Roots and tubers in the global food system: A vision statement to the year 2020

Roots and tubers have myriad and complex parts to play in feeding the world in the coming decades. Far from being one sort of crop that serves one specific purpose, they will be many things to many—very many—people. In some cases, they will mean the difference between subsistence and achieving a leg up on the economic ladder; in others, they will mean the difference between survival and starvation. In all instances, their potential to help improve food security and eradicate poverty will be important. We propose, therefore, a vision for the contribution that these crops will make to the global food system by the year 2020. This vision can be summarized as follows:

By 2020, roots and tubers will be integrated into emerging markets through the efficient and environmentally sound production of a diversified range of high-quality, competitive products for food, feed, and industry. These crops' adaptation to marginal environments, their contribution to household food security, and their great flexibility in mixed farming systems make them an important component of a targeted strategy that seeks to improve the welfare of the rural poor and to link smallholder farmers with these emerging growth markets.

The CGIAR Centers, with their partners, will contribute to achieving this vision through the application of science; dissemination of information, tools, and methodologies; policy support; and, strengthening of national research and development systems.

Mission of the CGIAR

The mission of the Consultative Group on International Agricultural Research (CGIAR) is worthy and far-reaching—with profound implications for humanity's most basic necessities now and for generations to come. The CGIAR seeks "To contribute to food security and poverty eradication in developing countries through research, partnership, capacity-building, and policy support, promoting sustainable agricultural development based on the environmentally sound management of natural resources" (CGIAR, 1998: viii).

A vision of the future

"Vision" comes from the Latin "to see." A modern dictionary demonstrates the term's several meanings: It can be something that is seen to "convey a revelation." Alternatively it can be "the act or power of imagination." Or—and this is the sense in which we look ahead and try to glimpse the future of an important component of the foods that keep people alive—it can mean an "unusual discernment or foresight." Here that foresight is based on the accumulated knowledge of hundreds of scientists and policymakers at CGIAR and allied organizations.

The questions addressed in this statement concern an extremely important element in that battle for food security and poverty elimination: How can the CGIAR best ensure that the different species of roots and tubers—cassava, potato, sweetpotato, yam, as well as the aroids and Andean roots and tubers—each make the greatest contribution to its overall mission, and, in so doing, to the global food system?* And how will these crops' roles evolve by the year 2020, when the world will be quite a different place, filled with many more people, all of them needing to be fed?

These questions deserve particular attention because many of the developing world's poorest and most food insecure households look to roots and tubers as a contributing, if not the principal, source of food, nutrition, and cash income (Alexandratos, 1995). Among other things, farm households see the value of roots and tubers "in their ability to produce large quantities of dietary energy and in their stability of production under conditions where other crops may fail" (Alexandratos, 1995:189). In 1995–97, farmers in developing countries produced 439 million metric tons (mt) of the major roots and tubers—cassava, potato, sweetpotato and yam—with an estimated annual value of more than US$41 billion, nearly one-fourth the value of the major cereals (Table 1).

* The different species are cassava (*Manihot esculenta*), potatoes (*Solanum* spp.), sweetpotato (*Ipomoea batatas*), and yams (*Dioscorea* spp.). Other roots and tubers includes aroids such as taro (*Colocasia esculenta*) and Andean roots and tubers such as ulluco (*Ullucus tuberosus*), arracacha (*Arracacia xanthorrhiza*), maca (*Lepidium meyenii*), and oca (*Oxalis tuberosa*).

The answers are complex, covering a diversity of areas, activities, and actors, each of which is in constant flux and each of which affects the others. They include population growth; nutrition; protection of the environment; the evolution of farming systems; traditional and emerging research technologies; tastes that change as income rises and people throng to urban areas; and the opportunities as well as sometimes traumatic alterations brought about by falling trade barriers and the increasing globalization of economic activity.

Perhaps the most influential of these trends for root and tuber crops are those noted by Pinstrup-Andersen, Pandya-Lorch, and Rosegrant (1999) in their recent assessment of the world food situation to 2020:

- The increase in global population from 5.7 to 7.5 billion people (United Nations, 1999), more than 95 percent of which will take place in developing countries. Hence, the proportion of the world's population living in developing countries will increase from nearly 80 percent to 84 percent.

- The growing urbanization of the developing world; the developing world's urban population is expected to double to 3.4 billion (United Nations, 1996).

- The differentiated growth rates in income in particular with higher per capita incomes in Asia and considerably lower levels in Sub-Saharan Africa.

As a result, tremendous pressure will be placed on the global food system to produce more food and to provide

Table 1. Production, edible energy and protein, and value of major roots, tubers, and cereals in developing countries, 1995–97.

Commodity	Price (US$/mt)	Production (million mt)	Edible energy (trillion kilocalories)	Edible protein (million mt)	Value (US$ billion)
Cassava	53	165.3	142	0.7	8.8
Potato	157	105.3	65	1.8	16.5
Sweetpotato	88	137.0	127	1.9	12.1
Yam	130	31.5	28	0.5	4.1
Major roots/ tubers		**439.1**	**362**	**4.9**	**41.4**
Wheat	146	272.2	687	27.4	39.7
Maize	126	257.6	786	20.1	32.5
Milled rice[a]	284	350.0	851	15.7	99.4
Major cereals		**879.8**	**2,324**	**63.2**	**171.6**

Source: Scott, Rosegrant, and Ringler (2000).
Note: Production data based on FAO (1998 June, accessed July); coefficients for calculating edible energy and protein are based on Horton (1988); prices are based on estimates for 1993 and 2020 baseline scenario interpolated for 1995–97, see Table A9; totals may not sum due to rounding.
[a] Milled rice is more readily comparable to the other commodities for the purposes of calculating utilization, hence the production figures are presented here in comparable units.

Food security—and insecurity

What is "food security" and its opposite, "food insecurity"? Here are some recent definitions, gathered from the literature on international agricultural research:

- People suffer from food insecurity when they do not get enough food to lead healthy, active lives. "Healthy, active lives" is a component of virtually all definitions of the term. Insecurity often applies to the majority of people in a region, but it also can refer to individuals who live in an otherwise affluent area.
- When food security is lacking, people have a reduced capacity to cope with unexpected setbacks in their economic or natural environments.
- "Food security…exist[s] when all people at all times have physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life. Food insecurity exists when the availability of nutritionally adequate and safe foods, or the ability to acquire acceptable foods in socially acceptable ways, is limited or uncertain." (United States of America General Accounting Office, 1999:1-2).
- "Food security means access by all people at all times to the food needed for a healthy life. Sustainable food security aims to achieve this goal without compromising the productive capacity of natural resources, the integrity of biological systems, or environmental quality." (FAO and UNDP, 1994.)

increasing percentages of that output to urban as well as rural areas. Furthermore, agriculture and food systems will remain the principal means for income generation among the rural poor in Asia, Africa, and Latin America in the decades ahead.

The decisions and research investments that the CGIAR and its partners make today will strongly affect the role of roots and tubers in the global food system over the next fifteen or twenty years and as a result the potential of these crops to help improve food security and eradicate poverty. Our underlying hypothesis is that the developing countries' benefits from root and tuber crops in 2020 will be strongly related to the strength of the support the CGIAR provides at the beginning of the new century—right now. We further believe that these commodities, often underestimated in accountings of "the crops that feed the world," are vital elements in carrying out the CGIAR's mission. Over two billion people in the tropics and subtropics depend on roots and tubers for their sustenance and livelihood.

Multipurpose commodities

More than is the case with most of the commodities in the CGIAR's repertoire, roots and tubers mean different things to different people in different regions of the world, and at different levels of economic well-being. Far from being simply bulky, perishable starchy staples produced for on-farm consumption, the crops fulfill a number of basic roles in the global food system, all of which have fundamental implications for meeting food requirements, increasing food security, and reducing poverty. Demographic changes and the evolution of per capita incomes will continue to differentiate those roles by commodity and region. Thus, we estimate that by 2020 well over two billion people in Asia, Africa, and Latin America will use roots and tubers for food, feed, or sources of income. Many of these people will be among the poorest of the poor. Here are some examples:

- In **Sub-Saharan Africa**, where economic growth will be slow but population growth fast, cassava will be a favored source of cheap carbohydrates in the countryside and also continue to serve as a food security crop (Scott, Rosegrant, and Ringler, 2000a). Furthermore, as urbanization continues in the region, more people in cities and towns will purchase their food, rather than grow it themselves. That will continue to give small farmers a source of cash income from cassava; some of it will reach the market in processed form (Nweke, 1992). The resulting gains in poverty eradication and greater food security will depend in part on an integrated set of research outputs that include higher-yielding, pest-resistant varieties; improved crop management as well as processing equipment and procedures; better linkages among producers, processors, and consumers through capacity-building in market analysis and enterprise development; and improved policies that facilitate the development and adoption of these innovations.

- In **West Africa**, yam will be a preferred local vegetable (in some locations a staple) and will be increasingly important as a source of cash income; in parts of **Central**, **Eastern**, and **Southern Africa**, sweetpotato will play a supplementary role to cassava and maize as a seasonal source of food, food security, and cash. Both sweetpotato and yam can help eliminate poverty and improve food security in their respective areas of greatest concentration. Research is needed to develop pest-resistant varieties, improve the availability of planting material, and exploit the growing demand for inexpensive nutritious foods and processed products.

- In **Asia**, generally, faster economic growth and slower population expansion will shape the future of roots and tubers. Higher incomes will bring less dependence on cereals and greater demand for potatoes in fresh and processed form (FAO, 1995). Potato will be the most important vegetable in Asia, with increased production providing more food, income, and employment. The crop's expansion will be speeded by development and adoption of yield-increasing technology and policies aimed at continuous improvement of storage and marketing.

- In **China**, higher incomes and increased urbanization will stimulate further increases in the demand for meat and prepared foods. This will translate into greater use of sweetpotato as a source of starch for processed food and other starch-derived products and as an inexpensive source of animal feed—particularly in poorer, more isolated areas—and hence into higher incomes for less well-off households engaged in sweetpotato processing. Again, research will help produce the most useful type of roots, commercially viable procedures and products as well as policies to induce adoption of improved production and postharvest technologies.

- In **Southeast Asia**, there will be demand for cassava, also, for use as processed food and feed, and for specialized starch products (dTp Studies, Inc., 1998). The competitiveness of these products, and the resulting benefits to low-income households, will be assured by the continued reduction of production costs through the diffusion of higher-yielding varieties with higher dry matter content so as to maximize conversion rates from raw material to processed product, the adoption of fertility and erosion management practices, and the incorporation of improved processes and management practices by agro-enterprises.

- In parts of **Oceania**, yam and other roots and tubers such as taro will continue to be utilized in more localized production and consumption systems.

- In **Latin America**, production of cassava and potato will remain important in quantitative terms but will become less and less important from a global perspective. Private sector investment will make an increasing contribution to research and development of cassava for use as processed food and feed. Sweetpotato, yam, and Andean roots and tubers such as achira (or canna), ulluco, and arracacha will continue to be important to poor households in much more specific locations. Once the properties of these roots and tubers are better understood by science, they too may become candidates for specialized markets.

Thus, any projections of consumption and output patterns for roots and tubers in developing countries must pay careful attention to the different ways in which the crops are used. While the versatility of all the root and tuber crops in terms of why they are grown and how they are used will remain an enduring attraction for producers and consumers alike, we envision an overall trend toward greater specialization in end use, in the location of production, and in the types of production systems in which these crops are cultivated.

From a global perspective, cassava and sweetpotato will be increasingly used in processed form for food, feed and starch-derived products, e.g. high fructose syrup, monosodium glutamate. Non-food, non-feed uses will grow in volume as a result of research that enhances varietal characteristics (as through biotechnology) and lowers their cost as a source of raw material. Potato and yam will be used largely as food and primarily in fresh form. The rise in consumption of potato, though, will involve more processed products, made possible largely by more environmentally friendly varieties with the appropriate processing characteristics. Research on the quality characteristics of yam starch may identify additional market segments beyond those for fresh roots (Berthaud, Bricas, and Marchand, 1998).

Our collaborative work on projections for roots and tubers to 2020, using IFPRI's IMPACT model (see box, p. 17), indicate continued positive growth rates in output (Table 2), but noticeably higher for some crops than others. They will be particularly strong for potato (2.7 percent per year) and yam (2.9 percent per year). Growth for cassava as well as sweetpotato will expand at a more modest pace—1.95 and 1.0 percent per year respectively—although in Sub-Saharan Africa the growth rates in production for cassava and sweetpotato will be

IFPRI's IMPACT model

Global projections of root and tuber supply and demand were based on an updated version of IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). IMPACT covers 37 countries and regions and 18 commodities, including all cereals, soybean, roots and tubers, meats, and dairy products (accounting for virtually all of the world's food and feed production and consumption). The model is specified as a set of country-level demand and supply equations linked to the rest of the world through trade (see Rosegrant, Agcaoili-Sombilla, and Perez, 1995).

The results presented here are from a revised and updated version of IMPACT. These projections attempt to go beyond past estimates of future root and tuber supply and demand in a number of important respects, including disaggregating roots and tubers in a multi-commodity model (see Scott, Rosegrant and Ringler, 2000, 2000a for details).

Table 2. Production of roots and tubers in 1993, and projections and growth rates to 2020.

	Cassava[a]			Potato			Sweetpotato and yam[b]		
	Production		Growth rate	Production		Growth rate	Production		Growth rate
Country/region	1993	2020	1993–2020	1993	2020	1993–2020	1993	2020	1993–2020
	(million mt)		(percent/yr)	(million mt)		(percent/yr)	(million mt)		(percent/yr)
China	4.8	6.6	1.21	42.5	87.8	2.72	108.5	136.0	0.84
Other East Asia	na	na	na	2.4	3.3	1.18	0.8	1.1	1.36
India	5.8	7.1	0.76	16.3	43.3	3.67	1.2	1.3	0.44
Other South Asia	0.8	1.3	1.61	3.5	7.7	2.98	0.5	0.7	1.27
Southeast Asia	42.0	48.2	0.51	1.3	2.3	2.08	5.3	8.0	1.49
Latin America	30.3	42.0	1.22	12.6	20.2	1.76	2.6	3.7	1.41
W. Asia/N. Africa (WANA)	0.1[c]	0.2[c]	1.61	13.0	23.4	2.21	0.1	0.2	1.55
Sub-Saharan Africa	87.8	183.8	2.77	2.6	6.0	3.06	36.0	78.0	2.90
Developing	172.4	290.3	1.95	94.3	194.0	2.71	155.9	230.2	1.45
Developed	0.4	0.4	0.67	191.0	209.5	0.34	2.1	2.3	0.36
World	172.7	290.8	1.95	285.3	403.5	1.29	158.0	232.5	1.44

Source: IFPRI's IMPACT simulations, high demand/production growth scenario, as presented in Scott, Rosegrant, and Ringler (2000).

Note: 1993 signifies the three-year moving average for 1992–94; na signifies not applicable; totals may not sum due to rounding. Other East Asia covers Hong Kong, Macau, Mongolia, North Korea, and South Korea. Other South Asia covers Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka. Southeast Asia covers Brunei, Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. Latin America covers Central and South America plus Mexico. West Asia/North Africa (WANA) covers Algeria, Bahrain, Cyprus, Egypt, Gaza Strip, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, United Arab Emirates, Western Sahara, and Yemen. Sub-Saharan Africa covers Central, West, Eastern, Northern, and Southern Sub-Saharan Africa.

[a] These figures are for cassava and other roots and tubers such as taro. For developing countries, cassava alone accounts for over 97 percent of the total.

[b] Estimates for Sub-Saharan Africa are largely for yam, given the 80/20 distribution of production in the region of the two crops according to FAO (1998 June); in Asia and WANA for sweetpotato only as FAO (1999 April) indicates only the Philippines produces yam and less than 30,000 mt on 5900 ha; and, in Latin America 68/32 for sweetpotato versus yam.

[c] FAO indicates very high yields in Egypt for a small area.

comparable to those for potato and yam. Moreover, the projected growth rates for cassava, potato, and yam in developing countries exceed those projected for the major cereal crops such as rice and wheat (Figure 1).

While these growth rates may appear high for potato and yam as well as cassava in Sub-Saharan Africa, they actually represent a considerable slowdown in the recent rates of expansion and from that historical perspective are quite reasonable. According to FAO (1999 April), growth rates for potato, yam and cassava (in Sub-Saharan Africa) production in developing countries over the last decade have been 4.7 percent, 8.7 percent, and 3.5 percent. Farmers worldwide are increasingly aware of the capacity of roots and tubers to out-produce the cereals in terms of quantities of edible energy harvested per hectare per day (Figure 2). To cite but one of a series of recent examples, according to FAO (1999 April) India now produces over 25 million mt of potato annually—up from 16 million mt in 1992–94 (Table 2). IFPRI's IMPACT model shows that production rising to 43 million mt by 2020.

Our projections also indicate increased regional and/or continental concentration of production (Table 3). By 2020, over 60 percent of global cassava production will be in Sub-Saharan Africa. Potato production in West, South, and East Asia will account for nearly 80 percent of developing-country totals. Sweetpotato will be heavily skewed toward China with over 82 percent; with the bulk of the remainder in Sub-Saharan. Yam will be even more highly concentrated, over 90 percent in West Africa.

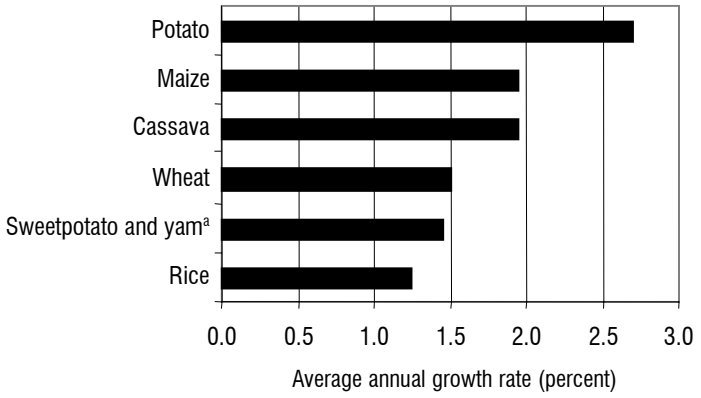
There will be strong differences, too, in the production systems in which these commodities are cultivated. Thus, while the diversity among roots and tubers means that different crops are capable of contributing to different developing-country food systems in different ecological regimes, potato will increasingly be dominant in two systems—the subtropical lowlands in Asia and North Africa, and the subtropical highlands throughout the developing world—whereas cassava and sweetpotato will increasingly achieve prominence in several other, quite distinct systems.

To add to this complex portrait of diversity is a dichotomous set of supply-side versus demand-side constraints. Each of the commodities faces constraints from both sides, but potato and yam are more vulnerable to supply-side problems, while broadly speaking cassava and sweetpotato face more demand-side limitations. Research, of the sort at which the CGIAR system excels, can cope with both kinds of constraints. Research and development can remove or reduce barriers to increased output, and such techniques as germplasm improvement to lower raw material costs and enhance quality can deal with demand-side constraints. Strengthening grower-processor linkages and small- to medium-scale enterprises, as well as improved policies, can also remove constraints.

The beneficiaries

With the help of the kind of technological expertise that the CGIAR system can provide to overcome these constraints, the beneficiaries of roots and tubers in terms of poverty eradication and greater food security can cover a range as broad as the crops' uses. When research is oriented toward development, as it is in the CGIAR, by definition it has an overriding focus on people. Thus it is appropriate to consider who the intended beneficiary groups are; what their needs are for improved income and food security;

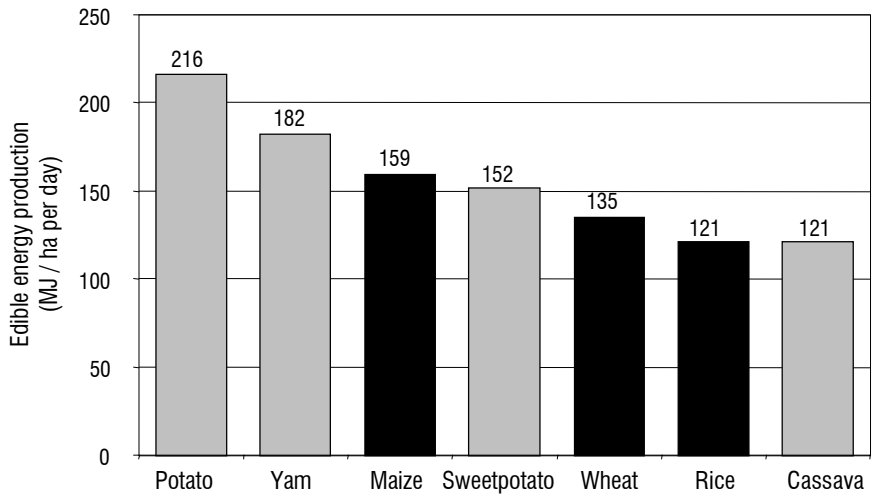
Figure 1. Projected growth rates for major food crops in developing countries, 1993–2020.



Source: IFPRI's IMPACT simulations, high demand/production growth scenario, as presented in Scott, Rosegrant, and Ringler (2000).

[a] Disaggregated growth rates for sweetpotato (1.0) and yam (2.9) are estimated outside IFPRI's IMPACT, but calculated based on those simulations and historical trends.

Figure 2. Production of edible energy from roots, tubers, and major cereal crops.



Source: Horton and Fano (1985).

Table 3. Projected regional distribution of root and tuber production in 2020.

	Cassava[a]		Potato		Sweetpotato[b]		Yam[b]		All R&T	
Country/region	**2020** (million mt)	**(%)**	**2020** (million mt)	**(%)**	**2020** (million mt)	**(%)**	**2020** (million mt)	**(%)**	**2020** (million mt)	**(%)**
China	6.6	2.3	87.8	45.3	136.0	82.2	-	-	230.4	32.2
Other East Asia	0.0	0.0	3.3	1.7	1.1	0.7	-	-	4.4	0.6
India	7.1	2.4	43.3	22.3	1.3	0.8	-	-	51.7	7.2
Other South Asia	1.3	0.4	7.7	4.0	0.7	0.4	-	-	9.7	1.4
Southeast Asia	48.2	16.6	2.3	1.2	8.0	4.8	…[c]	...	58.5	8.2
Latin America	42.0	14.5	20.2	10.4	2.5	1.5	1.2	1.9	65.9	9.2
W. Asia/N. Africa	0.2[d]	0.1	23.4	12.1	0.2[d]	0.1	...[e]	...	23.9	3.3
Sub-Saharan Africa	183.8	63.3	6.0	3.1	15.6	9.4	62.4	98.1	267.7	37.5
All Developing	290.3	100.0	194.0	100.0	165.4	100.0	63.6	100.0	714.6	100.0

Source: IFPRI's IMPACT simulations, high demand/production growth scenario, as presented in Scott, Rosegrant, and Ringler (2000). See also notes c, d, and e below.

Note: R&T= roots and tubers; ellipses (...) signify negligible data; na signifies not available; totals may not sum due to rounding. For country/region definitions see note, Table 2.

[a] These figures are for cassava and other roots and tubers such as taro. For developing countries, cassava alone accounts for over 97 percent of the total.

[b] The figures for 2020 for sweetpotato and yam are estimates calculated outside IFPRI's IMPACT, but based on those simulations and historical trends. See also note b Table 2.

[c] According to FAO (1999 April), only the Philippines produces yam and less than 30,000 mt on 5900 ha.

[d] FAO indicates very high yields in Egypt for a small area.

[e] According to FAO (1999 April), West Asia/North Africa (WANA) produces no yam and in 1992–94, Egypt produced some 128,000 mt of sweetpotato on 5100 ha.

how other, unintended groups might be affected; and, how these groups are linked in ways that should influence a research strategy.

There are several actors in the global food system that benefit from the sort of advances in roots and tubers that research can provide.

Producers constitute the largest group of people directly affected by research and development outputs. Their diets, health, and incomes are the principal focus of these endeavors. They are typically farmers with small holdings, on less-favored or marginal lands, and at the lower end of the economic scale, but also include farm workers and their families who help cultivate and transform these crops.

Processors, manufacturers, and traders are fewer in number, compared to producers and consumers, but they have important links to those who grow and those who use these crops. Furthermore, they manage many of the resources that can influence demand for the products farmers can offer in the marketplace. They are catalysts in the global food system, and they should be integrated into a research and development strategy.

Consumers of roots and tubers include those who make traditional use of food and feed as well as those who use products derived from processing, such as starch (Bricas and Attaie, 1998; Hermann and Heller, 1997; Nweke, 1992; Woolfe, 1987, 1992) in one way or another. The consumer market includes practically everyone, for starch from roots and tubers is used in pharmaceuticals, paper, and textiles (dTp Studies, Inc., 1998). We focus here though solely on the consumer benefits from research at the direct-use or basic processing levels.

Research and development has the potential to strongly impact the **providers of products and services** that surround the world of roots and tubers. Employment of landless labor, for example, is critical for potato production in South Asia; the starch industry in southern Brazil is a growing market for manufacturers of industrial machinery; women in Sub-Saharan Africa in particular often look to root and tuber crops as a source of food and income. Agricultural research can shape its products

Production systems for roots and tubers

Roots and tubers are found in a wide variety of production systems and do well under various levels of management, from low-input systems to high-input systems. This is a distinctive feature of roots and tubers which makes them important for improving the productivity and richness of agro-ecosystems. Some prominent examples include the following.

- **Cassava** in Sub-Saharan Africa is often grown on marginal soils, under hot, rainfed conditions. Few purchased inputs are applied. Cassava is most often grown in association with other commodities such as maize or groundnuts. The crop takes from 8 to 12 months to mature and the roots may be left in the field for months after that as a form of in-ground storage. The roots are often processed prior to use or sale for human consumption.
- **Potato** production has expanded most rapidly in the subtropical lowlands, e.g. West Bengal in India during the cool, dry, winter months, where the crop is grown as a monoculture under irrigated conditions, utilizing hefty doses of chemical fertilizers and pesticides, and in tight crop rotations with rice. The tubers are harvested 110–130 days after planting with the bulk of the output sold fresh for cash.
- **Sweetpotato** in Asia is cultivated predominantly under lowland conditions. One common system involves a variety of different rotations with rice. In this system, the crop is irrigated and harvested at maturity after four to five months. Long grown as a food security or famine crop, sweetpotato is increasingly cultivated for cash where both vines and roots are processed into feed or starch prior to sale.
- **Taro** is locally important in many parts of the humid tropics and subtropics. Taro is often intercropped with corn, beans, sugarcane, fruit trees, and vegetables in the rainfed and irrigated uplands, or with rice in the paddy fields, or is rotated with winter crops such as garlic and broad bean.
- **Yam** is cultivated predominantly in the humid forest, forest/savanna transition, and the southern Guinea savanna (SGS) zones of West Africa with most of the current production in the SGS. It is grown as the sole crop or in various combinations with maize, vegetables, cassava, plantain, sorghum, or coffee. The crop matures in 7 to 12 months, depending on species and cultivar, and the tubers may be stored in fresh form for over six months under ambient conditions.

to explicitly influence the service sector, and that influences the relationship between this sector and producers and consumers.

It is difficult to make generalizations about the interaction between roots and tubers and **the environment**, but one common feature is the need for soil disturbance at harvest, which in some cases can encourage erosion. Cassava can be (and is) grown on low-fertility, erodible hillsides (Howeler, Oates, and Costa Allem, 1999), potato on highland slopes in fragile ecosystems. Potatoes may also (and do) need frequent applications of pesticides, with exposure to these chemicals a concern for human health (Crissman, Antle, and Capalbo, 1998). As roots and tubers are sought more as sources of starch, the risk of pollution from a high concentration of small processing plants in particular locations increases (Goletti, Rich, and Wheatley, 1999). Some root crops, most notably sweetpotato, offer the promise of environmental benefits—in this case by being planted as quick cover crops to reduce soil erosion.

All food crops are constantly evolving, not only in terms of their genetic makeup but also their social, economic, and environmental relationships with the people who grow, sell, and consume them. That truism applies even more emphatically to cassava, potato, sweetpotato, yam, and other roots and tubers. These plants play multiple, changing roles as food and industrial economies evolve in response to population growth and relocation, changes for better or worse in financial well-being, pressures on the environment, and claims for recognition from women, community groups, and farmers insisting on a role in the research process.

Roots and tubers will continue to provide basic food security (as in Africa), but they increasingly will function as sources of income (as in parts of Asia, Africa, and Latin America). As foods of the new urban majority, they will provide diversity in the diet: as a vegetable for some, a basic calorie source for those less affluent, and an additional source of essential vitamins (vitamins A and C) and minerals for many. Producers are increasingly inclined to exploit their potential as animal feed, as sources of starch and specialty foods, and as competitors for grains (Best, 1996). All this requires integration of supply and demand, as well as capitalizing on growing commercial demand for processed food, feed and intermediate products such as starch. Ensuring that food security and income benefits reach all the target groups requires a careful integration of research, and that must include the non-target groups who serve as important catalysts—the processors and traders. All these needs for multifaceted research are especially important because, with few noteworthy exceptions in the case of potato, the private sector has demonstrated a relatively low level of involvement in roots and tubers.

As a complement to the projections of future aggregate supply, Table 4 presents an overview of selected, major

An overview of cassava in Africa *by Felix Nweke.*

In 1993–1995, 84 million mt of cassava were produced per year in Sub-Saharan Africa. Of this, 75 percent was produced in four countries: Nigeria, 31 million mt; the Democratic Republic of Congo, 19 million mt; Tanzania, 7 million mt; and, Ghana, 6 million mt. In the same period, 95 percent of cassava production (after discounting for waste) was used for human consumption, according to FAO. The remaining 5 percent was used for feed; use for industrial raw material or export was minimal.

The Collaborative Study of Cassava in Africa (COSCA)* shows that cassava serves multiple roles: it is a family food staple in producing countries; it is a famine-reserve crop in countries such as Tanzania, where rainfall is uncertain; and, is a cash crop in Ghana and Nigeria, where improved processing and food preparation methods are used to prepare the cassava roots for sale in urban markets. In both Nigeria and Ghana, an average of 45 percent of total cassava fields are planted for sale, which is higher than the percentage for other staples. The remaining 55 percent of the cassava fields are planted for home consumption. Cassava production is the most important source of income in the cassava-growing areas of Nigeria and Ghana. To realize cassava's potential as an income-generating crop in Africa, opportunities now exist for diffusing the best practices for cassava processing and food preparation found in Ghana and Nigeria to other countries in order to satisfy the mushrooming demand for food in urban and rural areas.

*The COSCA study was a multinational and multi-institutional study carried out during 1989–1997 under the leadership of the International Institute of Tropical Agriculture (IITA) and funded by the Rockefeller Foundation and IITA.

Table 4. Selected markets for roots and tubers in 2020 and their associated traits.

Market	Region (crop)	Factors driving growth	Priority areas for research[a]	Beneficiaries	CGIAR mission
Rural/urban starchy staple; leaves for protein[b]	Sub-Saharan Africa (cassava); West Africa (yam); West, South and East Asia (potato); Oceania (other roots and tubers)	Population growth	Stability in marginal areas; yield; processing; policy	Poor farmers and consumers	Food security; income
Urban vegetable	Metropolitan areas close to production (all crops)	Urbanization	Product quality; marketing	Farmers and consumers	Income
Competitor with grains for starch, flour, animal feed	Asia, Latin America (cassava, sweetpotato[c])	Income growth	Yield efficiency; soil management; processing; marketing; policy	Farmers; industry; non-farm labor	Income
Specialty markets (specialized starch, snack foods, leaves)	Asia, Latin America, West Africa (all crops)	Income growth	Product quality; processing; product development; marketing	Farmers; industry; non-farm labor	Income; biodiversity

Source: Compiled for this study.
Note: For country/region definitions see note, Table 2.
[a] In addition to these more market-specific research needs, there are research thrusts that go across all markets, such as integrated pest and disease management, or environmentally sound crop production practices.
[b] For cassava leaf (primarily for parts of West, Central, and Southern Africa, Brazil, and Indonesia) and sweetpotato stems, petioles, and leaves (primarily parts of West Africa and East Asia).
[c] Primarily for China and Vietnam.

markets for roots and tubers in 2020. This representation of the utilization of roots and tubers shows how their many dimensions relate to one another and to the CGIAR mission.

Our projections of the economic value of these commodities (Table 5) indicate that, based on the best available information to date, they are likely to sustain their importance in the decades ahead. It is noteworthy that these calculations take into consideration the production of nearly all the major food commodities in the global food system: cereals, roots and tubers, soybean, and meat. Roots and tubers' share of the total value of these products in 2020 is projected to remain at 10.5 percent of that total, identical to the estimated value in the base period 1993.

What the CGIAR brings to the vision

If roots and tubers are already projected to remain an important component in the global food system, it might be asked, why is the CGIAR's help needed? The answer lies in the unique set of assets and activities of the CGIAR. When the CGIAR's founders looked around the world of 30 years ago, they saw a place that faced the distinct possibility of widespread famine. They also saw looming gaps in agricultural research and development that had to be filled. Their vision to alleviate poverty and improve food security resulted in the justly celebrated assets of the CGIAR today:

- well-characterized germplasm collections
- plant varieties with value-added traits
- collections of the major pests and pathogens and the beneficial organisms that control them
- databases and other accumulated knowledge on field production and management, and on postharvest processing and market development
- innovative research facilities that range from the well-lighted laboratory to the tiniest village's community meeting hall—from the latest techniques in molecular biology to the newest methods of farmer participation in research
- a dedication to scientific excellence and fair-mindedness that have given the CGIAR and its constituent organizations reputations as honest

Table 5. Total value of selected food commodities for developing countries, 1993 and 2020.

Commodity	1993[a]				2020			
	Price (US$/mt)	Production (million mt)	Value (million US$)	(%) of total	Price (US$/mt)	Production (million mt)	Value (million US$)	(%) of total
Potato	160	94.3	15,094	4.1	145	194.0	28,131	4.9
Sweetpotato and yam	91[b]	155.9	14,185	3.9	82[b]	230.2	18,879	3.3
Yam	135[c]	31.2[c]	4,209[c]	1.1[c]	115[c]	66.9[c]	7,693[c]	1.4[c]
Cassava[d]	54[b]	172.4	9,307	2.5	48[b]	290.3	13,937	2.4
All roots and tubers		**422.6**	**38,586**	**10.5**		**714.6**	**60,946**	**10.5**
Wheat	148	249.3	36,901	10.0	133	372.7	49,575	8.6
Maize	126	231.6	29,181	7.9	123	390.1	47,977	8.3
Other grains	122[b]	105.9	12,912	3.5	106[b]	171.1	18,133	3.1
Rice[e]	286	341.4	97,628	26.5	266	475.6	126,510	21.9
All cereals		**928.1**	**176,622**	**48.0**		**1,409.5**	**242,195**	**41.9**
Soybean	**263**	**57.7**	**15,176**	**4.1**	**235**	**106.2**	**24,958**	**4.3**
Sub total			**230,384**				**328,099**	
Beef	2,023	22.1	44,583	12.1	1,771	43.9	77,805	13.4
Pork	1,366	39.3	53,624	14.6	1,212	81.3	98,594	17.0
Sheep and goat meat	2,032[b]	6.0	12,225	3.3	1,845[b]	10.7	19,815	3.4
Poultry	1,300	21.0	27,321	7.4	1,159	46.8	54,253	9.4
All meats		**88.3**	**137,752**	**37.4**		**182.8**	**250,467**	**43.3**
Total			**368,136**	**100.0**			**578,567**	**100.0**
Percent share of R&T in all commodities				**10.5**				**10.5**
Percent share of R&T in cereals + R&T + soybean				**16.7**				**18.6**

Source: IFPRI's IMPACT simulations, high demand/production growth scenario, as presented in Scott, Rosegrant, and Ringler (2000a).
Note: R&T = roots and tubers; totals may not sum due to rounding.
[a] Average for the three years; 1993 equivalent to 1992–94.
[b] Composite price.
[c] Prices, production, and growth rates for yam alone are estimated outside IFPRI's IMPACT, but based on TAC (1996, 1997a), IMPACT simulations and historical trends.
[d] These figures are for cassava and other roots and tubers such as taro. For developing countries, cassava alone accounts for over 97 ercent of the total.
[e] Production figures for rice have been multiplied by 0.65 to estimate the quantities of milled rice listed. Milled rice is more readily comparable to the other commodities for the purposes of calculating production. Similarly, these prices are for milled rice.

brokers and capacity-builders among its partner organizations

- the ability, thanks to the CGIAR system's uniquely international nature, to serve as the transfer point for information across frontiers or between developing countries and advanced laboratories in developed countries.

These assets pertain to any of the commodities with which the CGIAR organizations are associated–roots and tubers among them. Our best attempt at a vision for roots and tubers, however, clearly shows that the well-being of these crops and their contribution to future food security and poverty elimination can benefit most from the CGIAR's continued and enthusiastic involvement.

Need for a systems approach

In roots and tubers perhaps more than other commodities, these contributions are best considered in a systems framework covering production through to utilization and policy.

- The backbone of the CGIAR is the **value-added germplasm** that it conserves and maintains. It is this germplasm that can stabilize or increase yields or quality, and that leads directly to greater food security and income. The CGIAR Centers hold in trust, for the public good, the world's largest collections of cassava, potato, sweetpotato, and yam. CIP also holds collections of several other root and tuber crops. These responsibilities should continue to 2020 and beyond. Nevertheless, the collections are still incomplete, and collection and characterization —especially of the crops' wild relatives— needs to continue. Compared to cereals and some grain legumes, roots and tubers, with the possible exception of potato, lag behind in terms of our basic knowledge and exploitation of their genetic diversity. It is likely, too, that by 2020 there will be a wide range of commercially available transformed and patented genotypes. Their availability in developing countries may depend on negotiated agreements in which the CGIAR plays important parts.

- Certainly by 2020 there will be advances in molecular techniques that will make it possible to better manage pests and diseases and **practice environmentally sound production methods**. But history has shown that pests and pathogens have a near-perfect record of outwitting whatever science can throw at them. Maintaining crop competitiveness, yield sustainability, and adequate environmental protection will require continued investment in pest and disease research. The CGIAR Centers, with their sources of genetic diversity, their location in the crops' centers of origin, and their scientists who are expert in pest and disease research, are well placed to undertake such research. Important here also is the CGIAR's ability to disseminate the results of its research among national agricultural research systems.

- **Post-production research** on roots and tubers is a recent but important addition to the CGIAR agenda, albeit at relatively low levels of investment compared to production-related research. The linking of root and tuber farmers and processors to growth markets is a key to achieving our vision for these crops, particularly for cassava and sweetpotato. This is especially true in the more isolated, marginal areas of the developing world, situated far from growing urban markets. Exploiting market opportunities for cassava- and sweetpotato-based products through new product development research will be fundamental requirements of our global research strategy. There is a need for the parallel dissemination of business and management skills for root- and tuber-based enterprises. It is likely that by 2020, these opportunities will be recognized by the private sector, and research and development will enjoy private funding. Given the limited resources in this area in national agricultural research institutes, what is needed now are catalysts and champions to, as Plucknett, Phillips, and Kagbo (1998:12) indicate, "keep the needs of industry before the public and decision makers…[and]…for research and development, provision of infrastructure and investments, and changes in policies to grasp the new opportunit[ies]."

- The CGIAR excels at dealing with **institutions and policy** across a wide range of actors, including governmental, nongovernmental, and private sectors, and gathering those actors around a common research and development agenda. This is an asset that needs to be strengthened in the future. For example, recent research has highlighted the importance of policies in both developed and developing countries to catalyze continued increases in production and utilization of root and tuber crops in Asia, Africa, and Latin America (dTp Studies, Inc., 1998; Scott, Rosegrant, and Ringler, 2000a; Spencer and Associates, 1997). For example, developed countries should eliminate trade barriers to root and tuber imports from developing countries, who in turn should remove subsidies on substitute products in domestic markets. At a minimum, the CGIAR should be able to draw upon expertise from within and outside its own doors; develop relevant strategic research projects that seek solutions to common problems; and analyze and synthesize across cases for the development of tools that can be used by partners to design and execute successful research and development projects.

In the current configuration, five different CGIAR Centers undertake root and tuber research. The three principal root and tuber Centers account for over 95 percent of the total CGIAR budget for these commodities. They are: CIAT, with headquarters in Colombia, which works on cassava for Latin America and Asia; CIP, in Peru, which has the global mandate on potato, sweetpotato, and Andean roots and tubers; and, IITA, in Nigeria, which works primarily in Sub-Saharan Africa on cassava and yam. Additional, complementary work on food policy research is done by IFPRI, with headquarters in the United States. IFPRI's mandate is not specific to roots and tubers, but it places those crops in the wider context of production, utilization, and trade. IPGRI, in Italy, focuses on genetic resources. This includes research on Andean roots and tubers in Latin America and the Caribbean,

Table 6. CGIAR research projects on roots and tubers and their budgets, 1998.

Center, project title	Commodity	Budget[a] US$ million
CIAT		
Integrated conservation of neotropical plant genetic resources	Cassava	
Assessing and using agro-biodiversity through biotechnology	Cassava	
Genetic enhancement of cassava	Cassava	
Integrated pest and disease management in major tropical agro-ecosystems	Cassava	
Assessment of past and expected impact of agricultural research	Cassava	
Linking smallholders to growth markets for improved resource management	Cassava	
Integrating improved germplasm and resource management for enhanced crop and livestock production	Cassava	
		6.96
CIP		
Integrated control of late blight	Potato	
Integrated control of bacterial wilt	Potato	
Control of potato viruses	Potato	
Integrated management of potato pests	Potato	
Propagation of clonal potato planting materials	Potato	
Sexual potato propagation	Potato	
Global sector commodity analysis and impact assessment for potato	Potato	
Potato production in rice-wheat systems	Potato	
Conservation and characterization of potato genetic resources	Potato	
		15.9
Control of sweetpotato viruses	Sweetpotato	
Integrated management of sweetpotato pests	Sweetpotato	
Postharvest utilization of sweetpotato	Sweetpotato	
Breeding for high dry matter in sweetpotato	Sweetpotato	
Global sector commodity analysis and impact assessment for sweetpotato	Sweetpotato	
Conservation and characterization of sweetpotato genetic resources	Sweetpotato	
		5.0
Conservation and characterization of Andean roots and tubers	Andean roots and tubers	
		0.8
IITA[b]		
Cassava productivity in the lowland and mid-altitude agro-ecologies of Sub-Saharan Africa	Cassava	
Integrated management of cassava pests and diseases	Cassava	
		9.4[b]
Improvement of yam-based production systems	Yam	
		2.8[b]

Contd.

Contd.

Improving postharvest systems	Cassava and yam	
Molecular and cellular biotechnology for crop improvement	Cassava and yam	
Conservation and genetic enhancement of plant biodiversity	Cassava and yam	
Short fallow stabilization	Cassava and yam	
Agro-ecosystems development strategies	Cassava and yam	
Farming systems diversification	Cassava and yam	
IFPRI		
CGIAR micro-nutrients project	Cassava	
Starch industry development as a strategy for agro-food based rural industrialization	Cassava and sweetpotato	
Policy options for using livestock as a strategy for rural income diversification	Cassava and sweetpotato	
Policies for improved land use management in Uganda	Cassava and sweetpotato	
Ending hunger in the 21st century	All roots and tubers	
Global water resources and food security	All roots and tubers	
2020 vision for food, agriculture, and the environment	All roots and tubers	
		0.24[c]
IPGRI[d]		
Support to plant genetic resources programs and regional networks in the Americas	Andean roots and tubers, cassava and potato	
Support to plant genetic resources programs and regional networks in Europe	Potato	
Support to plant genetic resources programs and regional networks in Asia, the Pacific and Oceania	Sweetpotato, taro and yam	
Support to plant genetic resources programs and regional networks in Sub-Saharan Africa	Yam	
CGIAR genetic resources support program	Cassava, potato, sweetpotato and yam	
Ex situ conservation technologies and strategies	Cassava, potato, sweetpotato, taro and yam	
Locating and monitoring genetic diversity	Taro	
In situ conservation of crop plants and their wild relatives	Taro	
Human and policy aspects of plant genetic resources conservation and use	Taro	
Support to plant genetic resources programs and regional networks in West Asia and North Africa	Roots and tubers	
Global capacity-building and institutional support	Roots and tubers	
Promoting sustainable conservation and use of genetic resources	Roots and tubers	
Linking conservation and use	Roots and tubers	
Information management and services	Roots and tubers	
Public awareness and impact assessment	Roots and tubers	
		2.9
Total		**44.0**

Source: Compiled for this study.
[a] Based on 1998 Center budgets; includes overheads.
[b] These figures are estimates drawn from different research projects as IITA does not break down its budget by commodity.
[c] This figure is an estimate as IFPRI does not break down its budget by commodity.
[d] Some of these projects include work on aroids such as taro and Andean roots and tubers.

aroids in East Asia and the Pacific region, and sweetpotato in Asia. These activities are currently carried out in some 35 projects at a cost of about US$44 million (Table 6). This figure represented 14 percent of the total CGIAR budget in 1998, a percentage that has remained fairly constant since 1972 (Figure 3). A series of impact studies have found these investments have paid very high rates of return (Fuglie et al., 1999; Johnson, 1999; Norgaard, 1988; Walker and Crissman, 1996).

To these contributions must be added another that is distinctively fundamental to the CGIAR's modus operandi and infrequently found elsewhere: working together. CGIAR scientists do this in two ways that are central components to our vision. First, they participate in a number of research and development networks, consortia, and initiatives alongside scientists from national agricultural research institutes and collaborators from organizations in developed countries (see also Annex, Section 6).** These organizations cover a broad range of topics and geographic regions (Table 7). Prominent examples are the Cassava Biotechnology Network (CBN); the User's Perspective with Agricultural Research and Development network (UPWARD); the Eastern Africa Rootcrop Research Network (EARRNET); the System-wide Genetic Resources Programme (SGRP); and, the recently launched CGIAR initiative on Urban Agriculture.

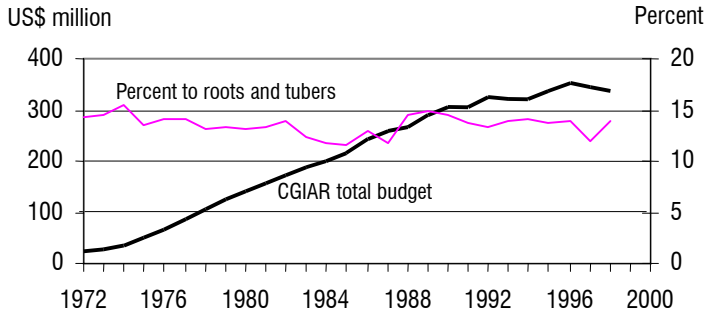
** In addition, the Centers support and participate in a number of professional societies to encourage research on roots and tubers in developing countries. Prominent examples include the International Society for Tropical Root Crops (ISTRC) with its regional branches, the African Potato Association (APA), and the Asociación Latinoamericana de la Papa (ALAP).

Second, complementarity and synergy among the CGIAR staff and the private sector is a key to bringing the best of science to the beneficiaries we seek to assist. Activities where complementarity and synergy already make the CGIAR system more effective in root and tuber research include (but certainly are not limited to) germplasm management (ranging from seed generation of vegetatively propagated crops to *in vitro* collection techniques) at IPGRI, CIAT, CIP, IITA, and their partners; genetic improvement at CIAT, CIP, IITA, and members of different biotechnology networks; studies of starch, the carbohydrates which roots and tubers produce very efficiently, at CIAT, CIP, IITA, and IFPRI; and, integrated pest management (from whitefly to soil pathogens to cassava bacterial blight) at CIAT, IITA, CIP, International Centre for Insect Physiology and Ecology (ICIPE), Asian Vegetable Research and Development Center (AVRDC), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and other Centers.

There are four major areas covering interrelated aspects of the food systems for these commodities within which the Centers' expertise, channeled through partnerships and collaborative efforts, can be particularly useful in realizing the future potential of roots and tubers.

- The vegetative propagation of the root and tuber crops presents a wide range of common problems, but also some opportunities. The problems include transmission of many pests and pathogens from one generation to another; quarantine complications; low rates of multiplication; bulkiness; and, perishability of planting material. Cryopreservation of germplasm is one common area of work with similar techniques applicable to all these crops. Collaboration on the

Figure 3. Annual total CGIAR budget and percent spent on roots and tubers, 1972–1998.



Source: CGIAR Secretariat.

Table 7. CGIAR networks, initiatives, and programs that include work on roots and tubers.[a]

Network	Commodity	Centers
Asian Cassava Research Network	Cassava	CIAT[b]
ANSWER (Asian Network on Sweet Potato Genetic Resources)	Sweetpotato	IPGRI, CIP
AHI (African Highlands Ecoregional Program)	Potato	CIP
CBN (Cassava Biotechnology Network)	Cassava	CIAT[b], IITA
CMPGR (Caribbean Committee for the Management of Plant Genetic Resources)	Roots	IPGRI[c]
CONDESAN (Consortium for the Sustainable Development of the Andean Ecoregion)	Potato and Andean roots and tubers	CIP
EARRNET (Eastern Africa Rootcrop Research Network)	Cassava	IITA
EPHTA (Ecoregional Program for the Humid and Sub-humid Tropics of Africa)	Cassava, yam and other roots	IITA[b]
FOODNET (Postharvest and Marketing Research Network for Eastern and Central Africa)	Cassava and sweetpotato	IITA[d], CIP
Global experiment on *in vitro*/slow growth of sweetpotato	Sweetpotato	IPGRI
GILB (Global Initiative on Late Blight)	Potato	CIP[b]
The Global Mountain Program	Potato and Andean roots and tubers	CIP[b]
GRENEWECA (Genetic Resources Network for West and Central Africa)	Roots and tubers	IPGRI
Manihot Genetic Resources Network	Cassava	CIAT[b]
CGIAR Micro-nutrients Project	Cassava	IFPRI[b], CIAT
Pan-American Network for Cassava Improvement	Cassava	CIAT[b]
PRAPACE (Regional Potato and Sweetpotato Improvements Program for Eastern and Central Africa)	Potato and sweetpotato	CIP[b]
PRECODEPA (Programa Regional Cooperativo de Papa)	Potato	CIP[b]
PRGA (Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation)	Roots and tubers	CIAT, CIP, IFPRI, IITA, IPGRI
RECSEA-PGR (Regional Collaboration in Southeast Asia on Plant Genetic Resources)	Roots and tubers	IPGRI
REDARFIT (Andean Network on Plant Genetic Resources)	Roots and tubers	IPGRI[c], CIP
REMERFI (Mesoamerican Network of Plant Genetic Resources)	Roots and tubers	IPGRI[c]
SARRNET (Southern Africa Rootcrop Research Network)	Cassava and sweetpotato	IITA[b], CIP

Contd.

Contd.

SGRP (System-wide Genetic Resources Programme)		IPGRI[b],
	Cassava	CIAT
	Potato, sweetpotato and Andean roots and tubers.	CIP
	Cassava and yam	IITA
SPGRC (Southern African Development Community [SADC] Plant Genetic Resources Centre)	Roots and tubers	IPGRI
UPWARD (User's Perspective with Agricultural Research and Development)	Potato and sweetpotato	CIP[b], CIAT
Urban Agriculture Initiative		CIP[b], CIAT

Source: Compiled for this study.
[a] Many of these networks, initiatives, and programs include participation by one or more CGIAR Centers than those listed here. This list is intended to indicate those Centers who participate in these activities for work specifically on root and tuber crops.
[b] Convening Center.
[c] Subregional networks on plant genetic resources in the Americas. Most of them are the result of collaboration between IPGRI, Instituto Interamericano de la Cooperacion para la Agricultura (IICA), and other partners including Centro Agronomico Tropical de Investigacion y Enseñanza (CATIE).
[d] Executing Center.

documentation associated with germplasm characterization, the movement of germplasm across international borders, and the development of effective policies to help protect the property rights of national programs while facilitating the exchange of materials merits a continued, coordinated effort.

- The root and tuber crops produce large quantities of starch (edible energy) in relatively less time than other crops, although each of them also provides other important nutrients. This starch content endows these crops with an extraordinary range of potential end uses; already it is employed in manufacturing monosodium glutamate and plywood in Thailand, and sorbitol, manitol, and noodles in China. Priority areas for coordinated future investigation include i) root and tuber processing and enterprise development involving CIAT, CIP, and IITA in Sub-Saharan Africa; ii) cassava and sweetpotato for processed food, animal feed, and starch in East and Southeast Asia involving CIAT, CIP, and IFPRI. In the former instance, over 80 percent of the total increase in supply and demand for cassava in developing countries is projected to occur in Sub-Saharan Africa (Table 2). Virtually all of the increase in yam output, a large share of the increase in sweetpotato production, and a sizeable proportion of the additional supply of other roots and tubers e.g. taro and cocoyam, are also projected to occur in this region.

  Achieving or surpassing that projection will depend certainly in part on the ability of farmers and entrepreneurs to provide more processed food products to meet growing food requirements in both the countryside and towns. East and Southeast Asia is the second largest area for cassava production in the developing world, and the largest by far for sweetpotato. Combining limited resources and comparative areas of expertise within CIAT, CIP, and IFPRI to exploit commercial opportunities for starch-based and animal feed products plus capacity-building in the area of small agro-enterprise development, and drawing in additional partners is highly complementary.

- Many of the tools of biotechnology are broadly applicable across species, including the aroids and Andean roots and tubers. Molecular research into tomatoes, for example, is expected to increasingly benefit their relatives in the potato fields; a similar linkage exists between research on *Hevea brasiliensis* (natural rubber) and *Manihot esculenta*. It is increasingly obvious that the sort of biotechnology research that is being done by industry in the developed countries does not see the developing world as its primary beneficiary. There is, and will continue to be, a need for researchers such as those of the CGIAR who appreciate the needs of the less-affluent world. An example is the late blight pathogen in potato. The CGIAR's approach to *Phytophthora infestans*, which emphasizes integrated pest management, is quite different from that of the multinational seed and chemical companies. By working together in genomics—a new science applicable to humans, livestock, and plants that permits sequencing and mapping of the genome (a

genetic map of a living organism)—the Centers working on roots and tubers can capture economies of scale in developing the basic tools in this fast-moving and costly area of research.

- Institutional and policy issues, including those related to commodity projections, the underlying databases on which those calculations are based, as well as work in the area of market analysis and trade policy, constitute another area for synergy among the Centers, drawing upon their respective areas of expertise that each individually cannot afford. From the institutional perspective, the Global Cassava Development Strategy that International Fund for Agricultural Development (IFAD) has been leading, with the very active participation of the cassava IARCs (international agricultural research centers), is an example of trying to gather actors around a common agenda. This process of consensus building might be adopted for root and tuber crops as a whole through the work of the Committee on Inter-Centre Root and Tuber Crop Research (CICRTCR – see Preface) itself.

We believe that there are other areas that will continue to emerge in the future that will justify closer interaction between two or more Centers (see Annex, Section 7). However, we believe that the above-mentioned deserve top priority.

Conclusions

It is clear from our vision that the root and tuber crops will remain a vital component of the global food system in the world of 2020. All the trends show this. It also is clear that these commodities, the farming systems in which they are produced, and the people who produce, process, and consume them will value and depend on roots and tubers in the decades ahead. This is particularly true for many of the world's poorest and most food-insecure households.

Root and tuber crops provide a wide variety of beneficiaries with the basic needs: food, employment, and income. Continuing to meet these needs will become more of a challenge in the future as more people populate the Earth. However, as the roles of these commodities in the global food system evolve, the differences across crops (such as potato and yam for food in fresh form versus sweetpotato and cassava for processed foods, starch-based products, and feed; cassava production in Sub-Saharan Africa versus potato in Asia) will become more conspicuous. Specialization in end use, i.e. fresh versus processed, will become more pronounced by commodity.

Production of roots and tubers will increase, and they will maintain their relative economic importance versus the other major food commodities. The growth rates projected for cassava, potato, and yam actually exceed those for the major cereals such as rice and wheat. With continued population growth and partly as a result of food systems in poorer areas of Asia, Africa, and Latin America coming under increasing stress, considerations like the capability of roots and tubers to produce more carbohydrates per hectare per day than other food crops, and also to yield well even under adverse growing conditions, will loom all the more important in the decades ahead. These projections therefore engender a real sense of the value of continued support to realize that potential and to capture the projected benefits for developing countries, most notably poverty eradication and improved food security. Consequently, support from the CGIAR to enable the member Centers to help realize the associated benefits becomes all the more critical in terms of the implications for the global food system. With that continued support comes the challenge to the Centers to prioritize and exploit synergies.

Recommendations

Given the projected increases in supply and demand, the importance of roots and tubers in developing countries is unlikely to diminish by 2020 or long afterward. In order to attain food security and the eradication of poverty, it is fit, proper, and necessary for the CGIAR as well as other national, bilateral, and multinational organizations to retain these crops as an integral part of a global strategy to improve food production and utilization in Asia, Africa, and Latin America in the decades ahead.

Having considered a variety of alternative organizational arrangements for research on roots and tubers, we have identified the following three future scenarios.

- **Continued informal collaboration.** The first of our scenarios would build on the existing organization but modify it to reduce the effects of its vulnerabilities. The role of the CICRTCR would be strengthened, converting it to a permanent mechanism for incorporating the views and needs of our partners. Each Center would dedicate resources to a common fund for financing or "seeding" projects of common interest in program areas that had been assigned high priority. The collaborative projects could either be commissioned by the CICRTCR itself or generated through a competitive bidding mechanism. Under this scenario, there would be organizational adjustments within the individual Centers in terms of both inter-Center relations and the costs of projects.

- **A global collaborative root and tuber program.** A convening Center would oversee a wide range of global collaborative root and tuber research that would constitute the System-wide Root and Tuber Crop Program (SRTCP). The SRTCP would be governed by a directing committee drawn from the participating Centers and from non-CGIAR organizations and national and regional representatives with interests in root and tuber research. This committee would construct a common planning, prioritizing, and evaluating framework that would be used to develop global, high-priority research projects in those specific areas where past experience has shown that individual Centers, and organizations outside the CGIAR, lack sufficient expertise or infrastructure to undertake singlehandedly, let alone capture, the gains from such endeavors. This would include work on biotechnology, post-production research (e.g. research on starch, feed, and agro-enterprise development), and institutions and policy.

  The specific intent would be to realize efficiencies and achieve greater impact by closer collaboration between Centers in these fields, as well as between the Centers and their collaborators in developed and developing countries. The SRTCP would provide an organizational mechanism whereby the potential breakthroughs related to research on root and tuber crops could be more effectively captured, to the benefit of small farmers and low-income consumers worldwide. These projects would constitute the global program. The projects would be funded by core resources from each participating Center, and managed by the global program. In this scenario, the SRTCP would not represent the totality of root and tuber research. Individual Centers would continue to mount their own projects in those areas where collaboration provides no benefits.

- **A root and tuber Center.** This is the most ambitious of the scenarios: unifying all research on roots and tubers in the CGIAR under the mandate of a single Center. It also would be the most costly in terms of its establishment, although in the medium term the transaction costs of collaboration among the existing Centers that presently do root and tuber research would be virtually eliminated. Creation of this Center would require the naming of a board and selection of management. We envisage the adoption of a decentralized approach to research and outreach, making use of the infrastructure already in place. Once the Center's research strategy had been established, the new organization would decide on placing research projects in the most appropriate existing facilities of the CGIAR Centers that presently are conducting root and tuber research, or other CGIAR Centers, or third party organizations.

At its annual meeting in Washington during International Centers' Week (ICW), October 1999, the CICRTCR reviewed these options and recommended the System-wide Root and Tuber Crop Program. This recommendation is now being considered by the respective Centers. It is envisioned that adoption of this scenario would have profound effects, not only on the CGIAR and its constituent members, but also on roots and tubers—the potato, sweetpotato, cassava, yam, and Andean crops—and the two billion plus people in developing countries who rely on them for their staple foods, for their livelihoods, and for even their survival. These are the most vulnerable people in the global society, and the CGIAR is one of the few organizations that consistently looks out for their interests.