgar Salazar, Ing. Agr., Soils (stationed in Carimagua, Colombia)
Ana Milena Varela, Biologist, Entomology
Ana Cecilia Velasco, Med. Tech., Plant Pathology

* Left during 1979.
** Assigned to Training and Conferences.