CASSAVA IN ASIA: DESIGNING CROP RESEARCH FOR COMPETITIVE MARKETS[1]

Clair H. Hershey[2] and Reinhardt H. Howeler[3]

ABSTRACT

This paper reviews cassava in Asia from a broad perspective, culminating in a definition of the research areas that will contribute effectively to development goals in the region. The first section outlines regional trends in production, trade and utilization, drawing comparisons to global trends. A basic tenet of the paper is that the competitive marketplace – at local, regional and international levels – is rapidly changing cassava's roles in development. Hence, in the second section the discussion is placed in the context of the external social, economic and political environments that impact the cassava sector. The third section then indicates specific constraints and opportunities in the cassava system. Finally, we outline the role of key research areas for the cassava systems of Asia.

INTRODUCTION

Successful agriculture underlies the progress of most societies. Even many of today's more economically advanced countries continue to rely heavily on the productivity of the land as one of the key driving forces for economic growth and human development. The benefits come from diverse and adequate diets; employment and income generation throughout the entire system of production, processing and trade; and export earnings for balancing trade. When agriculture is economically viable, farmers are more likely to invest in practices that protect the environment (Kawano, 2001).

Curiously, after many years of international concern about food shortages, there is an evolving sense that food *overproduction* is becoming a serious economic menace to many producers, even for farmers of the third world. In fact, most farmers are keenly aware of this, as most have moved away from subsistence, toward dependence on the marketplace for income and livelihood. Market prices for basic commodities that are barely above production costs, and sometimes below costs, are common. This either drives producers out of business (and often precipitates migration to cities) or toward greater efficiencies and higher production, thereby putting even greater pressure on markets. As markets are opened to free trade, international competition exacerbates this trend. Conversely, open trade can also bring new market opportunities, and the possibility to have increased production without depressed markets.

The challenges of producing enough food for all are certainly not behind us, but much progress has been made. Among many agricultural scientists and policy-makers, emphasis is shifting toward assuring an appropriate balance between production, market development, and distribution systems, such that efficient producers are assured a fair income, while consumers have access to food and other agricultural products at affordable prices. There is also increasing awareness of the need to employ methods that preserve the environment for long term productivity.

---

[1] Based on Hershey *et al*., 2000

[2] Farmer and cassava consultant, 2019 Locust Grove Road, Manheim, P.A. 17545, USA.

[3] CIAT Cassava Office for Asia, Dept. Agriculture, Chatuchak, Bangkok, 10900, Thailand.

Cassava fills a number of basic roles around the world. In subsistence and poorly-developed market economies, it is usually a starchy staple. This role is declining in importance in Asia, but remains a key in some areas, especially parts of Africa. With urbanization and rising incomes, per capita demand for staples stops rising. Cassava's high versatility allows it to be processed into a very wide array of higher value products, such as convenience and snack foods. With higher income, people also tend to consume more animal products, and drive the demand for production of the ingredients of balanced rations. There is already a long history of research and practical experience in the use of cassava in animal feed. The rapidly growing global market for starch will absorb increasing quantities of cassava. These markets may compete directly with grain sources, or may be specialized markets where cassava's specific starch traits are required.

The vast majority of cassava growers in Asia produce the crop because they view it as their best alternative for generating income. This is not, however, the result of a high per-unit value. On the contrary, it is generally a low-value crop, often one of few alternatives in areas where it is grown. Rice continues a long tradition as the principal and preferred staple food in much of Asia, but where soils are marginal in fertility, and rainfall is uncertain, cassava may have a strong adaptive advantage.

The links between cassava and environmental protection revolve mainly around implications of the large proportion of this crop grown in fragile or otherwise marginal ecosystems. Cassava's historical reputation as a crop that causes soil degradation grew out of the plant's ability to produce on poor soils, where most other crops would fail. Managing erosion is a critical need when cassava is grown on slopes and in light soils, especially during the first months before the canopy closes. Disposal of waste products from processing is another environmental concern especially when processing plants become larger. The solutions lie in research on environmentally and economically sound waste management, by-product development, and reasonable regulation (Howeler *et al*., 2000).

A. TRENDS IN PRODUCTION, TRADE AND UTILIZATION[4]

Cassava in Asia has succeeded in diverse physical, socio-economic, and political environments. The species is a relatively recent introduction to the agriculture of Asia, in comparison to the several-thousand-year-old rice culture. Best evidence indicates it was first introduced to the Philippines during the Spanish occupation. By the beginning of the 19th century, explorers and traders had effectively distributed the crop throughout tropical Asia. Colonial administrators promoted cassava culture by developing a starch processing and export industry in Malaya in the 1850s, and later in Java. The Dutch in Java and the British in southern India also promoted cassava as a famine reserve crop. In this heavily rice-dependent region, cassava found a niche in environments where rice was risky or difficult to grow. Production was concentrated on Java and in Malaysia for much of the period up to World War II. The disruptions of the war and the rising prominence of maize as a source of starch brought a decline to the cassava starch export industry. Markets for internal consumption remained strong in Indonesia, and this country led production in Asia up to the late 1970s.

[4] This section draws heavily on Lynam, 1987, for the period up to the mid-1980s.

Two powerful influences dominated the cassava sector in the post-World War II era, through the 1970s. First, the *green revolution* in rice brought a measure of food security in the region, diminishing the importance of cassava as a famine reserve crop. Secondly, rapid growth in the animal feed industry in developed countries, and a twist on Europe's import policies, brought opportunities for dried cassava exports. From the beginning, Thailand dominated the export market for animal feeds.

From the 1980s to the present, the main influences on cassava production and commerce were: (1) rapid growth in many Asian economies, with accompanying changes in food consumption patterns; (2) increased demand from industry for starch; and (3) increasing implementation of trade policies that reduced cassava's preferential treatment in European markets. Except for a few products such as *krupuk* in Indonesia, cassava generally enters markets where other calorie or industrial starch sources may readily be substituted. Future growth, therefore, is largely linked to cost competitiveness. Alternatively, there is growth potential for new products that require specific characteristics that only cassava provides.

This section concentrates on seven countries which together account for 99% of current production: Thailand, Indonesia, India, China, the Philippines, Vietnam, and Malaysia (**Figure 1**). Thailand and Indonesia alone produced 70% of the region's cassava in 2000. Sri Lanka was a significant producer in the 1970s, with over 150,000 ha, but this has declined to about 30,000 ha. Cambodia, Laos and Myanmar each produce cassava on about five to eight thousand hectares.

1. Production Trends

FAO monitors cassava area and production in thirteen countries of South and Southeast Asia (**Table 1**). Together, these represent 32% of global production. To a large degree, Thailand has defined the variations in total annual output for Asia over the past 30 years. Other countries have made relatively modest contributions to the fluctuations in aggregate production (**Figures 2** and **3**).

Production trends for Asia divide roughly into three periods:

(1) *pre-1960s*. Internal consumption and early international trade in starch absorbed most of the production. There were overall modest increases in area planted over time.

(2) *1960s and 1970s*. This era was defined by growth in the export market for dried cassava for animal feed, mainly to Europe. Other countries, especially India and Indonesia, were also responding to deficits in rice production and increased the planting of cassava as a food security crop. In post-war Vietnam, production surged in the late 70s as the country began to rebuild its economy, and then gradually decreased during the 1980s.

(3) *1980s and 1990s*. Area planted and production leveled off overall. Indonesia steadily decreased area planted, but realized steady slow growth in production due to greater use of fertilizer, to satisfy growing internal demand in the starch markets. Production in Thailand fluctuated strongly from year to year in response to pressures to reduce exports to Europe and the search for new external and internal markets. Area planted peaked in 1989 at 1.6 million hectares, with a steady decline thereafter and reaching levels of a decade earlier (1.2 million hectares) by 1996.

Supply growth in the decade 1976-1985 was almost equally divided between area expansion and yield increase. In the period 1986-1995, aggregate annual decline in area planted (0.9%) was slightly less than the annual average yield increase (1.2%), giving a

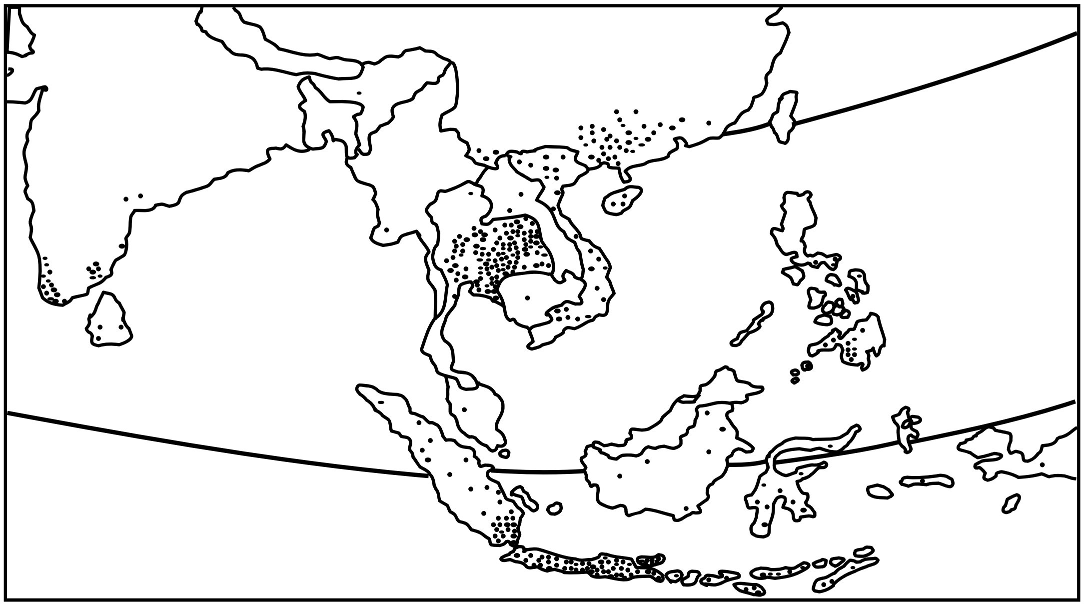

Figure 1. Cassava production zones in Asia in 1999. Each dot represents 10,000 ha of cassava.

nearly stable production over the period (**Table 2**). In some countries, especially Thailand, reduction in area is not being offset fully by yield increases, as the crop was pushed toward more marginal land. It appears that this trend may have been reversed over the past few years in Thailand, with widespread adoption of new varieties and improved production practices.

2. Production Systems

Most crops occupy the micro-environments where they are best adapted within a region. Cassava, though, rarely does. Paddy rice predominates in most lowland farming systems in tropical Asia. It is the highly preferred calorie source in the diet, and cassava does not normally compete on land suited to its cultivation. In rainfall-limited areas such as eastern Java, northeast Thailand, or non-irrigated southern India, few crops can match the stability of production of cassava. Cassava normally occupies the hillsides and drought-prone areas, and acid soil regions where other crops can be successfully grown only with high input levels.

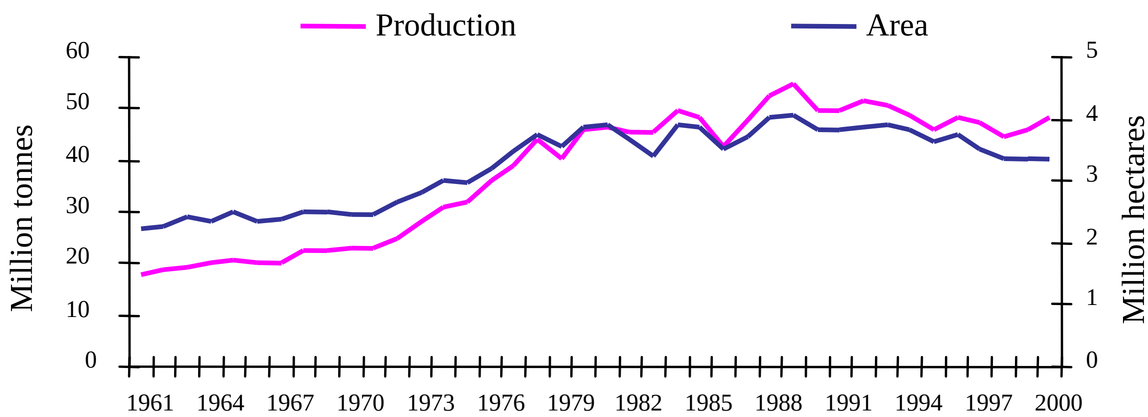

Figure 2. Aggregate area and production of cassava in Asia, 1961-2000
Source: *FAOSTAT, 2001.*

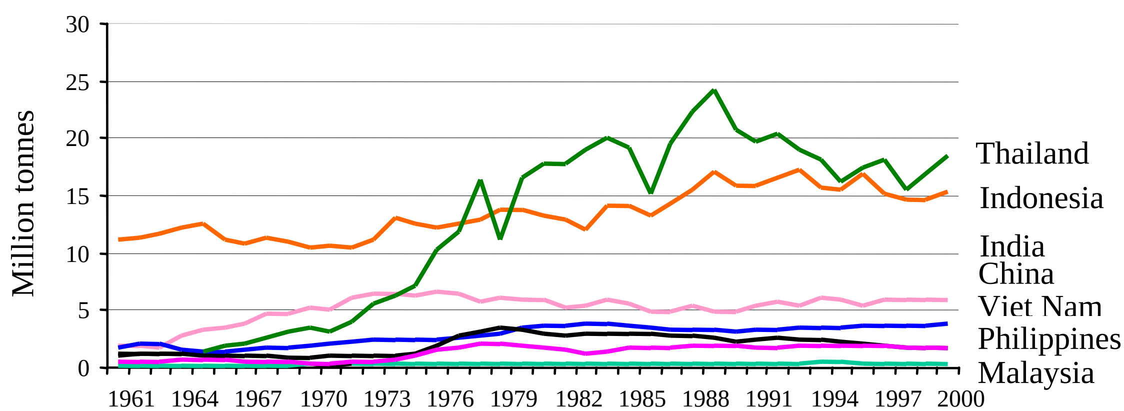

Figure 3. Cassava production trends in Asia's principal producing countries.
Source: *FAOSTAT, 2001.*

Table 1. Area, yield and production of cassava in Asia, 2000.

Country	Area (ha)	Yield (t/ha)	Production (tonnes)
ASIA	**3,351,119**	**14.4**	**48,163,007**
Brunei	135	11.9	1,600
Cambodia	7,000	9.6	67,500
China	235,045	16.0	3,750,658
India	250,000	24.0	6,000,000
Indonesia	1,205,330	12.8	15,421,885
Laos	5,200	13.7	71,000
Malaysia[a]	39,000	10.3	400,000
Maldives	9	4.7	42
Myanmar	7,736	11.4	88,144
Philippines	210,000	8.5	1,786,710
Sri Lanka	29,470	8.8	260,000
Thailand	1,135,394	16.3	18,508,568
Vietnam	226,800	8.0	1,806,900

[a]According to Dr Tan Swee Lian, MARDI, FAO data for Malaysia are highly inaccurate. National figures show that current area is on the order of 7000 ha, with average yields of about 20 t/ha.

Source: *FAOSTAT, 2001.*

Table 2. Annual growth rates (%) in cassava production, area and yield, by continent, 1976-1995.

	Production		Area		Yield	
	‘76-85	‘86-95	‘76-85	‘86-95	‘76-85	‘86-95
Africa	2.6	4.1	1.3	2.2	1.3	1.9
Asia	**3.0**	**0.3**	**1.4**	**-0.9**	**1.7**	**1.2**
Latin America	-1.2	0.0	-1.1	-0.3	-0.1	0.2

Source: *Henry and Gottret, 1996.*

Table 3 compares the area planted in broadly-defined agro-ecological zones. Compared to either Latin America or Africa, a higher proportion of cassava in Asia is planted in dry climates (sub-humid or semi-arid). By these estimates, about 67% of cassava is seasonally drought-stressed in Asia, compared to about 40% in Latin America and 46% in Africa. Area planted in the subtropics is midway between that of Latin America and Africa, at about 15%. Almost none is grown in highlands (over 1500 masl), which may be due in part to scarcity of adapted germplasm. Early introductions from the Americas probably did not include highland-adapted materials, and this never developed as a priority in Asia.

Table 3. Global cassava area (%) by continent and climatic zone.

	Latin America	**Asia**	Africa	World
Lowland humid tropics	15	**18**	34	27
Lowland sub-humid tropics	33	**41**	38	38
Lowland semi-arid tropics	8	**26**	8	13
Highland tropics	15	**0**	10	8
Sub-tropics	29	**15**	10	14
Total area (‘000 ha, 1993)	2781	**3921**	8921	15623

Source: *Henry and Gottret, 1996.*

Production practices vary widely across the region (**Table 4**). The vast majority of farms in Asia are small, usually in the range of 0.5-5 ha. In the more land-rich areas, cassava competes principally with tree crops: coconuts in the Philippines; coconuts and rubber in Kerala, India; oil palm and rubber in Malaysia and the outer islands of Indonesia; cashew in southern Vietnam and rubber in eastern Thailand.

Cassava is mainly monocropped, but intercropping is common on parts of Java where there are not severe soil and water constraints. Main intercrops here are upland rice, maize and various grain legumes. In Tamil Nadu of India, intercropping with vegetables has become relatively common. In China and Vietnam, maize, peanuts, black beans and various minor species, such as watermelon or pumpkin, may be intercropped, usually at a low density. Cassava is commonly used as an intercrop during the establishment of young tree crops like rubber and cashew, especially in China and South Vietnam.

In contrast to both Latin America and Africa, genetic diversity is extremely limited in commercial plantings in Asia, with the exception of Indonesia. In most countries only a few varieties account for most of the production. The narrow genetic base has apparently not led to any major production disasters. It did, however, limit the possibilities to extend the range of adaptation, or to make adequate improvement in some characters. By good fortune, few of the pests and diseases of the New World found their way to Asia, so a broad genetic base was less critical for supplying resistance genes, as compared with Africa or Latin America.

Table 4. Characteristics of cassava production and utilization in Asian countries.

	China	India	Indonesia	Malaysia	Philippines	Thailand	Vietnam
Cassava production('000 t) 1997	3,501	5,979	16,102	22	1,900	18.084	1,983
Cassava harvested area ('000 ha)	230	244	1,300	2.1	215	1,230	239
Cassava yield (t/ha)	15.2	24.5	12.4	10.3	8.8	14.7	8.3
Utilization -main	Starch -domestic	Human consumption	Human consumption	Starch -domestic	Human consumption	Animal feed (50%) -exp. (90)/dom. (10)	On-farm pig feed
-secondary	On-farm pig feed	Starch -domestic	Starch -dom./export		Starch -domestic	Starch (50%) -exp. (60)/dom. (40)	Starch -export/dom.
Farm size (ha/farm)	0.5-1.0	0.4-0.6	0.4-1.0	2-3	3-4	4-5	0.6-0.8
Cassava area (ha/farm)	0.2-0.4	0.3-0.4	0.3-0.5	-4	-	2-3	0.25-0.30
Crop. system (%) -monocrop	40	70	40	99	60	95	65
-intercrop	60	30	60	1	40	5	35
Time of planting	March	Apr/Sept	Oct/Nov	year round	May-Aug	Apr-May Oct-Nov	Feb-May
Land preparation	manual/oxen	manual/oxen	oxen/manual	tractor	oxen	tractor	oxen/manual
Planting position	horizontal	vertical	vertical	horizontal	horizontal	vertical	horizontal
Weed control	manual/ herbicides	manual/gorru	manual/ herbicides	herbicides/ manual	manual/ oxen	manual/mech./ herbicides	manual
Fertilization -organic	some	some	some	none	some	some	some
-chemical	low	rel. high[1)]	rel. low (N only)	high	low	Low-medium	low
Labor cost (US$/day)	1-2	2-3	1-2	4-5	2-3	3-4	1-2
Production costs (US$/ha)	300-500	500-1,000	300-500	390-520	300-700	300-400	200-700

[1)]in irrigated areas

Source: *Adapted from Howeler, 2000.*

Production practices may be fully manual, or with mechanized/animal-powered land preparation. The broadly rising incomes and labor costs in Asia are motivating increased mechanization, especially in Thailand and Malaysia, and in the plantation systems of other countries. Most other operations are manual. The largest production cost for cassava in Asia is consistently labor, especially for land preparation, weed control, and harvest. For example, Ratanawaraha *et al*. (2000) indicate that labor requirements are 96 mandays/ha in Thailand, comprising 65% of production costs. But many of the labor inputs for cassava are technically difficult to substitute with mechanization on small holdings with irregular terrain.

Production costs vary significantly across the region (Howeler, 2001b). In general, Asian countries are comparatively efficient producers, by use of some inputs, good management, and low pest and disease pressures. **Table 5** illustrates production costs for Thailand, Brazil and Colombia, and the competitive advantage that Thailand has had in world markets in part because of lower costs, both in production and processing.

Table 5. Cassava production costs, farmgate prices, and product prices in three major producing countries (average for 1990-1994, US$/tonne).

	Cassava production costs	Farmgate price of cassava		Domestic chip price	Cassava starch price
		For industrial use	For fresh consumption		
Thailand	$20.34	$28.67	-	$85.70	$233.34
Brazil	$27.80	$31.63	$128.18	-	$357.17
Colombia	$34.85	$42.20	$85.30	$177.77	$522.95

Source: *Henry and Gottret, 1996.*

3. Products and Markets

Diversity is the defining characteristic of cassava products and markets in Asia, both within and across countries. About 40% of cassava in the region is destined for human consumption (in Indonesia, the level is about two-thirds) (FAOSTAT, 1997). Most of the remainder is processed for industrial purposes, principally pellets for animal feed, and starch. Fresh roots are not traded on any significant scale. The initial processing defines to some degree the market sector to which roots can be destined. This is unlike the grains such as maize which are traded as whole, unprocessed grain, to be converted into any number of products in the importing country.

a. Fresh for human consumption

Outside of Kerala, India and some poorer districts of China and Vietnam, nearly all cassava for food is first processed; direct consumption of baked or boiled fresh roots is minor. This form of consumption is largely a rural practice, and often by households having cassava in their own backyard garden. Fresh consumption has limited growth potential, and in fact will probably decline with increasing urbanization and changes in dietary preferences.

b. Chips and pellets for animal feed

The commercial cassava pellet industry has its origin in Thailand, which has a long history of an agricultural economy driven by exports. With a surplus land base, rice exports became the foundation of Thai trade up to World War II. Development of the upland sector in the North and Northeast brought diversification to agriculture, adding maize, cassava, pineapple and sugarcane.

Exports of dried cassava products climbed steadily up to 1990, but declined afterwards as Europe began to withdraw its favorable import conditions. Thailand has aggressively sought alternative markets, with some success, but not nearly at levels absorbed by Europe in the 1980s (**Figure 4**, **Table 6**). While the potential for development of internal markets remains promising, the generally low commodity prices of the past several years have made this difficult.

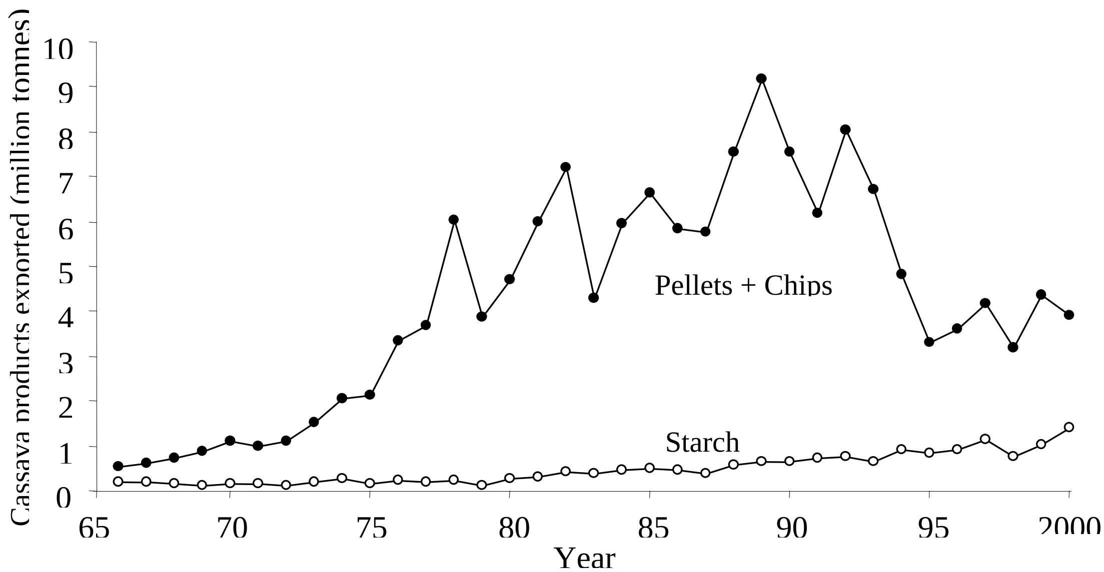

Figure 4. Quantities of cassava products exported from Thailand from 1966 to 2000.
Source: *Adapted from TTTA, 2000.*

Table 6. World trade of cassava products (chips, pellets and starch: million tonnes).

	1994-1995 avg.	1996-1997 avg.	1998-1999 avg.
World exports	**6.30**	**6.39**	**5.47**
Thailand	5.00	5.16	4.62
Indonesia	0.60	0.43	0.23
China & Taiwan	0.40	0.39	0.20
Others	0.25	0.42	0.43
World imports	**6.30**	**6.39**	**5.47**
European Union	4.20	3.72	3.58
China & Taiwan	0.65	0.61	0.62
Japan	0.35	0.38	0.32
Korea, Rep.	0.35	0.46	0.35
Others	0.70	1.23	0.61

Source: *FAO Commodity Market Review 1999-00.*

c. Starch for food and industry

Starch for industry is classified as *native* or *modified*. The technology for modifying starches with physical, chemical and biological processes is highly advanced and evolving rapidly. These modified starches are absorbing an increasing market share. At the same time, there is pressure in some industries, especially foods, to move away from modification based on chemicals.

Starch-derived products include sweeteners (high fructose syrup, glucose syrup), dextrins, monosodium glutamate, pharmaceuticals and various chemicals. Starch is used in large quantities in the manufacture of paper, plywood, textiles, and as a filler/stabilizer in processed foods. New products from starch are continually entering the marketplace. Bio-degradable plastics appear to be especially promising. Throughout the region, the industry is moving toward larger, more technologically advanced plants, and small, less efficient factories are closing.

Thailand is leading the Asian *starch boom*, surpassing Indonesia in recent years (**Figure 5**). Both export sales and domestic use have increased significantly. Although the starch export industry of Thailand has been active since the 1940s, it was rejuvenated in the 1980s when Europe began to set limits on imports of cassava chips and pellets (**Figure 4**). This was also a time of rapid economic growth in Thailand, and the starch industry attracted the attention of entrepreneurs. The focus for exports has been on modified starches, to get around some of the import barriers imposed against native starch. Nonetheless, the increase in starch exports has not nearly kept pace with the decline in pellet exports. Private and public sectors are cooperating to identify and exploit internal growth markets for starch as a complementary strategy to export-orientation.

Internal markets absorb most of Indonesia's starch. Nearly two-thirds goes into *krupuk*. Because of the specific starch characteristic required for this product, maize starch is not a competitor. This gives some insulation from the fluctuations of world starch prices. Both China and Vietnam have significantly expanded and modernized their starch industries. Monosodium glutamate and glucose (starch derivatives) are rapidly growing markets in both countries. In Thailand, Indonesia and Vietnam, cassava is virtually the only raw material for starch production. Any growth in starch demand should benefit the cassava sector. In China, India and the Philippines, there are other starch sources (especially sweetpotato and maize in China), but these are often used in industries such as noodle-making where cassava starch does not compete. Hence, even in these countries the market potential for cassava starch is strong.

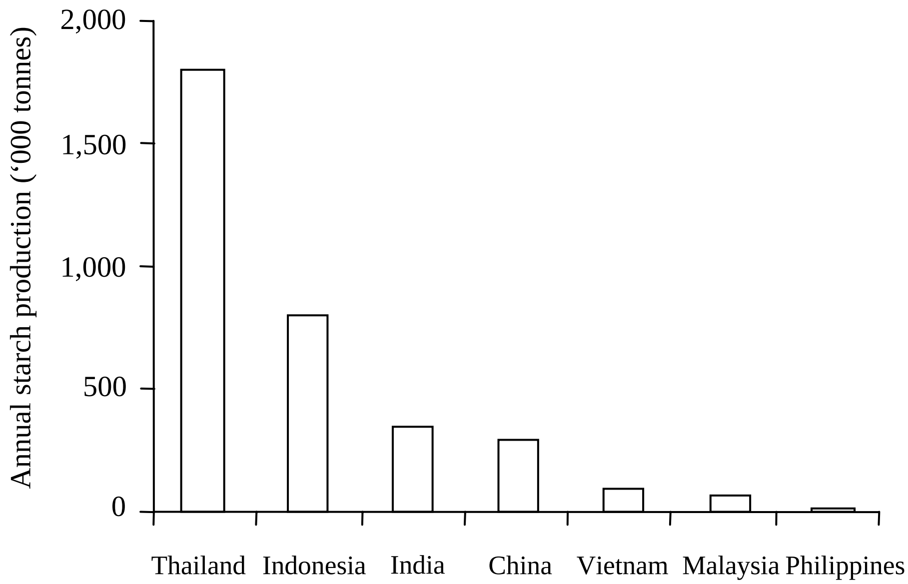

Figure 5. Cassava starch production in various countries in Asia (in 1992).
Source: *Ostertag, 1996.*

d. Flour

Cassava flours come in many forms. The most common is *gaplek* in Indonesia. Roots are peeled, chipped or sliced, and dried. The dried chunks are ground or milled to a meal, which is then used in a wide array of food preparations. It is consumed especially in times of rice scarcity, and partially substitutes for rice in rural daily diets. Cassava flour may also partially substitute for wheat flour in bakery and other products. This is still minor in Asia, but is reported unofficially from several countries (Henry and Gottret, 1996).

4. Projections

Thailand's continuing efforts to reduce its dependency on the European animal feed market will dominate directions of the Asian cassava sector for the next decade. This will take several forms: introducing production technology to keep prices competitive with alternative energy sources; aggressively seeking new markets outside Europe; development of internal feed markets; and further diversification into starch and flour, with strong support for research on new processes and products. Other countries of the region, once with aspirations to penetrate export markets for pellets, are now recognizing that opportunities will depend very much on increasing production and processing efficiencies (**Table 7**).

Prospects for starch vary widely depending on the specific market. There are two extremes: purely commodity starches with generic application, and highly specialized starches reliant on functionality. The latter are often derived from modified starches. However, in the middle, there are starches that are comparatively specialized, though sharing functionality with other starches. In this group, functionality is the initial criteria of suitability, followed by price and supply. For generic starch, the different sources (maize, cassava, sweetpotato, white potato) compete with one another on the basis of price. The markets for specialized starch are rather uncertain. On the one hand there is increasing demand, but on the other, there is a continually evolving technology for modifying starches to meet specific product properties. While technology for modification is moving rapidly, at the same time there is a strong trend away from modified starches in some products and in some key markets like the US and EU. For example, baby foods use virtually no modified starches, and the amounts used in soups is much reduced compared to just five years ago. Ostertag (1996) suggests that most developing countries will use their resources most effectively to first concentrate on developing internal starch markets, to reduce the risks inherent in the export sector.

In a recent study of the major tropical root crops, Scott *et al*. (2000a) project cassava production and utilization in the year 2020, based on a model that takes into account virtually all the world's food production and consumption (International Model for Policy Analysis of Commodities and Trade (IMPACT)). Moderate demand growth for cassava products in Asia through 2020 will sustain viable cassava-based development. The growth sectors vary within the region. In China, growth in feed demand will be among the strongest anywhere, at 2.1% per year, accompanied by a continuing trend for lower direct use as food. Southeast Asia should see healthy growth in all sectors: 1.4% in food, 0.13% for feed, and a total of 1.25% (including industrial use) (**Table 8**). The import demand in the non-cassava producing countries of East Asia will rise at 1.0% per year, providing some additional market possibilities.

B. THE EXTERNAL ENVIRONMENT: INFLUENCES ON THE FUTURE OF THE CASSAVA SECTOR

Agricultural research has a key role in development. But for maximum impact it must be attuned to the broader social and economic environments of the target area. Progress towards improvement of production, processing and market development systems that will broadly benefit society is intimately related to broader trends and influences.

Table 7. Present constraints in cassava production, processing and marketing, and potential future cassava products.

Country	Constraints	Future potential
China	Crop competition Small farms Soil erosion Low soil fertility	Starch MSG Modified starch Animal feed
India	Crop competition Mosaic disease Small farms Markets	Starch Modified starch Converted starch Sweeteners Snack foods
Indonesia	Small farms Price fluctuations Soil erosion Low soil fertility	Starch Modified starch Animal feed Flour MSG
Malaysia	Crop competition High labor cost	Starch Modified starch Animal feed Snack foods
Philippines	Financial resources Markets Low soil fertility	Starch Animal feed Alcohol
Thailand	Price fluctuations Labor shortages Low soil fertility Soil erosion	Modified starch Domestic animal feed MSG Lysine
Vietnam: North	Small farms Financial resources Low soil fertility	Animal feed
Vietnam: South	Small farms Financial resources Low soil fertility Crop competition	Starch MSG Animal feed

Source*: Compiled by R. Howeler from interviews, personal observations and national program data.*

Table 8. Projected production and utilization of cassava in 2020.

	Growth rate for utilization 1993-2020 (percent per year)			Utilization in 2020 (million tonnes)	Production in 2020 (million tonnes)
	Food	Feed	Total		
China	-1.27	2.08	1.19	3.9	4.2
India	1.00	0.00	1.00	7.6	7.8
Other East Asia	-0.95	1.09	0.63	3.5	0.0
Other South Asia	1.00	0.00	0.83	0.6	0.6
Southeast Asia	1.4	0.13	1.25	27.0	51.1
Latin America	0.26	1.26	0.78	39.3	40.5
Sub-Saharan Africa	2.51	0.29	2.47	166.0	166.0
Developing	2.01	1.18	1.88	248.8	271.1
Developed	0.03	0.01	0.02	22.7	0.4
World	2.01	0.59	1.68	271.6	271.6

Source: *Adapted from Rosegrant and Gerpacio, 1997; and Scott et al., 2000.*

1. Trade and Economic Policy

The policy arena, possibly more than any other influence, sets the stage for cassava's role in a given country. Agricultural policy, as well as broader economic and trade policies, impact the cassava sector in several ways. Liberalized trade became the economic mantra of the 1990s. The watershed Uruguay round of multilateral trade negotiations, under the General Agreement on Tariffs and Trade (GATT), was a fundamental influence on the direction of the global economy. While more recent attempts at broad trade agreements under the World Trade Organization, successor to GATT, have been less successful, there is little likelihood of reversing the broad trend toward freer trade. Trade liberalization will bring complex and sometimes unpredictable adjustments to agriculture. The implementation of regional trade agreements is well-advanced in Asia. The Asia Pacific Economic Co-operation forum (APEC) has 18 members, which in total comprise half the world economy. Most of the major cassava-producing countries of the region (excepting India) are members. APEC aims to achieve free and open trade and investment by 2010 for its industrialized members and by 2020 for the others. The Economist© magazine called APEC "*potentially the most far-reaching economic agreement in history*" (27 Sept. 1997).

Previously-protected sectors of the economy are in flux as they are subjected to the open market. Countries that expect to export their products are under strong pressure to open their markets to imports as well. Agriculture has been one of the sectors most broadly affected by this trend, since it is of nearly universal relevance to countries' economies, and touches fundamentally on the lives of nearly all people. On the whole, liberalized trade agreements should drive broad-based growth through specialization, efficiency gains, and increased trade in agricultural products. In a free trade environment, commodity prices typically fluctuate more (based on supply and demand) than in a regulated environment.

Producers are more likely to switch in and out of crops to take best advantage of these fluctuations. The dilemma that cassava-producers often face, however, is the fact that they have little flexibility in choice of crops. First, on the more marginal soils, cassava may be the only choice without resorting to costly inputs. Secondly, the nature of cassava's propagation does not allow quickly gearing up for production if a supply of planting material has not been assured by the previous year's crop. Stabilizing demand in an environment of freer trade will depend on the ability of the industry to respond quickly to shifts in product demand.

Projections on the evolution of trade of agricultural products generally assume a continuation of the trend, first for regional trade agreements, followed by more broadly open global trading systems. There is, however, bound to be a certain cyclic nature to this long-term movement toward freer trade. When free trade has a negative impact on local economic sectors affecting people with political power, there will be temporary retreats to some type of trade restrictions. This will create regional shifts in market opportunities for various products. The more broadly a particular commodity or product is integrated into the global economy, the more of a buffer it will have against imposition of restrictions in a given country or trading block. Diversity and flexibility of processes and products will be another important way of weathering the cyclic effects of policy shifts.

A second trend important to trade is the tendency to add value at the site of origin, and to trade in processed products. By 2020, there will be far less trade of the traditional raw agricultural products (e.g., grains); most will be products with value added either by processing or through genetically engineered specialty traits incorporated for specific end-uses. Often, trade policies affecting processed products are different from those imposed on raw products.

2. Demographics, Income and Food Demand

Population increase remains a major driving force that will shape development progress, at least for a few more decades to come. Poorer countries absorb most of the impact. While on a global level it seems that food production can keep pace with population increase, poverty and hunger persist in many countries, especially in the tropical belt. The consequences of these dual scourges of poverty and hunger then reverberate throughout all areas of human and environmental well-being.

The United Nations projects that global population will continue to rise to about the year 2040, when it will have doubled from today's level, to 8-11 billion. Growth rate should decline from about 1.4% to 1.0% by 2020. This mean rate hides the highly disproportionate differences between developed and developing countries – a 3.4% population increase in the former, compared to 35.8% in the latter, in the period from 1998 to 2020. By far the greatest burden of this continued population growth will be felt in urban areas. Latin America is already at a level of almost three-quarters of its population living in cities. Like much of the rest of the world, Asia has been moving toward greater urbanization for at least several decades (**Figure 6**). Both Africa and Asia appear set to continue a nearly linear trend toward greater urbanization, with about equal numbers of rural and urban residents in both regions by 2020 (FAOSTAT). This is largely the dynamic that drives commercial agriculture -- urban dwellers need to purchase nearly all their food.

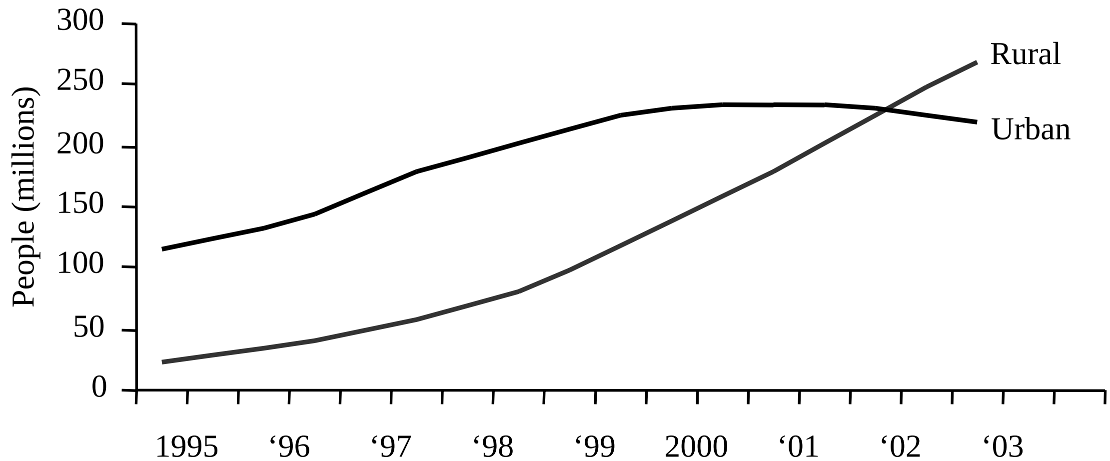

Figure 6. Historical and projected population growth in Asia.
Source: *FAOSTAT, 2001.*

Population dynamics affect cassava production and marketing in various ways. In the simplest of cases, population increase imposes a proportional increase on food demand. With most of the productive land already cultivated, this places pressure on marginal environments where cassava has strong adaptive advantages. On the other side, urbanization typically reduces demand for cassava and its products for direct food use. Huang and Bouis (1996) note several reasons for shifts in food demand that follow urbanization:

- A wider choice of foods is available in urban markets
- People are exposed to new dietary patterns from different regional traditions
- Urban lifestyles place a premium on foods that require less time to prepare
- Transaction costs are lower
- Urban occupations generally require fewer calories than more physically demanding rural ones

Except in Indonesia and southern India, cassava has never been broadly popular as a dietary staple in Asia. In several countries there remains a considerable stigma against cassava as a food -- a reflection of past difficult economic times. Rising incomes will further erode cassava's direct role in Asian diets. The overwhelming preference for rice as the starchy staple, and the increasing demand for meat (**Figure 7**), will keep per capita consumption levels low throughout Asia. The growth in meat consumption, however, is the basis for projecting strong potential to use cassava for on-farm feeding, or in balanced rations, especially for pigs and chickens.

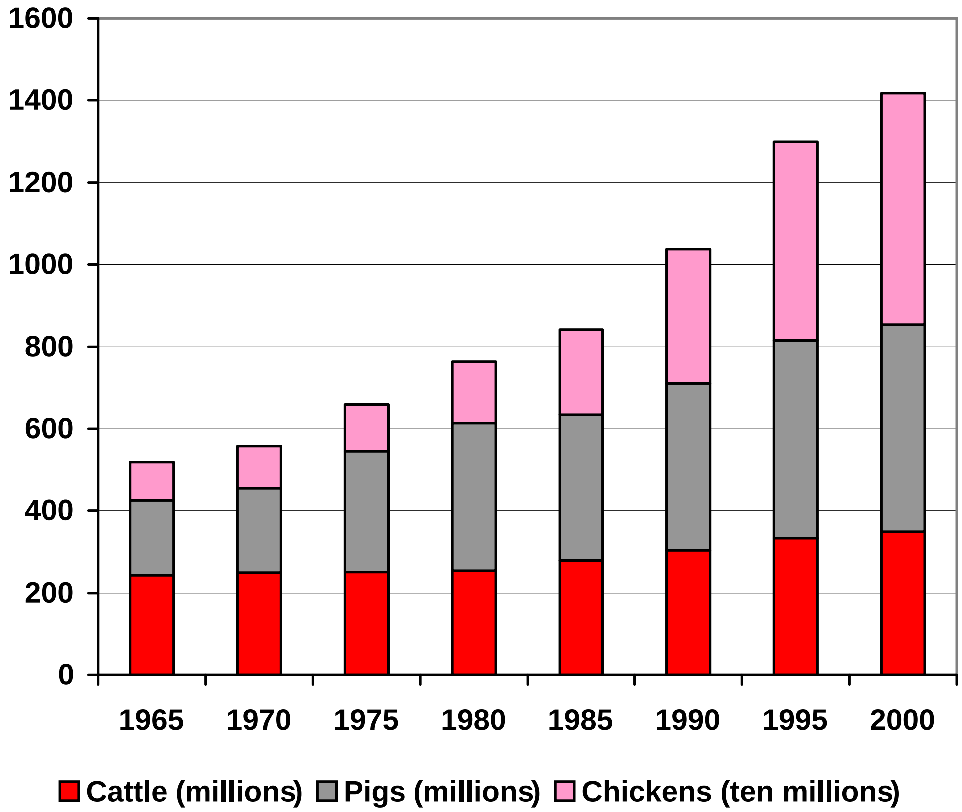

Figure 7. Animal stocks in seven major cassava producing countries of Asia.

While not all countries have benefited equally, Asian economies on the whole have seen healthy growth in the past two decades (**Table 9**). Industrial development, the service sector, and labor demand, have all had an impact that affects all sectors of society. Rising household incomes open the way for purchase of consumer goods, education and health care. Improved tax bases contribute to public infrastructure in the form of roads, schools and public services. In this scenario, cassava tends to move toward industrial uses, such as animal feed and starch-based products.

3. Trends in Competing Commodities

Cassava's competitive position in national and international markets is closely linked to internal and world supplies and market prices of alternative commodities or products. Because of cassava's versatility, it may compete with a range of products in different markets. In the market for balanced feed rations, cassava in dried chip or pellet form competes mainly with sorghum or maize, and sometimes barley. On a global level, maize is the principal source of starch.

Table 9. Growth in gross domestic product and rural population in principal cassava -producing Asian countries.

	Gross domestic product growth (%)		Share of agriculture in GDP (%) in 1999	Rural population (%) in 1999
	1980-1990 avg.	1990-1999		
China	10.1	10.7	18	68
India	5.8	6.0	28	72
Indonesia	6.1	4.7	19	60
Malaysia	5.3	9.9	11	43
Philippines	1.0	3.2	18	42
Thailand	7.6	4.7	10	79
Vietnam	4.6	8.1	25	80

Source: World Bank, 2001 (http://www.worldbank.org/data/).

In the cassava-producing countries of Asia, rice, maize and cassava production all increased three to five-fold in the past twenty-five years (**Figure 8**). Even this dramatic success, however, was not adequate for supplying growing and somewhat more affluent populations. Grain imports, dominated by wheat, maize, rice and soybeans, rose from just over ten million tons in 1960 to 47 million tonnes in 1995, with some decline again in the latter part of the decade during the Asian economic slowdown (**Figure 9**).

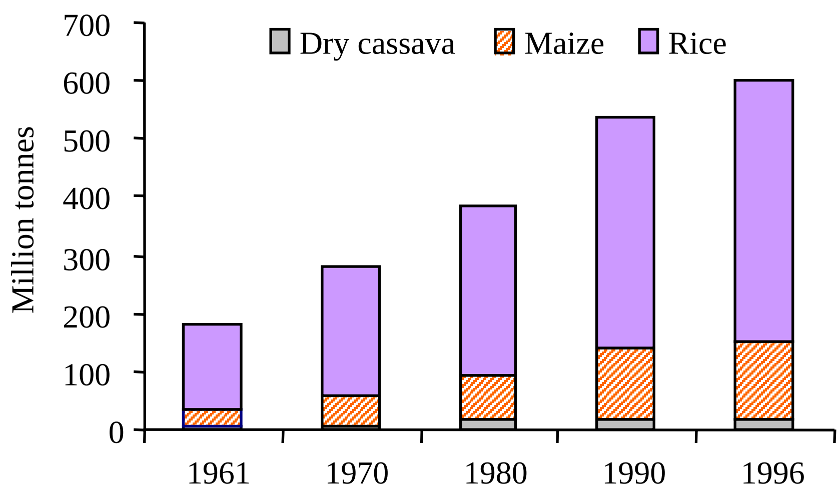

Figure 8. Crop production trends in seven major cassava-producing countries of Asia.
Source: *FAOSTAT.*

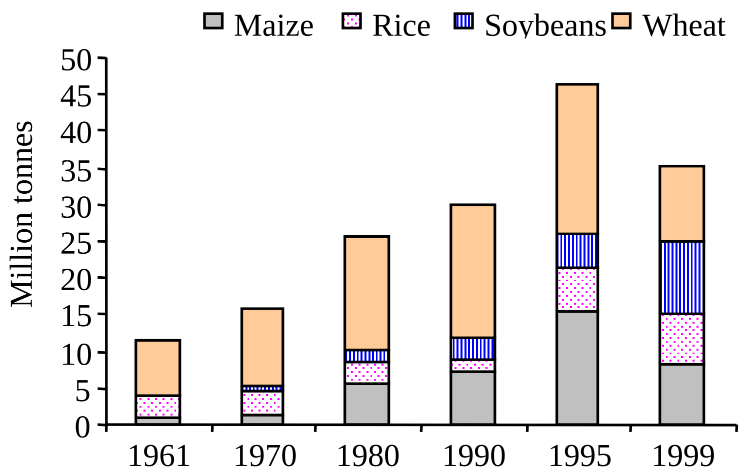

Figure 9. Grain imports to seven major cassava-producing countries.
***Source:** FAOSTAT.*

However, on a global basis, grain supplies have increased steadily and prices have been declining in inflation-corrected terms. Decline during the last five years has been particularly steep. Prices in 1999 were virtually identical to those in 1985 (uncorrected for inflation) (**Figure 10**). Projections by IFPRI and FAO indicate that if governments pursue appropriate economic policy and invest in agricultural research, cereal prices will continue their downward trend (Pinstrup-Anderson and Garrett, 1996). The cassava market will, for the most part, parallel these declining commodity prices. Rosegrant and Gerpacio (1997) project a price decline for cassava on world markets of 3.4% by the year 2020. While this is a lesser decline than projected for other roots and tubers, it represents a substantial challenge to growers.

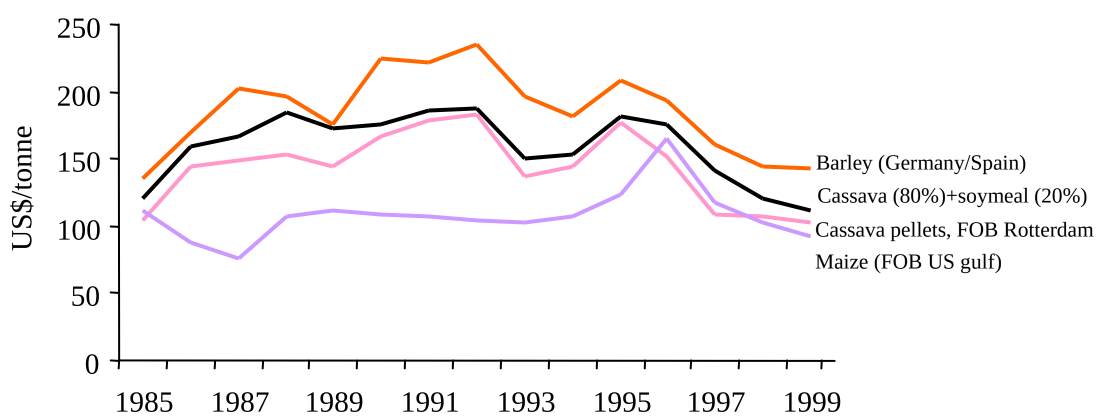

Figure 10.World prices of cassava and competing grains (unadjusted for inflation).
***Source:** FAOSTAT.*

4. The Environment

While a certain level of environmental consciousness has swept much of the world over the past twenty-five years, the actual progress toward ameliorating serious threats remains mixed. The industrialization of previously agrarian societies presents clear environmental threats, but seems to be far less serious than the heavy use of non-renewable energy by developed countries. Population increases in fragile environments often offsets progress in other areas.

The fact of global warming is broadly accepted, but the likely effects, and appropriate remedial measures, are highly controversial. Within the next decade there will be greater consensus as the sensitivity and reliability of monitoring devices improve, and more widely accepted models are developed.

5. Evolution of Farming Systems

Food for mass markets will increasingly be produced by managing larger units of production to take advantage of economies of scale. It is a normal outgrowth of competition within commercial agriculture. In Latin America, this will generally mean larger individual farms or land-holdings. In most of Africa and Asia, there will be greater need for associations among small-holders, and coordinated production by contract to vertically integrated production, processing and marketing firms.

The trend toward less biologically complex (e.g., monocropping) systems will spread throughout the tropics as crop risk is managed by inputs rather than diversity. However, irrigation will increase only modestly because of cost and supply constraints.

6. Science and Agricultural Research

Scientific advances underpin development. Four elemental shifts underway will define the agricultural landscape in the next few decades in developing countries: (1) the privatization of knowledge and technology; (2) the biotechnology and information revolutions; (3) the increasing policy focus on low-cost food supplies for urban centers as compared to income-generation and food security concerns for producers; and (4) increasing sector specialization in world markets; the trend toward specialized value-added traits for most commodities.

These shifts have fundamental implications for the gap between science in developing and developed countries. Without sweeping agreements on equitable interchange of information, genetic resources and technology between North and South, there will be a continual further eroding of competitiveness in developing countries. The recognition that, in the long term, this gap is detrimental to everyone, should drive new interest in mechanisms to improve investment in research in developing countries. During the next decade the large multi-national agricultural research firms will begin to see the developing countries as a major growth market for biotechnology-derived, IPR-protected technology. However, a turn-around in narrowing the science and technology gap that exists between developed and developing country capacity in science is not yet on the horizon.

7. Economic and Political Empowerment

The next decades will bring a widening gap between income levels within developing countries. This gap is already historically wide in Latin America, and continues in spite of a rising middle class. The inequities will be widely and intimately perceived through the pervasive reach of communications technology to even the poorest people. The natural reaction to this widening gap will be some form of search for justice. In the future, governments will be under relentless pressure to address these inequities, which will then be recognized as a global threat to social stability.

People will continue to strive for greater freedom of economic and political choices, and make those choices more wisely. This will be driven in part by education and the communications revolution, but also by the recognized failure of many systems that restrict these freedoms.

Empowerment is importantly a gender issue. It is expected that the next generation will be more conscious of the value and the right of gender equity.

8. Infrastructure

Subsistence farming requires virtually no infrastructure -- no need for purchased inputs, and no need for highways for reaching markets. Commercial agriculture, on the other hand, depends heavily on infrastructure. Rapid economic expansion and urbanization have outstripped the capacity of existing infrastructure, and created serious impediments to further investments and growth. Insufficient electricity generation capacity, outdated and inadequate telecommunications facilities, poor roads and inefficient ports are the most crucial infrastructure problems.

Purchased inputs for agriculture are for the most part available, but may not be used on cassava because of other constraints. There is little likelihood of major investment in infrastructure aimed solely at supporting cassava development, but the general development of the region will bring collateral benefits to growers, processors and consumers.

9. Institutional Resources

Cassava research in Asia is generally supported by departments of agriculture and/or universities, along with CIAT through its office in Bangkok. India and Thailand have major root crop centers with full interdisciplinary research teams. As in much of the world, government attempts to control spending growth have cut into agricultural research budgets in many Asian countries. The private sector has filled this gap in a few cases, but for the most part there remain serious deficiencies in support to the cassava sector.

Table 10 compares national research and development capacity across different disciplinary areas and sectors. Overall, the highest research capacity is in varietal development. Thailand has a clear predominance in broad-based R&D strength, with 22 researchers working on cassava (Ratanawaraha *et al*., 2000)

There are three cassava-specific networks active or semi-active in Asia. These networks have a considerable potential to facilitate and coordinate research, in order to make efficient use of scarce resources. Funding is a continual challenge, and none of the existing networks has been able to reach the potential that its members represent.

Cassava breeders in Asia formed an informal network in 1984 during a regional meeting. The group later incorporated agronomy, and became the *Cassava Breeding and Agronomy Network*, and later, simply, the *Asian Cassava Research Network*. It has held triennial scientific meetings and published widely-read proceedings. The network serves to inform members of research activities, provides guidelines and resources for germplasm exchange and testing, and coordinates specific regional projects with high regional priority. A coordinated series of soil fertility maintenance and erosion control trials were an important project of this network.

Table 10. Relative strengths of national cassava research and development systems in Asia.

	Varietal development	Pest/crop interactions	Crop/soil interactions	Processing/ marketing	Basic extension services
Thailand	✶✶✶✶	✶	✶✶✶	✶✶✶	✶✶✶
Indonesia	✶✶	✶	✶✶	✶	✶✶
India	✶✶✶✶	✶✶✶	✶✶✶	✶✶	✶✶
China	✶✶	✶	✶✶	✶✶	✶✶
Vietnam	✶✶	✶	✶✶	✶	✶✶
Philippines	✶✶	✶	✶✶	✶✶	✶
Malaysia	✶✶	✶	✶		

The *Cassava Biotechnology Network* (CBN) has acted as a stimulus to interest a number of research institutes and private companies in advanced cassava research since the late 1980s. The network has seen considerable fluctuation in support and coordination, but appears newly energized in the early 21st century. Projects include work in propagation, transformation and regeneration, cyanogenesis and starch modification. The network is evolving toward a regional structure, in order to bring a better focus to addressing specific regional problems and opportunities.

The *Manihot Genetic Resources Network* (MGRN) is the newest of the networks, formed in 1992. It does not have specifically funded coordination or activities, and operates on an informal basis. Its principal activity in Asia has been to plan the transfer of the CIAT cassava core collection to Thailand to improve security of conservation, and to broaden the genetic base of Asian cassava. This transfer is presently underway.

C. OPPORTUNITIES AND CONSTRAINTS FOR SYSTEM IMPROVEMENT

1. The Resource Base and Production Technology

There are several fundamental issues surrounding development strategies that exploit marginal lands, both from the economic and environmental vantage points. Although less-favored areas make up only about 24% of the total land area in developing countries, they contain more than 36% of all the rural poor. The largest share of these people, 263 million, live in Asia. In the past, governments and donors adopted a strategy of investment in high-potential areas, since by definition, these generate more agricultural output and higher economic growth at lower cost. Even with these strategies, however, population growth and pressure on the environment have continued to worsen in less favored areas. A consensus is now evolving that critical investment in these areas is socially necessary, economically viable, and imperative for reversing serious land degradation.

Cassava can be a key component within this strategy. The comparative advantage that the crop has here is quite strong, but there are trends that could change this. First, other crops may begin to offer broader alternatives to cassava farmers. Breeders of several species, especially maize and sorghum, have paid more attention to stress tolerance in the past twenty years. There are certainly practical limits to which breeders can take a given species in adapting it to new environments, but there is also apparently considerable margin for improvement for most crops in stressed environments. This progress could displace cassava from some areas, and perhaps continue to push the crop toward the very poorest soils. The need for effective and economical soil fertility maintenance and erosion control will increase with this trend.

Secondly, farmers' increased purchasing power, and technology for soil stabilization, will allow improvement in some areas, from marginal to moderately productive conditions. This would also tend to displace cassava with higher value, more demanding crops. In either scenario, cassava will probably be pushed further toward the very poorest soils, exacerbating the risk of environmental degradation. Clearly, if there are crops that provide better income to growers than cassava, and/or are less of a threat to the environment, these should be encouraged.

Most national cassava programs have given research priority to resolving production constraints, especially through varietal improvement, and crop and soil management. This approach evolved from the era of explosive growth in cassava markets, and the need to meet market demand with increased production. As the challenges of marketing cassava products become more acute, and environmental concerns more apparent, programs are shifting the balance of research investment to include both demand and supply factors.

In an exercise to quantify constraints on global production, processing and marketing, CIAT surveyed a broad range of scientists and others knowledgeable about the cassava system, for their experience and perspectives (Henry and Gottret, 1996). A follow-up study (Van Norel, 1997) obtained further information from national programs, intending especially to upgrade information on post-harvest constraints. **Table 11** summarizes key information for Asia, with comparison to global estimates. In spite of the rather hypothetical nature of some of these estimates, the relative values across categories of constraints, and across continents, give a tangible basis for prioritizing research. The following sections review the constraints that could be targeted to achieve the greatest economic impact.

a. Yield potential

Intrinsic yield potential of varieties may be the single most important factor limiting yields in Asia (**Table 11**). The definition of yield potential for cassava needs to be considered within the context of the crop's predominant role in Asia as an upland crop, in poor soils and with irregular rainfall. The CIAT survey specified a moderate level of management inputs, within the reach of most farmers of the region. This would be a *moving target*, presumably increasing as agriculture develops.

Table 11. Cassava constraints analysis for Asia, with comparison to global.

Constraints	Yield gain from alleviating constraint (%)	Yield gain from alleviating constraint ('000 tonnes)	Asia's contribution to global yield gain (%)[a]
Production			
Soil management	35	17,067	36
Crop management	21	10,291	22
Intrinsic yield potential	24	11,384	31
Climate	11	5,153	25
Diseases	2	929	3
Pests	3	1,478	7
Total	**96**	**46,301**	**2396**
Post-harvest			
Quality	13	6,390	31
Processing	4	1,806	30
Product marketing	4	1,727	47
Total	**21**	**9923**	**32**
Total Cassava Sector	**116**	**56,224**	**24**

[a]Yield gain in Asia as percent of expected global yield gain from alleviating a given constraint.

Source: *Adapted from Henry and Gottret, 1996.*

For the medium-term future (10-15 years), this would rarely include irrigation, with the exception of existing irrigated areas. The definition specifies nutrient use at low to moderate levels, but with most other agronomic practices at optimum levels -- land preparation, planting systems (time of planting, stake position, spacing), and weed control. Within these parameters, the analysis suggested a possible 26% yield gain across 89% of the Asian cassava-growing area, or a 24% potential increase over all Asia.

A number of pathways are possible for increasing that potential. These can be broadly divided into approaches that, (1) increase harvest index (direct a greater proportion of photosynthate to the roots as compared to top growth); and/or (2) increase total biological yield. Much of the research in recent years has aimed at improving distribution of photosynthates, but both approaches have been successful. Probably the greater difficulty and greater potential lie in improving total biological yield, since many individual mechanisms may be involved -- increased efficiencies in photosynthesis, nutrient uptake or utilization, and starch synthesis, for example. Breeders are already combining higher biological yield and higher harvest index as an effective multi-pronged strategy to improve yield potential (Kawano *et al., 1990).*

Biologically, cassava is relatively straightforward as a target for genetic improvement. Two particular constraints confront the breeder: a low reproductive rate, either by vegetative or sexual means; and a long breeding cycle. On the other hand, vegetative propagation allows additional options in design of breeding schemes.

Until 15-20 years ago, the germplasm base in Asia was very narrow, with most countries relying on only a handful of varieties. This was undoubtedly one of the principal constraints to improving yield potential. Thailand was the extreme case, where all but a small percentage of area was planted to Rayong 1. Indonesia has reasonably broad diversity, but still narrow in comparison to Latin America. With the establishment of the CIAT Regional Office in Bangkok in 1983, one of the main thrusts has been to increase genetic diversity in the region. Typically, breeders introduce ten to thirty thousand seeds, each genetically distinct, every year from nurseries in Colombia. Even though only a small fraction of this diversity ever reaches farmers' fields, there is little doubt that far more genetic diversity was introduced into Asia in the past twenty-five years than in the previous two hundred.

b. Soil management

Significant constraints from low soil fertility and erosion affect much of Asia's cassava. Nitrogen is frequently the limiting nutrient, in contrast to Latin America, where potassium and phosphorus tend to be more limiting (Howeler, 1995; 2001). Fertilizer recommendations have been established on the basis of extensive soil analyses and fertilizer trials. Fertility constraints are as much a function of education and credit availability as the lack of scientific information. In India, China, Vietnam and Thailand, about half the farmers use small amounts of fertilizer, usually not at economically optimum levels. In Indonesia, associated crops tend to be fertilized, with some residual benefit to cassava. Elsewhere, fertilizer use is very limited except for special situations, such as large commercial plantations. It is estimated that economically optimum use of practices to improve soil fertility could add 22% to current yields across the region, or over ten million tonnes.

Limiting soil erosion is a challenge in virtually any system involving annual crops on sloping fields. Cassava has two features that increase this challenge somewhat: it is easy to plant on steep slopes, with minimal land preparation; and it has a relatively slow rate of canopy formation. On the positive side, the long growing season means that the soil is covered by vegetation and is undisturbed over a long period of time once the canopy is established (Howeler *et al*., 2000). The survey estimated potential yield increases of 0-10% by adoption of erosion control practices. More importantly, erosion control is indispensable for sustaining longer term productivity. Soil fertility maintenance and erosion control are closely inter-related. An obvious relationship is the loss of nutrients that accompanies erosion. A more subtle association follows from the effect of better fertility on more rapid canopy development. In trials throughout Asia, as well as Latin America, appropriate fertilization is consistently one of the most cost-effective ways to reduce erosion. It may not be enough on its own to reduce erosion to acceptable levels, but it is often a good starting point (Howeler *et al.,* 2001).

c. Crop management

On a regional basis, Asia has higher average yields than either Latin America or Africa. Farmers tend to manage their crops intensively, because of high population density and the need to optimize productivity of land. Hence, only modest yield increases can be expected from improving crop management (excluding *soil management*) in the Asian situation. According to the CIAT survey, quality planting material (*stakes*) and better weed control could contribute 7-8% each to yield, while optimum land preparation and spacing would provide modest yield improvements of only 3-4% each.

Farmers are often unaware of the multitude of influences on stake quality. Many constraints do not conspicuously affect stake appearance, and are not recognized as yield-reducing constraints. Given the generally low incidence of pest and disease problems in Asia, it is likely that sub-optimum quality of planting material derives primarily from a complex of physical rather than biological constraints. These may include: nutrient status, as an outcome of soil conditions or length of storage; poor stake selection (too young, too old, etc.); poor storage conditions; or poor post-storage management.

Weed control consumes the second highest level of labor input among crop management operations in Asia, from a low of 13 mandays/year in Malaysia and the Philippines, to a high of 97 in Tamil Nadu, India. In general weed control is good; survey results indicate inadequate control in about 37% of area planted, for an overall potential yield increase of about 7%. Most weed control is manual, but herbicide use is increasing in all countries, and is most wide-spread in Thailand. As demand for herbicides grows, agro-industries will find it profitable to develop herbicides targeted more specifically to the cassava plant and cropping systems. Currently herbicides are adapted from other crop systems to cassava, and often have not been adequately researched to optimize their use.

A herbicide-resistant cassava could prove highly beneficial to growers. Herbicide resistance, especially to glyphosate, is already incorporated into several crops and is widely used in the United States and Argentina, especially in soybeans and maize. The last few years have seen some increase in consumer concern about food safety and environmental impact for these genetically engineered crops. So it is somewhat uncertain how quickly the technology will spread to other crops, even where there is high potential grower demand.

d. Climate constraints

Drought imposes severe constraints on cassava growth and yield in parts of Asia, particularly northeast Thailand, eastern Java, and southern India (especially Tamil Nadu). Survey results indicate a potential yield increase of 9%, through a combination of practical management, and breeding for varietal adaptation. Management can include improving the soil's water-retaining capacity through incorporating organic matter, surface mulching to reduce evaporation, or ridging to capture maximum rainfall. No increase is projected through expansion of area under irrigation.

e. Pests and diseases

Perhaps the single most striking contrast between production in Asia and elsewhere is the severity of pest and disease constraints. With a few important exceptions, these constraints are very limited in Asia. The Indian cassava mosaic disease, with etiology and symptoms similar to the African strain, occurs exclusively in India. Control is mainly through resistant varieties. The survey estimated a potential medium-term yield increase of

6% within the affected area. This low figure reflects the fact that moderately resistant varieties are already widely used by farmers. Root rots and bacterial blight are endemic in the more humid environments, especially in the Philippines, and the sub-tropics. Root rots can be controlled mainly through management (rotation, land preparation) and bacterial blight through resistance breeding.

Among the arthropod pests, only the red spider mite is of broad importance. Its control through host plant resistance or biological control could contribute about 2% to overall yields in Asia. The pest and disease situation will require constant monitoring, since introduction of new pests or pathogens, or changes in cultural practices could set the stage for new yield-reducing outbreaks.

2. Production Potential

The sum of individual components defines a potential yield increase of 96% by moderate alleviation of constraints. Given the existence of technology components to address nearly all these constraints to some degree, it should be possible to test the reality of these figures. The Asia Cassava Research Network has carried out well-managed trials in Asia for almost two decades. While breeding trials are aimed mainly at identifying potential new varieties, the trials also include good soil preparation, optimum plant spacing and weed control, and moderate fertilizer use. Yields of the hybrids, under good management in representative cassava areas, have been two to five times greater than the national average. Most of this increase appears to be from management, since hybrids yielded about 30% more than local varieties, similar to the potential increase projected by the constraints analysis.

3. Post-harvest

In the context of the survey, post-harvest constraints do not quite fit into the same analytical scheme as production factors, for projecting yield gains from constraint alleviation. In order to be consistent with units for yield gain, the post-harvest elements are divided into three parts: quality improvements are based on expected price premiums; gains in processing on reduced costs per unit; and gains in marketing on reduction in marketing margins (mainly reducing consumer prices). These estimates have some highly subjective components, and are biased toward the very conservative side.

Improved root quality will have the highest overall positive impact on post-harvest constraints (**Table 11**). Two traits are especially relevant: starch and post-harvest deterioration. Starch content is key to nearly every use of cassava in Asia, and especially the industrial sectors of starch extraction and pellets for animal feed. Raising starch content by breeding is clearly feasible, and has been a major objective of genetic improvement in most programs. Much of the recent success of new varieties in Thailand derives from a higher starch content as compared to the landrace variety, Rayong 1 (CIAT, 1996).

Cassava roots normally begin to deteriorate within a few days after harvest. The processing industry has had to develop elaborate systems for coordinating supply of raw material with processing capacity. This has often worked best when roots are converted at the farm or village level to a more stable product, such as dried chips. When fresh roots are delivered to a central factory, many small producers must coordinate their harvests. Even under the best circumstances factories processing fresh roots cannot operate at full capacity throughout the year. Extending the shelf-life of fresh cassava roots could add valuable flexibility to cassava management systems.

Currently-known management techniques include refrigeration, paraffin-coating of roots, and treatment with microbial inhibitors, followed by storage in plastic bags. None of these are practical for managing large volumes of roots destined for processing. A genetic approach seems most appropriate, given the ease and low cost of implementation. Longer term, there is reason to believe biotechnology approaches could offer innovative solutions (Wenham, 1995).

D. CASSAVA AS A CATALYST FOR DEVELOPMENT: ROLES AND STRATEGIES FOR RESEARCH

Cassava thrives in Asia because of the ability of growers, entrepreneurs, R&D institutions, and policy-makers to adapt to evolving physical, biological, economic and social environments. Optimizing the role of cassava as a catalyst for development in the coming years will build on these attributes and resources. Strategies revolve around the constraints and opportunities described in preceding sections.

There are three broad priority areas for intervention by R&D institutions: (1) stimulating higher demand through market development; (2) adding post-harvest value through process and product development; and (3) improved production systems through technology for increasing production efficiency and profitability. In addition, institutional support, including education of policy-makers, is an *umbrella* activity covering all these areas. Interventions in production, processing and marketing cannot be undertaken independently -- there is continual interaction and feedback among these system components.

1. Market Development: Stimulating Higher Demand for Cassava Products

Sometimes market demand drives product development, and sometimes new products create market opportunities. For either to succeed, products and markets need to develop in coordination.

Cassava markets are of two broad types: markets where cassava competes directly with other carbohydrate sources; and markets that make use of the specific traits of cassava. The non-specific markets include animal feed and most of the uses for starch. It is by far the largest current type of market for cassava in Asia. These markets will be driven by macro-economic forces such as growing demand for meat in developing countries, and the ever-widening range of uses for starch. The cassava sector, mainly processors, will need to drive product development for replacement of existing ingredients, including convincing the user that the alternative product is as good, if not better, than that already used.

There is a clear need to promote research on markets that exploit cassava's unique starch characteristics. In markets where starch-consuming industries are beginning to use functional ingredients, tremendous market opportunity presents itself. Success depends on the ability of the starch industry to assist the processors in technical issues relevant to application development. This is a strategy with considerable risk, as noted by Ostertag (1996). The technology for starch conversion is well-advanced and evolving rapidly. New technologies will allow native starch from almost any source to be converted to specific market needs, and thus the differential between raw materials tends to disappear. There is, nonetheless, considerable concern about the engineering of microorganisms (for converting starch) that could have unknown consequences in the environment, or the health and environmental effects of chemical modification. With that caveat, there certainly is still some opportunity for developing markets that favor cassava starch, or expanding existing ones. Success will come mainly from partnerships between public R&D institutions and the private sector.

2. Process and Product Development: Adding Post-harvest Value

A subsistence crop has a very short pathway from production to utilization -- it is usually destined either for direct consumption by the producer, or fed to animals to obtain meat, eggs or milk. The global trend in commodity markets is to continually add value to products as consumers increase their economic position. Low-value raw products at the farm level pass a series of transformations, each of which produces income or other value to a particular consumer. In developed countries, even basic food products may be valued at hundreds of times the price received by the farmer for the raw product. A box of white rice in a U.S. grocery store costs the equivalent of about $3000 per tonne. A box of rice-based breakfast cereal may sell for the equivalent of $8,000 per tonne. That cereal will have passed through ten or fifteen value-adding steps before reaching the consumer. As consumers become more affluent, the more they are willing to pay for the convenience, quality, status, aesthetics, etc., that these value-added steps represent.

Cassava in Asia has moved well beyond the subsistence stage; there is almost always a series of steps between producer and consumer. Each of these steps adds value to the product, and someone receives income from that added value. Often, public-supported R&D institutions have an interest in making the rural poor the beneficiaries of the highest possible proportion of this added value. This is not easy. Adding value usually takes place after cassava leaves the farm, and the grower may receive little benefit. *A thriving cassava sector is not necessarily indicative of success in meeting targeted development goals*. On the other hand, a cassava-based development strategy has little chance of success unless it taps into markets with potential for overall demand growth, even if a large share of benefits do not come back to the growers. This is the perennial conundrum of rural development, probably even more formidable for a cassava-based strategy: how to target a reasonable proportion of development benefits to cassava growers when the driving force of development is the commercial sector?

Without a tradition of consuming fresh cassava, Asia has been a leader in processing innovations to meet demands of new and changing markets. All of these began at the household and cottage-industry level. At the level of household processing, Indonesia is the leading example of diversity and innovation. Also at the household level, Thailand has fine-tuned chipping and drying to a highly efficient and cost-effective system that gets a high quality product to the market in a timely manner. In Vietnam and China, farmers feed cassava to pigs to obtain a value-added and more marketable product.

Animal feed and starch are the principal growth markets for the medium-range future. Both have a very broad range of levels of sophistication -- from rudimentary on-farm exploitation to high-tech industries. Across this range, there are interventions that have high potential to benefit the rural poor. The principal need for processing innovations lies in the early stages of product conversion. These are the stages closest to the producer, and more likely to bring benefit to the rural poor. They are the stages where a product is converted to something that is more likely to be used by an already-developed industry. For example, the animal feed industry can very readily use hard cassava pellets in balanced rations. No new technology is required. However, converting fresh roots to hard pellets came from a series of innovations specific to cassava's characteristics. Likewise, the efficient extraction of high quality starch from cassava requires technology specific for cassava, but the use of that starch in any number of industries is often the same as for any other starch. A major focus of cassava R&D institutions should be on innovations that bring additional value to growers.

The animal feed export sector, which so much defined the dynamics of the Asian cassava industry for more than twenty years, is still a major force for economic development. It is, however, a market that will require every innovation and efficiency just to retain current market share, because of the increasing competitiveness of coarse grains on world markets. No country of Asia is basing its plans for the cassava sector on dramatically expanded possibilities for export of cassava pellets.

Demand for animal feed will continue rapid expansion in developing countries. It is a growth sector for which several cassava-growing countries should be able to create viable *internal* industries. These industries may be successful across a range of scales of operation -- from rudimentary on-farm feeding of pigs to large, intensive poultry operations. There is, however, as in most industries, a continual move toward larger operations that exploit economies of scale. The animal feed market will thrive with or without a cassava component. For cassava to reach its full potential participation will require aggressive R&D input. The animal feed market for cassava is a very mature market. The potential for additional market share lies in cost reductions, and added value by way of conversions that target specific markets. For example, the pelleting industries could develop capacity to mix complete rations, or even begin contracting the growing of chickens or pigs.

Because of the technical level of the starch and starch derivatives industries, there are possibilities for adding value at the farm level for this sector, by improving the level and consistency of root quality. The starch industry will contribute to rural development mainly through a higher demand for raw roots, and premiums for starch content and quality. Research should continue to focus on pre- and post-harvest crop management that meets the increasingly demanding standards of industry.

Markets for flour substitution seem to be more difficult to penetrate on a large scale. Quality and supply are very critical. There has been a tendency for demand to fluctuate too widely to interest major commitment from processors. This market needs continued research because of its high potential if price-competitiveness, high quality, and constant supply can be assured.

3. Improved Production Systems: Increasing Efficiency and Profitability for Farmers

In broad terms, producers have three possible alternatives to increase their net income from growing cassava: (1) *increase yields*, to reduce per-unit production costs; (2) *reduce costs*, while maintaining production levels; or, (3) *increase the value* of the product offered for sale while keeping costs and production levels the same.

Of course these are not mutually exclusive pathways, and each category has a number of possible variations. Successful crop technology in this century has been overwhelmingly based on the first of these -- on use of inputs to increase yields. The g*reen* *revolution* set the tone for crop improvement strategies, with emphasis on *total system output*. Consumers have been the greatest beneficiaries, with more abundant food at lower prices. It is a strategy that is eminently sensible in a world of food shortages, where increased supply has high social priority. The developing world is now a mosaic of food shortages and food surpluses, and a monolithic strategy for increasing agricultural production is clearly not a universal goal. In Asia's comparatively mature market economy, cassava producers can benefit economically from expanded areas of production, lowered production costs, higher productivity per unit of production cost, higher market value, or value-added features. They can benefit nutritionally both from the greater purchasing power of higher income, and from nutritional enhancements to cassava itself. Indirectly, they can benefit nutritionally from an increase in production that permits feeding cassava to animals. Less tangibly, technology provides avenues for lifestyle improvements such as less arduous physical labor inputs, or more time to pursue education or leisure.

a. Environmental resources

Farming practices are inextricably linked to environmental resources. Characteristics of the environment set limits on the types of agriculture that are economically feasible; and in turn agriculture can enhance or degrade the environment where it is practiced. Tradition, education, regulation, and economics all influence a farmer's attitude and relationship with the land. Generally, education and regulation can be applied successfully to environmental stewardship only if the economics are favorable. On the other hand, farm profitability is not in itself necessarily an incentive for adopting practices that improve the environment.

This interlacing of attitude and economics is a complex target for R&D institutions. Often the technology for preserving the environment is not complex, but there are inadequate economic incentives.

b. Crop management

The greatest returns to research investment in crop technology development should be for interventions that lower the very high labor inputs into cassava, increase yield, and increase starch content.

(1) *Agronomic practices***.** Crop management is already more intensive in Asia than elsewhere. Rearrangements of existing practices or resources (i.e., if no *new* external inputs are applied) probably offer limited potential for improved productivity or profitability. For example, changes in stake planting position or plant density normally offer little advantage, unless in conjunction with another major system modification. There are good possibilities for increasing profitability with management in the areas of fertilizer application and efficient weed control. There are, nonetheless, substantial environmental concerns with both these inputs, and these must be addressed as part of any technology development. The fact is, however, that cassava will have great difficulty competing in the marketplace with crops where high efficiencies of production are achieved with intensive inputs, unless some of those same inputs are applied to cassava.

The economic response of cassava to fertilizer application is well-established (Howeler, 2001a). The constraints to increased use are socio-economic rather than technical. Farmers usually do not have cash reserves that can be tied up for a full year, between planting and harvest. Commercial or government-supported credit are not common. Nonetheless, most farmers now have experience with purchase and use of fertilizer on rice, and translating this to use with cassava should not be an insurmountable obstacle when the economic return is favorable.

(3) *Mechanization***.** Cassava is still a very labor-intensive crop for most growers. Labor productivity has not been a major goal for cassava research, often based on the assumption that public institutions should be wary of technology that displaces labor in situations where underemployment is already high.

In any case, mechanization is typically difficult for cassava -- *economically* because of small landholdings, and *physically* because of cultivation on slopes and uneven terrain, or intercropping. While no-til systems have had limited success in cassava, there may be more potential for *zone tillage* systems, where a type of deep-penetrating tool is pulled through the soil only along the row to be planted. This leaves nearly all the residue on the surface for erosion control, while creating a tilled, aerated zone for rainwater penetration and root development.

The nature of the plant itself also mitigates against easy mechanization. Planting pieces are bulky and irregular in form. Harvest may need to be in a two- or three-stage process, first to cut stems for planting material, then to lift roots, and finally to remove individual roots from the root mass. Mechanical harvest is energy-intensive because of the size and shape of roots. Most mechanization developed for cassava is only appropriate for large commercial plantations, on level, well-prepared land. There is a need for smaller scale, flexible mechanization to manage some of the more labor-intensive tasks for cassava. Asia has typically been a leader in small-scale mechanization, and this industry will develop spontaneously as labor costs rise to the level of justifying the investment. There would be considerable benefit to partnerships between universities/research institutes and private industry to develop mechanization for cassava.

c. Varietal development

Cassava has moved through three *mega-phases* of genetic improvement, characterized by a focus on: (1) yield potential; (2) production efficiency under conditions of environmental stress; and (3) incorporating value-added traits with (1) and (2). This latter phase is in the initial stages, and will probably define cassava genetic improvement in Asia for the next several years.

Cassava has a relatively long breeding cycle compared to many crops. And after successful new varieties are developed, distribution is slowed by the low multiplication rate. In Thailand, both government and private industry participate in promoting new varieties. In India, the extension service has developed innovative methods for facilitating distribution. However, in most countries, distribution relies mainly on informal farmer-to-farmer channels. National programs are now recognizing the importance of extension service involvement in variety promotion.

Many Thai farmers have had considerable exposure to new varieties through various promotion channels. Elsewhere, the practice of introducing and evaluating varieties through extensive on-farm trials is less common. The initial tests by farmers that prove the value of a new variety can translate into a continued, long-term interest in variety evaluation, and thereby greatly simplify the job of the extension service. If the momentum for adopting new varieties grows strong enough, there could eventually be motivation to bring the private sector into the picture to develop and sell varieties. This will be difficult, however, given the ability of farmers to save their own seed from one planting to the next.

The bottom line is that public support for cassava breeding will need to remain strong. The ongoing success of new varieties is significant. This will generate widespread interest in accelerating the pace of variety development, and in expanding the options in terms of varietal characteristics offered. Response to these demands will only be possible with continued, and increased, investments in research.

Breeding offers possibilities of adding value to the products that growers move to the marketplace. A prime example is development of the high starch varieties developed jointly between national programs and CIAT. Although higher starch varieties were available early in Thailand's breeding program, the real impetus for their adoption and further development did not come until industry began paying premiums for this trait. The time is now ripe to move into more advanced value-added traits – because the diversification and specialization of industry create a demand, and also because the technology for targeted genetic modification of cassava is on the horizon. Genetic transformation and regeneration will open the door for applying technologies that are already routine in other crops (insect resistance, herbicide resistance), but more importantly for mapping a future for cassava that meets its specific production and market needs and opportunities. Partnerships involving all sectors will be the key to identifying appropriate research goals, as well as funding and executing the research. Some of the areas with highest potential to provide broad benefits through value-added traits are genetic modification of starch characteristics, tailored to specific markets; and increased post-harvest root storability by genetic means.

4. Institutional Support

Viability of the cassava sector in Asia has been very much the result of both private and public interests. Process, product and internal market development has been primarily in the hands of the private sector. Export development, on the other hand, has had very strong governmental support. While there are some notable examples of private sector participation in support to cassava research, the movement in this direction has been very slow. There is no doubt that in Asia cassava will continue as a basic energy source for food, feed and industry. If public support to research were to decline substantially, there may even be private funding to take on some of the research needs. Certainly, though, the private sector will have a very different development agenda, which would likely include lower priority for directing benefits to the rural poor. Social goals such as food security, poverty alleviation, equity and environmental protection, do not normally attract large sums of private sector investment. On the other hand, private enterprise seems to have a far better track record than does government, of successfully establishing efficient and profitable business practices. It is apparent that the potential synergy between public and private sectors is worth developing further.

Given that cassava producers will rely heavily on public research investment for at least a few more decades, the planning for adequate support is crucial. This support is needed for training of scientists, research infrastructure, and operational costs. The Asian countries that are developing rapidly might well take responsibility for full funding of cassava research. Others will be hard-pressed to provide for more than rudimentary programs, and will need outside support.

R&D institutions can have an important role in policy analysis, as an educational resource for policy-makers who need to have access to comprehensive and unbiased information. With few exceptions, cassava producers have little political clout to influence policy that affects their ability to earn a livelihood. Development organizations can take the role of empowering the cassava sector to effectively present its interests before policy-makers. Farmers' organizations can be highly effective policy lobbyists, but these are still not common. Industry and commodity organizations are often well-positioned to speak for the interests of growers, processors and marketers. They usually recognize the need for a healthy total system, for any one sector to benefit. Prominent examples of such groups are the Thai trade associations. Their principal activities are in the realm of industry promotion and trade, but they also promote supply-side benefits such as training of cassava farmers and the distribution of new varieties by the Thai Tapioca Development Institute (TTDI).

Cassava networks have not been active in policy debate, but this is a role for which they have some unique qualifications. The Asia Cassava Research Network, as the only one with a strictly regional focus, is in the best position to take on policy issues. While an international network would have limited direct voice in national policy debates, it is well-positioned to provide individual members with information and technical backup.

E. CONCLUSIONS: ORGANIZING FOR SHARED SUCCESS IN A COMPETITIVE WORLD

Market competition is becoming the defining trend that drives success in agriculture. Competition, brought about in large part by the global trend of more open markets, is almost universally welcomed by consumers, who benefit from more choices and lower prices. But it is a *double-edged sword* for growers. Market alternatives may be greatly expanded, but successfully entering any of them may require substantial adaptation in production, processing and distribution systems. In particular, cost efficiencies become critical, along with quality and timeliness of production. This can be a major challenge for cassava, when it confronts a commodity like maize, with a long history of global commerce and a massive research support system. On the other side of the equation, more demanding markets also open opportunities for specialized products outside the mainstream commodities trade. Cassava has particular possibilities in snack food and specialized starch markets, where it does not compete directly with other energy sources.

Perhaps the most profound lesson of the past is the critical importance of integrated development of production, processing and marketing components of the system. There are now several models where this type of broad integration has shown both some of the potential pitfalls and the benefits of an integrated approach.

The urgency of finding solutions to today's problems in food and agriculture is clear, and the tools to accomplish this are at hand. The greatest scientific advances in recent years have often been the outcome of partnerships -- between public and private concerns, among countries sharing common problems, and among thousands of motivated people sharing complementary skills and information. Communications technology now allows breaking many of the seemingly intractable barriers to developing effective partnerships – across geographic distance, across professions and disciplines, and across belief systems.

In February of 2001, two of science's most respected journals, *Nature* and *Science*, collaborated to publish results of the complete mapping of the human genome. It is a momentous landmark accomplishment in our understanding of life. It is also a powerful lesson in the advantages of broad-based collaboration among private and public sector institutions, and a sobering reminder of the need for long-term vision and commitment of funding. On the surface there may seem to be little connection between this level of highly sophisticated, lab-based research, and the plight of cassava farmers in difficult tropical environments; but unless connections are made between the best of science and a general benefit to all of society, we are investing poorly in our future.

REFERENCES

Centro Internacional de Agricultural (CIAT). 1996. Project 2: Improved cassava gene pools. Annual Report. CIAT, Cali, Colombia. 32p.

FAOSTAT. 2001. http://www.fao.org//giews/

Henry, G. and V. Gottret. 1996. Global Cassava Trends. Reassessing the Crop's Future. CIAT Working Document No. 157. CIAT, Cali, Colombia. 45 p.

Hershey, C., G. Henry, R. Best, K. Kawano, R.H. Howeler and C. Iglesias. 2000. Cassava in Asia: Expanding the Competitive Edge in Diversified Markets. Review document prepared for the Global Cassava Development Strategy Validation Forum, held in Rome, Italy. April 26-28, 2000. FAO/IFAD, Rome, Italy. 58 p.

Howeler, R.H. 1995. Agronomy research in the Asian Cassava Network -- towards better production without soil degradation. *In*: R.H. Howeler. (Ed.). Cassava Breeding, Agronomy Research and Technology Transfer in Asia. Proc. 4th Regional Workshop, held in Trivandrum, India. Nov 2-6, 1993. pp. 368-409.

Howeler, R.H. 2000. Cassava production practices – Can they maintain soil productivity? *In*: R.H. Howeler, C.G. Oates and G.M. O'Brien (Eds.). Cassava, Starch and Starch Derivatives. Proc. Intern. Symp., held in Nanning, Guangxi, China. Nov 11-15, 1996. pp. 101-117.

Howeler, R.H. 2001a. Cassava Mineral Nutrition and Fertilization. *In*: R.J. Hillocks, M.J. Thresh and A. Bellotti (Eds.). Cassava: Biology, Production and Utilization. CABI Publishing, Wallingford – Oxen, UK. (submitted for publication)

Howeler, R.H. 2001b. Cassava agronomy research in Asia: Has it benefited cassava farmers. *In*: R.H. Howeler and S.L. Tan (Eds.). Cassava's Potential in Asia in the 21st Centura: Present Situation and Future Research and Development Needs. Proc. 6th Regional Workshop, held in Ho Chi Minh city, Vietnam. Feb 21-25, 2000. (this Proceedings)

Howeler, R.H. 2001b. Overview of the Nippon Foundation project on Improving the Sustainability of Cassava-based Cropping Systems in Asia. *In*: R.H. Howeler and S.L. Tan (Eds.). Cassava's Potential in Asia in the 21st Century: Present Situation and Future Research and Development Needs. Proc. 6th Regional Workshop, held in Ho Chi Minh city, Vietnam. Feb 21-25, 2000. (this Proceedings)

Howeler, R.H., C.G. Oates and A.C. Allem. 2000. Strategic Environmental Assessment: An Assessment of the Impact of Cassava Production and Processing on the Environment. Review document prepared for the Global Cassava Development Strategy Validation Forum, held in Rome, Italy. April 26-28, 2000. IFAD/FAO, Rome, Italy. 153 p.

Huang, J. and H. Bouis. 1996. Structural changes in the demand for food in Asia. 2020 Brief 41, IFPRI, Washington, D.C. USA. (http://www.cgiar.org/ifpri/2020/briefs/number41.htm)

Kawano, K. 2001. The role of improved cassava cultivars in generating income for better farm management. *In*: R.H. Howeler and S.L. Tan (Eds.). Cassava's Potential in Asia in the 21st Century: Present Situation and Future Research and Development Needs. Proc. 6th Regional Workshop, held in Ho Chi Minh city, Vietnam. Feb 21-25, 2000. (this Proceedings)

Kawano, K., S. Sarakarn, A. Limsila, A. Tongglum and D. Suparhan. 1990. Cassava cultivar evolution viewed through harvest index and biomass production. *In*: R.H. Howeler (Ed.). Proc. 8th Symp. Intern. Soc. Trop. Root Crops, held in Bangkok, Thailand. Oct 30-Nov 5, 1988. pp. 202-210.

Lynam, J.K. 1987. The Cassava Economy of Asia: Adapting to Economic Change. CIAT, Cali, Colombia.

Ostertag, C.F. 1996. World production and marketing of starch. *In*: D. Dufour, G.M. O'Brien and R. Best (Eds.). Cassava Flour and Starch: Progress in Research and Development. CIRAD/CIAT, Cali, Colombia, pp. 105-120.

Penning de Vries, F.W.T., H. Van Keulen, R. Rabbinge and J.C. Luyten. 1995. Biophysical limits to global food production. 2020 Brief 18, IFPRI, Washington, D.C. (http://www.cgiar.org/ifpri/2020/briefs/number18.htm)

Pinstrup-Andersen, P. and J.L. Garrett. 1996. Rising food prices and falling grain stocks: short-run blips or long-term trend? 2020 Brief 30, IFPRI, Washington, D.C. (http://www.cgiar.org/ifpri/2020/briefs/number30.htm)

Pinstrup-Andersen, P. and R. Pandya-Lorch. 1995. Poverty, food security, and the environment. 2020 Brief 29, IFPRI, Washington, D.C. (http://www.cgiar.org/ifpri/2020/briefs/number29.htm)

Ratanawaraha, C., N. Senanarong and P. Suriyaphan. 2000. Status of cassava in Thailand: implications for future research and development. Review document prepared for the Global Forum to Validate the Cassava Development Strategy, held in Rome, Italy. April 26-28, 2000. FAO/IFAD, Rome, Italy. 34 p.

Rosegrant, M.W. and R.V. Gerpacio. 1997. Roots and tubers in the 21st century: their role and importance in the global food market. IFPRI discussion document, IFPRI, Washington, D.C.

Scott, G.J., R. Best, M. Rosegrant and M. Bokanga. 2000a. Roots and tubers in the global food system: A vision statement for the year 2020 (including Annex). A co-publication of the International Potato Center (CIP), Centro Internacional de Agricultura Tropical (CIAT), International Food Policy Institute (IFPRI), International Institute of Tropical Agriculture (IITA), and International Plant Genetic Resources Institute (IPGRI). CIP, Lima, Peru.

Scott, G.J., M. Rosegrant and C. Ringler. 2000b. Roots and tubers for the 21st century: Trends, projections, and policy options. A co-publication of the International Food Policy Institute (IFPRI) and the International Potato Center (CIP). IFPRI, Washington, D.C. May 2000.

Van Norel, J.G. 1997. Priority setting for research and development in cassava. An assessment of needs of cassava production and post-harvest sectors in Latin America and Asia. Mimeo. CIAT, Cali, Colombia, Oct. 1997.

Wenham, J.E. 1995. Post-harvest deterioration of cassava. A biotechnology perspective. FAO Plant Production and Protection Paper 130. NRI/FAO. Rome, 90 p.