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Roots and Tubers for the 21st Century

Trends, Projections, and Policy Options

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Foreword

The tremendous importance of roots and tubers as a source of income for poor farmers and of food for the rural and urban poor is often overlooked in the debate about improving food security and eradicating poverty in developing countries. Hopefully, the analyses in this report, prepared jointly by the International Potato Center (CIP) and the International Food Policy Research Institute (IFPRI), will help give these crops appropriate consideration in future deliberations about the global food system at the national and international levels and thereby improve efforts to ensure access to sufficient food and income for all people.

The assessment of past trends, future prospects, and policy options reported here stems from the tradition of joint studies of roots and tubers in developing countries by the centers of the Consultative Group on International Agricultural Research (CGIAR). While this report builds on that previous collaboration, it also represents the first intercenter effort to produce future projections of demand and supply for these crops.

This research began as a project on potato and sweetpotato, but when a recent intercenter review of root and tuber crops in the CGIAR called for more formalized, albeit still informal collaboration in this area, this initiative became part of a larger activity involving not just CIP and IFPRI, but also the International Center for Tropical Agriculture (CIAT), the International Institute of Tropical Agriculture (IITA), and the International Plant Genetic Resources Institute (IPGRI). The focus of the work also expanded to include cassava and yam. In so doing, this report became the empirical foundation of a broader effort aimed at documenting not just trends and projections but also describing research activities and organizations with the overall objective of providing a vision for research on roots and tubers in the CGIAR.

Gregory J. Scott, Mark W. Rosegrant, and Claudia Ringler have synthesized a significant amount of data and information on roots and tubers in an effort to provide a clearer vision of their past, present, and future roles in the food systems of developing countries. How the production and use of these commodities have changed and will continue to change over time are all the more important to understand because of the contribution they make to the diets and income-generating activities of the rural and urban poor in Asia, Africa, and Latin America. This paper provides a fuller understanding of the prospects of roots and tubers for food, feed, and other uses in developing countries in the decades ahead. In that regard, the authors note that cassava, potato, sweetpotato, and yam will remain important commodities in the coming years, particularly in many of those poorer regions and countries that merit broader international support in their efforts to increase food production, reduce rural poverty, and improve food security while protecting the environment.

Per Pinstrup-Andersen Director General, IFPRI	Hubert Zandstra Director General, CIP

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1. Introduction

The world food situation has been the focus of a flurry of recent publications aimed at providing greater insights into the evolution of global food supply, demand, and trade over the next few decades (Alexandratos 1995, 1996, 1997; Alexandratos and Bruinsma 1998; Delgado et al. 1999; Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1999; Rosegrant, Agcaoili-Sombilla, and Perez 1995; TAC 1996, 1997a). Most of this analysis, however, has focused on the past performance and future prospects for cereals and livestock. This paper analyzes recent trends in and alternative projections of the supply, demand, and trade for roots and tubers (R&T). In doing so, it seeks to provide a clearer vision of the contribution that these crops can make to the food systems of developing countries through the year 2020. A key objective of this paper is to clarify and, as much as possible, to quantify the complexity and magnitude of that contribution.

In 1995–97, the major R&T—cassava, potato, sweetpotato, and yam—occupied about 50 million hectares worldwide. Farmers produced 639 million metric tons (mt) of these crops annually, 70 percent of which were harvested in developing countries.[1] (See Box 1 for an overview of the variety of R&T.) Around 250 million mt of R&T were eaten in Asia, Africa, and Latin America, and nearly 100 million mt, almost all of it potatoes, in developed countries. The remainder was used as animal feed, planting material, processed products (for example starch), and other purposes. Production of the major R&T in developing countries alone had an estimated annual value of more than US$41 billion in 1995–97, nearly one-fourth the value of the major cereals (Table 1).

Individually, cassava, potato, sweetpotato, and yam rank among the most important food crops worldwide and, in terms of annual volume of production, cassava, potato, and sweetpotato rank among the top 10 food crops produced in developing countries.

The Roles of R&T in Developing-Country Food Systems

Many of the developing world's poorest producers and most undernourished households depend on R&T as a contributing, if not principal, source of food and nutrition (see, for example, Alexandratos 1995, 100–102). In part, these farm households value R&T because R&T produce large quantities of dietary energy and have stable yields under conditions in which other crops may fail (Alexandratos 1995, 189). R&T produce remarkable quantities of energy per day, even in comparison to cereals. Potatoes lead the way in energy production, followed by yam (Figure 1). In addition, some R&T are an important source of vitamins, minerals, and essential amino acids such as lysine (Low et al. 1997; Spencer and Associates 1997; Woolfe 1987, 1992).

In many parts of Sub-Saharan Africa (SSA), R&T are a major source of sustenance. They account for 20 percent of calories consumed in the region (Table 2). In 31 African countries with annual cassava production of more than 10,000 mt each, annual per capita consumption averaged 140 kilograms (kg) during the last four decades (Phillips 1998). Consumption in production centers and among the rural poor in many parts of the region greatly exceed this figure. Per capita consumption levels for cassava and the importance of R&T in

[1] Unless cited otherwise, the source data on historic supply and demand of agricultural commodities is FAO 1999a (updated April 1999, accessed July).

Box 1: The Variety of Roots and Tubers

R&T are frequently grouped together because they are bulky, perishable, and vegetatively propagated. At the same time these crops are highly differentiated in terms of origin, production and nutritional traits, and use. More than 30 edible and nonedible species of R&T are grown today. Foremost among them in terms of aggregate output and estimated value of production are cassava, potato, sweetpotato, and yam. Potato, cassava, and sweetpotato originated in Latin America (Horton 1988). Yam includes some species that have moved from Africa to North and South America, and others that have traveled from Asia to Africa (Hahn et al. 1987).

Other prominent R&T include cocoyam, ginger, taro, and yam bean, as well as Andean R&T such as arracacha, mashua, oca, and ulluco. The latter group of plants is grown in the Andean region, other parts of South America, and East Asia. They are of minor importance globally in terms of total production and commercial value. Nevertheless, for particular countries, regions, or agroecologies, one or more of these other R&T can and do play an important role in food systems (Hermann and Heller 1997; Horton 1988).

The variation in R&T growth patterns and production requirements helps to explain how particular commodities wedged their way into distinct production systems and varied consumption uses. For example, while a potato crop grown under irrigation in the lowland subtropics can mature in 100–120 days, cassava can take 9 to 24 months (see Appendix, Table 24). However, potato production requires adequate and timely availability of water during the crop's vegetative cycle, whereas cassava can be cultivated under near drought-like conditions. Conversely, cassava has been used more often for processed products because, among other things, it has a higher starch content on average (27–36 percent) than potato (13–16 percent) or sweetpotato (18–28 percent) (Appendix, Table 25). Moreover, in spite of their bulkiness and perishability, most R&T have proven remarkably mobile over millennia. Other differences among R&T include such things as their enormously dissimilar genetics; the diverse strategies required for genetic improvement to take account of their variable production systems and end-uses; the distinctions between their pest and pathogen complexes; and the differences in their policy environment (see TAC 1997a, 20–24 for further details).

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

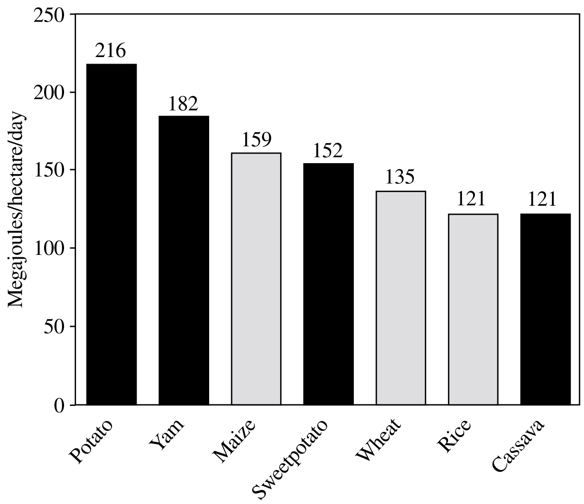
Commodity	Price (US$/mt)	Production (million mt)	Edible energy (trillion kilocalories)	Edible protein (million mt)	Value (billion US$)
Cassava	53	165.3	142	0.7	8.8
Potato	157	105.3	65	1.8	16.5
Sweetpotato	88	137.0	127	1.9	12.1
Yam	130	31.5	28	0.5	4.1
Major R&T		**439.1**	**362**	**4.9**	**41.4**
Maize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

Source: Basic data from FAO 1998a (FAOSTAT June 1998, accessed July 1998).

Note: Coefficients for calculating edible energy and protein are based on Horton 1988. Prices are based on estimates for 1993 and 2020 IMPACT baseline scenario (see Chapter 4) interpolated for 1995–97.

[a]Milled rice is more readily comparable to the other commodities for the purposes of comparing international prices.

Figure 1—Edible energy produced by major roots and tubers and cereals



Source: Horton and Fano 1985.

Table 2—Percentage of calories and protein from consumption of roots and tubers as food, 1983 and 1996

Country/region[a]	Calories 1983	Calories 1996	Proteins 1983	Proteins 1996
	(percent)			
China	8.5	5.6	4.2	2.7
Other East Asia	1.9	1.8	1.1	1.4
India	1.9	1.3	1.2	0.9
Other South Asia	1.7	1.3	1.0	1.0
Southeast Asia	5.7	4.3	1.8	1.4
Latin America	4.8	4.3	2.8	2.6
WANA	1.9	2.3	1.4	1.6
Sub-Saharan Africa	18.7	20.1	6.6	8.0
Developing	6.3	5.4	2.9	2.6
Developed	4.3	4.3	3.4	3.3
World	5.7	5.1	3.1	2.8

Source: FAO 1999b.

Note: 1983 is average for 1982–84 and 1996 is average for 1995–97 for all tables unless indicated otherwise; WANA is West Asia and North Africa.

[a] Other East Asia includes Hong Kong, Macau, Mongolia, North Korea, and South Korea. Other South Asia includes Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka. Southeast Asia includes Brunei, Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. Latin America covers Central and South America and the Caribbean. WANA includes 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 includes Central West, Eastern, Northern, and Southern Sub-Saharan Africa.

the diet of many Africans, particularly less-well-off consumers, have remained remarkably constant despite drought, famine, wars, political and economic instability, regional population growth rates that averaged nearly three percent per year during the last 30 years, and growing urbanization. In addition, cassava leaf is an important source of protein in many parts of West and Central Africa (Spencer and Associates 1997).

In much of Asia and Latin America, R&T provide an important, supplemental source of carbohydrates, vitamins, and amino acids in food systems that are dominated by other commodities. India, for example, is now among the world's largest potato producers, having achieved a phenomenal growth rate in potato production of 6 percent per year during 1962–96. India produced 25 million mt in 1997—a level surpassed only by China and the Russian Federation.[2] Nearly all of India's production is harvested in the cool, dry, winter months, when cereals are in seasonally short supply in many parts of the country, and often in water-scarce areas where irrigated rice cannot be cultivated. Similar trends in production growth (4.4 percent per year in 1962–96) have prevailed in Bangladesh, where results of a national rural nutrition survey carried out during 1981–82 showed that 15 percent of the vitamin C intake came from potatoes (Scott 1988a).

Production and use of R&T tend to be concentrated in countries with lower per capita incomes (Scott and Maldonado 1999). Within low-income countries, R&T frequently play a relatively greater role in the food systems in remote, often marginal, areas with particularly low income levels and limited access to farm inputs. Production and use of sweetpotato is thus more prominent in Sichuan province, China (Gitomer 1996), in eastern India (Dayal et al. 1995), or northern Uganda (Scott et al. 1999). Cassava is more prominent in northeast Brazil (Ostertag and Herrera 1992) and northeast

[2] On a per capita basis, 7 out of the world's 10 largest potato producers in 1997 were located in Eastern Europe and the Former Soviet Union.

Thailand (Titapiwatanakun 1998), and potato in the highlands of Guatemala (El Cid 1992) or Peru (Scott 1985). In addition to their role as local staples or complementary sources of energy, R&T serve as food security crops. They alleviate seasonal shortages and fill food gaps caused by natural or man-made disasters (see, for example, Tanganik et al. 1999).

More than simply food crops for the rural poor, R&T can also serve as sources of cash income for low-income farm households and raw material for processed products for both rural and urban consumption. Growth in the latter uses of R&T is relatively new and reflects the underlying dynamism of the R&T sector in many developing countries. In Africa, cassava, in addition to being a cheap, starchy staple, graduated from on-farm consumption to cash crop for sale to both urban and rural consumers (Nweke 1992; Nweke et al. 1994).

R&T have also increased in importance in Asia. Potato production in Asia now accounts for nearly 80 percent of total production in developing countries. Asia's share of global potato output soared from 7.5 percent in 1961–63 to 28.2 percent in 1995–97. With rapid economic growth in many parts of Asia, consumers have increasingly diversified their food intake from strictly cereal-based diets to greater consumption of potatoes, milk, meat, and other commodities. Empirical evidence shows that the overwhelming bulk of potatoes produced in Asia are sold for cash by small farmers (Scott 1997). High yields mean that on-farm food needs can be met by only a fraction of the harvest, with strong off-farm demand using the surplus.

Feed, processed food, and other, nonfood uses for cassava and sweetpotato have also expanded considerably in Asia over the last three decades (Pham et al. 1996; Scott 1992; Titapiwatanakun 1998). Rapid growth in demand for meat has created growth opportunities for producers in more remote areas to use R&T as animal feed. Such is the case for cassava in northern Vietnam (Nguyen 1996) and sweetpotato in Sichuan province, China (Huang 1999). Small farmers in China who have long cultivated sweetpotato as a food security crop, now process roughly half of their annual harvest of 118 million mt (1995–97 value) into animal feed. It is estimated that these farmers convert another 20 to 30 percent of annual sweetpotato output into starch for noodles and other processed products (Huang 1999; Timmins et al. 1992). In Vietnam during 1995–97, roughly 50 percent of the annual cassava harvest of 2 million mt was processed into feed and an additional 25 percent was used to make starch (Goletti, Rich, and Wheatley 1999).

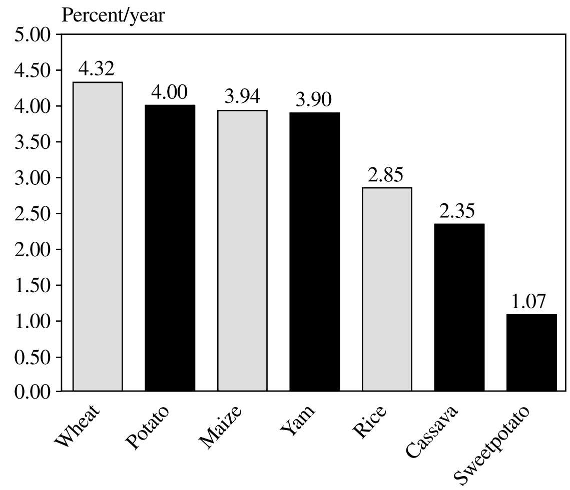
Roots and tubers also help alleviate poverty by providing employment opportunities in production, processing, and marketing. Farm surveys in Bangladesh (Scott 1988a), Egypt (Crissman et al. 1991), Colombia (Rodriguez 1996), and Rwanda (Braun, de Haen, and Blanken 1991), for example, found that potato production requires between 120 and 450 labor days per hectare per crop, work totals far greater than those for many other crops. In South Asia, jobs in potato production particularly help the landless, who make up a substantial percentage of the rural population (Scott 1988a). A recent study of the potato sector in Bolivia estimated that the crop generated over 12 million labor days per year nationwide (Zevallos 1997). Surveys on sweetpotato and cassava production have found that labor is the most important cost of production (see, for example, Achata et al. 1990; Pham et al. 1996; Cabanilla 1996). Root-crop processing for feed or starch also is often highly labor-intensive, thereby providing off-season employment and income to the rural underemployed (see, for example, Goletti, Rich, and Wheatley 1999; Nave and Scott 1992; Nweke 1992; Simpson, Cheng, and Miyazaki 1994; Timmins et al. 1992). Moreover, particularly in Sub-Saharan Africa, root and tuber production, processing, and marketing provides important income-earning opportunities for women (Gatumbi and Hagenimana 1998; Low 1998; Nweke 1992; Owori and Hagenimana 1998).

The role of R&T in developing-country food systems also raises interest about the impact of these crops on the environment. Recent case studies show instances of pesticide toxicity associated with potato production (Crissman, Antle, and Capalbo 1998); water pollution from cassava processing (Goletti, Rich, and Wheatley 1999); soil erosion linked to cassava cultivation (Howeler 1996); and loss of biodiversity for potato (Brush, Taylor, and Bellon 1992) and Andean roots and tubers (Hermann and Heller 1997) as a result of increased commercialization of production. But R&T also hold the promise of helping to alleviate environmental problems. Sweetpotato, for example, can serve as a quick cover crop to reduce soil erosion (Orno 1991). Production of potato using botanical or true potato seed can increase genetic diversity because each seed constitutes a distinct genetic entity (Upadhya et al. 1995).[3]

Production Performance of R&T

During the past four decades, developing-country food production policy has focused on achieving growth in wheat, rice, and, more recently, maize. With technological innovations resulting in high-yielding varieties of these basic staple foods, growth rates for cereal production in developing countries, and particularly in Asia, rose rapidly. Similar growth rates in production were achieved for potato and yam, particularly during the last two decades. Growth rates for cassava and sweetpotato were much lower (see Figure 2). The tendency to treat R&T as undifferentiated commodities has obscured their variable performance and clouded understanding of their future prospects (McCalla 1998). Furthermore, in contrast to cereals, growth rates for cassava, potato, and yam in developing countries were driven by an expansion in area planted rather than yields. Average yields for potato and sweetpotato in developed countries (cassava and yam are chiefly developing-country crops) remain well above those in developing countries, where yields fall far short of technically feasible levels. As the recent review of R&T by the Technical Advisory Committee (TAC) to the Consultative Group on International Agricultural Research (CGIAR) noted, ". . . one of the greatest similarities among root and tuber crops is unrealized yield potential that could be attained through yet-to-be-developed technologies. . . . All too frequently this is because the needed technology is not available to deal with yield-limiting factors (water, nutrients) and yield-reducing factors (disease, pests)." (TAC 1997b, 22). The review went on to note that prospects for increasing yields of R&T appear to be much greater than the "attempts to increase the physiological yield potential of crops already trapped on a yield plateau. . . ." This observation suggests that achieving R&T yield increases appears to be less formidable and costly a task than achieving similar gains with other crops.

Figure 2—Production growth rates of major roots and tubers and cereals, developing countries, 1961–63 to 1995–97



Source: FAO 1999a.

Given the important contribution R&T can make to the diets and livelihoods of over 2 billion people in the tropics and subtropics, and the potential that exists for expanding production and use, R&T have recently become the subject of increasing attention (see, for example, dTp Studies 1998; Horton 1981, 1988; Horton, Lynam, and Knipscher 1984; Plucknett, Phillips, and Kagbo 1998; Sarma 1989; Scott 1994a, 1997; TAC 1997b, 15; Woolfe

[3] True potato seeds are the tiny seeds—smaller than tomato seeds—found in potato fruits. Potato plants and tubers grow from these seeds. The tubers can then be consumed or replanted as potato seed (Upadhya et al. 1995).

1987, 1992).[4] And yet, there is a growing sense that the role and importance of R&T in the global food system are often poorly understood. This situation makes the present study on trends and future prospects for R&T particularly timely and relevant. A better understanding of the contribution R&T can make to poverty alleviation, food security, economic growth, and environmental sustainability in developing countries can improve the livelihoods and well-being of more than a third of the world's population. At the international and, perhaps even more importantly, national level, results from the analysis presented here can help guide investment decisions in agricultural research, extension, and capacity development to make R&T even more productive, marketable, and accessible for developing-country populations.

Objective and Scope of This Study

This paper attempts to provide a better understanding of the contribution roots and tubers will make to global food systems in the decades ahead. It analyzes trends and projections for the production and use of the major R&T (potato, sweetpotato, yam, and cassava) in developing countries and discusses the factors that have influenced and will influence the supply of and demand for these commodities.

Given the important differences in the patterns of production, use, and trade among R&T commodities, as well as differences at the regional and national levels, the analysis will disaggregate R&T by crop. Limited time, resources, and available data prevent further specificity. It is hoped that this study will serve as the basis for detailed reviews of other R&T, both at the global and regional levels, particularly in cases where such crops are important for local food security.

The rest of this paper is divided into six chapters. Chapter 2 discusses recent trends in the demand and use of R&T. Chapter 3 examines production trends for R&T, emphasizing the sharp regional and commodity-specific differences among these crops. Chapter 4 describes the IMPACT global food projections model and then presents baseline projections of demand and supply for R&T to the year 2020. Chapter 5 offers projections based on an alternative, high demand and production growth scenario. Chapter 6 considers the environmental implications of R&T production and use. The final chapter discusses the principal technological, institutional, and policy implications of this analysis.

The paper argues for the sustained and possibly increased importance of R&T in developing countries in the decades ahead. It also contends that achieving the potential for R&T is not a given. Rather this will require continued investments in agricultural research and institutional development, and a policy framework conducive to R&T.

Improved technology that raises productivity will be critical for increasing the availability of R&T in developing countries in the next two decades, as will post-production innovations. The historical record suggests that it is feasible to expect such innovations to occur during the time period in question. The paper points out that for research planning and resource allocation purposes, as well as for developing appropriate policy measures, it is useful to distinguish between supply-side constraints and demand-side constraints and to determine their relative importance for particular R&T in specific developing-country contexts. Ample scope exists for overcoming both types of constraints.

The paper argues that policy issues for developing countries include (1) removing policy distortions that bias market signals in favor of other agricultural commodities, and (2) giving farmers and entrepreneurs nondistorting incentives to invest in production and post-production innovations for R&T. Policy measures in industrialized countries include (1) removing subsidies on competing crops, and (2) lifting trade restrictions on imports from developing countries.

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[4] De Bruijn and Fresco (1989) estimated cassava alone as an important food crop for 500 million people in developing countries. The 1993–94 national survey of consumer expenditures in India interviewed over 115,000 households as a representative sample nationwide and found that over 85 percent—both rural and urban—reported consuming potato and that consumption was remarkably widespread across states and throughout the year (GOI 1997). Potato consumption elsewhere, combined with sweetpotato and yam in Asia, Africa, and Latin America, according to our estimates, put the aggregate figure between two and three billion (see Gitomer 1996; Lev and Shriver 1998; Woolfe 1987, 1992).

2. Trends in the Use of Roots and Tubers

Utilization of R&T in developing countries continued to expand and diversify during the last two decades. But both the growth in use and increase in the number and relative importance of particular end-use categories (food, feed, processed food products, industrial inputs) evolved in a highly uneven fashion across crops and geographic regions. This evolution reflects a series of structural changes in consumption and use of these commodities that began in some instances several decades earlier. Five structural changes bear mentioning: (1) the continuous surge in potato demand, particularly in Asia, beginning in the early 1960s (Scott 1983a; FAO 1995b); (2) the shift in use of cassava from food for domestic consumption to feed for export beginning in the late 1960s in Thailand (Konjing 1989) and occurring more recently (mid-1980s) for feed in Colombia; (3) the shift in use of sweetpotato from food to feed in China in the 1960s (Scott 1992); (4) the surge in yam consumption in West Africa in the late 1970s (FAO 1998a); and (5) the growing importance of cassava as a source of cash income and, hence, growing demand for cassava roots and processed products as purchased food in Sub-Saharan Africa since the late 1970s and early 1980s (Nweke 1992). Growth in total food and feed use was strongest for cassava and potato. Uses of cassava and sweetpotato continued to diversify into feed and processed products, particularly in Asia and to a lesser extent Latin America. The absolute increase in the consumption of R&T as food was highest in Sub-Saharan Africa. In light of these divergent tendencies, trends in R&T use merit a disaggregated analysis.

Total Consumption

Between 1983 (average of 1982–84) and 1996 (average of 1995–97), consumption of R&T as food in developing countries increased by 45 million mt, or 22 percent, to 253 million mt (Table 3). Use of R&T as animal feed increased by 32 million mt, or 50 percent, to 96 million mt during the same time period. In 1996, cassava accounted for the largest share of R&T consumed as food (93 million mt), followed by sweetpotato (69 million mt) and potato (65 million mt). The largest absolute increase in food consumption was for potato (26 million mt), followed by cassava (22 million mt). Consumption as food increased most rapidly for yam, at 8.6 percent per year during 1983–96, albeit from relatively low levels. Consumption of potato as food increased at 4.1 percent per year and consumption of cassava increased at 2.1 percent annually. Consumption of sweetpotato actually contracted by 1.8 percent annually. However, sweetpotato use as animal feed increased rapidly, at 3.4 percent per year during 1983–96, and it contributed the most (58 million mt) to animal feed in 1996. This was followed by cassava at 22 million mt and potato at 15 million mt. China dominates sweetpotato feed use. Cassava in Latin America and potato in China account for the bulk of the remainder of R&T as feed. The data in Table 3 illustrate the regional segmentation in R&T use: for example, cassava and yam as food in Sub-Saharan Africa, potato as food and sweetpotato as food and feed in China; and cassava as food and feed in Latin America.

Growth of cassava as food has been particularly rapid in Sub-Saharan Africa, at 3.1 percent per year. The region has experienced low or negative economic growth and booming populations, and has continued to rely on R&T as major contributors to food consumption. Cassava (62 percent) and yam (33 percent) accounted for nearly all of the total increase in human consumption of R&T in Sub-Saharan Africa; the increase for potato was negligible and that for sweetpotato modest in absolute terms (Table 3).

Table 3—Food and feed utilization of roots and tubers by region, 1983 and 1996

	Cassava		Potato		Sweetpotato		Yam		All R&T[a]	
Country/region	**1983**	**1996**	**1983**	**1996**	**1983**	**1996**	**1983**	**1996**	**1983**	**1996**
	(million metric tons)									
Food										
China	1.5	1.6	10.5	19.4	72.4	54.8	na	. . .	85.7	77.0
Other East Asia	. . .	. . .	0.8	0.9	0.6	0.3	. . .	. . .	1.4	1.2
India	5.2	5.4	7.6	14.9	1.5	1.1	na	na	14.4	21.3
Other South Asia	0.5	0.2	1.8	3.1	0.8	0.4	na	na	3.4	4.3
Southeast Asia	14.1	16.1	0.7	1.6	4.4	4.0	. . .	. . .	19.7	22.3
Latin America	10.3	11.4	8.4	11.2	1.0	0.9	0.2	0.3	20.3	24.3
WANA	na	na	6.8	11.6	0.1	0.2	na	na	7.0	11.9
Sub-Saharan Africa	38.4	57.3	1.8	1.9	4.7	5.9	4.8	14.9	53.0	87.3
Developing	70.7	92.5	38.8	65.1	86.4	68.5	5.4	15.8	207.8	252.7
Developed	0.1	0.1	89.6	96.1	1.6	1.5	0.1	0.2	91.8	98.2
World	70.8	92.6	128.4	161.2	88.0	70.1	5.5	16.0	299.6	350.9
Feed										
China	1.3	2.6	7.7	14.5	36.4	57.1	na	na	45.5	74.3
Other East Asia	na	0.1	0.2	0.1	0.2	0.1	na	na	0.4	0.4
India	na	na	na	na	na	na	na	na	na	na
Other South Asia	0.2	0.1	. . .	. . .	. . .	. . .	. . .	. . .	0.2	0.1
Southeast Asia	0.7	0.6	. . .	. . .	0.3	0.3	. . .	. . .	1.0	1.0
Latin America	13.5	14.9	0.4	0.4	0.3	0.3	0.1	0.1	14.3	15.7
WANA	na	0.1	0.1	0.1	na	na	na	na	0.1	0.2
Sub-Saharan Africa	2.0	3.5	. . .	. . .	0.1	0.2	0.2	0.3	2.4	4.1
Developing	17.7	22.0	8.5	15.3	37.4	58.0	0.3	0.4	64.2	95.9
Developed	18.7	9.0	55.5	39.6	0.4	0.2	. . .	. . .	74.6	48.9
World	36.4	31.0	64.0	54.9	37.8	58.1	0.3	0.4	138.8	144.8

Source: FAO 1999b.

Note: Ellipses (. . .) signify very small values; na signifies no recorded use. WANA is West Asia and North Africa. Data for 1983 are averages for 1982–84 and data for 1996 are averages for 1995–97. These values do not include locally produced R&T that are exported in fresh or processed form. See Table 2 footnote for regional breakdown.

[a]All R&T include cassava, potato, sweetpotato, yam, and other roots and tubers such as taro. For these other roots and tubers, utilization was less than 1.5 million mt for all uses in all regions, except for food use in Sub-Saharan Africa. In 1983 use of other R&T as food in Sub-Saharan Africa totaled 3.5 million mt, rising to 7.3 million mt in 1996.

Growth in R&T consumption in Asia was mixed. Consumption of potato as food nearly doubled in absolute terms in almost every part of the region while consumption of sweetpotato as food declined. This decline was more than offset by an increase in use of the crop as animal feed in China, where roots and vines annually provide an additional 19 million mt of feed on a dry-matter-equivalent basis.[5] Consumption of yam is insignificant in Asia and consumption of cassava remained flat, with the exception of Southeast Asia. Annual growth in R&T consumption in Latin America was moderate for food (1.4 percent) and nearly stagnant for feed (0.7 percent). However, consumption of potato as food increased by 33 percent to 11 million mt in 1996.

Per Capita Consumption

As can be seen in Table 4, aggregate per capita consumption of R&T as food has remained virtually constant over the last decade and a half. In developing countries, consumption fell slightly from 60 kg per capita in 1983 to 57 kg per capita in

[5] Total dry matter (DM) for sweetpotato includes vine DM equivalent to roughly 20 percent of the root-yield DM, although vine DM content and total volume also vary by variety and cultural practices (León-Velarde et al. 1997). Moreover, in China, moisture content in grains is traditionally not factored into conversion rates for R&T to grain equivalents (see Gitomer 1996, 21–22; Zhang 1999, 42).

Table 4—Per capita consumption of roots and tubers as food and feed, 1983 and 1996

	Cassava		Potato		Sweetpotato		Yam		Total Food[a]		Total Feed[a]	
Country/region	1983	1996	1983	1996	1983	1996	1983	1996	1983	1996	1983	1996
	(kilograms per capita)											
China	2	1	10	16	70	45	na	. . .	82	63	44	60
Other East Asia	. . .	. . .	13	12	10	4	. . .	. . .	24	17	7	5
India	7	6	10	16	2	1	na	na	20	22	na	na
Other South Asia	2	1	8	10	3	1	na	na	14	13	1	0
Southeast Asia	37	33	2	3	12	8	. . .	. . .	52	46	3	2
Latin America	29	25	24	25	3	2	1	1	57	54	40	35
WANA	na	na	28	34	. . .	. . .	na	na	29	35	1	1
Sub-Saharan Africa	102	106	5	4	12	11	13	28	140	162	6	8
Developing	20	21	11	15	25	16	2	4	60	57	19	22
Developed	. . .	. . .	75	75	1	1	. . .	. . .	77	76	63	38
World	15	16	28	28	19	12	1	3	64	61	30	25

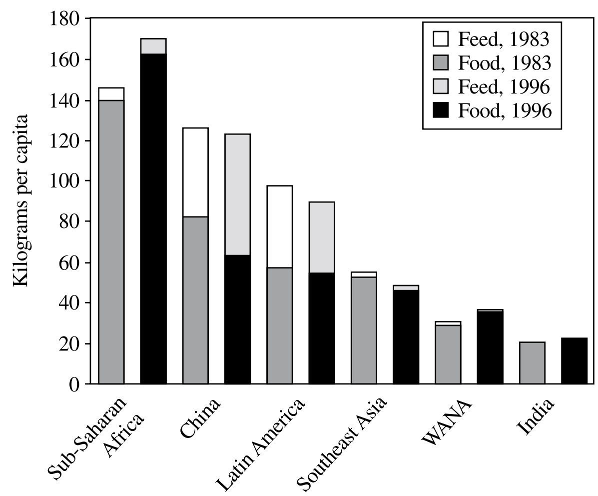
Source: FAO 1999b.
Note: Ellipses (. . .) signify very small values; na signifies no recorded use. For other roots and tubers, consumption was less than 2 kilograms (kg) per capita for all uses in all regions, except for food use in Sub-Saharan Africa, where other R&T totaled 9.2 kg per capita in 1983, rising to 13.5 kg per capita in 1996. WANA is West Asia and North Africa. Data for 1983 are averages for 1982–84 and data for 1996 are averages for 1995–97. See Table 2 footnote for regional breakdown.
[a]All R&T includes cassava, potato, sweetpotato, yam, and other R&T such as taro.

1996. In developed countries, per capita consumption declined from 77 kg to 76 kg. In spite of this apparent stagnation, the evolution of R&T use in developing countries has been quite dynamic. It has varied considerably across commodities by form (that is, particular food, feed, processed product, and seed forms); by end use; and by geographic region. Policy-oriented analyses and comparisons with other agricultural commodities therefore necessitate a disaggregated assessment of R&T use.

On a regional basis, Sub-Saharan Africa achieved both the highest level and the sharpest absolute rise in per capita food consumption of R&T between 1983 (140 kg) and 1996 (162 kg) (Table 4, Figure 3). In 1996 the region consumed almost three times the developing-country average. The increase in Sub-Saharan African per capita consumption is particularly remarkable given the region's high population growth rate (nearly 3 percent per year) during the same period. Per capita consumption as food has also been increasing in India and WANA, which experienced the largest per capita percentage increases (almost all of it in potato).

With the exception of China and Latin America, use of R&T as animal feed is of little importance in most developing regions (Table 4). Per capita use of R&T as animal feed increased in developing countries from 19 kg in 1983 to 22 kg in 1996, and in China from 44 kg to 60 kg over the same period. Feed use levels remained high in

Figure 3—Per capita food and feed consumption of roots and tubers, selected countries and regions, 1983 and 1996



Source: FAO 1999b.
Notes: WANA is West Asia and North Africa. Data for 1983 are averages for 1982–84 and data for 1996 are 1995–97 averages. See Table 2 footnote for regional breakdown.

Latin America, at 35 kg per capita in 1996. In contrast, per capita feed use dropped steeply in developed countries, from 63 kg in 1983 to 38 kg in 1996. Use of potatoes for pig feed declined sharply in Europe, particularly in Western Europe, driven by a decrease in the demand for pork (Delgado et al. 1999) and by the structural shift in the pork industry from a vast number of small, family-run farms to relatively few, large, feed-intensive operations. These farm factories typically use other, more efficient feed rations to reduce costs and capture economies of scale (Horton and Anderson 1992). Recent changes in the European Union's Common Agricultural Policy also resulted in a sharp decline in imports of cassava for feed (Henry 1998).

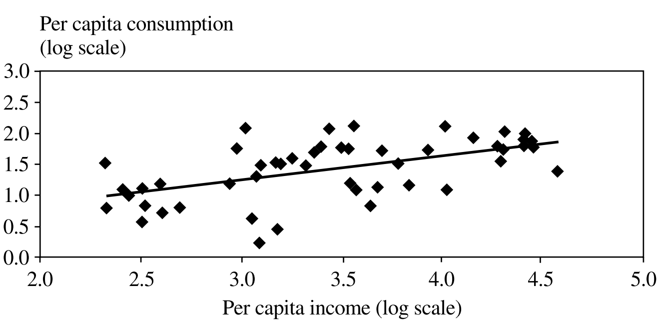
The share of calories and proteins in developing-country diets coming from R&T remains modest, with the exception of Sub-Saharan Africa (Table 2; see also Horton 1988, 17). The large share in Sub-Saharan Africa reflects the high per capita consumption of R&T, the lesser importance of cereals, and the lower average number of calories per capita in that region. These aggregate figures on the calorie- and protein-shares provided by R&T should be interpreted with caution, however, as they mask within-year (seasonal) and within-region (national and subnational) variations. They also do not show R&T's contribution of dietary essentials, such as calcium, potassium, iron, and ascorbic acid, that are less available in other foods, particularly cereals.

Factors Influencing Changes in Per Capita Use

Figure 4a presents the positive relationship between income and consumption of potato. At the relatively low levels of per capita income (and per capita food consumption) characteristic of many developing countries, potato consumption is far below the saturation point. Consumption of potato increases as income increases. The relationships for cassava and sweetpotato are different. As per capita incomes increase, per capita consumption declines, as shown in Figures 4b and 4c. This income/consumption relation for cassava and sweetpotato needs to be interpreted with caution. Data on aggregate per capita food consumption can mask shifts among food uses, for example from fresh to processed foods.

In addition to per capita income, the growth rates of per capita use of R&T are influenced by a number of other measurable variables, including existing use levels, relative prices, and availability of substitutes. The growth rates are also a function of tastes, preferences, and demographic and cultural factors, but in less easily quantifiable ways. Illustrations of how some of these factors played

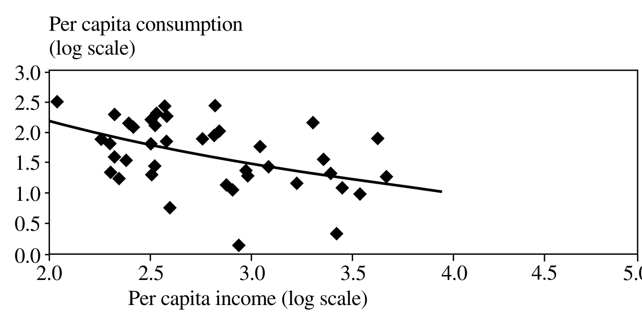
Figure 4a—The relationship between per capita potato consumption and income



Source: FAO 1999a (April 1999; accessed in July) and World Bank 1998.

Note: Per capita income is 1997 and per capita consumption is 1995–97 average.

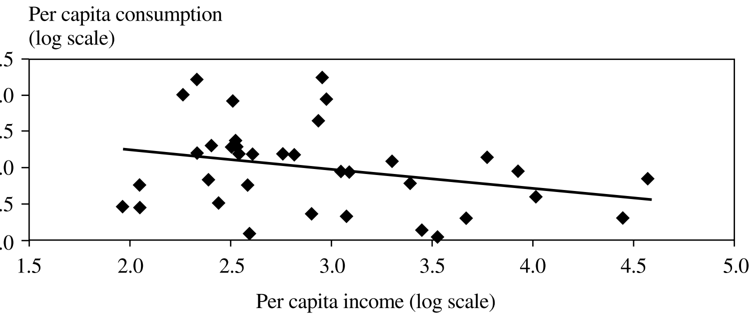
Figure 4b—The relationship between per capita cassava consumption and income



Source: FAO 1999a (April 1999; accessed in July) and World Bank 1998.

Note: Per capita income is 1997 and per capita consumption is 1995–97 average.

Figure 4c—The relationship between per capita sweetpotato consumption and income



Source: FAO 1999b (April 1999; accessed in July) and World Bank 1998.
Note: Per capita income is 1997 and per capita consumption is 1995–97 average.

out in the use of R&T in various countries are presented in Box 2. In the absence of more detailed statistics, such as long-term time-series data on international prices for R&T, local information can shed light on the influence of R&T prices and other agricultural commodity prices on the use of R&T.

Whereas potatoes are typically considered a cheap, starchy staple in industrialized countries, they tend to be high-priced and sometimes are luxury vegetables in the developing world (Bottema et al. 1989; Scott 1988a, 1988b). As economies in Asia have developed rapidly during the last few decades and incomes have increased, consumers have increasingly diversified their diets, with additional consumption of potatoes among other foods. As a result, potato production expanded rapidly in a number of Asian countries during the 1960s and 1970s, bringing down relative prices versus cereals, an outcome that fueled additional consumption (Horton 1987).[6] In other countries such as Bolivia, relative price changes made potatoes more expensive, discouraging increases in consumption (Thiele et al. 1999).

The relationship between prices and sweetpotato consumption is less clear (Horton 1989; Overbeek 1994). Whereas a decline in relative prices can spur some increase in consumption, as in the case of Peru (Collins 1989) or, more recently, Uganda (Scott et al. 1999), a major increase in supply can quickly saturate the market. Evidence from several countries including the Philippines (Cabanilla 1996), Rwanda (Tardif-Douglin 1991), and Peru (Collins 1989) suggests that consumers are much less inclined than in the case of potato to appreciably expand their consumption of sweetpotato in fresh form as a result of a decline in price. The same holds for cassava in Latin America and Asia.

Lifestyle changes, historical and cultural factors, and evolution in tastes also influence R&T consumption trends. The rapid increase in urbanization in developing countries over the last three decades, the greater participation of women in the labor force, and the pervasive exposure to advertisement of food commodities and to the eating habits of tourists and foreign residents have increased the proportion of purchased foods in total food intake. These changes in consumption patterns have affected the demand for R&T in various ways.

In much of Asia, particularly China, consumption of preferred foods, such as potato (FAO 1995b; Ye and Rozelle 1993; Zhang et al. 1999) and meat (Delgado et al. 1999) has increased, whereas the consumption of less preferred commodities, such as fresh sweetpotato, has declined (Woolfe 1992). The divergence in consumption trends among R&T crops in urban settings likely has been reinforced by the association of potatoes with Western, more modern, tastes, and of sweet-

[6] More recent evidence from a number of countries further substantiates this relationship between declines in relative prices (versus cereals) and increases in per capita potato consumption (Bouis and Scott 1996; Byerlee and Sain 1991; Scott 1999).

Box 2: Case Studies on Factors Influencing R&T Use

Potato in Peru. Although the potato is part of the traditional Peruvian diet and has long been ranked as the country's most important food crop, per capita consumption dropped from a high level of 100 kg in the early 1960s to about 45 kg by the mid-1980s. The principal forces driving the contraction in potato consumption included (1) years of overvalued exchange rates that made cereal imports cheap, combined with food subsidies that lowered domestic cereal prices, and (2) price controls, restrictive credit policies, and anti-middlemen marketing regulations that discouraged production, marketing, and consumption of potatoes (Horton 1987). By the late 1980s, the overall economy had gone into a tailspin, per capita incomes had declined sharply, and the relative potato/rice price had reached historic high levels in the capital city of Lima, where roughly half the country's effective demand is concentrated. Projections for future growth in production and consumption of potatoes were modest at best.

After 1990, the government adopted a series of market-liberalizing policies. As the economy recovered, potato production and productivity increased and its relative price versus rice declined. As a result, per capita consumption rebounded to 65 kg by 1995 (see Byerlee and Sain 1991 for a similar situation in Ecuador).

Sweetpotato as Animal Feed in Sichuan Province, China. With rapid economic growth and rising incomes, demand for meat products in China increased by 6.3 percent per year during 1982–94 (Delgado et al. 1999). The need for animal feed rose sharply as a result. More than 57 million mt of sweetpotato roots alone were used annually as animal (largely pig) feed, during 1995–97. Several factors account for this development: (1) China is now the world's largest pig producer; (2) more than 80 percent of pig production takes place at the household or village level (Ke 1997); (3) the largest pig-producing province in China is Sichuan; (4) Sichuan is not only a maize-deficient province, but geographically isolated from both domestic, maize-surplus provinces and international markets; and (5) processing sweetpotato roots and vines into feed adds value to the commodity and creates employment at the farm level. Sichuan province alone produces more sweetpotato (Gitomer 1996) than all other developing countries combined (Scott and Maldonado 1999). In rural Sichuan, which is poorer than the more affluent coastal provinces, farmers and village-level enterprises use sweetpotato to sustain feed security at the farm level. This strategy helps to reduce China's potential dependence on feed imports. According to Simpson, Cheng, and Miyazaki (1994) China used some 75 million mt of cereals as feed in the early 1990s. Estimates based on Food and Agriculture Organization of the United Nations (FAO) Food Balance Sheet data show that sweetpotato (both roots and vines) provide large amounts of additional feed on a dry-matter equivalent basis. Furthermore, the extraction of starch from roots to make noodles for sale and the use of the remaining mash to feed pigs is a highly lucrative combination, more so than pig production alone (Peters 1997).

Cassava as Food and Processed Food Products in Nigeria. According to Ouraga-Djoussou and Bokanga (1998), annual consumption of cassava in Nigeria doubled to 250 kg per capita between 1983 and 1994. Cassava production increased from 14.4 million mt to 31.1 million mt during 1982–97 (FAO 1999a). The increase in consumption and output of cassava can be attributed to several factors. Given Nigeria's low per capita income and rapid population growth, cassava has served as both a basic staple and a food security crop; the ban on cereal imports between 1987 and 1990 provided an added stimulus to production (Adeniji et al. 1997). The crop's multiple uses have also facilitated greater consumption. Roots are consumed in fresh, boiled form; as toasted granules widely known as *gari;* as chips/flour (or *lafun*); and as unsteamed wet paste (or *fufu*) (Nweke 1994). Cassava leaf is also eaten, often in the form of a sauce with meat or fish on rice, boiled roots, or *fufu.*

Because the demand for cassava as a food commodity has remained strong, commercial sales of both processed products and fresh roots as raw material for food processing have become a highly profitable undertaking, due in part to technical improvements in processing and the introduction of high-yielding varieties (Nweke, Ezumah, and Spencer 1988). Increasing urbanization has prompted entrepreneurial farmers to expand production close to major cities and towns in order to capitalize on the concentration of prospective consumers. According to estimated expenditure elasticities for processed cassava (*gari*), urban households treat it as a normal good (Nweke et al. 1994). More recent estimates, based on the six-country Collaborative Study of Cassava in Africa (COSCA), indicate that expenditure elasticities for rural households hover around 1.0 for fresh and processed cassava (Ezemenari, Nweke, and Strauss 1998), which is similar to the elasticities for high-value foods. Hence, continued urbanization and improvements in income are likely to translate into continued strong demand for cassava in Nigeria.

potato in fresh form with traditional, local customs, and times of hardship or food scarcity (Gitomer 1996; UPWARD 1991). The picture for cassava is more mixed. In urban Latin America—Colombia or Brazil, for example—fresh cassava is often considered a tasty and nutritious food (see, for example Janssen 1986; Lynam 1989a). In West Africa, urban consumers regard cassava in processed form as a highly preferred food. In West Africa as well, yam is a high-status, preferred food wherever it forms part of the diet, for example, in Nigeria, Ghana, and Côte d'Ivoire. Some evidence suggests that yam actually retains a higher status in urban areas than do other staples (Bricas and Attaie 1998 and Nweke et al. 1994).

Cultural factors influencing consumption of R&T are both traditional and modern in nature. The rituals associated with yam in several West African countries certainly contribute to its continued place of prestige in the diets of many consumers in that region (Bricas and Attaie 1998). For potato, the explosive growth of fast food restaurants and snacks has given the commodity a new image, reinforced by advertising and promotional campaigns (Scott 1994a; Scott, Basay, and Maldonado 1997; Zhang et al. 1999). Consumers typically not only like the taste of such products but also consider their consumption fashionable and cosmopolitan as well as convenient for shorter lunch hours. But traditional images of sweetpotato, particularly in Asia, are also often associated with positive traits such as medicinal uses (Gitomer 1996). The modern quest for healthy foods has given new impetus to the consumption of sweetpotato leaves or tips in some Asian countries, including Korea and Japan, even though consumption of fresh roots has declined considerably in these countries (Woolfe 1992). Cassava's cultural recognition remains high and positive in much of rural and urban Sub-Saharan Africa. Currently, researchers are attempting to develop easier forms of preparation for cassava and yam and to improve their preservation in an effort to better cater to the tastes, preferences, and pocketbooks of the region's growing number of urban consumers (Legros et al. 1995; Westby and Graffham 1998).

The driving forces behind the trends in R&T use include different growth rates in income and population across regions and countries and the increasingly complex structure of R&T food and feed demand. The ability of R&T to lend themselves to both traditional and more modern uses has facilitated their rapid growth in food and feed use in several developing-country regions.

Given rapid population growth over the next few decades, aggregate production will have to increase substantially simply to maintain existing per capita use levels for R&T. Income increases and emerging new uses will likely raise aggregate demand for R&T still further. Other factors, such as changing tastes and preferences due to rising incomes and increasing urbanization, will stimulate additional demand for these crops. The next chapter reviews trends in the production of R&T.

3. Trends in the Supply of Roots and Tubers

Growth in Production of R&T

Rates of growth for area, yield, and production of major R&T have varied substantially by crop and country over the past two decades. Annual production growth for R&T during 1983–96 averaged a modest 2.1 percent in developing countries. This overall rate of growth masks significant differences across R&T and regions ranging from a rapid 8.3 percent annual rate of growth for yam in Sub-Saharan Africa, to a –6.8 percent per year decline for sweetpotato in East Asian countries other than China (Table 5). Thus, the analysis of the dynamics of R&T production requires a variety of vantage points from which to draw a comprehensive picture of the evolution of these crops.

In the last two decades, yam and potato achieved the highest annual growth rates in production among R&T in developing countries: 8.0 percent and 4.1 percent, respectively (Table 5). Yam production grew from a small base and increased largely in one region (West Africa). Cassava production grew at a more modest pace, 1.8 percent annually. Growth in sweetpotato production was flat over the period, with an initial decline in production followed by a recovery to earlier levels.

In developing countries, total production of R&T crops increased by 30 percent, from 344 million mt in 1983 to 449 million mt in 1996 (Table 6). Production increases varied substantially by commodity. The production increase was largest for yam in percentage terms. Output reached 32 million mt in 1996, a 170 percent increase over the 13-year period, albeit from low production levels. The crop contributed 19 percent to the total increase in R&T output. Sweetpotato production, on the other hand, barely increased during the same period, rising by 1.8 percent to 134 million mt in 1996. Cassava and potato contributed 33 percent and 42 percent, respectively, to growth in R&T output. Production of cassava grew by 27 percent between 1983 and 1996 to 164 million mt, and production of potato grew by 68 percent to 108 million mt.

On a per capita basis, production of R&T in developing countries increased from 99 kg in 1983 to 101 kg in 1996. Developing-country production of cassava remained virtually constant at 37 kg per capita, supported mainly by the per capita production growth in Sub-Saharan Africa. Per capita production of potato increased by 6 kg to reach 24 kg in developing countries in 1996, and yam production per capita grew by 4 kg to reach 7 kg. Yam production is significant only in Sub-Saharan Africa where it reached 56 kg per capita in 1996, up from 28 kg per capita in 1983. Between 1983 and 1996 sweetpotato production declined from 38 kg to 30 kg per capita.

Production of individual R&T tends to be highly skewed toward particular countries and regions. Figure 5 shows the locations of R&T production in 1996. More than 60 percent of global potato production was harvested in developed countries, followed by China with a 17 percent share and India with 7 percent. Potato production has been shifting back toward developing countries; they have increased their share of global output from 11 percent in 1961–63 to 37 percent in 1995–97 (Scott and Maldonado 1998). Slightly more than half the global production of cassava takes place in Sub-Saharan Africa, followed by Southeast Asia with 23 percent and Latin America with 20 percent. Sweetpotato production is concentrated in China, which has an 88 percent share of global production. Ninety-six percent of the world's yam is produced in Sub-Saharan Africa (mostly West Africa).

The importance of particular crops in specific regions and subregions can also be seen from the share of each crop in total R&T production (Figure 6). In WANA, virtually all R&T production con-

Table 5—Annual growth rates in area planted with and production of roots and tubers by commodity and region, 1983–96

	Cassava		Potato		Sweetpotato		Yam		All R&T[a]	
Country/region	Production	Area	Production	Area	Production	Area	Production	Area	Production	Area
	(percent per year)									
China	–0.53	–0.47	4.60	3.03	0.21	–0.84	na	na	1.20	0.30
Other East Asia	na	na	–1.00	–2.09	–6.77	–5.69	na	na	–3.24	–3.26
India	0.30	–1.94	5.12	3.77	–2.50	–3.33	na	na	3.35	1.73
Other South Asia	–6.64	–4.69	3.73	2.69	–4.25	–3.16	na	na	1.50	1.13
Southeast Asia	0.17	0.18	5.42	2.53	–0.73	–1.31	4.28	–0.55	0.22	–0.02
Latin America	0.80	0.02	1.95	0.32	–1.18	–1.60	2.97	1.22	1.09	0.05
WANA	na	na	4.75	2.59	3.67	3.46	na	na	4.71	2.59
Sub-Saharan Africa	3.56	2.38	0.62	0.70	1.75	2.64	8.32	4.70	4.32	2.75
Developing	1.83	1.37	4.08	2.42	0.14	–0.50	7.96	4.49	2.06	1.31
Developed	na	na	–0.83	–1.40	–1.00	–2.00	2.73	1.61	–0.84	–1.40
World	1.83	1.37	0.60	–0.07	0.12	–0.52	7.91	4.48	1.07	0.61

Source: FAO 1999a.
Note: na signifies no recorded production. WANA is West Asia and North Africa. Data for 1983 are averages for 1982–84 and data for 1996 are averages for 1995–97. See Table 2 footnote for regional breakdown.
[a]All R&T includes cassava, potato, sweetpotato, yam, and other R&T such as taro.

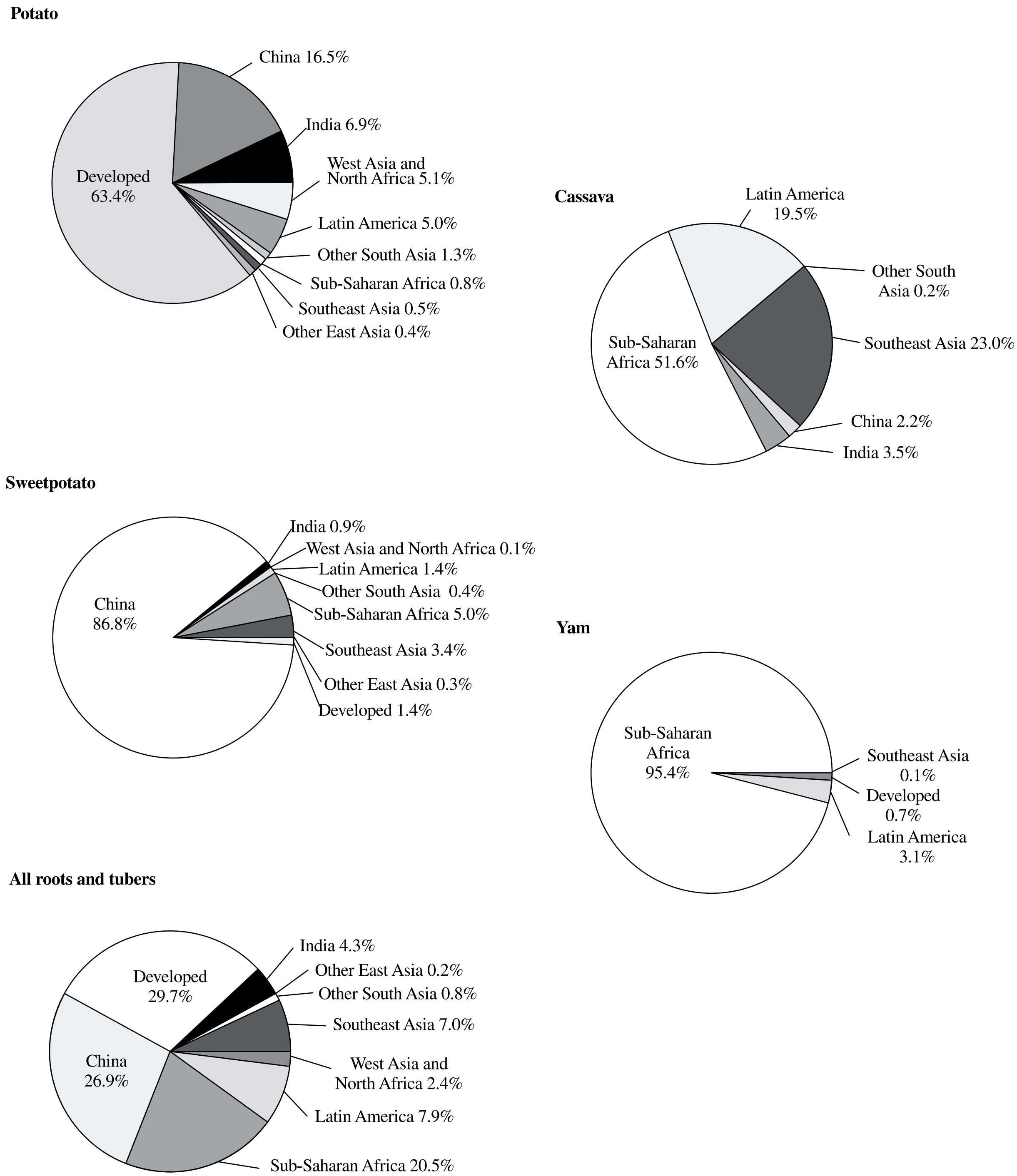
Table 6—Production of roots and tubers by commodity and region, 1983 and 1996

	Cassava		Potato		Sweetpotato		Yam		All R&T[a]	
Country/region	1983	1996	1983	1996	1983	1996	1983	1996	1983	1996
	(million metric tons)									
China	3.8	3.6	27.3	48.9	114.6	117.8	na	na	147.1	171.7
Other East Asia	na	na	1.2	1.1	1.1	0.5	na	na	2.4	1.5
India	5.5	5.7	10.7	20.4	1.6	1.2	na	na	17.8	27.3
Other South Asia	0.7	0.3	2.4	3.8	0.9	0.5	na	na	4.2	5.1
Southeast Asia	36.9	37.7	0.8	1.6	5.1	4.6	. . .	. . .	43.4	44.6
Latin America	28.9	32.1	11.4	14.7	2.2	1.9	0.7	1.0	43.9	50.5
WANA	na	na	8.3	15.1	0.1	0.2	na	na	8.5	15.4
Sub-Saharan Africa	53.8	84.7	2.3	2.5	5.4	6.8	10.7	30.3	75.6	131.0
Developing	129.8	164.3	64.3	108.1	131.6	133.9	11.7	31.6	344.4	448.8
Developed	na	na	209.2	187.6	2.2	1.9	0.1	0.2	211.9	190.0
World	129.8	164.3	273.5	295.6	133.7	135.8	11.8	31.8	556.4	638.8

Source: FAO 1999a.
Note: Ellipses (. . .) signify very small values; na signifies no recorded production. WANA is West Asia and North Africa. 1983 is average for 1982–84 and 1996 is average for 1995–97. See Table 2 footnote for regional breakdown.
[a]All R&T includes cassava, potato, sweetpotato, yam, and other R&T such as taro.

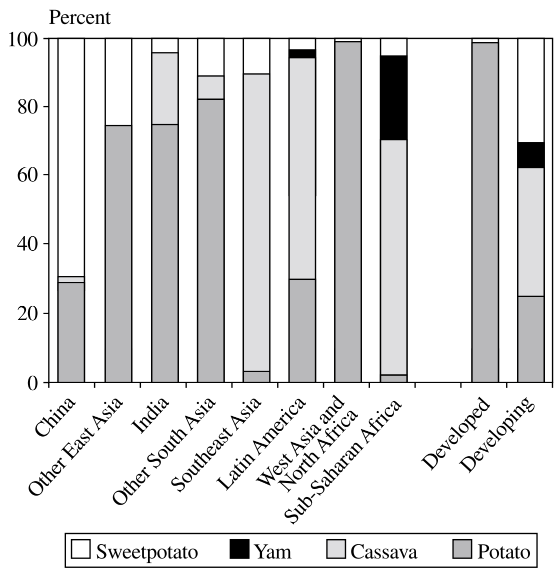
sists of potato. Potato is also of relatively high importance in India and other South Asian countries and in East Asian countries other than China. Production of cassava plays a major role in Southeast Asia (86 percent of R&T production), Latin America (65 percent), and Sub-Saharan Africa (68 percent). Yam production accounts only for 24 percent of R&T output in Sub-Saharan Africa, but it has become increasingly concentrated in this region. China continues to dominate sweetpotato production, which accounts for almost 70 percent of the country's R&T output. Sweetpotato also plays a major role in R&T production in the rest of East Asia.

Figure 5—Location of root and tuber production, 1996



Source: FAO 1999a.
Note: 1996 is average of 1995–97. See Table 2 footnote for regional breakdown.

Figure 6—Relative importance of major roots and tubers in countries and regions, 1996, based on production volumes



Source: FAO 1999a.
Note: 1996 is average of 1995–97. See Table 2 footnote for regional breakdown.

Sources of Growth in Output

Expansion in area and higher yields have contributed almost equally to output growth for R&T during 1983–96. Increase in area accounted for 57 percent of total output growth and yield improvements accounted for the remaining 43 percent. The role of area expansion as a source of output growth is significantly larger for R&T than for other major food crops. This is due, in part, to the location of a significant share of the harvested area for R&T in Sub-Saharan Africa. Twenty-six and 34 percent of total R&T area could be found in this region in 1983 and 1996, respectively. Other factors contributing to this evolution include the relatively low investments in agricultural R&D for these crops compared to investments in wheat, maize, and rice, for example. The greater adaptability of some R&T to marginal areas, combined with their flexible growth cycle, also facilitated area expansion in some countries and regions.

Globally, the area harvested in R&T increased during 1983–96 from 45.8 million hectares to 49.5 million hectares. The largest expansion of R&T area occurred in Sub-Saharan Africa, from 11.9 million hectares in 1983 to 16.9 million hectares in 1996. The distribution of area planted in R&T across regions largely coincides with that of production and use levels because only a small proportion of R&T output is traded internationally.

Sub-Saharan Africa

In Sub-Saharan Africa, the increase in cassava output has been driven largely by growth in area planted. A synthesis of the results from the comprehensive COSCA study found that the most important reasons for farmers to increase cassava production are famine, hunger, and drought (Spencer and Associates 1997). Cassava's low input requirements, a trait that fits well with the region's resource endowments (relatively abundant land, relatively scarce labor), make it suitable for the difficulties African farmers face. The shortage of chemical inputs and organic matter and the limited irrigation facilities in the region also make cassava a crop of choice for African farmers. Moreover, as farm size shrinks under population pressure, food requirements per hectare of land cultivated rise, increasing the prospects that farmers will shift to crops with higher output of energy per hectare as one strategy for overcoming hunger.[7] Food shortages precipitated by a combination of political and civil unrest, wars, economic stagnation, erratic rainfall patterns, and rapid population growth have had a much greater influence on R&T production in this region than anywhere else.

Another important reason for cassava's burgeoning presence in Sub-Saharan Africa is the crop's resistance to pests and diseases (Spencer and Associates 1997). Higher prices, increased market access for farmers, and higher yields have also played a role in cassava's emergence as a cash crop in much of the region (Nweke 1992). This commercialization of the crop is particularly significant, given that the share of the urban population is expected to increase from 30 to 50 percent by 2020 (FAO 1998b).

[7] Ruthenberg (1980, 361) predicted a shift in cropping patterns to more energy productive crops as farm size in developing countries declined and population growth pushed up food (that is energy production per hectare) requirements per given land area.

Table 7—Yields and annual growth rates in yield for roots and tubers, 1983–96

Country/region	Cassava Yield 1983	Cassava Yield 1996	Cassava Growth rate	Potato Yield 1983	Potato Yield 1996	Potato Growth rate	Sweetpotato Yield 1983	Sweetpotato Yield 1996	Sweetpotato Growth rate	Yam Yield 1983	Yam Yield 1996	Yam Growth rate	All R&T[a] Yield 1983	All R&T[a] Yield 1996	All R&T[a] Growth rate
	(mt/hectare)		(percent per year)	(mt/hectare)		(percent per year)	(mt/hectare)		(percent per year)	(mt/hectare)		(percent per year)	(mt/hectare)		(percent per year)
China	15.6	15.5	–0.06	11.3	13.8	1.52	16.7	19.1	1.06	na	na	na	15.3	17.1	0.89
Other East Asia	na	na	na	13.3	15.4	1.12	20.0	17.2	–1.15	na	na	na	15.8	15.9	0.02
India	17.5	23.5	2.28	14.0	16.5	1.30	7.4	8.3	0.85	na	na	na	13.7	16.9	1.60
Other South Asia	11.5	8.8	–2.05	9.7	11.1	1.01	10.4	9.0	–1.12	na	na	na	10.1	10.6	0.36
Southeast Asia	12.1	12.1	–0.01	9.1	13.1	2.82	6.2	6.7	0.59	2.6	4.7	4.85	10.7	11.0	0.24
Latin America	10.8	12.0	0.78	11.1	13.7	1.63	7.2	7.6	0.43	6.7	8.4	1.73	10.3	11.8	1.04
WANA	na	na	na	14.8[b]	19.4[b]	2.10	21.8[b]	22.4[b]	0.21	na	na	na	15.0	19.5	2.06
Sub-Saharan Africa	7.1	8.2	1.15	6.1	6.0	–0.08	5.0	4.5	–0.86	6.4	9.9	3.46	6.4	7.8	1.53
Developing	9.3	9.9	0.46	11.6	14.2	1.62	13.8	15.0	0.64	6.5	9.9	3.32	10.6	11.7	0.74
Developed	na	na	na	16.0	17.2	0.57	16.3	18.6	1.02	18.1	20.9	1.10	16.0	17.2	0.57
World	9.3	9.9	0.46	14.6	16.0	0.67	13.8	15.0	0.64	6.5	9.9	3.29	12.2	12.9	0.46

Source: FAO 1999a.
Note: na signifies no recorded production. mt is metric ton. WANA is West Asia and North Africa. 1983 is average for 1982–84 and 1996 is average for 1995–97. See Table 2 footnote for regional breakdown.
[a]All R&T includes cassava, potato, sweetpotato, yam, and other R&T such as taro.
[b]FAO indicates very high yields in Egypt on small areas.

Evidence from the COSCA study further indicates that the increased area planted is in many instances replacing fallow land. New cassava production is also crowding out other crops, especially yam in the humid zone and maize in the nonhumid zone (Spencer and Associates 1997).

On the post-production side, a key food security role played by cassava in Sub-Saharan Africa is its ability to be stored in the ground for 36 months or more after the formation of the edible roots is complete. Hence, cassava cultivation serves as something of a household food bank that can be drawn upon when adverse agroclimatic conditions or civil unrest limit the availability of and access to other foods. The wide variety of food products that are made from the roots and the highly nutritious leaves widely consumed as a regular part of the diet, particularly in Central, Southern, and West Africa, are added reasons why cassava cultivation is expanding (NR1 1992).

About 95 percent of the world's yam output is produced in Sub-Saharan Africa. Nigeria, Ghana, and Côte d'Ivoire account for more than 80 percent of the worldwide yam harvest (Lev and Shriver 1998). The growth in area planted to yam accelerated in recent years and accounted for 56 percent of total output growth during 1983–96.[8] In West Africa, particularly in Nigeria, the increase in area planted represents an expansion in yam cultivation from its traditional growing area in the humid forests to the moist savannahs (Manyong et al. 1996). Higher solar radiation, less pressure from pests and diseases, and lower costs of production due to less labor-intensive cultivation practices appear to have induced this shift.

Increases in yam area and production have also been driven by strong demand for the tubers in fresh form as food and a growing interest in their use as raw material for processed food products (Attaie, Zakhia, and Bricas 1998).

Sweetpotato production in Sub-Saharan Africa during 1983–96 has been entirely driven by growth in area planted; average yields actually contracted in this period (Tables 5 and 7). Most of the growth in production occurred in Eastern, Central, and Southern Africa in response to steadily increasing

[8] Global and regional statistics for yam are highly influenced by data for Nigeria that show serious inconsistencies between production and consumption estimates (see Bricas and Attaie 1998 and Dorosh 1988).

pressure on local food systems due to population growth, civil war, and economic hardship (see, for example, Bashaasha et al. 1995; Tardif-Douglin 1991). In the Kivu region, Democratic Republic of the Congo, for example, sweetpotato has been used as a staple food for disaster relief (Tanganik et al. 1999). Declines or stagnation in output of other staples have also contributed to the interest by farmers and consumers in sweetpotato in some countries, for example Malawi (Phiri 1998). Cash sales of the roots and a nascent processing sector have added to the momentum in production in Uganda (Scott et al. 1999) and Kenya (Gatumbi and Hagenimana 1998).

For potato in Sub-Saharan Africa, pressure on land to produce more food and the absence of government intervention in output markets for table potatoes (Rasolo et al. 1987; Scott 1988b, 1994b) have led to an increase in area planted of 0.7 percent per year during 1983–96. However, average yields remain too low to foster greater market participation by small-scale farmers in East and Southern Africa, mainly due to unfavorable growing conditions and lack of access to improved seed and chemical fertilizers.

Asia

In 1996, 29 percent of the global area harvested for potato was located in developing Asia, up from 19 percent in 1983. Most of the rest, 59 percent, was harvested in the industrialized countries. Following the break-up of the Former Soviet Union, China became the world's largest potato producer. In 1997, India ranked third after the Russian Federation. In China, India, and Asia in general, expansion in area planted has been driven in large part by strong off-farm demand. On the supply side, the potato's highly flexible vegetative cycle, which allows it to fit into a wide variety of cropping systems, has been another factor influencing area expansion. In the Indian Indo-Gangetic plain, where area expansion has been particularly rapid, potato can be harvested between rice and other crop harvests (Bardhan Roy et al. 1999). The spread of potato cultivation in the region has also been facilitated by ample availability of irrigation, chemical fertilizers, and cold storage facilities, and improvements in cultivation techniques and road and rail transport. And with relatively high yields in 100–120 days, potato represents an extremely lucrative crop for even the small farmers who dominate production in many Asian countries (Bardhan Roy et al. 1999; Bottema et al. 1989; Dahiya and Sharma 1994; Scott 1983b, 1988a).

Seventy-eight percent of global area planted to sweetpotato is located in Asia, 68 percent alone in China, down from 83 percent in 1983. Some of the same factors that contributed to expanded potato production have led to a decline in area planted in sweetpotato. With the spread of irrigation, farmers in some parts of China (Stone 1984; Ye and Rozelle 1993; Zhang 1999, 46) and Korea (Chin 1989) switched to crops with higher returns per hectare. Moreover, with increasing economic growth and rapid urbanization in many parts of Asia, consumers decreased their demand for traditional starchy staples, such as fresh sweetpotato, in favor of meat, bread, potato, and other preferred foods. Hybrid maize or imported feed rations displaced sweetpotato as a feed source as countries such as Korea (Chin 1989) and Taiwan (Chiang 1992) became more integrated into the global economy. An exception is sweetpotato production in Sichuan province, China (see Box 2). Bulkiness, perishability, and erratic year-to-year, season-to-season movements in supply and prices made it difficult to establish local sweetpotato-based agro-industries in the Philippines (Cabanilla 1996), Indonesia (Setyono, Damardjati, and Malian 1992), and elsewhere in Asia (Woolfe 1992).

Growth in area planted to cassava in Asia has been negative primarily due to the contraction in demand for cassava chips and pellets in the European Union. Stagnant demand for meat in industrialized countries, in particular pork, has also contributed to this trend (Delgado et al. 1999). Use of cassava as feed in developed countries in 1996 was less than half the 1983 level of 19 million mt (Table 3). In India, cassava has come under increasing pressure from competing raw materials in the markets for processed products (Balagopalan, Padmaja, and Kurup 1992) and has been hurt by adverse policies, including subsidies favoring substitute crops such as *Hevea brasiliensis* (natural rubber) (Best 1996).

Since the early 1990s, however, the cassava industry in South and particularly Southeast Asia has aggressively pursued alternative market outlets

(Dang, Le, and Henry 1996; FAO 1994, 1995a; Titapiwatanakun 1996). The growth in the use of cassava for starch and as raw material for livestock production has raised expectations that the sector's decline may have bottomed out, and that cassava production may rebound, capitalizing on the same favorable set of factors that led to spectacular growth in the 1970s and 1980s (Konjing 1989). These factors include climate conditions that facilitate low-cost solar drying, ample transportation infrastructure, technology transfer through joint ventures, well-organized commodity associations, and attractive returns to production (Titapiwatanakun 1998).

Latin America

In Latin America, area planted to R&T has been either flat or negative. Production of cassava and sweetpotato stagnated or contracted due to urbanization and its associated shifts in eating habits. Moreover, imports of wheat flour for food, and maize or concentrates for feed, provided stifling competition for R&T in countries such as Peru (Blondet and Espinola 1998; Meerdink 1995). In other countries, such as Argentina, sweetpotato use was confined to niches for processed products in the domestic market or to exports of fresh roots. Weak demand, high relative prices, and more attractive returns to other crops have dampened potential production increases (Brescia and Parellada 1994; Maggi 1990). Where cassava production did increase—on the north coast of Colombia and in northeast Brazil—it followed the pattern first established in Thailand. Markets for cassava as animal feed and links between small farmers and these alternative commercial outlets provided the incentives for growers to expand output, often through yield-increasing technologies. This pattern offers promise to cassava-producing countries where the absence of emerging markets has led to a decline in cassava production (Henry 1992).

Potato production in Latin America increased by more than 3 million mt and yam by 0.3 million mt during 1983–96, with growth in area accounting for 16 percent and 41 percent of this increase, respectively. The continued popularity of yam as a food item and source of cash income was largely confined to Jamaica and Haiti. The emergence of a fast-food sector and processing industry in the region spurred domestic output of potato (Scott, Basay, and Maldonado 1997). However, the elimination of credit schemes (as part of a broader effort to reduce public spending and government participation in the marketplace) raised the costs of production per hectare, driving many smaller potato producers out of the sector (Rodriguez 1996). The more efficient farms were able to respond to growing market opportunities by expanding area planted.

Sources of Productivity Growth

Although growth in area planted has contributed more to increases in R&T production in developing countries than improvements in yields, noteworthy increases in productivity have taken place in some countries and regions (Table 7).

Sub-Saharan Africa

Yield growth rates in Sub-Saharan Africa have been disappointing except in the case of yam. Increases in yield are often difficult to achieve in the region because of nutrient-poor soils, lack of irrigation, and weak infrastructure (Spencer and Badiane 1995). In addition, R&T have suffered from the tendency of governments, with a few noteworthy exceptions, to focus their policies and resources on cash crops for export, or, in parts of East and Southern Africa, on cereals. One consequence of this relative neglect is that national research programs for R&T are often poorly funded and understaffed.

But as population growth and urbanization have continued apace, many governments and researchers are reappraising the potential of R&T to help meet food, feed, and income requirements in the decades ahead (Adeniji et al. 1997; Bashaasha and Mwanga 1992). Research on R&T has focused more on efforts to control pests and diseases through a combination of better biological control, improved cultural practices, and the introduction of disease-resistant varieties. Several of these production interventions have been successful (see, for example, Rueda et al. 1996). But with the noteworthy exception of integrated pest management for cassava mealybug (Norgaard 1988), the area cultivated using these new technologies has been limited to date.

Asia

Yields have increased more rapidly in Asia. In the case of potato, yield increases have been catalyzed in part by the introduction of high-yielding varieties, which made the crop more profitable for farmers (see, for example, Bofu et al. 1996; Scott 1988a). Introduction of improved seed multiplication techniques meant that farmers could achieve higher yields by having seed available at optimum planting time. In the Indo-Gangetic plain, these techniques were complemented by the expansion of cold storage facilities for seed and table potatoes (FAO 1995b). Potato yields also benefited from the earlier introduction of improved rice and wheat varieties. Successful adoption of the cereals prompted increases in the supply of chemical fertilizers, irrigation, and rural infrastructure, with subsequent spillover benefits to potato, which also is an input-intensive crop. After taking hold in prime locations, potato production expanded to somewhat less favorable soils, which led to a slowdown in yield improvement.

Production growth for sweetpotato is now positive in China, although it had contracted. The rebound is largely due to the explosive demand for meat and animal feed in the feed-deficit, inland, sweetpotato production centers. Growth in demand both at home and abroad for processed food products made from sweetpotato has also contributed to the upsurge in sweetpotato output (Fuglie et al. 1999; Zhang 1999). Improved, small-scale processing of sweetpotato roots has also boosted production by making household or village-level processing less onerous and more profitable (Wheatley, Liping, and Bofu 1997). In addition, new varieties have been adopted more widely, in part because of the rebound in off-farm demand. But China's earlier isolation from Western science and sweetpotato's much lower priority than cereals or industrial crops such as cotton have handicapped more rapid improvements in productivity.

Cassava productivity has followed trends similar to sweetpotato productivity. Cassava and, even more so, sweetpotato have been neglected in hard-pressed national agricultural research programs. Policies that have favored cheap imports or domestic products that could serve as substitutes have also hurt the potential for improving cassava productivity.

Latin America

For the region as a whole, cassava and sweetpotato productivity has been affected by weak demand. Most farmers have had little incentive to use yield-increasing technologies because potential commercial opportunities have yet to be exploited. Existing market outlets are limited and relatively thin, with the exception of cassava for feed or processed food in Colombia and northeast Brazil. Remaining growers are generally resource-poor farmers who choose to cultivate these commodities in part to avoid the financial risks associated with more input- and cash-intensive crops. As area planted with cassava and sweetpotato has declined or at best stagnated, cultivation often has been pushed onto or confined to more marginal soils. Productivity increases therefore have become more difficult to achieve. With a few notable exceptions, for example cassava in Colombia, weak national research programs have further handicapped productivity improvements for these crops. R&T are also often overlooked in policy deliberations regarding exchange rates and trade and tariff agreements. Because the farmers who make up these commodity subsectors typically have smallholdings and are poorly organized, they lack the political clout of more formidable farmers' groups, such as the national rice-growers' associations, to press for more public and private sector investments.

For potato and yam, improvements in yields have been larger. Average potato yields in Mexico are now 20 mt per hectare, after increasing at more than 4.1 percent per year during the last decade. Strong off-farm demand, fueled by contracts with agro-industry, have helped catalyze this upward trend. Potato productivity in Mexico has also benefited from the introduction of improved varieties; the spread of potato cultivation to lowland, irrigated farming areas; the high returns per hectare that have attracted large, highly technical commercial growers to the sector; and the spillover benefits—fertilizers, pesticides, and local infrastructure—associated with the spread of improved cereal varieties (Biarnès, Colin, and Santiago Cruz 1995). Colombia has witnessed similar developments, though production remains concentrated in highland and rainfed areas (Rodriguez 1996). In contrast, yield growth for potato in Bolivia and Ecuador, for example, has been negative or stagnant during the last decade, with average productivity in Ecuador still nearly 30 percent below levels reached in the early 1980s. Complex agroecologies; a heterogeneous set of target farmers in terms of size, education, and market orientation; slower introduction of and demand for new products; and trade and exchange rate policies that have favored cereal crops have all played a role in this negative trend (Zevallos 1997).

In summary, trends in production, area planted, and yield for R&T have been highly variable by crop and by region. Increases in potato and yam production have been most impressive in Asia and Sub-Saharan Africa, respectively. Cassava output growth has been strongest in Sub-Saharan Africa.[9]

For cassava and sweetpotato in Asia and Latin America, trends have been more mixed. Issues that need to be explored include the potential for increased productivity, the reduction in per unit costs to make these crops economically attractive sources of raw material, and the increased ability of existing public and private organizations to respond to the demand for new uses. The following chapter will address these issues and assess future prospects for R&T in a framework that encompasses all the major food commodities.

[9] In WANA, potato production nearly doubled during 1983–96, from 8.3 million mt to 15.1 million mt (Table 6). Area planted expanded at an annual rate of 2.6 percent in response to both strong domestic demand (see, for example, Fuglie 1994) and shifts in government policy in countries like Egypt that served to spur exports (Pautsch and Abdelrahman 1998). Yields increased at a rate of 2.1 percent per year. With access to irrigation facilities, chemical fertilizers, and improved seed (from foreign and local sources) farmers in the region had both the incentive (strong off-farm demand) and technical capability to raise productivity.

4. Baseline Projections of Production and Use

Changes in the volume, rate of growth, form, and location of R&T production and use have continued to evolve in a highly heterogeneous fashion over the last two decades. Two aspects of this evolution have been particularly noteworthy: the versatile uses of R&T and the adaptability of these crops to the emerging needs of local food systems in developing countries. These aspects of R&T will be even more important in the face of future increases in population, urbanization, and persistent poverty in the midst of rising incomes. Assessing the future role of R&T in the global food system requires careful consideration of the relative capacity of these different food commodities to respond to the challenges ahead. For this assessment to be transparent, key assumptions about the most likely track for the global economy and population growth, as well as the most likely responses of particular food commodities to these trends, need to be made explicit. The rationale behind these assumptions also need to be delineated.

In this and the following chapter two alternative scenarios for the role of R&T in the food systems of developing countries up to 2020 will be analyzed. The baseline projections are presented in detail in this chapter, and the alternative high demand and production growth projections are presented in Chapter 5. These global projections of food supply and demand are based on IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which is continually refined and updated and covers 37 countries or country groups and 18 commodities, including all cereals, soybeans, the major R&T, meats, and milk (see Box 3). The assumptions behind the estimates are based on assessments of the future outlook for production and use of R&T; the prospects for expansion in area planted and increases in productivity; and the implications of these growth patterns for future net trade, international prices, and value of production of these commodities.

Baseline Scenario to 2020

Under the baseline scenario, projections for R&T are driven by conservative estimates of the effects of income growth on the demand for these commodities (see Appendix, Table 26) and of the effects of technological change and other parameters on increases in production and yield. As a corollary, the rate of growth of output is modest in relation to recent historical trends.

Total use of R&T in developing countries is projected to increase by 232 million mt to 635 million mt, or by 58 percent, between 1993 (1992–94 average) and 2020 (Table 8). The largest increase in terms of volume is projected for cassava: 103 million mt, or 44 percent of the total increase in R&T use over the period. Potato ranks second, with 68 million mt, or 29 percent of the increase in R&T use. Sweetpotato and yam will account for an additional 62 million mt, about 27 percent.[10]

Total demand for cassava is expected to increase at 1.9 percent per year during 1993–2020 in developing countries; potato at 2.0 percent per year; and sweetpotato and yam combined at 1.3 percent per year. These rates of growth compare well with projected increases in demand of major cereals during this period: demand for wheat is projected to grow at 1.8 percent annually; maize at 2.2 percent annually; and rice at 1.2 percent annually (Tables 9 and 10).

[10] IMPACT implicitly assumes that the relative importance of the volume of production (fresh weight) of sweetpotato versus yam in Sub-Saharan Africa will remain roughly constant during 1993–2020. The results presented here are based on the June 1998 IMPACT baseline.

Box 3: The IMPACT Model

IFPRI's IMPACT model is specified as a set of country-level demand and supply equations linked to the rest of the world through trade. Food demand is a function of commodity prices, per capita income, and population growth. Feed demand is a function of livestock production, feed prices, and feeding efficiency. Total demand equals the sum of food, feed, and other demand. Crop production is determined by the area and yield response functions; area is projected as a function of crop prices, investment in irrigation, and estimated rates of loss of land to urbanization and land degradation. Crop yield is a function of crop price, input price, investment in irrigation, and yield growth due to technological change. Growth in productivity due to technological change is, in turn, estimated by its component sources, including advances in management research and, in the case of food crops, plant breeding research. Other sources of growth considered in the model include private-sector investments in agricultural research and development, agricultural extension and education, markets, infrastructure, and irrigation (see Rosegrant, Agcaoili-Sombilla, and Perez [1995] for details on the methodology).

The projections presented in this paper go beyond past estimates of future R&T supply and demand in a number of important respects. Previous attempts typically focus on a single root and tuber crop, for example, potato (see FAO 1995b; Henry and Gottret 1996) or aggregate R&T into one commodity. These approaches do not allow for the estimation of the possible linkages among R&T and between R&T and other food commodities.[11] Previous projections have relied heavily on past commodity trends and are seldom explicit about key parameters, such as income elasticities of demand. Given concerns about the accuracy of time-series data on production and use of R&T (Alexandratos 1995, 100), IMPACT integrates an analysis of past trends and projections with a synthesis of surveys and case studies of these commodities. Previous attempts at multicommodity projections were often carried out without the full collaboration of R&T specialists. Given the relative shortage of published information on projections of supply and demand for R&T, consultation with specialists, as is the case here, represents an important aspect of any modeling exercise for these commodities.

[11] Although sweetpotato and yam are combined in this analysis some results are disaggregated outside IMPACT when discussing the findings and associated contributing factors at the regional and subregional level. Cassava refers to cassava and other roots and tubers, including aroids such as taro; however, cassava alone accounts for more than 97 percent of the cassava total.

Demand for potato in developing countries is expected to increase by 2.3 percent annually for food and 0.4 percent annually for feed during 1993–2020 (Table 9). These projected food and feed growth rates are well below the annual rates achieved during 1983–96 of 4.1 percent and 4.6 percent, respectively. The combined annual growth in use of sweetpotato and yam is projected at 0.4 percent for food and 1.8 percent for feed over the next two decades compared with annual growth in human consumption of –1.8 percent and 8.6 percent per year, and annual growth in feed demand of 3.4 percent and 2.7 percent during 1983–96. According to IMPACT, cassava demand will grow at 2.0 percent annually for food and 1.6 percent per year for feed in developing countries (Table 9). These are virtually the same rates of growth achieved during 1983–96.

Per capita consumption of cereals as food is expected to decline slightly in both developed and developing countries, from 144 kg in 1993 to 140 kg in 2020, and from 172 kg to 170 kg, respectively (Table 11). But per capita consumption of R&T as food is projected to increase, albeit marginally, in both developed and developing countries, from 77 kg to 78 kg and from 56 kg to 58 kg, respectively. Declines in per capita R&T demand in China, Southeast Asia, Latin America, and Sub-Saharan Africa will be more than offset by increases in India and other South Asian countries, and in East Asian countries other than China.

Sub-Saharan Africa

Sub-Saharan Africa is expected to experience the most rapid growth in food demand in all R&T

Table 8—Total use of roots and tubers in 1993, and projected to 2020, baseline scenario

Country/region	Cassava[a] 1993	Cassava[a] 2020	Potato 1993	Potato 2020	Sweetpotato and yam[b] 1993	Sweetpotato and yam[b] 2020	All R&T 1993	All R&T 2020
	(million metric tons)							
China	5.1	6.4	42.7	63.3	108.0	126.9	155.9	196.7
Other East Asia	1.8	1.9	2.6	3.7	0.9	1.2	5.4	6.7
India	5.7	7.3	16.3	37.1	1.2	1.2	23.2	45.6
Other South Asia	0.9	1.4	3.5	7.6	0.5	0.7	4.9	9.7
Southeast Asia	18.9	24.4	1.4	2.7	5.3	7.7	25.6	34.8
Latin America	30.3	42.9	13.0	20.4	2.5	3.6	45.8	67.0
WANA	0.9	1.0	12.8	22.0	0.1	0.2	13.8	23.2
Sub-Saharan Africa	87.7	168.1	2.8	6.3	36.0	74.5	126.4	248.9
Developing	152.0	254.6	95.2	163.2	155.5	217.3	402.7	635.1
Developed	20.7	20.5	190.1	206.2	2.5	2.7	213.3	229.4
World	172.7	275.1	285.3	369.4	158.0	220.0	616.0	864.5

Source: IMPACT Simulations, June 1998.

Notes: Total use includes food, feed, and other uses. WANA is West Asia and North Africa. See Table 2 footnote for regional breakdown.

[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

Table 9—Projected annual growth rates for food, feed, and total use of roots and tubers, 1993–2020, baseline scenario

Country/region	Cassava[a] Food	Cassava[a] Feed	Cassava[a] Total	Potato Food	Potato Feed	Potato Total	Sweetpotato and yam[b] Food	Sweetpotato and yam[b] Feed	Sweetpotato and yam[b] Total	All R&T Food	All R&T Feed	All R&T Total
	(percent per year)											
China	0.17	1.61	0.84	2.20	0.27	1.47	–1.02	1.81	0.60	0.00	1.55	0.86
Other East Asia	0.83	0.21	0.05	1.31	1.20	1.29	0.84	1.47	0.86	1.22	1.20	0.83
India	0.93	na	0.93	3.09	na	3.09	0.14	na	0.14	2.42	na	2.54
Other South Asia	2.03	na	1.62	2.97	na	2.95	1.31	na	1.18	2.63	na	2.58
Southeast Asia	0.97	0.89	0.96	2.31	2.58	2.30	1.31	2.41	1.39	1.13	1.45	1.14
Latin America	0.70	1.75	1.30	1.69	1.62	1.69	1.09	2.01	1.32	1.18	1.75	1.42
WANA	1.34	0.43	0.68	2.02	1.59	2.02	1.52	na	1.51	2.00	0.60	1.95
Sub-Saharan Africa	2.49	1.53	2.44	3.10	1.81	3.10	2.74	1.89	2.73	2.55	1.56	2.54
Developing	1.99	1.62	1.93	2.33	0.37	2.02	0.44	1.81	1.25	1.62	1.57	1.70
Developed	–0.50	0.01	–0.04	0.37	0.22	0.30	0.28	0.61	0.33	0.36	0.15	0.27
World	1.98	0.95	1.74	1.20	0.26	0.96	0.43	1.80	1.23	1.30	1.07	1.26

Source: IMPACT Simulations, June 1998.

Notes: na signifies no recorded use. Total use includes food, feed, and other uses. WANA is West Asia and North Africa. See Table 2 footnote for regional breakdown.

[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

categories with the total R&T growth rate averaging 2.6 percent per year through 2020. Growth in total use (food, feed, and other uses) in Sub-Saharan Africa will account for nearly 122 million mt or 53 percent of the increase in demand for all R&T crops in developing countries during 1993–2020. The increase in use will come largely from cassava, 80 million mt (66 percent of the total), and yam roughly 33 million mt (31 percent) (Table 8) and will be overwhelmingly for food (Table 12).

Table 10—Projected annual growth rates for food, feed, and total use of wheat, maize, rice, and all cereals, 1993–2020, baseline scenario

	Wheat			Maize			Rice	All Cereals		
Country/region	Food	Feed	Total	Food	Feed	Total	Total	Food	Feed	Total
					(percent per year)					
China	0.90	3.46	1.11	-0.50	3.46	2.53	0.58	0.58	3.37	1.37
Other East Asia	1.20	2.55	1.64	0.29	2.15	1.86	0.44	0.64	2.22	1.44
India	1.90	3.65	1.98	0.81	7.39	2.44	1.56	1.56	4.96	1.69
Other South Asia	2.77	2.83	2.77	2.21	2.88	2.34	1.84	2.30	2.85	2.32
Southeast Asia	2.28	2.46	2.29	0.84	2.81	2.27	1.23	1.31	2.66	1.53
Latin America	1.36	2.19	1.44	1.22	2.00	1.74	1.66	1.36	2.04	1.70
WANA	2.02	2.45	2.05	1.22	2.40	2.01	2.19	1.98	2.47	2.12
Sub-Saharan Africa	3.30	3.65	3.30	2.58	3.43	2.64	3.20	2.91	3.45	2.92
Developing	1.67	2.92	1.77	1.07	2.92	2.24	1.23	1.43	2.81	1.75
Developed	0.31	0.42	0.35	0.00	0.70	0.66	0.29	0.21	0.59	0.49
World	1.29	1.08	1.22	0.94	1.72	1.49	1.19	1.21	1.41	1.27

Source: IMPACT Simulations, June 1998.
Note: Total use includes food, feed, and other uses. Rice demand for animal feed is negligible. All cereals includes wheat, maize, rice, and other coarse grains. See Table 2 footnote for regional breakdown.

Table 11—Per capita use of roots and tubers and cereals as food in 1993, and projected to 2020, baseline scenario

	Cassava[a]		Potato		Sweetpotato and yam[b]		All R&T		Cereals	
Country/region	1993	2020	1993	2020	1993	2020	1993	2020	1993	2020
					(kilograms per year)					
China	2	2	14	20	45	28	61	50	214	206
Other East Asia	1	1	18	21	6	6	24	27	157	149
India	6	5	13	21	1	1	20	27	163	175
Other South Asia	3	3	9	11	2	1	13	15	159	170
Southeast Asia	32	30	3	3	10	10	45	43	169	169
Latin America	25	21	22	24	3	3	50	48	128	129
WANA	1	1	28	28	. . .	. . .	29	29	214	210
Sub-Saharan Africa	131	124	3	3	36	36	169	164	112	119
Developing	24	28	13	16	19	14	56	58	172	170
Developed	. . .	. . .	75	77	1	1	77	78	144	140
World	19	23	27	27	15	12	61	62	165	165

Source: IMPACT Simulations, June 1998.
Notes: Ellipses (. . .) signify very small values. WANA is West Asia and North Africa. See Table 2 footnote for regional breakdown.
[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

Continued strong growth in food demand for cassava (2.5 percent per year) reflects the important role that cassava plays in many African diets and the relatively high rates of population growth projected for the region. The growth rate in food demand also stipulates that cassava will maintain its importance in regional diets as Sub-Saharan Africa continues to urbanize and increase its share of processed food products for consumers in the countryside and the cities. In major cassava-producing countries such as Nigeria, the bulk of annual production is already processed into food products (Adeniji et al. 1997). Finally, despite what some might consider relatively high growth

Table 12—Food and feed use of roots and tubers in 1993, and projected to 2020, baseline scenario

Country/region	Cassava[a] 1993	Cassava[a] 2020	Potato 1993	Potato 2020	Sweetpotato and yam[b] 1993	Sweetpotato and yam[b] 2020	All R&T 1993	All R&T 2020
				(million metric tons)				
Food								
China	2.7	2.8	15.9	28.5	53.2	40.3	71.7	71.6
Other East Asia	0.1	0.1	1.8	2.5	0.5	0.7	2.4	3.2
India	5.4	6.9	11.8	26.9	1.1	1.2	18.4	35.0
Other South Asia	0.7	1.3	2.5	5.6	0.4	0.6	3.7	7.4
Southeast Asia	15.0	19.5	1.2	2.2	4.6	6.6	20.8	28.2
Latin America	11.5	13.9	9.9	15.6	1.6	2.1	23.0	31.6
WANA	0.2	0.3	10.5	18.0	0.1	0.2	10.8	18.5
Sub-Saharan Africa	67.0	130.2	1.4	3.1	18.2	37.9	86.6	171.2
Developing	103.3	175.9	55.0	102.5	80.5	90.5	238.8	368.9
Developed	0.4	0.4	96.2	106.2	1.7	1.8	98.3	108.4
World	103.7	176.3	151.2	208.7	82.2	92.3	337.1	477.3
Feed								
China	1.9	3.0	12.3	13.3	49.4	80.2	63.7	96.4
Other East Asia	. . .	. . .	0.4	0.6	0.1	0.1	0.5	0.7
India	na	na	na	na	na	na	na	na
Other South Asia	0.1	. . .	na	na	. . .	. . .	0.1	. . .
Southeast Asia	0.7	0.9	. . .	. . .	0.3	0.6	1.0	1.5
Latin America	13.7	21.9	0.4	0.7	0.4	0.6	14.5	23.2
WANA	0.6	0.7	0.1	0.1	na	na	0.7	0.8
Sub-Saharan Africa	5.0	7.5	. . .	. . .	0.4	0.7	5.4	8.2
Developing	22.0	33.9	13.3	14.7	50.7	82.3	86.0	130.9
Developed	19.4	19.4	37.0	39.3	0.4	0.5	56.8	59.2
World	41.4	53.4	50.3	53.9	51.1	82.8	142.8	190.1

Source: IMPACT Simulations, June 1998.

Notes: Ellipses (. . .) signify very small values; na signifies no recorded use. WANA is West Asia and North Africa. See Table 2 footnote for regional breakdown.

[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

rates, annual average per capita consumption of cassava as food in Sub-Saharan Africa is actually projected to decline slightly, from 131 kg per year in the base period to 124 kg per year by 2020 (Table 11).

The projected rate of growth for sweetpotato and yam as food is 2.7 percent per year during 1993–2020 (Table 9). This increase is driven largely by the projected high population growth rate and modest per capita income growth in West Africa, where production of these crops, particularly yam, will remain concentrated. Additional factors that will contribute to the growth rate include increased purchases of fresh sweetpotato by low-income, urban consumers as a cheap, starchy staple (see, for example, Hall, Bockett, and Nahdy 1998); the recurrent use of sweetpotato as a crop for food security and disaster relief; and, the moderate expansion of the use of processed food commodities made from sweetpotato as market niches emerge with population growth and urbanization (Gatumbi and Hagenimana 1998). The projected annual growth rate of potato as food (3.1 percent) reflects increasing urbanization and changes in tastes in the region and the relatively low level of per capita demand for potato as food (2.7 kg per year) in the base period (Tables 9 and 11).

Asia

Potato for food and sweetpotato for feed—the latter almost exclusively in China—dominate projected use patterns for R&T in Asia. Of the projected total increase in demand of 79 million mt of R&T in Asia by 2020, some 48 million mt (61 percent) will be contributed by potato, another 22 million mt (28 percent) by sweetpotato, and the remaining 9 million mt (11 percent) by cassava. Annual growth rates in R&T food demand will be driven largely by increased consumption of potatoes (Table 9). Growing urbanization, rising incomes, and a desire by consumers to increasingly diversify diets will help spur continued growth in demand for processed potato products (Pacific-Vision 1995a, 1995b; Scott 1994a; VIPDT 1999; Ye and Rozelle 1993; Zhang et al. 1999). Estimated growth rates of roughly 3.1 percent per year for India and 2.2 percent for China conform with the potato's status as one of the most preferred of the complementary vegetables in Asia and, in some areas in South Asia, as a seasonal staple. Continued increases in potato demand are also consistent with the effects on consumption of past increases in income and estimated income elasticities of demand (see, for example, Bouis and Scott 1996; Goletti 1993). Results from IMPACT suggest that per capita food demand for potato in developing Asia will increase from 11 kg in 1993 to 17 kg in 2020, on average, and growth in food demand for potato is projected at higher levels than growth for the major cereals (Tables 9 and 10). However, even in those countries with projected high growth rates in potato demand, estimated per capita consumption levels in 2020 will still be a third or less of current consumption levels in developed countries (Table 11).

Growth in sweetpotato use will be concentrated in China (which produces very little yam) and, to a lesser extent, in Southeast Asia. Projected growth in feed demand for sweetpotato in China (1.8 percent per year) continues a trend already well documented in field studies, which describe a growing tendency of farmers and small-scale village enterprises to use both roots and vines as animal feed, particularly in Sichuan province (see, for example, Jiang, Rozelle, and Huang 1996; Peters 1997). Despite overall negative growth in total demand for sweetpotato as food (–1.0 percent per year), some local processing of sweetpotato into food will likely continue (Fuglie et al. 1999; Jiang, Rozelle, and Huang 1996; Zhang 1999), given that these activities in many instances complement sweetpotato processing for feed at the small-entrepreneur level (Peters 1997). As for cassava, feed use and processed products will increasingly replace direct consumption as food. This pattern has already become evident in Vietnam (Goletti and Wheatley 1999; Howeler 1996), Thailand (Titapiwatanakun 1998), and Indonesia (Wheatley and Scott 1994).

Latin America

In Latin America, the increase in total R&T demand will be dominated by cassava (12.6 million mt or about 60 percent of the total increase in R&T demand) and potato (7.4 million mt or 35 percent of the total increase). Demand growth for cassava as feed (1.8 percent per year) is projected to be stronger than growth for food (0.7 percent per year) (Table 9). This slow growth in food demand will follow recent trends: per capita food demand declined from 29 kg in 1983 to 25 kg in 1993 and is projected to decline further to 21 kg by 2020 (Table 11). Lynam (1989a, 1989b) and Ostertag and Herrera (1992) point to the increasing availability and use of cassava substitutes such as wheat flour, especially in urban areas, a trend facilitated in recent years by trade liberalization. Although new or improved forms of processed cassava for human consumption have been developed, their entry into the market has been sufficient only to slow the decline in per capita food demand for cassava. Feed use has been and will continue to be more dynamic, because cereal-feed-deficit countries (such as Colombia; see, for example, Balcazar 1997) or regions within countries (like northeast Brazil; see, for example, Ospina and Wheatley 1992) exploit cassava as a local substitute for maize.

Per capita food demand for potato stood at 22 kg in 1993 and is projected to rise, albeit modestly, to 24 kg in 2020 (Table 11). Population and income growth combined with high levels of urbanization, will spur a greater intake of processed potatoes in countries like Colombia (Rodriguez and Rodriguez 1992), following a trend already manifest in some developed countries.[12] Potato will not be used

[12] Lucier et al. (1991) report that over 52 percent of the U.S. potato crop is used for processed food products. Hesen (1991) describes similar trends for Western Europe.

much for animal feed in the region: a mere 0.6 million mt out of a total use of 15.6 million mt in 2020; nor is this projected to change in the future (Table 12). Per capita consumption levels for sweetpotato and yam as food (roughly 3 kg in both 1993 and 2020) are low when compared to cassava and potato (Table 11). The growth rate in food demand for potato is highest of all R&T and surpasses those for the cereals (Tables 9 and 10).

Baseline Projections for Production, Area, and Yield

According to the baseline scenario, production of cassava in developing countries will grow at an annual average rate of 1.7 percent during 1993–2020 (Table 13) compared to the annual growth rate of 1.8 percent achieved during 1983–96 (Table 5). Production growth for sweetpotato and yam is projected at 1.3 percent per year during 1993–2020, and for potato at 2.0 percent. Thus, growth in potato production is expected to slow down considerably from the rate of 4.1 percent per year during 1983–96.

Total R&T production in developing countries will increase by some 230 million mt by 2020 according to the baseline scenario (Table 13). More than half of that increase (122 million mt) is projected to occur in Sub-Saharan Africa and will consist largely of cassava (81 million mt) and yam (roughly 30 million mt).[13] Over the next two decades, the source of output growth will shift away from expansion in area planted toward increases in yields (66 percent of total output growth) for total R&T (Tables 14 and 15). The projected growth rate for cassava production in Sub-Saharan Africa of 2.5 percent per year actually constitutes a 33 percent decline compared to the rate of increase during 1983–96 (Table 5). The growth rate for sweetpotato and yam production is also projected to decline between 1993 and 2020 to 2.7 percent annually (Table 13). Discrepancies between production and use data for yam in Nigeria (Bricas and Attaie 1998), agroclimatic constraints on further expansion in area planted for yam (M. Bokanga, personal communication, September 1998), and slower development of high-yielding varieties (Spencer and Badiane 1995) all support the more conservative projected growth rate for sweetpotato and yam.

Projected increases for R&T production in Asia will be led by potato. In fact, about 48 million mt out of the 68 million mt increase in potato production in developing countries will come from developing Asia. The bulk of this production increase will be driven by improvements in yields (Tables 14 and 15). With access to irrigation, chemical inputs, and relatively abundant labor, prospects for yield improvements are good. In Bangladesh, India, and Pakistan, the introduction of improved varieties and the expansion of cold storage facilities have provided additional incentives to growers (FAO 1995b). The liberalization of the internal market for cold storage has brought an expansion and modernization of India's storage industry that appears capable of keeping up with farm production of potatoes (Fuglie et al. 1997). Some farmers in Bangladesh and India, in fact, currently report yields double their respective national averages of 11 mt/ha and 16 mt/ha (see, for example, Dahiya et al. 1997; Khatana et al. 1997). Given that anywhere from 65 to 90 percent of the potato harvest in South Asia is sold for cash (Bottema et al. 1989; Dahiya and Sharma 1994; Fuglie et al. 1997; Kokab and Smith 1989), growers have a strong commercial incentive to improve productivity.

Sweetpotato production in China is projected to grow at 0.6 percent per year, due entirely to increases in yields because area planted is projected to contract. As irrigation and improved road networks penetrate into more isolated areas, growers will switch from sweetpotato to production of higher value-added crops unless new technology (for example improved varieties for use as feed), institutional development (such as improvements in small agro-enterprise management and marketing), and appropriate policies in support of these initiatives are implemented. Increases in pro-

[13] The figure of 30 million mt is for yam alone and assumes that the division of total sweetpotato and yam production conforms to the proportion in 1993.

Table 13—Production levels and annual growth rates of production for roots and tubers, 1993–2020, baseline scenario

	Cassava[a]			Potato			Sweetpotato and yam[b]			All R&T		
	Production		Growth	Production		Growth	Production		Growth	Production		Growth
Country/region	1993	2020	rate	1993	2020	rate	1993	2020	rate	1993	2020	rate
	(million mt)		(percent/yr)	(million mt)		(percent/yr)	(million mt)		(percent/yr)	(million mt)		(percent/yr)
China	4.8	6.5	1.18	42.5	63.4	1.49	108.5	128.3	0.62	155.8	198.3	0.90
Other East Asia	na	na	na	2.4	3.2	1.13	0.8	1.1	1.18	3.2	4.3	1.14
India	5.8	7.0	0.71	16.3	37.3	3.10	1.2	1.2	0.12	23.3	45.5	2.51
Other South Asia	0.8	1.3	1.56	3.5	7.5	2.90	0.5	0.7	1.00	4.8	9.4	2.53
Southeast Asia	42.0	48.2	0.51	1.3	2.3	2.06	5.3	7.5	1.29	48.6	58.0	0.65
Latin America	30.3	41.7	1.19	12.6	20.0	1.72	2.6	3.5	1.19	45.5	65.3	1.35
WANA	0.1	0.2	1.60	13.0	22.4	2.02	0.1	0.2	1.35	13.3	22.8	2.01
Sub-Saharan Africa	87.8	168.6	2.45	2.6	5.9	3.01	36.0	74.2	2.71	126.4	248.7	2.54
Developing	172.4	274.7	1.74	94.3	162.0	2.02	155.9	217.8	1.25	422.6	654.5	1.63
Developed	0.4	0.4	0.68	191.0	207.4	0.31	2.1	2.1	0.12	193.4	210.0	0.31
World	172.7	275.1	1.74	285.3	369.4	0.96	158.0	220.0	1.23	616.0	864.5	1.26

Source: IMPACT Simulations, June 1998.
Notes: na signifies no recorded production. WANA is West Asia and North Africa. See Table 2 footnote for regional breakdown.
[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

Table 14—Area planted and annual growth rates in area planted for roots and tubers, 1993–2020, baseline scenario

	Cassava[a]			Potato			Sweetpotato and yam[b]			All R&T		
	Area		Growth	Area		Growth	Area		Growth	Area		Growth
Country/region	1993	2020	rate	1993	2020	rate	1993	2020	rate	1993	2020	rate
	(million ha)		(percent/yr)	(million ha)		(percent/yr)	(million ha)		(percent/yr)	(million ha)		(percent/yr)
China	0.3	0.3	0.08	3.1	3.2	0.17	6.2	5.6	–0.39	9.6	9.1	–0.19
Other East Asia	na	na	na	0.2	0.2	–0.41	. . .	0.1	0.30	0.2	0.2	–0.25
India	0.2	0.2	0.02	1.0	1.4	1.19	0.1	0.1	–0.16	1.4	1.8	0.90
Other South Asia	0.1	0.1	0.21	0.3	0.4	0.89	0.1	0.1	0.10	0.5	0.6	0.67
Southeast Asia	3.5	3.5	0.04	0.1	0.1	0.59	0.8	0.8	0.04	4.4	4.4	0.06
Latin America	2.7	2.7	–0.01	1.0	1.1	0.41	0.3	0.3	–0.23	4.0	4.1	0.07
WANA	. . .	. . .	0.12	0.7	0.8	0.55	. . .	. . .	0.13	0.7	0.8	0.54
Sub-Saharan Africa	11.9	15.9	1.09	0.4	0.6	1.25	4.2	5.7	1.16	16.5	22.2	1.11
Developing	18.8	22.9	0.73	6.8	7.8	0.51	11.9	12.8	0.27	37.5	43.5	0.55
Developed	. . .	. . .	–0.04	11.6	11.0	–0.19	0.1	0.1	–0.09	11.7	11.1	–0.19
World	18.8	22.9	0.73	18.4	18.8	0.09	12.0	12.9	0.27	49.2	54.6	0.39

Source: IMPACT Simulations, June 1998.
Notes: Ellipses (. . .) signify very small values; na signifies no recorded production. WANA is West Asia and North Africa. ha stands for hectares. See Table 2 footnote for regional breakdown.
[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

Table 15—Yield and annual growth rates in yields for roots and tubers, 1993–2020, baseline scenario

Country/region	Cassava[a] Yield 1993	Cassava[a] Yield 2020	Cassava[a] Growth rate	Potato Yield 1993	Potato Yield 2020	Potato Growth rate	Sweetpotato and yam[b] Yield 1993	Sweetpotato and yam[b] Yield 2020	Sweetpotato and yam[b] Growth rate	All R&T Growth rate
	(mt/ha)		(percent/yr)	(mt/ha)		(percent/yr)	(mt/ha)		(percent/yr)	(percent/yr)
China	15.1	20.2	1.10	13.7	19.6	1.32	17.5	23.1	1.02	1.09
Other East Asia	na	na	na	13.2	20.0	1.55	15.9	20.2	0.89	1.40
India	23.6	28.4	0.69	15.6	25.9	1.89	8.4	9.1	0.29	1.60
Other South Asia	9.4	13.5	1.35	10.9	18.5	1.99	9.1	11.6	0.90	1.84
Southeast Asia	12.1	13.7	0.46	12.5	18.6	1.46	6.8	9.5	1.25	0.60
Latin America	11.3	15.6	1.21	12.9	18.3	1.30	7.6	11.2	1.43	1.27
WANA	32.5[c]	48.3[c]	1.48	18.6[c]	27.6[c]	1.46	17.8	24.7	1.23	1.46
Sub-Saharan Africa	7.4	10.6	1.34	6.5	10.4	1.74	8.6	12.9	1.54	1.41
Developing	9.2	12.0	1.00	13.8	20.7	1.50	13.1	17.0	0.97	1.08
Developed	12.1	14.7	0.72	16.5	18.9	0.50	17.9	18.9	0.22	0.49
World	9.2	12.0	1.00	15.5	19.6	0.87	13.2	17.0	0.96	0.87

Source: IMPACT Simulations, June 1998.

Notes: na signifies no recorded production. WANA is West Asia and North Africa; ha is hectares. See Table 2 footnote for regional breakdown.

[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

[c]FAO indicates very high yields in Egypt in small areas.

duction of cassava will also largely come from increases in yield.

In Latin America, cassava production will increase at a moderate rate (1.2 percent per year) during 1993–2020. This increase will be driven by growth in yields, even as market demand for traditional cassava production remains weak, compared to potential growth opportunities in alternative markets. A similar scenario plays out in the case of sweetpotato and yam, but from a much lower level of output in the base period. For potato, annual growth in yields and area planted, 1.3 and 0.4 percent, respectively, combine to form the annual production growth rate of 1.7 percent. Improvements in the management of pests and diseases—late blight, for example—will facilitate productivity increases. Demand for both fresh and processed potato products will induce farmers to adopt yield-increasing technologies—a tendency supported by falling tariffs (Scott, Basay, and Maldonado 1997).

Baseline Projections for World Prices and International Trade

IMPACT projections indicate that global production of R&T will grow fast enough for real world prices of these commodities to fall between 1993 and 2020. According to the baseline scenario, average root and tuber prices are projected to decline by 19 percent: potato prices by 14 percent; sweetpotato and yam by 23 percent; and cassava and other roots and tubers by 15 percent (Table 16).

This slow decline in prices will not be accompanied by a significant increase in aggregate world trade of major R&T according to the baseline scenario. In fact, as a share of developing country R&T production, trade in R&T is projected to decline over time.

Developing countries as a group will remain net R&T exporters and developed countries net importers. Total net exports are projected to de-

Table 16—Estimated world prices for roots and tubers and selected other foods, late 1980s, 1993, and projected to 2020, baseline and HDP scenarios

	Price (US$ per metric ton)					Price changes (percent)	
Commodity	**1987/89[a]**	**1989/91[b]**	**1993[c]**	**2020A[d]**	**2020B[e]**	**1993/2020A[f]**	**1993/2020B[g]**
Potato	180	110	160	137	145	–14	–9
Sweetpotato and yam	—	—	91[h]	70[h]	82[h]	–23	–10
Sweetpotato[i]	82	76	80	56	69	–30	–14
Yam[i]	105	137	135	105	115	–22	–15
Cassava and other R&T	—	—	54[j]	46[j]	48[j]	–15	–11
Cassava	66	68	—	—	—	—	—
All roots and tubers	**—**	**—**	**113**	**91**	**99**	**–19**	**–12**
Wheat	144	144	148	133	133	–10	–10
Maize	104	124	126	123	123	–2	–2
Other grains	—	—	122[h]	105[h]	106[h]	–14	–13
Barley	128	114	—	—	—	—	—
Sorghum	93	124	—	—	—	—	—
Millet	132	158	—	—	—	—	—
Milled rice	284	292	286	265	266	–7	–7
Soybean	265	234	263	234	235	–11	–11
Beef	—	—	2,023	1,768	1,771	–13	–12
Beef and buffalo meat	1,458[h]	2,226[h]	—	—	—	—	—
Pigmeat	—	—	1,366	1,209	1,212	–11	–11
Sheep and goat meat	1,652[h]	2,099[h]	2,032[h]	1,842[h]	1,845[h]	–9	–9
Poultry	—	—	1,300	1,157	1,159	–11	–11

Sources: 1987/89: TAC (1996, Annex II); 1989/91: Rao (1993); 1993, 2020A, 2020B: IMPACT Simulations, June 1998.
Note: — signifies not applicable/available.
[a]Prices used in 1992 analysis (TAC 1996, Annex II, Table 9).
[b]Prices used by Rao (1993).
[c]Base period prices used in present study.
[d]Baseline scenario.
[e]High demand and production growth scenario.
[f]1993/baseline scenario percent change in price, rounded to nearest percent.
[g]1993/high demand and production growth scenario percent change in price, rounded to nearest percent.
[h]Composite price.
[i]Disaggregation of sweetpotato and yam outside of IMPACT, but based on historical trends and IMPACT simulations.
[j]Composite price: cassava and other roots and tubers such as taro.

crease slightly from 19.9 million mt in 1993 to 19.4 million mt in 2020 under the baseline scenario. The slight decrease in net cassava exports largely reflects the current declining trend in cassava exports from Southeast Asia to the European Union and the almost offsetting exports of cassava products to other regions (Goletti and Wheatley 1999; Titapiwatanakun 1998). Potato imports by the developing world will show the biggest absolute increase in R&T trade, rising by nearly a third, from 0.9 million mt in 1993 to 1.2 million mt in 2020. The biggest increases in potato imports are projected for Southeast Asia and Sub-Saharan Africa (0.3 million mt each), the former region will import mostly processed food products and the latter a mix of food products and seed. China and India are expected to become net exporters on the order of 100,000 mt per year, but in absolute percentage terms this will represent less than one half of one percent of their projected domestic production in 2020.

Net exports of sweetpotato and yam by developing countries are projected to increase by 40 percent or 162,000 mt, a tiny fraction of total production in these countries. It should be noted that trade among developing countries causes their aggregate net exports of sweetpotato and yam (and other commodities) to be lower than the exports of some individual developing countries. China, for example, is expected to export 1.4 million mt of sweetpotato by 2020.

Net exports of cassava and other roots and tubers by developing countries are projected to decrease slightly, by 290,000 mt or 1.4 percent,

Table 17—Total value of selected IMPACT commodities for developing countries in 1993 and projected to 2020, baseline and HDP scenarios

	1993			2020A			2020B		
Commodity	Value[a]	Percent of total	Percent of subtotal	Value[a]	Percent of total	Percent of subtotal	Value[a]	Percent of total	Percent of subtotal
	(US$ million)			(US$ million)			(US$ million)		
Potato	15,094	4.1	6.6	22,193	3.9	7.0	28,131	4.9	8.6
Sweetpotato and yam	14,185	3.9	6.2	15,248	2.7	4.8	18,879	3.3	5.8
Yam alone[b]	4,209	1.1	1.8	6,642	1.2	2.1	7,693	1.4	2.4
Cassava and other R&T	9,307	2.5	4.0	12,636	2.2	4.0	13,937	2.4	4.2
All R&T	38,586	10.5	16.7	50,076	8.8	15.8	60,946	10.5	18.6
All cereals	176,622	48.0	76.7	241,253	42.6	76.3	242,195	41.9	73.8
Soybeans	15,176	4.1	6.6	24,839	4.4	7.9	24,958	4.3	7.6
Subtotal	230,384			316,168			328,099		
All meat	137,752	37.4		249,862	44.1		250,467	43.3	
Total	368,136	100.0	100.0	566,030	100.0	100.0	578,567	100.0	100.0

Source: IMPACT Simulations, June 1998.

Note: 2020A: baseline scenario; 2020B: high demand and production growth scenario (HDP).

[a]Value is calculated using production data (1993: IMPACT base year values; 2020A: IMPACT baseline scenario; 2020B: IMPACT HDP scenario) multiplied by price (see Table 16).

[b]Disaggregation for yam outside of IMPACT, but based on historical trends and IMPACT simulations.

from 1993 levels. This decrease will come about largely because India will switch from being a small net exporter to a small net importer. The opposite trend is projected for China. Latin America will see imports of cassava and other roots and tubers rise to 1.2 million mt by 2020. The major beneficiaries of a more diversified world market for cassava and other roots and tubers will be Southeast Asia and Sub-Saharan Africa.

An important development for the international R&T market is the projected increase in total use of R&T in some developing country regions at rates higher than the projected production growth rate in these regions. This trend will benefit traditional net potato exporters such as Canada, the United States, and the Netherlands. Eastern Europe will become a net exporter of potato at 411,000 mt, while Japan will increase its imports of all roots and tubers by 23 percent, from 1.5 million mt in 1993 to 1.9 million mt by 2020, under the baseline scenario.

The Value of R&T Crop Production in the Baseline Scenario

Policymakers and researchers are also interested in the projected value of root and tuber crops in the decades ahead. The projections of the rate of growth of supply, demand, and world market prices for R&T permit the estimation of the future value of root and tuber crops alone and in relation with the estimated values for other major food commodities produced in developing countries.

The IMPACT baseline scenario shows that the share of R&T in the total value of the major food commodities will decrease from 10.5 percent to 8.8 percent between 1993 and 2020, and R&T's share in the major food and feed crops will shrink from 16.7 to 15.8 percent (Table 17). The bulk of the change in the projected future values of R&T is due to the decline in the estimated world prices for cassava and sweetpotato and the relatively strong projected prices for maize and rice in 2020.

In summary, the projected baseline growth rates for supply and demand of R&T vary according to crop, region, and use. Furthermore, in several instances the projected growth rates in supply are rather conservative when compared with recent historical trends. This is most notably the case for potato. Nevertheless, even the baseline estimates indicate that the role of R&T in the food systems of developing countries will not deteriorate significantly over the next two decades.

The next chapter presents the outcome of an alternative scenario, based on more optimistic growth prospects for R&T.

5. *High Demand and Production Growth Scenario*

Past projections for some R&T in developing countries—most notably potato—have often underestimated actual increases in demand and supply (see Scott 1983a). These low projections have resulted from income elasticities of demand based on data from industrialized countries and the assumption that consumers in Africa, Asia, and Latin America will behave in a fashion similar to their developed-world counterparts (Horton 1981). In many cases, they have not. Estimates of actual income elasticities of demand for specific roots and tubers in developing countries are relatively few and far between, which partly accounts for the need to "extrapolate" from the experience of industrialized countries. Furthermore, the estimates that do exist are for particular time periods, often for a subsection of the population (for example, rural households), and invariably for fresh products. Moreover, trends beginning in some cases as early as the 1960s indicate that the structure of demand and supply for R&T in the developing world is undergoing fundamental shifts (Scott and Suarez 1992). As consumption of processed products increases, the small number of estimates for fresh roots and tubers becomes less and less appropriate. If the continued rapid increase in potato demand, for example, particularly in Asia and parts of WANA, is sustained for several more years, the upward shift in income elasticities may be even greater than accounted for in the baseline scenario.

These upward shifts make it necessary to explore a high demand and production growth (HDP) scenario that incorporates a more sustained increase in supply and demand for those developing countries and regions currently experiencing rapid growth in the R&T sector. This chapter examines the impact of this faster supply and demand growth on the regional and global supply/demand situation in 2020.

On the demand side, the HDP scenario incorporates food demand elasticities for potato that are 0.20 higher than in the baseline scenario for Egypt, India, and Turkey and 0.10 higher for China (selected baseline elasticities are given in the Appendix, Table 26). For sweetpotato feed in China the HDP scenario incorporates a higher ratio of sweetpotato per unit of livestock output. And for cassava and other roots and tubers, the HDP scenario uses demand elasticities that are 0.35 higher than in the baseline for Nigeria and central-west Sub-Saharan Africa, and 0.20 higher for the rest of Sub-Saharan Africa. On the supply side, area growth rates for potato are assumed to increase by 0.50 percent per year more than in the baseline scenario for China, Egypt, and India, and by 0.20 percent per year more for Turkey. Yield growth in China is assumed to be 0.70 percent per year above the baseline rate of growth, reflecting more rapid technological change. For cassava and other roots and tubers, area growth for Sub-Saharan Africa is assumed to increase by an additional 0.30 percent per year. The HDP scenario thus incorporates the assumption that the accelerating growth in supply and demand for R&T seen in the early 1990s tapers off more gradually than in the baseline scenario.

HDP Projections for R&T Use

According to the HDP scenario, total use of R&T in developing countries is projected to increase by 74 percent between 1993 and 2020, or an additional 64 million mt compared to the baseline scenario (Tables 8 and 18). More than half of the additional increase (35 million mt) is attributable to faster growth in use of potato, with the remainder roughly evenly divided between cassava and other roots and tubers (16 million mt) and sweetpotato and yam (13 million mt). Average annual increases in total use of potato during 1993–2020 are considerable: 2.8 percent versus 2.0 percent in the

Table 18—Total use of roots and tubers in 1993, and projections to 2020, HDP scenario

Country/region	Cassava[a] 1993	Cassava[a] 2020	Potato 1993	Potato 2020	Sweetpotato and yam[b] 1993	Sweetpotato and yam[b] 2020	All R&T 1993	All R&T 2020
				(million metric tons)				
China	5.1	7.5	42.7	89.2	108.0	136.8	155.9	233.6
Other East Asia	1.8	1.9	2.6	3.6	0.9	1.1	5.4	6.7
India	5.7	7.4	16.3	44.6	1.2	1.2	23.2	53.3
Other South Asia	0.9	1.4	3.5	7.5	0.5	0.7	4.9	9.5
Southeast Asia	18.9	25.3	1.4	2.7	5.3	7.7	25.6	35.7
Latin America	30.3	43.2	13.0	20.6	2.5	3.5	45.8	67.3
WANA	0.9	1.0	12.8	23.9	0.1	0.2	13.8	25.1
Sub-Saharan Africa	87.7	181.2	2.8	6.3	36.0	77.4	126.4	265.0
Developing	152.0	270.2	95.2	198.6	155.5	229.9	402.7	698.7
Developed	20.7	20.6	190.1	204.8	2.5	2.6	213.3	228.0
World	172.7	290.8	285.3	403.5	158.0	232.5	616.0	926.7

Source: IMPACT Simulations, June 1998.
Notes: WANA is West Asia and North Africa. See Table 2 footnote for regional breakdown.
[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

Table 19—Projected annual growth rates in food, feed, and total use of roots and tubers, 1993–2020, HDP scenario

Country/region	Cassava[a] Food	Cassava[a] Feed	Cassava[a] Total	Potato Food	Potato Feed	Potato Total	Sweetpotato and yam[b] Food	Sweetpotato and yam[b] Feed	Sweetpotato and yam[b] Total	All R&T Food	All R&T Feed	All R&T Total
						(percent per year)						
China	0.00	2.77	1.40	2.78	2.74	2.76	–1.03	2.24	0.88	0.22	2.35	1.51
Other East Asia	0.87	0.21	0.11	1.30	1.31	1.26	0.74	1.23	0.74	1.17	1.12	0.81
India	1.01	na	1.01	3.80	na	3.80	0.12	na	0.12	2.99	na	3.13
Other South Asia	2.10	. . .	1.69	2.90	na	2.89	1.08	. . .	0.95	2.57	. . .	2.53
Southeast Asia	1.11	0.91	1.09	2.40	2.38	2.55	1.28	2.25	1.35	1.23	1.40	1.23
Latin America	0.78	1.73	1.33	1.71	1.58	1.71	1.04	1.80	1.24	1.23	1.73	1.44
WANA	1.51	0.42	0.73	2.33	1.56	2.33	1.45	na	1.44	2.31	0.59	2.24
Sub-Saharan Africa	2.80	1.53	2.73	3.15	1.78	3.14	2.93	1.72	2.87	2.83	1.55	2.78
Developing	2.24	1.72	2.15	2.75	2.66	2.76	0.50	2.23	1.46	1.88	2.17	2.06
Developed	–0.52	0.03	–0.03	0.34	0.20	0.28	0.22	0.37	0.23	0.33	0.14	0.25
World	2.23	1.02	1.95	1.39	1.01	1.29	0.49	2.21	1.44	1.49	1.49	1.52

Source: IMPACT Simulations, June 1998.
Notes: Ellipses (. . .) signify very small values; na signifies no recorded use. WANA is West Asia and North Africa. Total use includes food, feed, and other uses. See Table 2 footnote for regional breakdown.
[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

baseline scenario. The HDP growth rate for use is more modest for sweetpotato and yam: 1.5 percent per year versus 1.3 percent. Annual growth in the use of cassava and other roots and tubers is estimated at 2.2 percent, versus 1.9 percent in the baseline scenario (Tables 9 and 19). For cassava and potato, these HDP growth rates are still below recent historical trends.

Asian countries, particularly China, will experience the bulk of the additional increase in food

Table 20—Per capita use of roots and tubers as food in 1993, and projections to 2020, HDP scenario

	Cassava[a]		Potato		Sweetpotato and yam[b]		All R&T	
Country/region	1993	2020	1993	2020	1993	2020	1993	2020
					(kilograms per year)			
China	2	2	14	23	45	28	61	53
Other East Asia	1	1	18	21	6	5	24	27
India	6	6	13	25	1	1	20	32
Other South Asia	3	3	9	11	2	1	13	15
Southeast Asia	32	31	3	3	10	10	45	44
Latin America	25	22	22	24	3	3	50	49
WANA	1	1	28	31	. . .	. . .	29	31
Sub-Saharan Africa	131	135	3	3	36	38	169	176
Developing	24	30	13	18	19	15	56	62
Developed	. . .	. . .	75	76	1	1	77	77
World	19	24	27	28	15	12	61	65

Source: IMPACT Simulations, June 1998.

Notes: Ellipses (. . .) signify very small values. WANA is West Asia and North Africa. See Table 2 footnote for regional breakdown.

[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

and feed demand for potato projected in the HDP scenario. In comparison to the baseline scenario, per capita consumption of potato in 2020 will increase by 3.3 kg to 23 kg in China, by 4.2 kg to 25 kg in India, and by 2.5 kg to 31 kg in WANA (Tables 11 and 20). For South Asia and WANA, where some estimates of expenditure elasticities for potato have been estimated using household survey (Bouis and Scott 1996; Goletti 1993) and time-series data (Fuglie 1994), the HDP increases reflect the available empirical evidence. A combination of field surveys (Ye and Rozelle 1993), marketing and demand studies (Pacific-Vision 1995b; Zhang et al. 1999), and commercial updates (VIPDT 1999) suggest that the higher R&T projections for China in effect do reflect recent trends. In short, a historical perspective shows that the additional per capita food demand for potato projected for Asia by the HDP scenario is a plausible alternative to the baseline.

The HDP scenario also indicates a substantial increase in the use of sweetpotato as animal feed in China: 2.2 percent per year during 1993–2020 compared to 1.8 percent per year in the baseline scenario (Tables 9 and 19). The projected slower decline in the world market price of maize over the next 20 years (when compared to Rosegrant, Agcaoili-Sombilla, and Perez 1995, 26) might make sweetpotato a more competitive feed source. Genetic improvements in sweetpotato varieties and improvements in feed preparation at the household and village levels could further boost the use of sweetpotato as feed.

Sub-Saharan Africa will account for nearly all of the additional demand for cassava under the HDP scenario: 13 million mt of the projected total increase of 16 million mt. As a result, per capita food demand for cassava in Sub-Saharan Africa will increase from 131 kg in 1993 to 135 kg in 2020 under the HDP scenario, instead of declining to 124 kg as projected under the baseline scenario (Tables 11 and 20). Total use of sweetpotato and yam in Sub-Saharan Africa in 2020 will increase by 3 million mt compared to the baseline scenario (Tables 8 and 18), and per capita food demand will increase from 36 kg in the baseline scenario to 38 kg under the HDP scenario (Tables 11 and 20).

HDP Projections for Production, Area, and Yield

Annual average growth rates for production of R&T in developing countries during 1993–2020

Table 21—Production levels and annual growth rates of production for roots and tubers, 1993–2020, HDP scenario

	Cassava[a]			Potato			Sweetpotato and yam[b]			All R&T		
	Production		Growth	Production		Growth	Production		Growth	Production		Growth
Country/region	1993	2020	rate	1993	2020	rate	1993	2020	rate	1993	2020	rate
	(million mt)		(percent/yr)	(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	155.8	230.4	1.46
Other East Asia	na	na	na	2.4	3.3	1.18	0.8	1.1	1.36	3.2	4.4	1.22
India	5.8	7.1	0.76	16.3	43.3	3.67	1.2	1.3	0.44	23.3	51.7	3.00
Other South Asia	0.8	1.3	1.61	3.5	7.7	2.98	0.5	0.7	1.27	4.8	9.7	2.62
Southeast Asia	42.0	48.2	0.51	1.3	2.3	2.08	5.3	8.0	1.49	48.6	58.5	0.68
Latin America	30.3	42.0	1.22	12.6	20.2	1.76	2.6	3.7	1.41	45.5	65.9	1.39
WANA	0.1	0.2	1.61	13.0	23.4	2.21	0.1	0.2	1.55	13.3	23.9	2.19
Sub-Saharan Africa	87.8	183.8	2.77	2.6	6.0	3.06	36.0	78.0	2.90	126.4	267.7	2.82
Developing	172.4	290.3	1.95	94.3	194.0	2.71	155.9	230.2	1.45	422.6	714.6	1.96
Developed	0.4	0.4	0.67	191.0	209.5	0.34	2.1	2.3	0.36	193.4	212.2	0.34
World	172.7	290.8	1.95	285.3	403.5	1.29	158.0	232.5	1.44	616.0	926.7	1.52

Source: IMPACT Simulations, June 1998.

Notes: na signifies not applicable. WANA is West Asia and North Africa. See Table 2 footnote for regional breakdown.

[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

Table 22—Area planted and annual growth rates in area planted for roots and tubers, 1993–2020, HDP scenario

	Cassava[a]			Potato			Sweetpotato and yam[b]			All R&T		
	Area		Growth	Area		Growth	Area		Growth	Area		Growth
Country/region	1993	2020	rate	1993	2020	rate	1993	2020	rate	1993	2020	rate
	(million ha)		(percent/yr)	(million ha)		(percent/yr)	(million ha)		(percent/yr)	(million ha)		(percent/yr)
China	0.3	0.3	0.09	3.1	3.7	0.67	6.2	5.6	–0.36	9.6	9.6	0.02
Other East Asia	na	na	na	0.2	0.2	–0.39	. . .	0.1	0.44	0.2	0.2	–0.20
India	0.2	0.2	0.03	1.0	1.6	1.71	0.1	0.1	–0.04	1.4	2.0	1.31
Other South Asia	0.1	0.1	0.22	0.3	0.4	0.92	0.1	0.1	0.22	0.5	0.6	0.71
Southeast Asia	3.5	3.5	0.03	0.1	0.1	0.58	0.8	0.8	0.15	4.4	4.4	0.06
Latin America	2.7	2.7	–0.01	1.0	1.1	0.43	0.3	0.3	–0.10	4.0	4.1	0.09
WANA	. . .	. . .	0.12	0.7	0.8	0.67	. . .	. . .	0.22	0.7	0.8	0.66
Sub-Saharan Africa	11.9	17.2	1.39	0.4	0.6	1.27	4.2	5.9	1.26	16.5	23.7	1.36
Developing	18.8	24.2	0.94	6.8	8.6	0.84	11.9	13.1	0.35	37.5	45.8	0.74
Developed	. . .	. . .	–0.07	11.6	11.0	–0.18	0.1	0.1	0.06	11.7	11.2	–0.17
World	18.8	24.2	0.94	18.4	19.6	0.23	12.0	13.2	0.34	49.2	57.0	0.54

Source: IMPACT Simulations, June 1998.

Notes: Ellipses (. . .) signify very small values; na signifies no recorded production. WANA is West Asia and North Africa; ha stands for hectares. See Table 2 footnote for regional breakdown.

[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

Table 23—Yields and annual growth rates in yield for roots and tubers, 1993–2020, HDP scenario

Country/region	Cassava[a] Yield 1993	Cassava[a] Yield 2020	Cassava[a] Growth rate	Potato Yield 1993	Potato Yield 2020	Potato Growth rate	Sweetpotato and yam[b] Yield 1993	Sweetpotato and yam[b] Yield 2020	Sweetpotato and yam[b] Growth rate	All R&T Growth rate
	(mt/ha)		(percent/yr)	(mt/ha)		(percent/yr)	(mt/ha)		(percent/yr)	(percent/yr)
China	15.1	20.3	1.12	13.7	23.7	2.04	17.5	24.2	1.20	1.44
Other East Asia	na	na	na	13.2	20.2	1.57	15.9	20.4	0.92	1.43
India	23.6	28.7	0.73	15.6	26.3	1.94	8.4	9.6	0.48	1.66
Other South Asia	9.4	13.7	1.39	10.9	18.8	2.05	9.1	12.1	1.05	1.89
Southeast Asia	12.1	13.8	0.49	12.5	18.7	1.49	6.8	9.7	1.34	0.62
Latin America	11.3	15.7	1.23	12.9	18.5	1.33	7.6	11.4	1.51	1.29
WANA	32.5[c]	48.6[c]	1.50	18.6[c]	28.1[c]	1.53	17.8	25.4	1.33	1.53
Sub-Saharan Africa	7.4	10.7	1.36	6.5	10.5	1.77	8.6	13.2	1.62	1.44
Developing	9.2	12.0	1.00	13.8	22.7	1.85	13.1	17.6	1.10	1.21
Developed	12.1	14.8	0.74	16.5	19.0	0.52	17.9	19.4	0.30	0.52
World	9.2	12.0	1.00	15.5	20.6	1.06	13.2	17.6	1.09	0.98

Source: IMPACT Simulations, June 1998.

Notes: na signifies no recorded production. WANA is West Asia and North Africa. ha stands for hectares. See Table 2 footnote for regional breakdown.

[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 roughly 80/20 distribution in favor of yam production in the region, according to FAO 1999a. Estimates for Asia and WANA are for sweetpotato only, and in Latin America estimates are 68/32 for sweetpotato versus yam.

[c]FAO indicates very high yields in Egypt on small areas.

are higher for all commodities under the HDP scenario compared to the baseline (Tables 13 and 21).

For developing counties as a whole, total root and tuber production under the HDP scenario is projected to expand at 2.0 percent per year between 1993 and 2020. This figure is about 20 percent higher than the annual growth rate of 1.6 percent projected by FAO for the period 1988/90–2010 (Alexandratos 1995), but just below the recent historical growth rate of 2.1 percent (Table 5).

According to the HDP scenario, the largest increase in production of R&T in Asia will be for potato and sweetpotato. Almost 80 percent of the additional potato output of 32 million mt in developing countries, compared to the baseline scenario, will be harvested in China (24 million mt) and 19 percent in India (6 million mt) (Tables 13 and 21). The difference between HDP and baseline production in China and India results from additional area planted and a larger increase in average yields (Tables 14 and 22 and 15 and 23). As robust as the potato area and production growth rates for China and India appear, the HDP projections constitute a slowdown in recent trends. Chinese production, for example, drops from an annual growth rate of 4.6 percent per year for 1983–96 (Table 5) to 2.7 percent per year for 1993–2020 (Table 21).

The additional production of sweetpotato in China of almost 8 million mt by 2020 under the HDP scenario will account for nearly all of the increase in Asia and for more than 60 percent of the increase for all developing countries (Tables 13 and 21). This added output will be used largely for animal feed. The higher production of sweetpotato and yam will result mostly from increases in yield. Area planted with sweetpotato and yam is projected to decline by 0.6 million hectares between 1993 and 2020 (Table 22). The higher yields for sweetpotato in China (Table 23) can well materialize through greater use of improved germplasm bred specifically for use as feed. China has considerable potential for yield improvement because it has had limited access to improved germplasm for sweetpotato. Davis and Ryan (1987) estimated that benefits from investments in sweetpotato research in China would outweigh those for any of the other 22 commodities they studied, except for rice, wheat, and potato. The relatively higher feed demand projected for sweetpotato under the HDP scenario could accelerate investments in this crop as growers seek out yield-increasing technology and cost-reducing procurement, processing, and feeding practices linked to specific postharvest uses, such as pork production.

Sub-Saharan Africa will account for practically all the additional output of cassava. The 15 million mt difference between HDP and baseline cassava production in Sub-Saharan Africa in 2020 will come from an additional 1.3 million hectares under cultivation and a slight increase in yield (Tables 14 and 22 and 15 and 23). Annual growth in area will increase to 1.4 percent from 1.1 percent under the baseline scenario.

It might be argued that the projected increase in area planted to R&T will be limited by disappearing agricultural frontiers and limits to the cropping index (the ratio of crop area harvested to arable land). This would affect Sub-Saharan Africa the most because some 7 million of the estimated 8 million hectare expansion of R&T area in developing countries is projected to take place in that region during 1993–2020. However, the overall projected increase in area planted to R&T is insignificant when compared to the 3.3 billion hectares of potential land area available for crop production, not to mention possible further intensification of the cropping index (Rosegrant et al. 1997).

HDP Projections for World Prices and International Trade

The faster growth scenario for R&T means that R&T prices will decline more slowly to 2020 (Table 16). On average, world prices for R&T will fall by 12 percent under the HDP scenario, instead of by 19 percent. The more modest price declines reflect the stronger demand, particularly for sweetpotato as feed in China. The HDP scenario has only minor effects on the commodity composition and volume of R&T trade.

The level of net exports of cassava and other roots and tubers by developing countries increases only slightly (by 81,000 mt), but the mix of importers and exporters changes. China switches from being a net exporter to a net importer. Net exports of cassava by Sub-Saharan Africa rise fivefold to 2.6 million mt.[14] China's altered trade position suggests that feed demand simply outpaces feed supply given the prices generated by the HDP scenario. In contrast, the more abundant supply of cassava and other roots and tubers in Sub-Saharan Africa facilitates exports from that region. A similar situation arises in the case of sweetpotato and yam for China and Sub-Saharan Africa.

Net imports of potatoes by developing countries jump from 1.2 million mt under the baseline scenario to 4.6 million mt under the HDP scenario as China, India, and WANA switch from being net exporters to net importers. Strong demand in developing countries under the HDP scenario generates greater imports of processed potato products from Europe and North America. Overall, however, international trade will remain a minor share of developing-country production of R&T and will continue to be highly skewed toward cassava and Southeast Asia under the HDP scenario.[15]

The Value of R&T Production Under the HDP Scenario

The more robust demand and production growth rates and the resulting higher prices under the HDP scenario lead to a larger value for R&T production in 2020. Under the HDP scenario, the share of R&T in the total value of the major food crops plus soybean and selected meat commodities remains at 10.5 percent, the share R&T contributed in 1993. R&T's share in the value of crop production (that is cereals, soybean, and R&T), however, increases from 16.7 percent in 1993 to 18.6 percent in 2020 (Table 17). In terms of individual commodities, potato's share in the total value of major foods rises to 4.9 percent in 2020 from 4.1 percent in 1993. Yam also increases its value share, but sweetpotato declines in relative importance. Cassava and other R&T slip in value, but by an insignificant amount

[14] These absolute figures for net exports should be interpreted with caution given that they represent only a small percentage of total output and use.

[15] These trade estimates must be interpreted with caution given uncertainties about the accuracy of the published trade data (see for example, Scott, Basay, and Maldonado 1997).

(Table 17). The bulk of the increase in R&T value is located in Asia and Sub-Saharan Africa. The value of R&T in Latin America declines in relative importance across all commodities.

To summarize, although the HDP growth rates for supply and demand of R&T are notably higher than those in the baseline scenario, they reflect recent accelerating trends in output and use, particularly in the cases of potato and yam.

Both scenarios project that the largest absolute increase in R&T production by 2020 will take place in Sub-Saharan Africa. China will account for the bulk of the projected sweetpotato output. China and India together will harvest between 62 percent (baseline) and 68 percent (HDP) of the future supply of potatoes in developing countries. Cassava production will expand the most—by 80–100 million mt—in Sub-Saharan Africa. The projected expansion in area planted falls well within the range available for crop cultivation, even after taking into account area expansion for the other major food crops.

Increases in R&T production will be driven by demand for food in the cases of potato (both fresh and processed) and yam. The demand for feed and starch (in both food and industrial products) will be met mostly by cassava and sweetpotato.

In the baseline scenario R&T will decline in economic importance vis-à-vis the other major food commodities over the next two decades, though the decline relative to other food and feed crops will be marginal. Under the HDP scenario, the economic importance of R&T will either remain unchanged or, in the case of food and feed crops, increase slightly. This latter finding contrasts with earlier projections that estimated significant declines in the importance of R&T (see, for example, Alexandratos 1995; McCalla 1998).

6. Roots, Tubers, and the Environment

Prospects for continued increases in supply and demand of R&T in developing countries have raised concerns about the impact of their output and use on the environment (see for example Bardhan Roy et al. 1999; Crissman, Antle, and Capalbo 1998; Goletti, Rich, and Wheatley 1999; Howeler 1996). Cultivation of some R&T can help slow soil erosion (see, for example, Orno 1991) and new technologies may systematically increase the level of genetic diversity under cultivation (Upadhya et al. 1995). Technological progress, institutional innovations, and changes in policy can and should be geared toward sustaining the resource base while increasing supply and demand.

This chapter briefly examines the environmental problems and potential associated with R&T. Not intended as an exhaustive review of the literature, it identifies instead a cross-section of issues, technologies under development, and associated policies that can help ensure that increased R&T production and use are environmentally sustainable. It should be noted that many of these problems or potential opportunities are by no means exclusive to R&T.

Pesticides

Improper use of pesticides is a major environmental concern in potato cultivation. Pesticide use is far less frequent and less potent with the other R&T. The vast majority of resource-poor farmers who cultivate cassava, sweetpotato, and yam have limited access to these products or cannot justify their use given other demands on their limited cash resources.

The most widespread and intensive use of pesticides in developing countries is for controlling late blight potato disease caused by *phytophora infestans.* Farmers in some countries spray their potato fields up to 15 times during a single growing season of 4 to 6 months in order to combat this disease (Hijmans, Forbes, and Walker 1999). Pesticide sales to potato producers in developing countries exceeded an estimated US$150 million in 1991 (Oerke et al. 1995, 459). Pesticides can also constitute a formidable health risk to farm families and farm workers engaged in potato production (Antle et al. 1998).

With the emergence of new, more virulent strains of *phytophora,* the fear now is that late blight and other pests and diseases will develop resistance to the current array of pesticides. Consequently, even heavier applications of chemicals may end up providing even less protection against plant damage, resulting in greater loss of food (Erselius et al. 1999) and potentially greater harm to human life (see, for example, Cole et al. 1999).[16]

Pesticides are also used against other potato diseases and pests, such as insects. In spite of the extremely high cost and potentially harmful consequences of many of these chemicals, users continue to apply them because the risk and value of crop losses are so high.

Concerns with environmental and health impacts, combined with a growing appreciation of the damage different pests and pathogens can do to R&T, have led to the development and diffusion of an array of alternative technologies. These include disease-resistant varieties (Landeo et al. 1997), pheromone traps (Alvarez et al. 1996), targeted use of natural predators, and integrated crop management techniques that combine reduced applications of pesticides with improved cultivars and natural barriers to pest infestation. Increased production

[16] The estimated value of the loss of production in developing countries in 1997 due to late blight was US$2.5 billion (CIP 1998, 16–17).

and use of potatoes may well boost the total cost of pest damage and the potential for adverse environmental effects from improper use of pesticides, but it will also increase the rewards associated with more environmentally friendly agricultural and postharvest practices.

Moreover, as Lee and Espinoza (1998) note in their case study of Colombia and Ecuador, changes in government policy, including greater market determination of exchange rates, liberalized trading regimes, elimination of government-administered pricing systems for imports such as pesticides, decrease in agricultural credit subsidies, and other domestic sectoral reforms can help discourage inefficient use of pesticides. Policies that facilitate farmer education and training programs as well as increase governments' ability to establish, monitor, and enforce appropriate regulations regarding proper pesticide use are also needed.

Fertilizers

Excessive, deficient, or incorrectly proportioned doses of chemical fertilizer represent various forms of environmental risk. For example, too much fertilizer may result in residues contaminating local water supplies, including ponds otherwise available for fish farming. Conversely, too little fertilizer can result in low yields, declining soil fertility, and, eventually, soil exhaustion. The nonavailability or high price of fertilizer is more of a problem in Sub-Saharan Africa than in Asia or Latin America (Scott 1988a; Tardif-Douglin 1991). African farmers on average use less than a tenth of the fertilizer per hectare that Asian farmers use.

Inefficient use of fertilizer has been identified in diagnostic studies of potato production in a number of countries, including Bangladesh (Scott 1988a), Mexico (Biarnès and Duchenne 1995), and Pakistan (Iqbal et al. 1995), and documented in farm surveys for cassava in Thailand (Howeler 1996). Improperly balanced fertilizer applications are of special concern in the case of cassava because so much of area planted is already produced on highly acid and infertile soils (Howeler, Oates, and Costa Allem 1999). The environmental and economic costs of nitrogen fertilizer use on R&T in developing countries have only recently become the focus of attention for researchers (Bowen et al. 1999). But based largely on an analysis and extrapolation of recent trends in nitrogen use in developed countries, Frink, Waggoner, and Ausubel (1999) suggest that farmers in developing countries, for example, China, are gradually ensuring that fertilizer applications conform to the proper proportions of nitrogen, phosphorus, and potassium.

Soils

Soil disturbance is a problem common to all R&T production (TAC 1997b). Regular working of the soil can degrade soils by decreasing soil carbon levels and fostering water and wind erosion. The effects can become accentuated as fallow periods decline and cropping intensity increases.

The degree of potential soil degradation is higher on hillside or highland fields where severe slopes can intensify the erosive effects of rainfall (or irrigation) and wind. Because some R&T are frequently cultivated on such fields—and cassava is grown on more marginal soils to begin with—the soil erosion associated with these crops can be substantial, though the association is not inevitable (see, for example, Howeler 1996; Howeler, Oates, and Costa Allem 1999). Although potato production in hilly areas can exacerbate erosion problems, some mid-elevation and highland cultivation of potatoes, particularly in Asia, is carried out in terraced fields otherwise used for irrigated rice. The latter form of potato cultivation causes less erosion. The case of sweetpotato is more complex, particularly for those varieties that produce abundant, rapidly growing vines (Léon-Velarde et al. 1997). This foliage can provide a quick crop cover over fragile fields and thereby naturally slow, if not reduce, soil erosion (Orno 1991).

As population increases in the countryside, and as the demand for food on and off the farm expands accordingly, cultivation of some R&T can also infringe on forests or high altitude natural grasslands, such as the *paramos* in the Andes. Expanded cassava production in northeast Thailand resulted in serious deforestation (Howeler, Oates, and Costa Allem 1999). A combination of better technology to increase net returns on existing farmland and policies that discourage cultivation of food crops in national parks, forests, and other preserves can prevent R&T-related degradation in these areas (see Duffy 1999).

Results of the COSCA surveys carried out in Côte d'Ivoire, Democratic Republic of Congo, Ghana, Nigeria, Tanzania, and Uganda indicate that in Sub-Saharan Africa cassava production is replacing fallow land, and that cassava producers are cultivating their plots more intensively, that is with shorter fallows (Spencer and Associates 1997). The danger is that when the fallow period becomes too short, rapid soil degradation may result. One possible solution is to integrate small-scale livestock production and cassava cultivation more closely, so that cassava foliage serves as livestock feed and livestock manure provides organic matter to help sustain soil fertility (Christiaesen, Tollens, and Ezedinma 1995). Another possibility involves returning the leaves and stems to the soil (Howeler, Oates, and Costa Allem 1999). Furthermore, good agronomic practices such as closer plant spacing, reduced tillage, and use of contoured grass hedgerows can be very effective in reducing erosion and possibly increasing cassava yield and total income (Howeler, Oates, and Costa Allem 1999). The set of best practices is highly site-specific, requiring both the identification of appropriate, improved procedures through farmer participation and government initiatives such as land titles, educational programs, and credit schemes that provide incentives for adoption.

Potato cultivation in input-intensive crop rotation systems, like those involving irrigated rice in South Asia, has come under closer scrutiny because it extracts considerable nutrients from the soil. But preliminary research results suggest that the problem—from the farmer's perspective—may not be as acute as originally thought (Bardhan Roy et al. 1999). At least some farmers appear to grow potatoes in these systems in part because potato production halts continuous flooding and allows farmers to interrupt continuous rice production, which is associated with nutrient depletion, absence of soil aeration, and soil compaction (Pingali 1998).

Water and Air Pollution

The spread of pesticide or fertilizer residues into water supplies through irrigation systems or field run-off has attracted growing attention in recent years (see, for example, Ducrot, Hutson, and Wagenet 1998). Not only does this form of water pollution damage plants, insects, and livestock, it also poses a threat to the drinking water supply of farm households. The trade-off between food production, pesticides, and human health is most acute in the case of potato production, which relies on chemicals more than any other R&T (Antle et al. 1998).

Water pollution is not restricted to production, but also includes postharvest activities. Recent research on cassava processing in Vietnam highlights the adverse impact that a rapid increase in small-scale processing of cassava roots into starch has on local water supplies (Goletti, Rich, and Wheatley 1999; Howeler, Oates, and Costa Allem 1999). In the absence of proper treatment facilities, the water used in starch processing contaminates local water supplies. Similar pollution problems have also been noted in processing the Andean root crop, canna, into starch in Vietnam (Hermann, Quynh, and Peters 1999). With the expansion of potato processing in developing countries (Scott 1994a; Scott, Basay, and Maldonado 1997) and the construction of large-scale processing facilities to satisfy increasing demand and capture economies of scale, concerns have emerged about plant effluents. These problems mirror those associated with large-scale potato processing in some developed countries (New York Times 1994).

The sheer volume of water required to cultivate potatoes under desert conditions has also emerged as an issue, particularly in areas such as the newly reclaimed land in Egypt, where production and processing of potatoes are drawing on groundwater from newly dug wells (Chilver, El-Bedewy, and Rizk 1997). The possible medium- to long-term implications for local water supplies remain unclear.

Roots and tubers have also attracted attention of late for their potential role in the development of urban and peri-urban agriculture (see, for example, Brochier et al. 1992; Nweke et al. 1994). Given the increasing pressure on urban water systems in developing countries and the practice of using a wide variety of water sources to cultivate and process R&T in urban and peri-urban settings (see, for example, Villamayor 1991), the implications for local water supplies and human health merit closer monitoring (Howeler, Oates, and Costa Allem 1999).

Finally, some traditional cassava-processing techniques in West Africa can involve prolonged exposure to inhalation of smoke. Studies have shown that this can be hazardous to women's and infants' health. New, improved processing techniques for cassava have gone a considerable way toward reducing the time required to produce processed cassava products and hence toward decreasing environmental and human health problems (Jeon and Halos 1992).

Biodiversity

A number of studies covering developed and developing countries have shown that as potato production becomes more technical, commercial, and oriented towards processing, producers have tended to reduce the number of varieties grown (Brush, Taylor, and Bellon 1992; Walker 1994). Similar concerns about the loss of genetic diversity in farmers' fields have been expressed about cassava (Howeler, Oates, and Costa Allem 1999), sweetpotato (Prain and Campilan 1999), and yam. The risk in the Andean region in particular—the center of origin for the potato and for several other R&T—is that more native varieties could go out of cultivation, only to be maintained in gene banks or lost forever (Alvarez and Repo 1999). One production initiative that not only enables small, resource-poor farmers to produce more food, but also increases the level of genetic diversity is botanical seed or true potato seed. With this technique, each seed is a genetically different entity (Upadhya et al. 1995). Hence, greater use of true potato seed would increase the number of different entities under cultivation.

The aroids such as taro, and the Andean roots and tubers such as canna or ulluco, present an even more formidable challenge. These crops have only recently attracted the attention of the global scientific community (NRC 1989). They are typically grown on a limited scale (Hermann and Heller 1997) and are often produced in heretofore isolated localities that can be threatened by rapid exposure to the full force of market penetration. Small, resource-poor growers of canna and ulluco may lack access to improved production and postharvest technology, credit to facilitate adoption, and related initiatives such as government-supported market promotion schemes, leaving them ill-equipped to compete with other food commodities produced on much larger farms and strictly for the market. As a result, these Andean R&T face the risk of extinction.

Increases in productivity will be a key requirement for improving the competitiveness of R&T in the decades ahead. One essential aspect of that effort will be the accelerated movement of germplasm across borders and between continents. For example, quicker transfer of germplasm native to Latin America to Sub-Saharan Africa would help raise cassava yields in the latter region (Spencer and Associates 1997). Concerns regarding protection of farmer's rights and national germplasm collections (see, for example, Schneider and Yaku 1996) can and must be addressed to ensure continued rapid transfer of materials between countries and regions.

Biotechnology

The advent of genetically modified plants has become reality in the case of potato (see, for example, Qaim 1999) and sweetpotato (see, for example, Cipriani et al. 1999; Newell, Lowe, and Merryweather 1995; Prakash, Egnin, and Jaynes 1998). Although these innovations offer tremendous promise for both R&T production (reduced application of pesticides, for example) and use (reduction in the level of trypsin inhibitor in sweetpotato for feed, for example), they raise a whole array of new issues, ranging from unanticipated effects on the environment to the distribution of economic benefits from such advances. These questions potentially stretch across the entire food system, from preproduction, or seed stage, to final use. The range of concerns includes property rights for specific postharvest traits (for example, starch properties for cassava, sweetpotato, yam, or Andean roots and tubers), specific processing techniques, and as yet unknown uses of some parts of particular R&T plants. The limited knowledge and capabilities in most developing countries regarding the regulation, accelerated development, and subsequent introduction of these new technologies suggest that, as with cereals (Morris and Byerlee 1998), the response to this challenge will require a combination of new technologies, policies, and institutional strengthening, with a critical role for the international agricultural research centers (IARCs). Efforts are already underway in this direction at the international agricultural research system level with the formation of the Committee on Inter-Centre Root and Tuber Crops Research (CICRTCR) in the CGIAR. This committee is formulating plans for intercenter synergy in, among other things, the area of biotechnology (Scott et al. 2000). The plans include collaborative efforts to access laboratory facilities in developed countries, and thereby reduce the cost of developing biotechnology for developing countries, as well as studies of and methodologies for risk assessment of related technological innovations.

In summary, production and use of R&T in developing countries have drawn attention to the potential benefits and raised a series of concerns regarding their impact on the environment and human health. The available evidence indicates that the incidence of potential environmental effects varies from crop to crop. Pesticides and fertilizer use, for example, are much more important in the case of potatoes and problems of soil erosion more acute in the case of cassava. While the environmental problems discussed merit greater attention in the future, there are also clear signs that new technology, institutional innovations, and better policies can not only meet the challenge but also more effectively exploit the potential of R&T and thus help sustain the natural resource base.

7. Conclusions and Recommendations

This paper has analyzed supply and demand trends and future projections for R&T in order to provide a clearer vision of the contribution that these crops can make to the food systems of developing countries over the next two decades. The paper has also stressed the important differences among these crops and the multiple roles they play in today's food systems. The analysis has shown that R&T will continue to play a significant role in developing-country food systems because 1) they contribute to the energy and nutrition requirements of over 2 billion people in developing countries today and will continue to do so over the next two decades; 2) they are produced and consumed by many of the world's poorest and most food insecure households; 3) they are an important source of employment and income in rural, often marginal areas, including for women; and 4) they adapt to a wide range of specific uses, from food security crop to cash crop, from food crop to feed crop, from the latter to raw material for industrial uses, and from fresh food to high-end processed product. To realize R&T potential in these areas, a combination of new technologies and improvements in the institutional and policy environment will be required.

With the foregoing in mind, the key questions addressed in this study can be reconsidered: 1) How have R&T contributed to the food systems of developing countries? 2) What role(s) will R&T play in the next two decades? And 3) What are the factors that have influenced and will influence the supply of and demand for these commodities?

The Changing Roles of R&T in Developing-Country Food Systems

The supply of and demand for R&T began to change significantly in the 1960s and 1970s. These changes—surging potato production in WANA, South Asia, and China, for example—accelerated over the next two decades, particularly during the 1990s. With a few noteworthy exceptions, the trend throughout has been toward greater diversification in use and greater specialization in production by crop and region.

In much of Asia and WANA, rising incomes, growing urbanization, and a desire by consumers to diversify away from strictly cereal-based diets have increased demand for potato as food in fresh and, more recently, in processed form. The same forces have influenced cassava and sweetpotato use in different ways. Growers, traders, and entrepreneurs capitalized on the raw material characteristics of these crops by shifting use toward starch, feed, and processed food products. In Sub-Saharan Africa, population growth, low and stagnant per capita incomes, and rapid urbanization have generated tremendous demand for a cheap, starchy staple to feed poor rural and urban consumers alike. Political instability and highly variable climatic conditions favor cassava as a low-cost, reliable source of carbohydrates, particularly in Central and West Africa. Yam continues to be consumed as a food crop in fresh form, but on a more modest scale compared to cassava.

In Latin America, changing diets in some countries (for example Colombia and Mexico) and the emergence of the fast food and snacks subsector in others (for example Argentina, Brazil, and Peru) have increased potato consumption. Many small producers have been driven out of production by rising costs per hectare and, most recently, by falling tariffs for imports of fresh potatoes and processed potato products. Cassava demand stagnated, with declines in fresh consumption offset by increases in feed use and processing for food and industry uses. Sweetpotato consumption stagnated as well due to weak demand. Growers had little incentive to adopt yield-increasing technology, except where they had access to markets. Increases in yam output were confined largely to Haiti and Jamaica.

Small farmers produce most of the potatoes in Asia and WANA. In most developing countries small farmers produce potatoes primarily for cash, though they have increasingly turned to sales of other R&T as a supplemental source of cash income. These farmers capitalize on the income-generating potential of potato, including its short vegetative cycle and broad adaptability. Relatively abundant labor supplies, new production technologies, improvements in infrastructure and input supply systems, and expansion of postharvest facilities, particularly cold storage, further facilitate their efforts to increase production and improve productivity. The lucrative export market to Europe provides an added incentive in North Africa. The principal policies that helped generate the rise in potato output and productivity includes limited intervention in output markets, credit and tax schemes to build and equip storage facilities, and programs to expand production and marketing infrastructure.

Sweetpotato production in China fell rapidly from the late 1970s to the late 1980s, primarily because the consumption of sweetpotato roots in fresh form declined. As cereal production increased and the overall economy grew rapidly, incomes improved and consumers switched from fresh sweetpotato to more preferred foods. But continued economic growth, diversification of diets, and the demand for meat and processed products led to a rapid increase in demand for sweetpotato as animal feed and starch. Growth rates for sweetpotato production began rising again in the early 1990s. New production technology (such as improved sweetpotato varieties and cleaner planting material) also contributed to increased yields and improved profitability, offering postproduction employment opportunities to poor farm households in the process.

In the past, growth in cassava output in Sub-Saharan Africa has been driven primarily by subsistence demand for food in low-income households. In recent years, cash sales have assumed near equal importance. Cassava production—particularly in West Africa—has increased due to a combination of additional factors, including the crop's ability to do well even on poor soils, with minimal rainfall and little or no purchased inputs; better production technologies (high-yielding varieties and integrated pest management techniques); improvements in postharvest practices; and policy measures intended to promote development of the local cassava processing industry.

The Roles for Roots and Tubers by 2020

IMPACT simulations indicate that R&T will play economically important and increasingly diversified roles in developing-country food systems over the next two decades.

In Asia, potato will serve as a complementary vegetable, occasional seasonal staple in parts of South Asia and China, and, increasingly, as raw material for processed food products. These multiple uses will reflect the continuing segmentation of the market into city versus countryside and low-income versus high-income. Increases in output and productivity for potato will translate into considerably higher levels of total production. But the rise in annual per capita intake will be much more modest, reaching only a third of the consumption levels in Europe or North America by 2020. Potato will not be traded in appreciable quantities. Nevertheless, higher potato production and consumption will help sustain food self-sufficiency, reduce the need for imports of cereal substitutes, and save foreign exchange in the process.

Sweetpotato in China and to a lesser extent in Vietnam will serve a much more diversified role in response to location-specific market requirements. In maize-deficit areas, such as Sichuan province, sweetpotato will be used for feed. In other locations like Shandong province, sweetpotato will be processed into starch for food products such as noodles. Improvements in sweetpotato productivity (yields and quality), processing (economic and technical efficiency), and product development (new uses for starch) will propel the evolution in sweetpotato use. The associated growth in employment and improvements in incomes will help alleviate rural poverty. Growth in sweetpotato feed use will reduce the need for and cost of imports. Its role as a food security crop will be limited to the most isolated, resource-poor, and least-developed food systems in Asia. In Indonesia, Thailand, and Vietnam cassava will follow a development path similar to that of sweetpotato in China.

In Sub-Saharan Africa cassava and yam will continue to be used overwhelmingly as food. Processed food products made from cassava will remain important in rural diets, particularly in West and Central Africa, where they will serve as a basic staple. Continued high rates of population growth and urbanization, combined with comparatively low levels of per capita income and limited economic growth, will promote growth in the use of cassava as food and catalyze its sustained penetration into urban markets. In East and Southern Africa, cassava will be used more as a supplementary staple and as a food security crop. The gradual emergence of processed food products from cassava in urban areas will open up new commercial outlets in cities and towns. Growth rates in cassava area planted and yields will be driven by the introduction of new, high-yielding, disease-resistant varieties; low-cost methods of pest control; and the spread of improved processing techniques to East and Southern Africa. Yam in West Africa as well as sweetpotato and potato in East and Southern Africa will also witness steady increases in consumption, but more modest in volume terms than for cassava. This consumption trend will be reinforced by market niches among higher-income consumers for processed food products and snacks made from yam and potato and among lower-income consumers for processed food and snacks made from sweetpotato. Improved production and postharvest technologies as well as institutional and policy innovations will facilitate the increases in output and productivity that match the increases in consumption.

Cassava and potato will dominate R&T use in Latin America. Cassava will be used in processed form (both for food and industry) and as feed. In contrast potatoes will continue to be used in fresh form, though the use of potato in processed and snack form will also continue to increase. Better varieties will increase yields and, for cassava in particular, the strengthening of small agro-enterprises will increase production further.

Prices of all R&T commodities are projected to decline by 2020, by 14–23 percent, depending on the commodity. The global impact of increased production and lower prices on R&T trade will be minimal. The decline in the economic value of R&T in developing countries, in relation to cereals, meat, and soybean, will be modest; the rise in importance of potato and yam will compensate for the fall in importance of cassava and sweetpotato.

The Influence of Technology, Institutions, and Policy

By 2020, we envision that the environmentally sound production of a diversified range of high-quality, competitive products for food, feed, and industry will integrate R&T into emerging markets. R&T 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 for improving the welfare of the rural poor and linking smallholder farmers to emerging markets (Scott et al. 2000).

Although the projections for future production and use of roots and tubers in developing countries are realistic, they are by no means guaranteed. The continuous generation and diffusion of improved production and postharvest technology is essential if the root and tuber sectors in Asia, Africa, and Latin America are to flourish. Additional socio-economic research on the most effective and efficient ways to facilitate development and adoption of this improved technology will also be required. These efforts will only prove successful provided there are substantial levels of public and private investment in agricultural research at both the national and international levels in the decades ahead. Past analysis of such investments has shown that they can offer high rates of return (see, for example, Norgaard 1988; Johnson 1999; Walker and Crissman 1996).

Emerging from this review of the production and use patterns for the major R&T is a dichotomous vision for capitalizing on the emerging opportunities for these crops. Potato and yam primarily face supply-side constraints; cassava and sweetpotato face mainly demand-side constraints. Given the linkages between production and postharvest activities, however, efforts to improve R&T should use a systems approach.

The removal or reduction of barriers to increased output of potato and yam—for example, through the development of disease- or drought-tolerant varieties, better pest management, improved systems for diffusing planting material, and policies and procedures aimed at stabilizing the within-year and year-to-year flow of supply onto the market—can enable producers to find outlets for their increased production of these commodities more easily. Producers can also identify and exploit the latent demand for feed and processed food products made from cassava and sweetpotato by lowering costs, raising quality, and improving availability. To minimize or overcome these constraints will require improved germplasm, more technically and economically efficient procedures for producing raw material and finished products, strengthened grower-to-processor linkages, and small-to-medium-scale enterprises for producing and marketing the products.

In addition to these concerns, a recent review of current research on R&T in the CGIAR identified the following commodity-specific priorities (Scott et al. 2000).

Research and Policy Priorities

• ***Cassava.*** Research priorities involve market appraisals and identification of linkages between producers, processors, and policymakers that capitalize on cassava's potential for expanded use in processed form. Such market-driven initiatives should be bolstered by germplasm research—including biotechnology research—on specific end uses (such as starch), tissue culture, rapid multiplication of planting material, pest and disease resistance (most notably cassava bacterial blight and cassava green mite), and appropriate technologies and procedures to ensure that cassava production and processing have a benign impact on the environment, with particular regard to soil erosion and water quality.

• ***Potato.*** Research priorities include enhancing resistance to prevalent diseases such as late blight by combining conventional plant breeding techniques and biotechnology; improving informal seed systems; and developing effective integrated crop management. Research on risk assessment for biotechnology and the impact of potato improvement on poverty, the environment, and human health also merit high priority, as does research on the demand and use of processed products.

• ***Sweetpotato.*** Concerted international efforts are under way to increase dry matter content and yield, exploit national and international germplasm for appropriate postharvest characteristics, including starch quality and pre-beta carotene content, and systematically support national efforts to foster greater product development for sweetpotato by small- and medium-scale farmers and entrepreneurs. Because sweetpotato cultivation is often concentrated in the poorest growing areas and among farmers with limited-resources, an evaluation of the impact of sweetpotato research on the food consumption and income-earning activities of the poorest countries is warranted.

• ***Yam.*** Areas of concentration for yam research include genetic improvement through more efficient germplasm screening; breeding for host-plant resistance to pests such as nematodes; reducing the high cost of planting material and labor-intensive field operations; and exploiting the crop's potential to be used in processed form.

While each of the major R&T has its commodity-specific priorities, recent appraisals of international agricultural research have stressed the need for and potential benefits from closer collaboration among IARCs (Strong et al. 1998). The recent TAC review of R&T highlighted the potential gains from capturing the synergies among the interested organizations involved with these commodities (TAC 1997b). At present, areas of potential gain include phytosanitary regulations, which affect the international exchange and transfer of germplasm and the speed of varietal improvement; biotechnology, which, among other things, involves the sharing of information and techniques for cryopreservation of germplasm (the storage of plant cuttings at $-190°$ C) so as to reduce the cost and improve the quality of the preserved R&T; and postharvest technology and marketing. The latter area entails collaborative assessments of the market for R&T and related products (Ferris et al. 1999; Prain et al. 1999); joint capacity building through methodology development in the area of market analysis (Scott 1995) and product development (Wheatley et al. 1995); the exchange of information about procedures, processes, and products; and mobiliztion of regional interaction between scientists and their respective organizations (Scott, Ferguson, and Herrera 1992; Scott, Wiersema, and Ferguson 1992; Scott et al. 1992). These collaborative efforts can produce gains from synergy. But equally if not more important, these efforts would help fill the gap left by the absence of the private sector in R&T development.[17]

The private sector has underinvested in R&T for three key reasons: (1) These crops are produced and consumed in developing countries, with the exception of potato (and, in the case of sweetpotato, Japan and the United States), hence there are few spillover benefits for industrialized countries. (2) While some R&T commodities have export potential, their commercial prospects abroad are generally more modest than for other agricultural products. As a result, the outlook for foreign exchange earnings is less attractive. And (3) R&T are cultivated and used by low-income households with limited means to purchase new technology. Moreover, most R&T producers are rarely organized into effective national organizations. These circumstances and the limited resources national agricultural research institutes have for R&T research (TAC 1997b), call for the creation of an advocacy group on behalf of these commodities in addition to closer collaboration. In individual countries such a body would serve as the rough equivalent to a growers' association or industry representative. It would seek to promote the needs of producers, traders, processors, and consumers of R&T in domestic policy deliberations, public resource allocation, private investment decisions, and trade negotiations. In that spirit, and in the case of cassava, Plucknett, Phillips, and Kagbo (1998, 12) have called for R&T supporters to "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 [commercial] opportunit[ies]." In a similar vein, a focal point is needed at the international level for gathering support and capturing the synergies of all those organizations working on R&T for the benefit of developing countries (Scott et al. 2000).

Policymakers should take increased cognizance of the growth prospects for particular R&T, and for particular uses in particular regions. Policymakers can do so by ensuring that the national and international databases for these crops are improved, particularly for R&T production and use in Sub-Saharan Africa (see, for example Minde, Ewell, and Teri 1999). More disaggregated and continuously updated projections at the regional and subregional levels for particular R&T can also be useful to prospective investors, multilateral agencies, and bi-lateral donors. Policymakers in developing countries should eliminate measures like overvalued exchange rates or subsidies on imported food, in order to benefit from the full potential of R&T (see, for example, Byerlee and Sain 1991).

Policymakers can also foster R&T development by removing policy distortions that promote artificial economies of scale in livestock production (Delgado et al. 1999). Policies that promote only large-scale, feed-lot hog production in China offer a prime example of the constraints placed on sweetpotato production for household- and village-level processing into pig feed. Policymakers can include R&T in national five-year plans in order to give research on these crops more legitimacy and public support. They can also encourage efforts to seek more nontraditional funding for research and development of R&T (Spencer and Associates 1997).[18] Policymakers can also facilitate the use of R&T as a means of alleviating poverty among the poor and most vulnerable groups in a variety of ways. For example, innovations and their benefits should be made available to all groups, including women. Credit schemes would enable women entrepreneurs to purchase improved cassava-processing equipment in Sub-Saharan Africa (Spencer and Associates 1997). Policymakers in developing countries must also be more vigilant in negotiations over tariff and nontariff barriers for

[17] Potato is perhaps the exception, albeit on a limited basis (Qaim 1999).

[18] In one practical example, financially consistent measures have been developed to cost and sell planting materials for potato (Espinosa, Crissman, and Hibon 1996). Revenues can then be recycled to support potato research and development, which are often entirely dependent on annual government appropriations and/or donor financial support.

R&T and their substitutes because these mechanisms can affect resource-poor households (Scott, Basay, and Maldonado 1997). Policymakers also need to be more sensitive to the allocation of resources within national R&T programs in order to ensure that postproduction activities—often most closely linked to income generation—are not underfunded in relation to production research.

In the environmental arena, policymakers can promote conservation of the natural resource base by making sure that research and extension efforts provide small farmers with viable technical alternatives to resource-depleting practices for soil, water, and forest resources, and by fostering farmer-based organizations to help disseminate the alternative technologies. Policies that discourage the improper use of pesticides and fertilizers should complement these efforts.

Policymakers in industrialized countries can also help improve the growth prospects for R&T in developing countries in a variety of ways. These include abandoning trade arrangements that limit import demand for R&T (see, for example, Henry 1998), eliminating subsidies on exports of competing food products (Spencer and Badiane 1995), and facilitating technology transfer (small- to intermediate-scale processing equipment, for example) to strengthen production and use of R&T in developing countries. Finally, access to developed-country markets can also help maintain genetic diversity for R&T in developing countries (Fano et al. 1998).

Appendix: Supplementary Tables

Table 24—Main agronomic characteristics of principal roots and tubers

Characteristics	**Cassava** (*Manihot esculenta*)	**Cocoyam (tannia)** (*Xanthosoma nigrum*)	**Potato** (*Solanum tuberosum*)	**Sweetpotato** (*Ipomoea batatas*)	**Taro (cocoyam)** (*Colocasia esculenta*)	**Yam** (*Dioscorea* spp.)
Growth period (months)	9–24	9–12	3–7	3–8	6–18	8–11
Annual or perennial plant	Per.	Per.	Ann.	Per.	Per.	Ann.
Optimal rainfall (centimeters)	100–150	140–200	50–75	75–100	250	115
Optimal temperature (°C)	25–29	13–29	15–18	>24	21–27	30
Drought resistant	Yes	No	No	Yes	No	Yes
Optimal pH	5–6	5.5–6.5	5.5–6.0	5.6–6.6	5.5–6.5	n.a.
Fertility requirement	Low	High	High	Low	High	High
Organic matter requirement	Low	High	High	Low	High	High
Growable on swampy, waterlogged soil	No	No	No	No	Yes	No
Planting material	Stem	Corms/cormels	Tubers[a]	Vine cuttings	Corms/cormels	Tubers
Storage time in ground	Long	Long	Short	Long	Moderate	Long
Postharvest storage life	Short	Long	Long	Short	Variable	Long

Sources: Derived from D. E. Kay, *Root crops,* London: Tropical Products Institute, 1973, as presented in Horton (1988).
Note: n.a. = Data not available.
[a]Whole tubers, cut tubers, or botanical seed.

Table 25—Raw material characteristics of roots and tubers

	Aroids	**Cassava**	**Potato**	**Sweetpotato**	**Yam**
Dry matter (%)	22–27	30–40	20	19–35	20–42
Starch (%FW)	19–21	27–36	13–16	18–28	18–25
Total sugars (%FW)	2.0	0.5–2.5	0–2.0	1.5–5.0	0.5–1.0
Protein (%FW)	1.5–3.0	0.5–2.0	2.0	1.0–2.5	2.5
Fiber (%FW)	0.5–3.0	1.0	0.5	1.0	0.6
Lipids (%FW)	0–1.5	0.5	0.1	0.5–6.5	0.2
Vitamin A (μg/100g FW)	0–42	17	Trace	900	117
Vitamin C (mg/100g FW)	9	50	31	35	24
Ash (% FW)	0.5–1.5	0.5–1.5	1.0–1.5	1.0	0.5–1.0
Energy (kJ/100g)	390	607	318	490	439
Antinutritional factors	Oxalate crystals	Cyanogens	Ylycoalkaloids	Trypsin inhibitors	Alkaloids, tannins
Starch extraction rate (%)	n.a.	22–25	8–12	10–15	n.a.
Starch grain size (micron)	1–12	5–50	15–100	2–42	1–70
Amylose (%)	3–45	15–29	22–25	8–32	10–30
Maximum viscosity (BU)	n.a.	700–1,100	n.a.	n.a.	100–200
Gelatinization temp. (°C)	68–75	49–73	63–66	58–65	69–88

Source: Wheatley et al. 1995, Bradbury and Holloway 1988.
Note: n.a. = Data not available. FW = fresh weight; μg = microgram; mg = milligram; BU = Brabender units; kJ = kilojoule.

Table 26—Key IMPACT parameters for selected countries and regions

Countries/region	Average annual growth rate, 1993–2020		Income elasticities of demand[a]					
			Cassava[b]		Potato		Sweetpotato and yam	
	Population	Income	1993	2020	1993	2020	1993	2020
	(percent)							
Brazil	1.12	3.2	–0.08	–0.18	0.40	0.30	–0.10	–0.25
Nigeria	2.67	3.2	0.30	0.20	0.20	0.18	0.50	0.40
Central and Western Sub-Saharan Africa	2.70	3.8	0.10	–0.05	0.40	0.38	0.30	0.20
Egypt	1.56	3.2	0.05	–0.15	0.40	0.25	0.10	0.00
Turkey	1.24	4.5	0.00	–0.20	0.35	0.20	0.10	0.00
India	1.30	5.1	0.15	–0.05	0.55	0.45	–0.10	–0.30
Thailand	0.63	5.4	–0.05	–0.10	0.40	0.25	–0.10	–0.25
China	0.72	5.6	–0.05	–0.15	0.45	0.35	–0.20	–0.35

Source: IFPRI IMPACT, June 1998.

[a]Estimates for the baseline scenario.

[b]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.

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