Cassava: A Basic Energy Source in the Tropics

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Cassava (*Manihot esculenta* Crantz) is a perennial vegetatively propagated shrub grown throughout the lowland tropics for its starchy, thickened roots (Fig. 1). The fresh roots of cassava contain 30 to 40 percent dry matter and have a starch content that approximates 85 percent of the dry matter. In developed countries, where it is a foodstuff of minor importance, cassava is commonly known only in the forms of tapioca, starch pearls or flakes, or as a component of animal rations. In developing countries, however, it is a major food staple. After rice, maize, and sugarcane, cassava is the fourth most important dietary source of calories produced within the tropics (Table 1).

Cassava has long been a basic staple. There is direct evidence of its cultivation 2500 years ago and circumstantial evidence that the crop may have been cultivated for 4000 years in the Americas. It has been suggested that many areas now under tropical rainforest were once cultivated with cassava and corn in shifting culture (*1*). On the arrival of the conquistadores from the Old World, cassava was found throughout the lowland tropics of the Americas and the Caribbean. The cassava was either eaten after boiling or was rasped, after which the toxic juices were eliminated by squeezing the mash in basket-weave tubes (known as a *tipiti* in Brazil) and the remaining mash was roasted to a meal. Cassava production appears to have decreased after the arrival of the conquistadores, when the population of lowland areas was decimated by introduced diseases.

With the opening up of trade between Africa and Brazil by the Portuguese, cassava was taken to the Congo Basin in the 16th century. Two centuries later the crop was independently introduced to Madagascar and the east coast of Africa from where it was taken inland and rapidly became established as a basic staple (*2*).

The introduction of cassava to Asia is not well documented, but the plant was probably taken to the Philippines in the Manila galleon from Acapulco, Mexico, in the 17th century. It was already grown in Indonesia by 1740, and it was probably introduced by the Portuguese to Goa somewhat earlier. By the end of the 19th century the crop was dispersed throughout lowland tropical Asia and the islands of Oceania (*3*).

Summary. Cassava (*Manihot esculenta*) is the fourth most important source of food energy in the tropics. More than two-thirds of the total production of this crop is used as food for humans, with lesser amounts being used for animal feed and industrial purposes. The ingestion of high levels of cassava has been associated with chronic cyanide toxicity in parts of Africa, but this appears to be related to inadequate processing of the root and poor overall nutrition. Although cassava is not a complete food it is important as a cheap source of calories. The crop has a high yield potential under good conditions, and compared to other crops it excels under suboptimal conditions, thus offering the possibility of using marginal land to increase total agricultural production. Breeding programs that bring together germ plasm from different regions coupled with improved agronomic practices can markedly increase yields. The future demand for fresh cassava may depend on improved storage methods. The markets for cassava as a substitute for cereal flours in bakery products and as an energy source in animal feed rations are likely to expand. The use of cassava as a source of ethanol for fuel depends on finding an efficient source of energy for distillation or an improved method of separating ethanol from water.

In the 20th century cassava production has continued to expand throughout the lowland tropics, mainly on the less-fertile, poor-quality agricultural lands. In Africa the capacity of cassava to grow and yield well on low-fertility soils, its ability to withstand locust attacks and drought, and its low cost of production have provided the economic incentive to use it as a replacement for other traditional root crops such as yams (*4*). In areas of Africa where population growth has caused a reduction of the rotation pattern in shifting culture and a commensurate decline in soil fertility, cassava is one of the few crops that can still be successfully grown provided some form of rotation remains. Similarly in southern India and Java, as population has increased, cassava has increasingly been grown as a basic dietary staple on low-quality land that is not suitable for rice production. In the 1970's, the area planted to cassava in Thailand increased fivefold, mainly on the poorer, unexploited land of the northeast.

Cassava Production

World cassava production for 1980 was estimated at 118 million tons, with 45 million tons in Africa, 41 million tons in the Far East, and 32 million tons in South America (*5*). This is the energy equivalent of 40 to 50 million tons of cereal grains. The area harvested was 13.7 million hectares, with a mean yield of 8.7 tons per hectare (equivalent to 3 to 3.5 tons of grain per hectare). During the last 20 years, total cassava production has increased at the same rate as population growth in developing countries. This increase is largely due to increases in area planted, since yields have remained constant (Fig. 2). The usual yield of about 9 tons per hectare is far below the maximum experimental yield of 80 tons per hectare in a 12-month growing season (*6*). However, since most cassava is grown within traditional farming systems, with little or no use of fertilizers, fungicides, insecticides, herbicides, and irrigation, these yields compare favorably with those of other basic energy crops such as the cereals. Although two grain crops can be harvested each year in some tropical areas, this is not possible in regions where there is a long dry season and irrigation is not feasible. In these regions only one cereal crop can be produced or cassava can be grown. With traditional management under these conditions, cereal yields are only 1 to 2 tons per hectare per year.

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Cassava is produced mainly by small farmers, although there are a few large plantations. Small farmers generally follow agronomic practices that do not depend on inputs normally associated with modern agriculture. Planting material is derived from mature plant stem-cuttings, which sprout axillary buds 2 to 3 weeks after being placed in the soil (Fig. 3). The plant grows, becoming well established after 3 to 4 months when it begins to produce thickened roots. The roots are generally harvested any time from 7 to 18 months after planting. In some areas cassava is grown as a famine, reserve crop, and the plants are left until required. Roots are harvested by pulling on the stem until the whole plant is uprooted (Fig. 4).

Table 1. Calories produced from major staples and utilized for direct human consumption. The data for tropical zones are compared with those for the world and are expressed as billions of kilocalories per day. [Data from (7)]

Crop	Tropical zones	World
Rice	924	2043
Sugar (cane and beet)	311	926
Maize	307	600
Cassava	172	178
Sorghum	147	208
Millet	128	204
Wheat	< 100*	1877
White potatoes	54	434
Banana	32	44
Plantain	30	30
Sweet potatoes	30	208

*Wheat figures are distorted by the fact that major production zones in Brazil, Mexico, and India are outside the tropics and have been adjusted to account for this.

Cassava Consumption

Approximately 65 percent of the total cassava production in the period 1975 to 1977 was used for direct human consumption, about 21 percent for animal feed, and lesser amounts for starch and industrial use (7) (Table 2). Of the cassava used for human consumption about half is eaten after the fresh roots are cooked, and the other half is processed in a number of different ways to make flours or meals (7). From FAO data (7) it can be inferred that at present 450 million to 500 million people from 26 tropical countries consume approximately 300 kilocalories per day as cassava. These data probably overestimate the number of people consuming cassava and underestimate the per person calorie intake, since the data are based on country means. Highest per capita consumption levels occur in Africa, with an estimated 50 million people consuming more than 500 kcal/day, and in southern India, where approximately 25 million people consume over 700 kcal/day.

There are many reports of chronic cyanide toxicity (*8, 9*) in regions of Africa where cassava consumption levels are high. Cyanide is liberated from root tissues, when they are damaged, by the action of linamarase on linamarin. Cassava clones which have a high cyanide content, and which are normally bitter to the taste, can cause acute cyanide poisoning if the roots are eaten without being processed. This type of poisoning is rare, however, and it is the long-term ingestion of low levels of cyanide from cassava that has more commonly been associated with goiter, cretinism, tropical ataxic neuropathy, and tropical diabetes. Cyanide is detoxified by the formation of thiocyanate from thiosulfate. Thiosulfate is formed from sulfur-containing amino acids, the presence of which is essential for detoxification. Cyanide decreases the concentrations of sulfur amino acids and increases the concentration of thiocyanate in the blood. Tropical ataxic neuropathy is associated with protein malnutrition and extremely low levels of sulfur amino acids in the blood. Thiocyanate inhibits thyroid uptake and iodine transport and is, thus, associated with goiter and cretinism.

Problems associated with cassava toxicity are not widespread outside western Africa, however, and occur only in areas where processing of the roots is rudimentary, dietary iodine levels are low, and the intake of protein and sulfur amino acids is suboptimal. Chronic cyanide toxicity is not reported in Kerala, southern India, where people consume more than 700 kcal/day as cassava. Protein consumption in Kerala is low (37.8 to 41.5 grams per person per day), but the amino acid content of the protein is reasonably well balanced, with fish being a major component (*10, 11*). This suggests that chronic cyanide toxicity need not occur when overall nutrition is adequate. This view is reinforced by recent work in Zaire by Ermans *et al.* (9) showing that administration of slowly absorbable, iodized oil is a cheap and effective prophylactic for chronic cyanide toxicity and may be a more appropriate solution to the problem than trying to change the dietary staple.

The amount of cyanide in cassava can be greatly reduced by adequate processing. In areas of northeast Brazil, large amounts of farinha (a type of cassava flour) are consumed. During farinha production most of the cyanide is eliminated when the cassava mash is squeezed and the water, containing much of the cyanide, is discarded. More cyanide is eliminated when the resulting mash is roasted. There is no evidence of chronic cyanide toxicity among the consumers of farinha.

Fig. 1. Cassava plants. The plant on the right is an efficient type with a good balance between shoot and root growth. [Photograph courtesy of CIAT]

Although cassava is of somewhat low

nutritional value, it is, at least in the dried form, among the least expensive available sources of calories (*2, 12–15*) (Table 3). While it is true that cassava is not a complete food, calorie deficiency is widespread in the developing countries. The International Food Policy Research Institute estimates that by 1985 some 1.5 billion people will suffer from malnutrition, which is highly correlated with calorie deficiency. It is here that the significance of cassava lies, in the nutrition of the poorer and most undernourished populations of the developing countries.

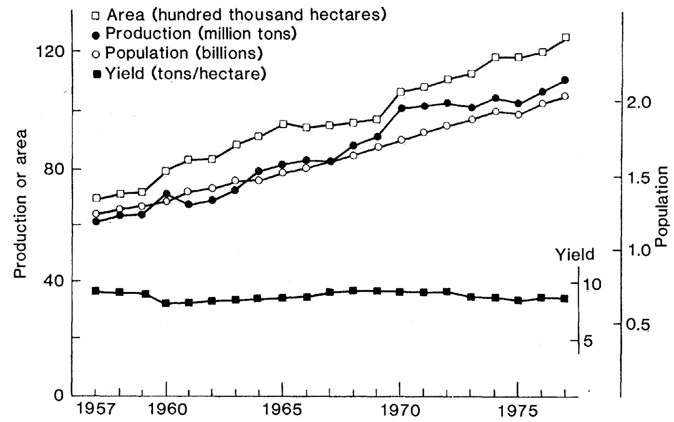

Fig. 2. Production, area, and yield of cassava and the population of the developing countries where almost all cassava is grown. [Data from (*5*)]

Biological Potential

Most cassava crops are grown between 30°N and 30°S, in areas where annual rainfall is greater than 750 millimeters and annual mean temperature is greater than 18° to 20°C. Small amounts of cassava are grown near the equator in South America and Africa at altitudes up to 2000 meters, under annual mean temperatures as low as 16° to 17°C, but with minimal seasonal fluctuations.

Cassava is potentially one of the most efficient crops in terms of starch production (*16*). Yields of 80 tons of fresh roots per hectare per year (29 tons of dry roots per hectare per year) have been obtained under optimum growing conditions but without supplementary irrigation (*6*). In areas with high rainfall, total radiation is reduced by cloud cover and yields of 30 tons of dry roots per hectare per year appear to be close to the theoretical yield limit (*17, 18*). Several other crops, such as sugarcane, maize, sorghum, and rice have yield potentials of a similar order when one, two, or three crops are harvested per year; hence, in these situations, cassava has no great advantage over other crops.

The yield potential of cassava is not based on a particularly high photosynthetic rate of individual leaves nor on a high maximum rate of growth (*18*). For cassava, the maximum recorded levels of these parameters are, in fact, much lower than the high rates for other major crops such as sorghum, maize, and sugarcane (*19*). Cassava has a relatively long, 9-month to 2-year growing season, and a remarkably high harvest index (ratio of weight of economically useful parts to total biomass production) (Table 4), and these two factors enable cassava to produce yields similar to, or greater than, other major crops under optimum conditions. It is, however, under suboptimal conditions that the yield potential of cassava excels when compared with other crops.

Yield potential under suboptimal conditions. Crops grown in many tropical areas suffer from uncertain rainfall, long dry periods, and soils with low *p*H, high aluminum concentrations, and low fertility. In the 1960's, the strategy of the Green Revolution to increase agricultural production was largely directed at removing these constraints through the use of irrigation, soil amendments, and fertilizer applications, and by combining the improved agricultural conditions with plant varieties capable of exploiting them. Since those halcyon days, high energy cost has made it necessary to search for crops and farming systems that are per se tolerant of adverse conditions and that have the capacity for an acceptable degree of productivity under a regimen of low inputs. The characteristics of cassava are in line with this new perspective.

In many tropical areas where there are Oxisols and Ultisols, heavy lime applications must be made to increase *p*H and reduce toxic aluminum levels in the soil. In the acid infertile eastern plains of Colombia, cassava gave acceptable yields without liming, whereas other crops tested, with the exception of cowpea, yielded essentially nothing (*20*) (Fig. 5). Cassava's tolerance for high alumi-

Fig. 3. Planting material is obtained from the stems (left) which are chopped into short cuttings like those in the farmer's hands for planting. [Photograph courtesy of CIAT]

Fig. 4. Cassava tops are cut off and the roots dug out using the stump to help uproot them. [Photograph courtesy of K. Kawano, CIAT]

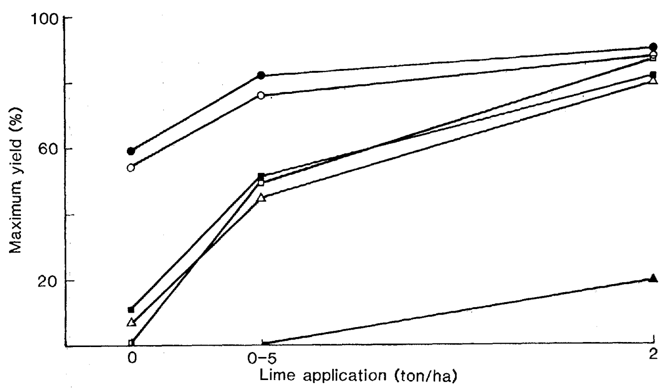

Fig. 5. Response of cassava (●), cowpea (○), rice (■), corn (□), black beans (△), and nonblack beans (▲) to lime on an acid infertile Oxisol in the eastern plains of Colombia. Data presented as percentage of maximum yield obtained by each species with 6 tons of lime applied per hectare. [Data from (*20*)]

Table 2. World cassava utilization, 1975 to 1977, and estimated production in 1980. [Data from (*5*) and (*7*)]

Area	Production (million metric tons)	Human food (%)	Animal feed in developing countries (%)	Industrial use and starch (%)	Exports* (%)	Waste (%)	Stock changes (%)
Africa	45.4	88.7	1.4	†	†	9.5	†
Asia	41.0	55.3	2.9	8.6	23.0	6.3	3.9‡
Americas	31.7	42.4	33.4	9.6	†	14.0	†
World	118.4	64.6	11.5	5.5	7.0	10.0	1.4

*Largely animal feed used in developed countries. †Less than 1 percent. ‡Changes in stocks of dried cassava chips mainly in Thailand.

Table 3. The relative cost of calories from dried cassava compared with two other basic energy staples in various tropical countries. The data are presented as relative cost of cassava with cost of compared staple fixed at 100.

Compared crop	Location	Relative cassava cost	Year	Reference source
Rice	Kerala, India	45	1970–1971	(*10*)
Rice	Indonesia	44	1976	(*12*)
Maize	Indonesia	76	1976	(*12*)
Rice	Ghana	31 to 55	1955	(*14*)
Maize	Ghana	75 to 89	1955	(*13*)
Rice	Nigeria	41	1973	(*13*)
Maize	Nigeria	93	1973	(*13*)
Rice	Northeastern Brazil	48	1975	(*15*)
Maize	Northeastern Brazil	57	1975	(*15*)

num concentrations and low pH has been unequivocally demonstrated (*21*).

At the University of Queensland, the nutritional requirements of cassava have been studied in nutrient solution (*22*). For maximum growth, cassava's requirements for nitrogen, potassium, and calcium are similar to other crops, but its phosphorus requirements in nutrient solution or sterilized soil are somewhat higher. However, with the exception of phosphorus, the reduction in growth at low nutrient levels is much less in cassava, suggesting that the crop is highly tolerant of low nutrient levels. In soils where mycorrhizal infection occurs, the phosphorus requirements of cassava are somewhat low (*23*) (Fig. 6). Thus, under natural conditions with low nutrient levels, cassava can yield nearer its potential total biomass than most other food crops. This picture looks even brighter when economic yield is considered. Under nutrient stress the proportion of total dry matter production diverted to the roots is greatly increased in the more vigorous clones, such as M Mex 59 (Table 4). The reduction in starch yield of these clones under nutrient stress is much less, proportionately, than the reduction in total biomass production. In anthropomorphic terms, it can be said that when cassava is under a tight budget system, it spends very wisely.

The tendency of cassava to increase the distribution of biomass to the roots also occurs under water stress. This effect was so marked in one trial that plots of one clone (stressed for 2 months), in spite of reduced total dry matter production, yielded more roots at final harvest than unstressed plants (*24*). During drought stress cassava follows a conservative pattern of water use, closing its stomata and reducing the formation of new leaves (*25, 26*). Leaves that remain on the plant have a remarkable ability to actively photosynthesize when moisture becomes available (*23*). Thus, the plant slows its growth during drought periods but rapidly recovers when they cease. Unlike many other crops, cassava, once established, has no critical period when drought will cause a disastrous decrease in yield (*27*) (Fig. 7). Hence, cassava is well adapted to areas that experience a long dry season or uncertain rainfall.

In traditional growing areas, the native cassava clones tend to be resistant to the disease and pest complexes of the region (*28*). Clones from the eastern plains of Colombia are usually resistant to cassava bacterial blight, superelongation disease, and anthracnose, which are endemic in this area, but are susceptible to phoma leaf spots, which occur in cooler climates. As with many other food crops, when cassava is introduced to new areas with initially low disease and pest pressures, diseases and pests that flourish in that environment may subsequently be introduced and cause severe yield losses (*28*). This has undoubtedly occurred in the cases of the green spider mite in East Africa and mealy bugs in West Africa, where the recently introduced pests have caused great reductions in yields (*29*). Nevertheless, in the Americas it appears that over the centuries farmers have selected clones that are highly resistant to the diseases and pests prevalent in their cassava growing areas. Biological control is often very effective for pests of cassava grown under traditional management practices.

Breeding for Increased Yield

The ability of cassava to survive low inputs and water stress and its demonstrated resistance to pests and diseases make this crop a leading candidate for low-input agricultural systems. Nevertheless, world mean yields for cassava are far below the yield potential. A major question is whether it is possible, through breeding, to obtain clones that are able to approach the demonstrated yield potential and maintain it over a number of years, even under marginal conditions.

Although farmers have already selected lines of cassava that give high yields under local cassava-growing conditions, they probably have not exploited the true yield potential of the crop. More than likely there is a degree of inbreeding depression in their selections. Furthermore, in traditional slash and burn culture, cassava is normally widely spaced and planted with other crops. Under these conditions selection may well be for yield per plant rather than for yield per hectare. There is evidence that yield per plant of segregating populations is negatively related to yield per unit area under dense planting (*30*). Highly vegetative plants that produce a large number of cuttings tend to have a low harvest index, which tends to be reduced further in dense stands; while at the same time vegetative cutting quality may also be reduced. Thus, when there is no conscious selection for high harvest index, selection may actually be for lower harvest index and, hence, for reduced yield potential.

A major factor causing reduced or unstable fields in cassava is the complex of diseases and pests that attack the crop. Although farmers have selected

Table 4. Effects of soil fertility levels on the harvest index of 9-month old cassava. The harvest index is the dry weight of roots divided by the total plant dry weight.

Clone	Fertility level		
	High	Medium	Low
M Col 22	0.80	0.81	0.81
M Mex 59	0.46	0.56	0.74
CMC 40	0.68	0.71	0.68

varieties that are relatively tolerant of diseases and pests, they have had relatively limited gene pools and a limited number of seedlings from which to select broad-based, tolerant types. It is now possible to bring together many clones representing a broad genetic base from different areas. Through breeding programs large numbers of crosses can be obtained, thus increasing the probability that higher yielding, disease- and pest-resistant clones can be selected. The results of breeding programs at the International Institute for Tropical Agriculture (IITA) in Africa and the Centro Internacional de Agricultura Tropical (CIAT) in South America suggest that this is indeed the case (*23, 31*).

Agronomic Considerations

Large improvements in yield will probably not be obtained solely by changing the clones grown but will also require concomitant modifications in agronomic practice. Farm surveys in Colombia (*32*), Ecuador (*33*), Nigeria (*34*), and Thailand (*35*) have shown that yields may be reduced because of diseases and pests, poor quality of planting material, mixed cropping, poor agronomic practices, and low soil fertility.

Diseases and pests may both limit current crop yields and reduce the quantity and quality of the planting material for the next crop. Apart from host-plant resistance, several practices can lead to improved vegetative cutting quality. Careful selection of planting material and pesticide treatment can greatly reduce germination losses and initial levels of infection (*36*). Once a plantation is established there are many pathogens and insect pests that may attack it and cause severe yield losses. Frequently, a farmer's first reaction to an insect attack on cassava is to apply a potent insecticide. This may lead to the destruction of beneficial insects and result in repeated at-

Table 5. Soil nutrients extracted by starchy staple crops. The data are expressed as kilograms nutrient extracted per ton of dry matter harvested.

Crop	Nitrogen	Phosphorus	Potassium
Cassava (roots)	6	1	11
Maize (grain plus cob)	21	5	6
Rice (grain plus hulls)	13	3	4
Potatoes (tubers)	10	2	22

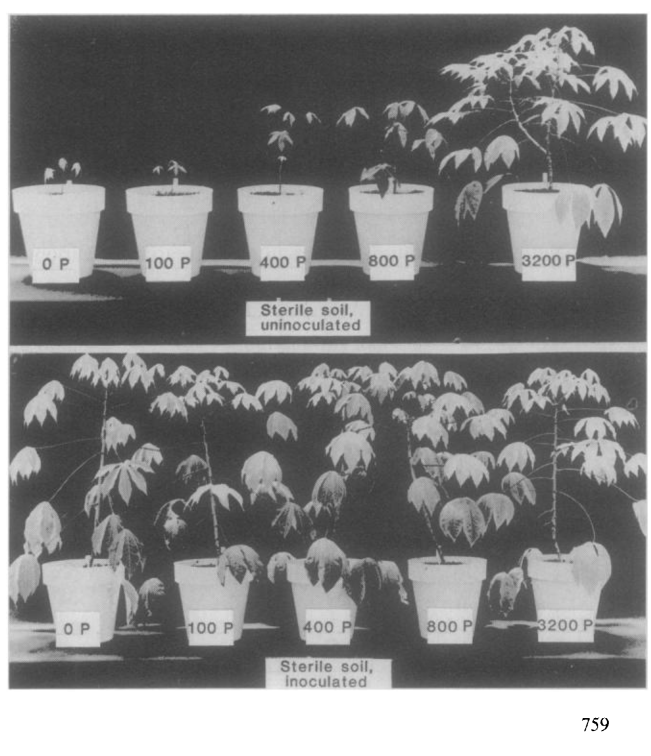

Fig. 6. On a sterilized soil with low phosphorus levels up to the equivalent of 3200 kg of phosphorus must be applied per hectare for maximum growth (top), whereas plants inoculated with mycorrhiza grow well with no applied phosphorus (bottom). [Photograph courtesy of R. Howeler, CIAT]

Table 6. Yield comparison between scientist-managed cassava trials and farmer-managed trials. Yields are expressed as tons of fresh roots per hectare. [Data from (51)]

Clone	Regional trial	Good farmer	Poor farmer
Traditional technology			
Secundina		10.0	6.1
CM 342-170		20.5	9.6
*Improved technology**			
Secundina	12.6	16.5	10.5
CM 342-170	20.8	21.4	19.7

*Unirrigated with no fertilizer application.

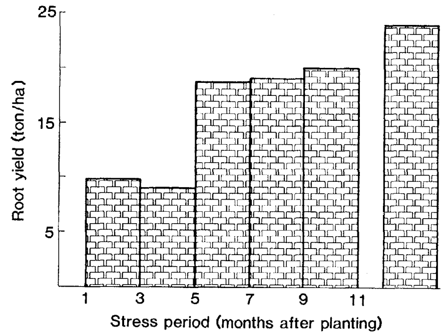

Fig. 7. Yield of cassava with water stress at different growth stages. [Data from (27)]

tacks. In some instances effective biological controls have been developed. For example, a biological control for the hornworm (*Erynnis ello*) is in commercial use (37). Sometimes much simpler control methods can be effective. For example, root rots, which are common in high rainfall areas, can be greatly reduced by crop rotation and by planting on ridges or mounds, as is traditional in Africa, India, and northeastern Brazil. Other examples could be given, but the few shown here illustrate that when host-plant resistance is not available, diseases and pests can often be controlled without resorting to chemical products.

Disease and pest incidence is usually reduced when cassava is intercropped (38). Cassava yields per hectare in mixed cropping are normally less than when cassava is the sole crop. Yield reduction is even greater when the cropping association is with vigorous, long-season crops. The slow, early establishment of cassava makes it possible to intercrop cassava with crops that have a short growth cycle, such as beans and cowpeas, with minimal competition and yield loss. It is more efficient to grow cassava intercropped with such legumes than to grow the root crop and the legumes separately in monoculture (39). Hence, although mixed cropping reduces cassava yield, the total food production per hectare is often enhanced. It is for this reason that much of the world's cassava is grown intercropped.

In traditional shifting culture cassava is grown with other crops. Cassava often becomes more important toward the end of the cropping cycle because of its ability to grow on depleted soils. This, however, has led to two misconceptions: first that cassava depletes the soil, and second that cassava does not require fertilization. Depleted soils that will not support other crops will often still support an economic yield of casava, but to do this will become further depleted. Hence cassava gains the reputation of a crop that depletes the soil. In fact, nutrient extraction per ton of dry matter harvested is no greater for cassava than for other crops (Table 5) and, with the exception of potassium, cassava actually depletes the soil less than most other crops when nutrient extraction per unit of dry matter produced is considered. Nevertheless, in order to obtain high cassava yields on infertile soils, fertilization is required (21).

CIAT has established regional trials of cassava growth at sites that vary for climatic, edaphic, and biotic conditions, to compare the best available, low-input agronomic practices with traditional practices. These trials have shown that in Colombia, where the national average cassava yield is close to 10 tons per hectare, yields of the best local clones could be doubled by simple improvements of management practices (not including irrigation). If new high-yielding clones were included, yields could be tripled to more than 30 tons per hectare (40). These agronomic practices with high-yielding clones have been field tested on poor soils by farmers with a very low resource base. The yield levels of a small farmer using good management practices were slightly greater than those obtained in the regional trials (Table 6). These data suggest that cassava yields could be greatly increased at the farm level by using good agronomic practices and the best local varieties. These yields could be further increased by the introduction of better adapted, higher yielding clones.

Before a new technology reaches farmers it should be tested and adapted to specific local conditions and practices by national programs. However, national research expenditure on cassava is extremely low in comparison with other starchy staples (Table 7) (41). Returns on investment in agricultural research are generally high and it would seem a priori that a crop such as cassava that has received so little attention from the scientific community should be no exception. One might even expect that, with a crop that has not been intensively researched, the returns could be greater than with most other crops. This viewpoint is reinforced by data from Cuba where threefold increases in yields have been obtained over a 5-year period as a direct result of an intensive research effort (42).

Table 7. National expenditure on agricultural research for various starchy staples. [Data from (41)]

Commodity	Gross value of production in developing countries 1972 (U.S.$ billion)	Research expenditure in national program 1971 (U.S.$ million)	National expenditure as percent of gross value of product
Sorghum	1.5	12.2	0.77
Maize	3.0 to 4.0	29.6	0.75
White potatoes	1.0	8.2	0.68
Wheat	5.0 to 6.0	35.9	0.65
Sugarcane	5.0 to 6.0	30.2	0.50
Rice	Over 13.0	34.7	0.26*
Sweet potatoes	3.0 to 4.0	3.4	0.09
Cassava	5.0 to 6.0	4.0	0.07

*Shallow water rice 0.40.

Present Demand and Future Potential Use

Fresh cassava. About half of the current cassava production is destined for fresh consumption, which is much greater in rural than in urban areas. The low level of urban consumption is a reflection of the high perishability of fresh cassava and the high marketing margins that result in high urban consumer cost. If the urban price of fresh cassava could be lowered, the urban consumption might increase. This possibility is supported by the fact that in the lower income strata the income elasticity of demand for fresh cassava is high in countries such as Ghana, Indonesia, and Brazil. Costs can be reduced in part by improved production technology aimed at lowering the "farm gate" cassava price, and also by improved storage techniques that reduce both the risks of transporting and of bulk purchasing and, thus, reduce marketing margins.

Cassava is a difficult crop to handle in the postharvest period. Roots start to deteriorate 1 to 7 days after they are harvested. Initial physiological deterioration is later compounded by microbial action. Physiological deterioration can be controlled by preharvest leaf pruning or by packing freshly harvested roots in polyethylene bags (*43*). Fungicide treatments help to control the microbial deterioration. Problems associated with quality changes under storage and possible toxic fungicide effects remain, but economical solutions to extending cassava shelf life could yet result in reduced consumer cost and increased urban demand.

Dried cassava. At low-income levels demand for fresh cassava is strong, but as income rises, demand flattens off. Dried cassava consumption for the lowest income strata tends to increase with increased income to a point, after which it declines (*44*). Nevertheless, currently and in the near future it is precisely those people in the lower income groups who consume the greatest amounts of cassava flour and are likely to be the major beneficiaries of increased production and lower costs. As countries develop and incomes rise it is likely that, in the short-term, consumption of dried cassava will increase slightly but that in the long run the consumption level will decline.

At the same time it is expected that demand for bakery products from wheat flour will increase rapidly. Few lowland, tropical, developing countries can meet the present demand for wheat flour from their own production, and increasing demand leads to ever increasing wheat imports. In order to satisfy urban demand for affordable bakery products, many national governments and aid agencies heavily subsidize locally produced and imported wheat. These subsidies make it difficult for wheat flour substitutes to compete and, hence, may prevent the development of local alternatives. It is technically feasible to substitute wheat flour with 10 to 20 percent cassava flour (*45*), yet this rarely occurs. This is partly because of the wheat subsidy and partly because of the lack of supplies of dried cassava flour. If, however, a reasonable price structure were to exist for wheat flour substitutes, it appears that cassava produced with the use of modern technology could be an attractive alternative.

Table 8. Net energy ratio (NER) of cassava and sugarcane alcohol with different fuel sources for the industrial process. [Data from (*48*)]

Substrate	Fuel for industrial process	NER
Sugarcane	Bagasse	8.06
Cassava	Oil	1.21
Cassava	Firewood	1.97
Cassava	Sun-dried cassava stalks	4.97

Feed market. Before cassava becomes a major component of bakery products it is likely to enter into the feed grain market as an energy source, as has already occurred in Europe. During the last 20 years developing countries have markedly increased their feed concentrate demand. This demand, which is particularly high for poultry rations, has thus far been met partly through increased local agricultural production and partly through grain imports. Direct competition between grain for human consumption and grain for feed concentrate occurs in some areas, heightening food supply problems. In addition, cereal grain importation has done little to create employment and nothing to develop local agriculture, while adding to the severe drain in foreign exchange.

In Europe cassava pellets are used as an energy component in balanced poultry, pig, and dairy rations. In the last 10 years cassava pellet exports from Thailand to the European Economic Community have increased from less than 1 million to as much as 6 million tons per year. While these figures amply demonstrate the feasibility of incorporating cassava in animal rations, the Thai case is exceptional. Thailand is one of the few developing countries that exports grain, and the Thais do not eat much cassava. Nevertheless, cassava production could be increased for use as animal feed within other countries that are at present net importers of food grains. Recent studies in Ecuador and Colombia suggest that if yields can be raised to 15 tons per hectare per year, cassava will become highly competitive in the feed grain market. In recent years Mexico has faced steeply increasing grain deficits. To reduce grain imports a major program was implemented to produce cassava on underutilized lands. An interesting aspect of the Mexican plan is that cassava is being planted on land that is normally considered too poor for crop production, with the goal of increasing total agricultural production rather than increasing one commodity at the expense of another. This strategy should be directly applicable to many other tropical countries that have both cereal grain deficits and underutilized areas of poor soils.

Energy. Dwindling fossil fuel supplies have resulted in renewed interest in alternative energy from biomass. Cassava is frequently mentioned as a potential biomass crop because of its ability to produce high yields of carbohydrates (*46–49*). These carbohydrates can be used to produce ethanol.

Brazil has vast areas of acid, infertile soils that are currently underutilized. It is in these areas that very small amounts of cassava are grown as a substrate for alcohol production. Locally grown tree crops are used to fire the boilers for anhydrous ethanol production. With this system net energy ratios (NER) are positive (Table 8). If, however, fossil fuels are used in the distillation, the NER is barely greater than one (*47–49*). This suggests that where liquid fuel is in short supply, and where sources of nonliquid energy such as coal are available, cassava may indeed have a role to play. In other areas the NER could be improved by using cassava stalks as an energy source in a manner similar to the use of sugarcane bagasse (Table 8), but this has not yet been achieved even on an experimental basis. With currently available technology, 70 percent of the energy used in alcohol production from cassava is used in the industrial process, mainly in the separation of alcohol from water. Until this requirement can be reduced, the benefits of using cassava for alcohol production are questionable. However, less conventional, more energy-efficient separation methods are being developed (*50*). These could radically alter the potential use of cassava in energy production.

Conclusions

Cassava is potentially one of the most efficient producers of carbohydrates under poor agricultural conditions. Average world yields of less than 10 tons per hectare remain below potential production levels. Production technology requiring low levels of purchased inputs but utilizing improved varieties could greatly increase yields obtained by farmers, even those with very limited resources.

Dried cassava is the cheapest energy source in large areas of the lowland tropics. If yields could be increased and prices reduced, its use by the very poor would increase. In many parts of Africa and in southern India, Java, and northwestern Brazil, large proportions of the populations have such limited resources that they are forced to depend on the least expensive available calorie source. Since these populations are expanding, the role of cassava in partially alleviating hunger must not be underestimated. In other areas, as incomes rise, the total per capita consumption of cassava will probably decrease slightly, with a shift occurring from consumption of the dried product to consumption of fresh cassava. Government policy changes that favor cassava use as a wheat flour substitute will be necessary to increase the demand for high-quality flour for use in bakery products.

The use of dried cassava in animal feed rations has a tremendous growth potential particularly in developing countries. Adoption of improved agronomic practices and high-yielding varieties could reduce costs to a level where cassava can compete with either imported or locally produced cereal grains. In the former case, foreign exchange could be saved and local industry stimulated, while in the latter case, cassava could be produced on land not used for cereal production, thus alleviating cereal grain deficits.

In spite of the emphasis on cassava alcohol production in Brazil, where economic circumstances are somewhat different from most other regions, present-day technology does not give very positive net energy gains. Nevertheless, cost reductions in making anhydrous alcohol will make cassava production more attractive as a renewable energy source.

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