
CRP-RTB 3.4
Roots, Tubers, and Bananas for Food Security and Income

**Consultative Group on International
Agricultural Research**

CGIAR Partners:

International Potato Center (Lead Center)
Bioversity International
International Center for Tropical Agriculture (CIAT)
International Institute of Tropical Agriculture (IITA)

And

**An international alliance of regional,
national, and private sector
research-for-development agencies**

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ACRONYMS AND ABBREVIATIONS

A

AMMI	Additive main effects and multiplicative interactions
ARI	Agricultural research institute
ARTC	Andean root and tuber crops

B

BBTV	Banana bunchy top virus
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C

CBO	Community-based organization
CGIAR	Consultative Group on International Agricultural Research
CGKB	Crop Genebank Knowledge Base
CIAT	International Center for Tropical Agriculture
CIP	International Potato Center
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CLAYUCA	Latin America and Caribbean Consortium to Support Cassava Research and Development
CRP	CGIAR Research Program
CS	Capacity strengthening
CSR	Corporate social responsibility

D

DDG-R	Deputy Director General of Research
DG	Director General
DRC	Democratic Republic of Congo

E

Embrapa	Empresa Brasileira de Pesquisa Agropecuária
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F

FAO	Food and Agriculture Organization
FFS	Farmer field schools

G

GBIF	Global Biodiversity Information Facility
GCDT	Global Crop Diversity Trust
GCP	Generation Challenge Programme
GIS	Geographic information systems
GM	Genetic modification

I

ICIS	International Crop Information System
ICT	Information communication technologies
ICT/KM	Information communication technology/knowledge management
ICWG-GR	Inter-Center Working Group on Plant Genetic Resources
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
INRA	National Institute for Agricultural Research
IPM	Integrated pest management
IPR	Intellectual property rights
IRD	Institut de Recherche pour le Développement
IRRI	International Rice Research Institute
IT	Information technology

L

LAC	Latin America and the Caribbean
LB	Late blight
LCB	Lead Center Board
LDC	Least developed countries

M	
M&E	Monitoring and evaluation
MC	Management Committee
MGIS	Musa Germplasm Information System
MGMS	Musa Genebank Management System
MRI	Magnetic resonance imaging
MSP	Multistakeholder platforms
MT	Million tons
N	
NARS	National Agricultural Research System
NGO	Nongovernmental organization
NIRS	Near infrared reflectance spectroscopy
NPV	Net present value
NUE	Nutrient-use efficiency
O	
OFSP	Orange-fleshed sweetpotato
P	
PCR	Polymerase chain reaction
PD	Program Director
PIPA	Participatory Impact Pathways Analysis
PL	Product line
PMCA	Participatory Market Chain Approach
PMU	Program Management Unit
PPP	Public-private partnerships
PVA	Pro-vitamin A
pVACs	Pro-vitamin A carotenoids
PVS	Participatory varietal selection
Q	
QTL	Quantitative trait locus
QUEFTS	QUantitative Evaluation of the Fertility of Tropical Soils
R	
R&D	Research and development
R4D	Research for development
ROI	Return on investment
RTB	Roots, tubers, and bananas
RTL	Research Theme Leader
S	
SAC	Science Advisory Council
SC	Steering Committee
SLO	System-level outcomes
SNP	Single nucleotide polymorphisms
SRF	Systemwide Results Framework
SSA	Sub-Saharan Africa
SSR	Simple sequence repeat
T	
TFP	Inter-center taskforce for priority setting
TILLING	Targeting Induced Local Lesions In Genomes
V	
VAD	Vitamin A deficiency
W	
WUE	Water-use efficiency

EXECUTIVE SUMMARY

About 200 million poor farmers in developing countries use roots, tubers, and bananas (RTB) for food security and income. The RTB crops—banana, plantain, cassava, potato, sweetpotato, yams, and other tropical and Andean root and tuber crops, sometimes termed “vegetatively propagated staple crops”—are linked by common management aspects. Most notably, the linkages are in seed and postharvest issues and by the frequency with which women are involved in their production and postharvest use. RTB are excellent sources of cheap energy and some varieties are rich in vitamins and essential minerals. They are mostly produced, processed, and traded locally, making them less vulnerable than grains to abrupt price changes in international markets. RTB can grow in marginal conditions and nontraditional areas, with relatively few inputs. Many tolerate stresses such as drought, heat, and poor soil conditions. They often complement cereals in cropping systems to reduce risk and make more efficient use of resources—for example, by providing food earlier in the farming calendar or entering into a fallow period between grain crops. Thus they play a key role in helping to build stronger, more diversified crop and farming systems to reduce the risk of food shortages and nutritional shortfalls.

RTB offer high potential yields, but farmers in developing countries often realize less than half that potential due to challenges such as the use of poor quality “seed” or limited genetic diversity, biotic and abiotic constraints, and poor management practices. Breeding for higher nutritional and processing quality and adaptation to stressful environments, access to improved quality planting material, and better management practices can address these challenges. A combination of dynamic conservation and on-farm use of crop genetic diversity can ensure resilient cropping systems and capacity to respond to evolving stresses. Methods to help poor farmers access higher value markets for fresh or processed RTB can strengthen capacities, increase incomes, and improve livelihoods.

The CGIAR Research Program on Root and Tuber Crops and Bananas (CRP-RTB) is a joint initiative of the Consultative Group on International Agricultural Research (CGIAR) and their partners to address these challenges more globally and efficiently. It brings together the RTB crop-related work of Bioversity International, the International Center for Tropical Agriculture (CIAT), the International Potato Center (CIP), and the International Institute of Tropical Agriculture (IITA). Each Center has extensive expertise in and wide networks of partners with at least one RTB crop. The collaboration for preparation of this CRP has established a strong base for cross-cutting activities among crops, across Centers and partners, and with other CRPs. With its combined scale and capacity, the CRP-RTB will capture significant additional synergies, increase the ability to advance research, share knowledge, and enhance uptake to increase research for development (R4D) impacts.

The CRP-RTB includes a participatory process for setting priorities and engaging partners and users to better integrate their ideas and feedback, build multidirectional communication pathways, and facilitate the two-way flow of knowledge between researchers and end-users. This process will give careful attention to gender and ensure that women and men both contribute and benefit. Stakeholders, including donors, partners, and beneficiaries, have provided extensive input into the development of the CRP-RTB. Together with these stakeholders, the CRP-RTB has proceeded to analyze the strengths and weaknesses of current R4D activities, focusing on the delivery of products that can effectively impact food security, nutrition, and income. The results of this analysis were used as the foundation to conceptualize a wide-ranging and integrated effort of R4D for the CRP, with shared research agendas across crops and Centers and have already stimulated the emergence of new concepts and modes of collaboration.

Seven themes, reflecting the strategy and vision of the CRP-RTB partnership and deriving from its impact pathway, have been identified as pillars of the program:

- Theme 1: Conserving and accessing genetic resources
- Theme 2: Accelerating the development and selection of varieties with higher, more stable yield and added value
- Theme 3: Managing priority pests and diseases
- Theme 4: Making available low-cost, high-quality planting material for farmers
- Theme 5: Developing tools for more productive, ecologically robust cropping systems
- Theme 6: Promoting postharvest technologies, value chains, and market opportunities
- Theme 7: Enhancing impact through partnerships.

The measures of success are taking on a new dimension, too. The CRP-RTB uses a results-oriented strategy that accounts for not just project outputs but *outcomes and impacts* as well. The program and its individual projects include quantified impact pathways that clearly model how outputs (e.g., products, tools, methods, knowledge, value chains) affect uptake by and impact on end-users. Through a continuous learning cycle with partners, the CRP-RTB will ensure that research is clearly aligned with strategic objectives and use evidence of outcomes and impacts to guide allocation decisions.

Delivery of research products will be based on an interactive model of across-theme topics that link partnership, gender strategy, communication and knowledge sharing, and capacity strengthening (CS). Gender issues are integrated and mainstreamed throughout the CRP-RTB, in needs assessment, research, targeting, and research interventions. Communication and knowledge sharing will be improved by implementing a unified RTB platform (including, but not limited to, a dedicated interactive website and a portal for inter-linked knowledge resource centers) that will interact closely with scientists and developers, stakeholders, donors, beneficiaries, and the general public. This CRP will thus serve as the authority and source for the full reach and exchange of RTB crops information, knowledge, and innovation. Capacity strengthening will reinforce expertise of national research institutions, other R4D partners, and end-users in developing countries.

The CRP-RTB will continue to actively involve partners in a productive interaction that integrates their needs and ideas, promotes innovation, and maximizes the impacts of the R4D and partner agendas. Through this ambitious program of high-quality, gender-sensitive, and results-oriented collaborative research, the CRP-RTB will use the full potential of RTB to increase the food security, nutrition, and income of poor populations, and as such contribute to the achievement of the vision of the CGIAR.

1. INTRODUCTION

About 200 million poor farmers in developing countries use roots, tubers, and bananas (RTB) for food security and income. RTB are a key source of food, nutrition, and income in some of the poorest countries and regions and for the most marginalized populations. Women are very often the main producers and processors of these crops. Though often neglected, RTB serve as critical elements in a strategy to diversify global food supplies, buffer against market shocks, and reduce the risk of food shortages around the world.

The purpose of the CGIAR Research Program on Roots, Tubers, and Bananas (CRP-RTB) is to more fully realize the potential of RTB for improving nutrition, income generation, and food security—especially among some of the world’s poorest and most vulnerable populations. The program is building on the expertise, complementarities, and comparative advantages of four CGIAR Centers—Bioversity International, the International Center for Tropical Agriculture (CIAT), the International Potato Center (CIP), and the International Institute of Tropical Agriculture (IITA)—along with their partners and stakeholders (see Annex 1). It will build on the common characteristics of RTB and strong cross-center collaboration to increase efficiencies and capacity. The greater scale and synergies of this new partnership offer a unique opportunity to enhance scientific advancements, share knowledge, and spur uptake to increase RTB research for development (R4D) impacts.

Not just business as usual, the CRP-RTB is characterized by innovations and an approach that:

- *Exploits the commonalities among RTB crops to capture complementarities, improve efficiencies, and stimulate cross-cutting activities among crops*
 - *Focuses on cross-organizational collaboration to increase synergies and enhance delivery—including collaborations with other CRPs*
 - *Uses participatory processes and integrates multidirectional communication/knowledge sharing in program planning, priority setting, and implementation*
 - *Develops and strengthens the use of motivated, dynamic partnerships to expand reach, relevance, and impact*
 - *Integrates a gender strategy that is mainstreamed and based on audits/research to identify needs and strategies for ensuring equity in access, participation, and benefits*
 - *Strengthens capacity of partners, institutions, and beneficiaries*
 - *Uses a results-oriented strategy with coordinated research activities that lead to clear outcomes and improve delivery pathways for higher impacts.*
-

Section 3 explores this approach in more detail.

1.1 Background: Why a Focus on RTB

1.1.1 RTB are an essential staple food for the poor in developing countries

With a mean production of 685 million tons (MT) on 55 million ha in 2006–2008 (FAO 2010), RTB represent the second most important set of crops in developing countries after cereals. Around 200 million poor families are involved in their cultivation and many others benefit as consumers. Some 400 MT of RTB are consumed as fresh or processed food; the remainder is used as animal feed, planting material, or industrial raw material.

Production and use of RTB tend to be concentrated in countries with lower per-capita incomes: in Sub-Saharan Africa (SSA), the region most dependent on RTB, these crops constitute nearly two-thirds of per-capita food production. The production of RTB in developing countries has increased from 247 MT to 685 MT over the last four decades (2.3% annually); this trend is projected to continue (FAO 2010).

Within the poorest countries, RTB frequently play a great role in the food systems in remote, often marginal areas with low-income levels and limited access to farm inputs. Cassava, for example, can survive and produce a crop when an unexpected dry period causes maize to fail, and year-round production of banana provides a food “bridge” between cereal harvest periods when food is scarce. Thus, RTB are true food security crops. Many of the developing world’s poorest producers and most undernourished households depend on RTB as a significant source of food and nutrition. In Africa, and particularly among less-well-off consumers, RTB are often the main source of calories. In the East African highlands, banana provides a staple food for around 20 million people and consumption may be as high as 1 kg per person per day (Edmeades, Smale, and Karamura 2006). In Asia and Latin America and the Caribbean (LAC), RTB provide an important, supplemental source of carbohydrates and vitamins in food systems often dominated by other staples, although in some areas they are a primary staple.

As crops that can survive periods of neglect, allow flexibility in planting time, and favor over- or underground maintenance and piecemeal harvesting, RTB play a vital role in filling hungry periods caused by seasonal shortages or natural and man-made disasters. For example, hardy cooking bananas served as emergency food during civil strife in Nicaragua, the Democratic Republic of Congo (DRC), and Rwanda-Burundi; potato and sweetpotato provided emergency relief after earthquakes in Haiti and China’s Sichuan Province. Cassava roots also serve as a household food bank as they can be left unharvested in the soil for 36 months or more after the formation of the edible root.

Another advantage of RTB is that because they are rarely traded in international markets, they are far less susceptible to large-scale market shocks experienced by more widely traded staples, such as grains, during international market crises. Thus they play an important role in contributing to a more stable world food system.

1.1.2 RTB have high nutritional value

RTB provide one of the cheapest and most important sources of dietary energy in developing countries (FAO 1989). The energy output per hectare per day of RTB is considerably higher than that of grains. RTB contribute to the energy and nutrition requirements of more than 2 billion people (Kenyon, Anandajayasekeram, and Ochieng 2006). In 2005, RTB provided an estimated 14% of the daily per capita calorie intake of the 741 million people living in the least developed countries (LDC). In some countries, this figure can be as high as 58%, as in the DRC, where they provide more than 800 calories per capita per day. In Africa, banana and plantain provide more than 25% of food energy requirements for around 70 million people (Frison and Sharrock 1999).

Varieties of banana, potato, and sweetpotato exist that are nutrient-dense and rich in dietary fiber, helping to ease the health burden caused by nutrient deficiencies. In countries like the DRC and Solomon Islands, they provide up to 23% of proteins per capita per day (FAO 2010). Potato is a rich source of energy; protein; vitamins C, B6, and B1; folate; potassium; phosphorus; calcium, Fe, and Zn. Orange-fleshed sweetpotato (OFSP) is a rich and highly bio-accessible source of vitamin A: just 50 g a day of the right cultivar can meet the vitamin A requirements of a young child—the group most affected by vitamin A deficiency (VAD) (Garmin and Ekesa 2008). The contents of pro-vitamin A carotenoids (pVACs) in some banana cultivars also have been found to approach those in the best-performing sweetpotato and carrot cultivars with indications of high bio-accessibility (Davey et al. 2009). In SSA and Asia, VAD is widespread, contributing to increased risks of blindness, illness, and premature death, particularly in small children and pregnant/postpartum women.

Other parts of RTB plants are important food and nutrition sources, too. The young leaves and vine tips of sweetpotato are widely consumed as a vegetable in West and East Africa (Abidin 2004).

Cassava leaves are rich in proteins (around 7%), and sweetpotato leaves and shoots are a good source of vitamins A, C, and B₂ (riboflavin) and lutein (FAO 1990). In Southeast Asia, the flowers and terminal bud of the banana plant are eaten cooked or raw and the pseudo-stem is mostly eaten in times of famine (Kennedy 2009).

1.1.3 RTB generate income

RTB can also serve as sources of cash income for low-income farm households and as raw material for processed products for both rural and urban consumption. In many countries, the use of RTB as cash crops is developing quickly, reflecting the dynamism of the RTB subsectors. There is evidence from many parts of the world that RTB for processing (often primarily a woman's activity) and high-value markets can help reduce rural unemployment, increase farmer income, and reduce poverty. With an expanded knowledge of markets, market agents, and business opportunities through a Participatory Market Chain Approach (PMCA) and stakeholder platforms, for example, Andean potato farmers have achieved higher incomes (e.g., \$300–700 annually in Bolivia) along with enhancements in capacities, self-esteem, contacts, and access to information (Devaux et al. 2007). Innovations in RTB have tremendous impact on poverty by enhancing non-agricultural employment, increasing farmers' income through linkages to markets and adding value, and by lowering food costs to consumers. A major part of potato and cassava growth in Asia and SSA is due to increasing demand for processing. It is estimated that 30% of the Chinese sweetpotato production is actually converted into starch for noodles, highlighting the value chain potential for processed products. Banana fruits are consumed and processed in many ways and at all stages of ripening and development, leading to products with increased shelf life, such as flour, chips, and beverages. In India and other Asian countries, banana is grown for its leaves (for plates or firewood) or fiber extracted from the pseudo-stem (for ropes and fishing nets). Some RTB (or their wild relatives) can be used for extracting high-value compounds (e.g., dye extracted from sweetpotato, pharmacologically active compounds extracted from wild yam).

1.1.4 RTB contribute to the sustainability of cropping and production systems

RTB also guarantee sustainability and resilience of cropping systems, particularly under harsh environmental conditions. Their adaptability for cultivation on varied soils, high water productivity, and stable yields under conditions in which other crops may fail add to their strategic importance. For example, certain cassava, sweetpotato, and banana cultivars respond well to simple cultivation methods, with minimal soil preparation and low external input use. Altogether, they are present in most cropping systems of both dry areas and humid tropics of concern to CRP 1 and its components CRPs 1.1 and 1.2 (Table 1.1).

Table 1.1 Cropping Systems—Dry Areas and Humid Tropics

Cropping System	Banana	Cassava	Potato	Sweetpotato	Yam	Others
Dry Areas (CRP 1.1)						
Africa						
Rain-fed mixed						
Asia						
Mixed irrigated arid/semi-arid systems						
Rain-fed mixed						
Latin America						
Rain-fed mixed						
Humid Tropics (CRP 1.2)						
Africa						

Cropping System	Banana	Cassava	Potato	Sweetpotato	Yam	Others
Highland perennial						
Root crop						
Cereals-roots based						
Forest-based						
Asia						
Upland intensive mixed						
Lowland rice						
Tree crop mixed						
Roots and tubers						
Rain-fed mixed						
Latin America						
Intensive highland mixed						
Maize and beans						
High altitude mixed						

Source: Dixon, Gulliver, and Gibbon (2001); Hyman et al. (2008).

The great adaptability of RTB to marginal areas and their flexible growth cycle facilitate their expansion worldwide and underscore their importance as part of a diversified and sustainable food system. Potato, a primary crop in the tropical highlands and temperate Asia, is also used as a winter rotation crop following rice or wheat, due to its highly flexible vegetative cycle. In the Indo-Gangetic plains, for example, potato is inserted in the rice-based cropping system and plays a vital role in drawing underused resources, both land and labor, in the winter season. Banana is cultivated as a monocrop and in mixed cropping systems. The hardy cooking bananas can survive under adverse conditions and periods of neglect, providing material for consumption or sale, permanent cover, and high biomass for mulch and soil organic matter. Sweetpotato yields in poor soil, dry conditions, and with limited inputs. Similarly, cassava and yam are being cultivated in increasingly dryer or low fertility areas, especially in SSA or in Asia, where the best soils are generally reserved for rice.

In addition, rapid growth in demand for meat has increased use of RTB as animal feed, contributing to a better integration of agriculture and livestock in the production system. Sweetpotato, cassava, or banana pseudostems are used as animal feed, especially for pigs, in China, Vietnam, and Thailand. In East Africa, intensive mixed farming systems use banana crop residues for zero-grazing livestock.

1.1.5 RTB play an important role in the livelihoods of women and vulnerable populations

RTB are produced mainly by small farmers and play an important role in the livelihoods of many vulnerable groups, including women, children/youths, tribal communities, and displaced populations. Their cultivation, use, and processing in many parts of the world are often in the hands of women. According to estimates by the International Fund for Agricultural Development (IFAD), across SSA as much as 80% of farming depends on women's labor (<http://allafrica.com/stories/200910310003.html>). The system of gender roles based on local culture in RTB cultivation and use can be complex. As an example, in Kagera (Tanzania), men are in charge of banana cultivation, whereas women complement household food supply from cassava and sweetpotato plots. Yet banana processing into beer is a common income-generating activity for women and the elderly. Several characteristics of RTB favor their use as food security crops in multiple systems. These include home gardens, small orchards, roadsides, wetland margins, and rain-fed hillside plots. Enhanced productivity and nutritional characteristics of these crops, and their integration

into well-balanced local food systems, can have a major impact on family food and nutritional security, especially for children and pregnant/lactating women.

1.1.6 RTB crop profiles

Table 1.2 shows crop production and food consumption crop data in developing countries and LDC. RTB contribute considerably to food energy, particularly in SSA countries (Table 1.3). However, an energy measure alone significantly underestimates their contribution to food security. For example, potatoes in many parts of the world are more a high-value vegetable than a starchy staple and contribute income to poor households by improving food access.

Table 1.2 Crop Production and Food Consumption Data (2005–2007)

CROP	Developing Countries						Least Developed Countries					
	Production (MT)	Rank	Food Consumption (MT)	Rank	Consumption Energy (billion kcal)	Rank	Production (MT)	Rank	Food Consumption (MT)	Rank	Consumption Energy (billion kcal)	Rank
Rice, paddy	619.9	1	496.8	1	1,391,040	1	94.8	1	69.9	1	195,720	1
Maize	355.4	2	96.2	5	342,472	3	24.9	3	19.5	3	69,420	2
Wheat	321.8	3	314.6	2	1,050,764	2	10.0	8	14.9	5	49,766	3
Cassava	218.8	4	105.3	4	114,777	4	58.3	2	43.4	2	47,306	4
Potatoes	158.7	5	118.2	3	79,194	7	14.8	5	11.5	6	7,705	11
Soybeans	131.1	6	9.0	14	30,150	12	0.7	16	0.3	15	1,005	14
Bananas & Plantains	117.2	7	79.5	6	53,663	9	24.9	4	15.3	4	10,328	7
Sweetpotatoes	109.8	8	60.6	8	55,752	8	10.6	7	9.1	8	8,372	8
Tomatoes	93.6	9	78.9	7	13,413	15	1.8	13	2.1	12	357	15
Cabbages and other brassicas	52.7	10	m.v.				0.7	15	m.v.			
Yams	49.5	11	20.8	11	21,008	13	4.1	12	2.8	10	2,828	13
Sorghum	47.5	12	25.3	9	86,779	5	14.2	6	9.9	7	33,957	5
Groundnuts, with shell	34.4	13	10.0	13	41,400	11	5.4	10	1.9	13	7,866	10
Millet	31.1	14	23.4	10	79,560	6	9.6	9	6.8	9	23,120	6
Barley	30.1	15	5.2	15	17,264	14	1.8	14	1.2	14	3,984	12
Beans, dry	18.2	16	13.4	12	45,694	10	5.2	11	2.4	11	8,184	9

Note: LDC group of 50 low income countries defined by FAO, developing countries is a broader group of 177 countries in LAC, Africa, and Asia.

Source: FAOSTAT. Production, updated: 2 September 2010; Food Supply updated: 2 June 2010; and Food Balance sheets FAO

http://www.fao.org/DOCREP/003/X9892E/X9892e05.htm#P8217_125315

Table 1.3 Food Consumption Data in Energy Equivalents by Region (2005–2007)

CROP	Developing Countries				Least Developed Countries			
	Kcal % (2005–2007)				Kcal % (2005–2007)			
	Africa	Asia	LAC	Total	Africa	Asia	LAC	Total
Bananas & Plantains	2.7	1.1	3.8	1.7	3.5	0.6	5.8	2.3
Cassava	12.4	1.1	4.7	3.6	17.9	0.4	7.5	10.7
Potatoes	1.5	2.7	2.9	2.5	1.3	2.4	0.2	1.8
Sweetpotatoes	1.8	1.9	0.5	1.7	3.0	0.3	3.5	1.9
Yams	3.3	0.0	0.3	0.7	1.0	0.0	4.2	0.6
ROOTS & TUBERS Total	21.6	6.7	12.1	10.1	26.7	3.8	21.1	17.3

CROP	Developing Countries				Least Developed Countries			
	Kcal % (2005–2007)				Kcal % (2005–2007)			
	Africa	Asia	LAC	Total	Africa	Asia	LAC	Total
Barley	1.7	0.3	0.2	0.5	1.5	0.1	0.0	0.9
Beans	1.6	0.8	6.0	1.4	2.6	0.6	4.9	1.8
Groundnuts (with shell)	1.8	1.2	0.6	1.2	2.6	0.4	2.1	1.7
Maize	22.3	4.9	30.8	10.6	22.9	5.3	14.6	15.7
Millet	6.7	1.7	0.0	2.5	8.3	1.0	0.0	5.3
Rice (milled equivalent)	10.6	46.5	17.6	37.0	11.7	76.1	33.4	38.0
Sorghum	9.4	1.2	0.2	2.7	12.4	0.9	3.4	7.7
Soybeans	0.4	1.1	0.8	0.9	0.1	0.4	0.0	0.2
Tomatoes	0.4	0.4	0.5	0.4	0.1	0.0	0.1	0.1
Wheat	23.5	35.2	31.1	32.6	11.0	11.5	20.4	11.3
Total kcal (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Bananas

Bananas (*Musa* spp.), including dessert banana, plantain, and cooking banana, are the fourth most important food crop in the LDCs ranked by total production and food consumption. Production (117 MT/year) across a broader group of developing countries is distributed among Asia (42%), Africa (29%), and LAC (27%). Banana production in many areas rests upon a narrow genetic base. Many major production zones are dominated by cultivar sets that are clonal variants of one or a few original seedlings. The Bioversity global clonal collection of ~1,300 *Musa* accessions includes less than 15% wild *Musa*. Therefore, both breeding and additional collection are very high priorities. Bananas share common traits with roots and tubers (vegetatively propagated polyploids, perishable product, large underground storage organ) that affect breeding, propagation, and distribution. Key traits for breeding include yield; crop cycle; resistance/tolerance to pests, diseases, and abiotic stress; nutritional qualities; postharvest attributes; and preferred end-user qualities. Breeding schemes include 2x and 4x improvement before intercrossing to produce seedless 3x hybrids, but progress is slow due to high sterility, hence the ongoing efforts in genetic engineering.

Cassava

Cassava (*Manihot esculenta*) is the second most important food crop in the LDCs, and the fourth most important in developing countries, with total production (218 MT), of which over half is in Africa and another third in Asia. It is mostly grown by smallholders. Commonly considered to provide only carbohydrates, cassava also contains significant minerals including micronutrients. High pro-vitamin A (PVA) cultivars exist and leaves are consumed as a nutritious vegetable in some countries. There is a significant global market for dehydrated cassava that is boosting production with new market opportunities. Originating in the Americas and adapted to the tropics and subtropics, wild *Manihot* exhibit significant variability for adaptation, nutritive content, and toxins (cyanogenic glucosides), and resistance to pests, diseases, and postharvest deterioration. This perennial species is handled as an annual crop that is tolerant to many abiotic and biotic stresses, including low-fertility soils, and can be left unharvested until needed. The short shelf-life requires efficient marketing/fresh consumption or processing. Cassava cultivars are heterozygous hybrids propagated by woody cuttings called stakes. Key breeding objectives are yield, high dry matter, resistance to viruses such as cassava mosaic disease and cassava brown streak disease, compatibility with integrated pest management (IPM), tolerance to drought and low fertility, and low toxins, high-carotene, and fodder.

Potato

Potato (*Solanum tuberosum*) is the world's fifth most important food crop in the LDC ranked by total production (159 MT) and the third most important ranked by food consumption (118 MT). Potato is grown in diverse environments in Asia, Africa, and LAC. Originating in the Americas, wild potatoes are a tremendous resource for breeding, with a wide range of ecological adaptation from the high Andes through cool temperate rain forests to coastal plains, and carry resistances to many important pests and diseases. They provide food, employment, and income as a cash crop for table, processing, and industrial use. Potatoes are a major source of energy and protein with significant amounts of vitamins C, B6, and B1, folate, potassium, phosphorus, calcium, Fe, and Zn. They are high in dietary fiber and rich in antioxidants, including polyphenols and tocopherols. As with other RTB, their reproductive biology allows variability to be rapidly generated and fixed, with sexual reproduction followed by vegetative propagation via tubers. Pollinated potato flowers set true seed in berries, with obligatory out-crossing for many species. Most cultivated potatoes are tetraploids ($2n = 4x = 48$). Key breeding objectives are stable tuber yield, durable resistance to diseases such as late blight (LB) and bacterial wilt, resistance to multiple viruses (potato virus Y, potato leafroll virus) and pests, adaptation to heat and drought, short vegetative cycle, tuber quality, and nutritional attributes.

Sweetpotato

Sweetpotato (*Ipomea batatas*) is the eighth most important food crop in the developing countries. Total production (110 MT) has historically been centered in Asia with Africa taking an increasing share. Like the potato, sweetpotato is a major energy crop, and some of its genotypes (OFSP) have very high levels of pro-vitamin A, which provides a means to reduce VAD in the tropics and subtropics. Whilst sweetpotato originated in the Americas, no wild form of *I. batatas* has been found, but domesticated *I. batatas* was probably selected from an inter-specific cross between diploid and tetraploid species in the *I. trifida* complex. Major pest and diseases are sweetpotato chlorotic stunt virus and the sweetpotato weevils (*Cylas* spp.). The crop has large genetic variation for crop duration, as adaptation, partitioning, and nutrient composition. Breeding has been limited to date, and this needs to be increased to produce optimum combinations of broadly adapted productivity of highly nutritious genotypes and high foliage production for animal feed. Transgenic approaches mainly serve for providing weevil and virus resistance. Marketing and processing of sweetpotato are still limited and require further research. The economic value of products varies with dry matter content and color. Hexaploid hybrids are propagated and distributed as tender cuttings called vines, or storage roots.

Yam

Yams (*Dioscorea* spp.) are a multispecies crop with a wide range of ploidies and rank eleventh among global food crops in both total production (49 MT) and food consumption in developing countries. Production is concentrated in tropical Africa (96%), mostly by smallholders. Guinea yams, *D. rotundata* (white yam) and *D. cayenensis* (yellow yam), originated in Africa and account for most of the yam production; they are preferred for the organoleptic properties of the tubers. The water yam, *D. alata*, originated in Asia and has superior agronomic flexibility and wide geographic distribution. Yams are adapted to the tropics and subtropics and can be propagated by seed tubers or vine cuttings. Breeding objectives include high and stable tuber yields, resistance to pests and diseases (nematodes, viruses, anthracnose, and scale insects), tuber quality, ease of harvest and long storage, suitability to cropping systems and markets, tolerance to abiotic stresses, and textural and nutritional attributes. In addition to common research needs with other RTB, agronomic research on soil fertility management investigates the role of mycorrhizal fungi in yam mineral nutrition, while product development looks at functional properties required for products for household and industrial purposes.

Minor Root and Tuber Crops

The minor root and tuber crops are a rich but neglected resource for food, nutrition, and income. The Andean root and tuber crops (ARTC) (achira, ahipa, arracacha, maca, mashua, mauka, oca, ulluco, yacón) play a major role in Andean potato-based farming systems, where they are of great economic and nutritional importance to subsistence farmers. They yield well with low inputs and withstand most biotic and abiotic stresses. They have a wide range and mix of desirable characteristics: high-vitamin, micronutrient, and starch content; high yields; and medicinal properties. Diploid Ahipa yam beans (*Pachyrhizus* spp.) are drought-tolerant legumes with considerably more protein and trace minerals (Fe, Zn) than better-known root crops.

The aroids, *Colocasia* spp. and *Xanthosoma* spp., are important food crops in the tropics (12.2 MT), especially in Africa (76%). Taro (*Colocasia* spp.) and cocoyam/tannia (*Xanthosoma* spp.) were domesticated independently in southeastern Asia and tropical America, respectively. Cultivation is concentrated in the coastal forest regions of West and Central Africa, but they are often intercropped with bananas in highland Eastern Africa. Cocoyam and taro are important traditional crops, playing a vital role for women in family food supply and income generation. Similar to yam, these crops are preferred staples, but they have not been sufficiently researched.

1.2 The Challenges for RTB to Contribute to Improving Nutrition and Alleviating Poverty

1.2.1 Closing the yield gap by investing in RTB research

Over the last five decades, growth rates in RTB have been largely driven by area expansion as opposed to increased yields resulting from technological innovations such as improved varieties and production techniques (Scott et al. 2000), and yield changes in the RTB crops in the LDC have been quite variable (Table 1.4). In sweetpotatoes and plantain, yields declined whilst they showed a strong upward trend for potatoes and cassava.

Table 1.4 Change in Production, Area, and Yield for RTB Crops in the LDC

	Production (MT)		Area (million ha)		Yield (t/ha)	
	1961–1963	2005–2007	1961–1963	2005–2007	1961–1963	2005–2007
Bananas	3.2	9.5	0.5	1.4	6.0	6.8
Cassava	21.5	58.3	4.3	6.7	5.0	8.8
Plantains	7.1	15.4	1.3	2.9	5.5	5.3
Potatoes	1.5	14.8	0.3	1.4	6.0	10.9
Sweetpotatoes	3.5	10.6	0.6	2.2	5.5	4.9
Taro (cocoyam)	0.4	0.8	0.1	0.2	4.6	4.9
Yams	1.7	4.1	0.3	0.5	6.1	8.5

Source: FAOSTAT. FAOSTAT reports bananas and plantains separately, and we followed their usage in this and following tables; however, no systematic criteria are used to make this separation and some cultivars are classified as banana in one country and plantain in other.

Despite their importance and high potential, RTB have historically received little attention by policymakers, donors, and researchers, with most efforts concentrated on cash crops or the more familiar grains. With the exception of potato, RTB crops are not widely grown in developed countries, receive minimal private research investment, and are often poorly funded and understaffed in many National Agricultural Research Systems (NARS). Recent research has shown that yield gaps are widening spatially and between commercially and subsistence-oriented crops. Although returns to research have been higher in marginal lands, past allocation has favored commercially oriented crops and disregarded subsistence cultivation. In particular, areas where

irrigated crops can be grown have received the largest share of research investments compared to those with rainfed conditions (Pardey, Wood, and Herford 2010).

The trend is reflected in the productivity increases of RTB, most of which are grown for own-consumption in the less-favored ecosystems of the world. Average annual growth rates of RTB yields in LDC (as classified by FAO) are lower compared to rice and wheat (Tables 1.5 and 1.6). Yields of sweetpotatoes, bananas, and plantains, which are only recently capturing the attention of the international research community—and can be considered “orphan” crops—have been stagnant on average. These crops have typically experienced less varietal change than the major cereals, which is one factor in stagnant yields. In the last 10-year period, yields of these crops have picked up, which may be a consequence of increased research investments. Cassava and potato yields have had higher growth rates but are still lower than those of rice and wheat, whose yield growth rates are representative of the focus of the green revolution investments. Cassava in Asia showed the most marked yield increase for any crop over this period, perhaps reflecting the successful development of varieties and other technology for industrial processing.

Table 1.5 Yield Annual Growth Rate (AGR) for RTB and Other Crops by 10-Year Periods for the LDC

Region	Crop	Yield AGR* (%)			
		1970	1980	1990	2000
Africa	Bananas	0.3	-1.0	0.3	1.4
	Cassava	1.0	1.8	-0.2	1.8
	Maize	1.6	0.5	1.1	0.6
	Plantains	1.8	-2.5	0.2	-0.2
	Potatoes	-0.2	1.0	0.3	0.9
	Rice, paddy	0.6	0.4	0.6	1.2
	Soybeans	2.3	-1.8	1.6	-1.4
	Sweetpotatoes	-1.4	0.5	-1.3	1.6
	Wheat	2.3	1.3	1.9	3.0
	Yams	0.8	0.9	0.9	1.0
Asia	Bananas	-0.2	1.0	-0.9	-0.2
	Cassava	0.6	2.1	-1.8	8.7
	Maize	0.3	-0.7	1.1	3.8
	Plantains	0.2	1.9	3.1	3.6
	Potatoes	2.5	1.5	0.7	2.6
	Rice, paddy	1.3	2.7	1.4	2.8
	Soybeans	-0.3	1.4	1.4	3.9
	Sweetpotatoes	0.9	-0.3	-1.8	0.1
	Wheat	2.5	1.7	-0.7	2.2
	Yams	0.9	-2.6	1.1	1.0
Latin America	Bananas	1.8	1.0	-0.5	0.1
	Cassava	0.6	-0.4	-0.3	2.2
	Maize	-0.7	-1.4	-0.5	-0.3
	Plantains	0.8	-0.4	-1.5	2.1
	Potatoes	-0.9	1.4	-1.1	-0.8
	Rice, paddy	3.2	-1.7	-0.9	-0.5
	Soybeans	N/A			

Region	Crop	Yield AGR* (%)			
		1970	1980	1990	2000
All	Sweetpotatoes	0.0	-2.3	-2.8	0.6
	Wheat				
	Yams	0.0	-1.3	3.6	-0.2
	Bananas	-0.1	-0.6	0.1	0.9
	Cassava	1.0	1.8	-0.2	1.9
	Maize	1.2	0.2	1.0	1.1
	Plantains	1.7	-2.4	0.2	0.0
	Potatoes	1.2	1.3	0.5	1.7
	Rice, paddy	1.2	2.4	1.3	2.6
	Soybeans	1.2	-0.1	1.7	1.1
	Sweetpotatoes	-1.2	0.3	-1.5	1.3
	Wheat	2.5	1.7	-0.2	2.5
	Yams	0.8	0.7	1.0	1.0

Source: FAOSTAT; *midpoint of the 10-year period (e.g., for 1970, 1974–1976 compared with 1964–1966).

Table 1.6 Average AGR for Selected Crops, 1964–2006, for LDC

Crop	AGR (%)
Sweetpotatoes	−0.3
Plantains	−0.1
Bananas	0.1
Maize	0.9
Yams	0.9
Cassava	1.2
Potatoes	1.2
Wheat	1.7
Rice, paddy	1.9

Source: FAOSTAT; midpoint of the 10-year period (e.g., 2004–2006 compared with 1964–1966).

This yield divergence of RTB from wheat and rice hurts smallholders around the world. Similar differences can be found among the RTB crops. Potatoes grown under irrigated or semi-irrigated conditions along the coast of Peru have been able to successfully utilize potato research outputs to innovate for market production. Meanwhile, potatoes grown in the Andean Highlands under larger production constraints lag in terms of innovation and productivity increases. Sweetpotatoes, almost exclusively a subsistence crop, is lagging farther behind the research investments in potatoes, explaining stagnating yield. The contrasting story from China, where since 1961 sweetpotato yields increased from 7.1 to 21.3 t/ha linked with a substantial R4D effort, certainly suggests that there is a lot of scope for research to contribute to improved yields (Andrade et al. 2009).

Banana and plantain have shown a moderate increase in productivity, and experience in some countries points to the potential to increase yields significantly through the introduction of new cultivars and/or new production technologies. In the Dominican Republic, the plantain-type hybrid FHIA-21 was selected as a promising alternative variety to the traditional plantain cultivated owing to its resistance to black leaf streak disease. Garming, Espinosa, and Guardia (2011) showed that farmers who switched to FHIA-21 increased their yields by about 30–50% compared with the traditional variety, with similar production technology. In Uganda and Tanzania, deployment of

banana FHIA hybrids reduces the vulnerability of households to yield losses from pests and diseases (Smale and Tushemereirwe 2007).

Drought-tolerant cassava has allowed resource-scarce farmers in Southeast Asia to secure food sources as well as monetary income in marginal highlands where soil fertility and moisture restrict the choice for any other crops. In Africa also, development and introduction of high-yielding, disease-resistant cassava varieties, coupled with processing technologies, have led to increased production and transformation of the role of cassava in Nigeria (Nweke et al. 2002).

Whilst we have identified trends in this section, finer grained analysis would be needed to disentangle the contribution of varietal change, new management practices, and increased intensity of input use. Further studies about prospects of RTB crops based on analysis of historical data and modeling in the spirit of those by Walker et al. (2011a, b) will also help define and set priorities for the RTB program.

1.2.2 Improving the quality of data and analysis for RTB

RTB crops, particularly in SSA, suffer from poorer data quality more than cereals. This reflects a neglect by policy makers and challenges to estimating yields and areas for crops that grow underground, may be harvested piecemeal, and are often grown intercropped or in rotation. In Mozambique, for example, a nationally representative rural household income survey indicated that sweetpotato-cultivated area for Mozambique in 2002 exceeded 90,000 ha, tenfold the comparable estimate from FAOSTAT of only 9,000 ha (Walker et al. 2011b). To make valid decisions about resource allocation and research priorities, it will be important to improve data quality and analysis.

The use of geographic information systems (GIS) mapping to overlay poverty and crop density will help improve targeting and priority setting. Preliminary analysis shows the relative relevance of RTB and other crops in areas where poverty is prevalent (Fig. 1.1). The total crop area for 26 crops in 10 x 10 km pixels was estimated and overlapped with poverty incidence in the same pixels. The same analysis shows the spatial distribution of people by crop (Figs. 1.2a and b provide examples for yam and cassava). A slightly different approach uses composite livelihoods indices overlayed with RTB production to identify target areas (Fig. 1.3, for potato). As data for other RTB become available, similar approaches will be used to pin-point critical hotspots where RTB are prevalent in the different regions. The method requires building a strong interdisciplinary team involving GIS specialists with social scientists. Some of this work will be best conducted as a coordinated effort across the CRPs.

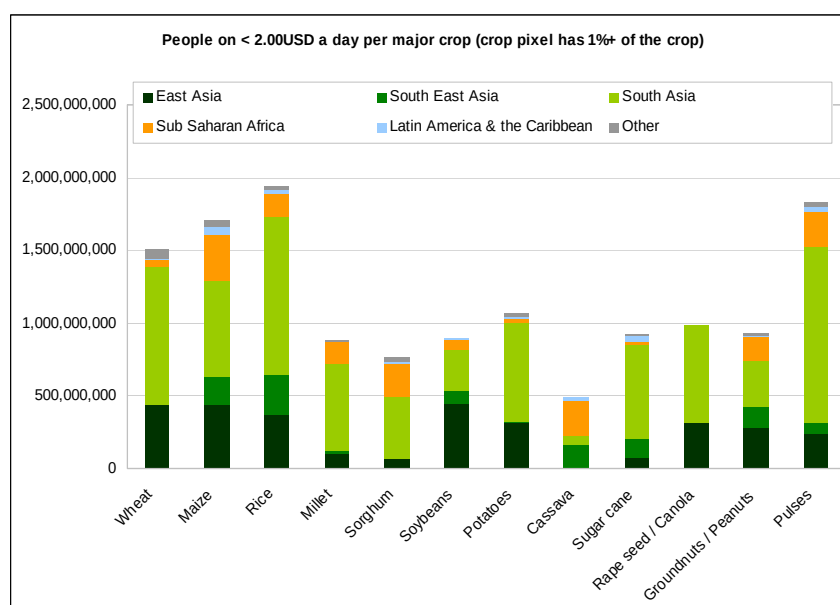


Figure 1.1 Numbers of people earning less than \$2/day in areas where the crop pixel has at least 1% of the crop. Source: Wood et al. 2010.

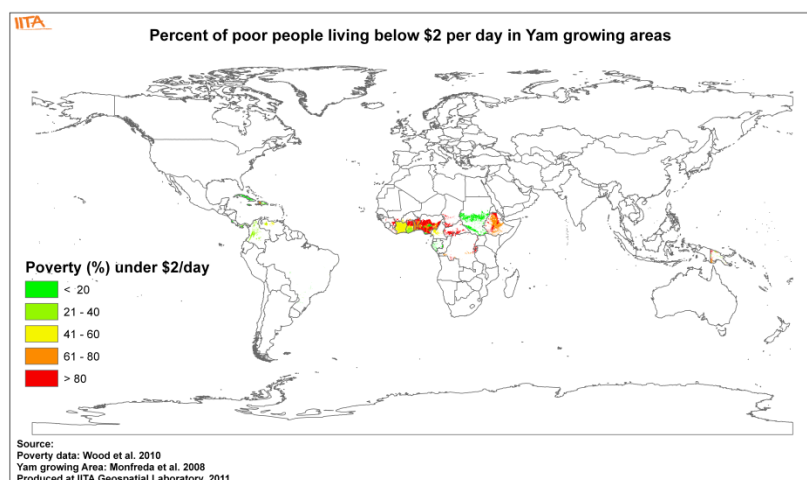


Figure 1.2a Percent of people living below \$2/day in yam-growing areas.

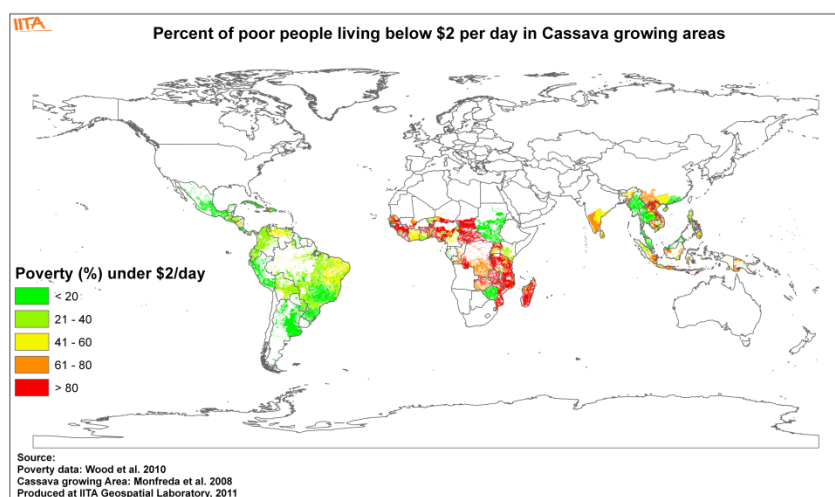


Figure 1.2b Percent of people living below \$2/day in cassava-growing areas.

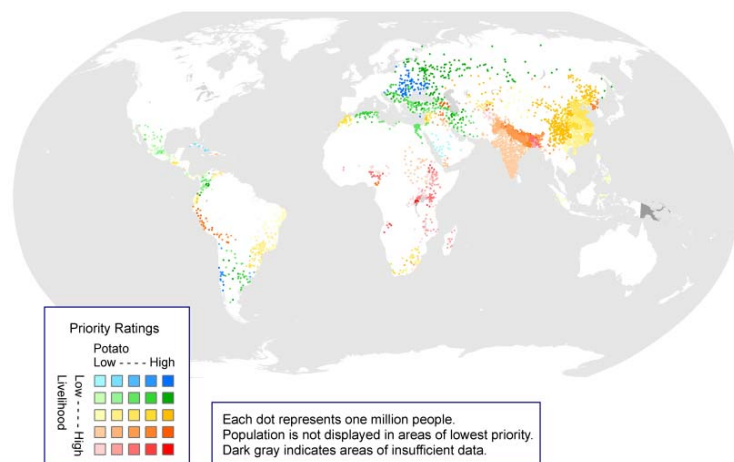


Figure 1.3 Population by priority for potato. Source: Thiesen and Thiele 2008.

The analysis will address the specific crop characteristics, growing conditions, production potential, and crop uses. It involves, for instance, identifying and improving measures to determine RTB crops' presence and density on GIS maps. Different GIS methods have been used and are available for use such as the Spatial Production Allocation Model (SPAM; You et al. 2000) and the Ecocrop model developed by FAO (<http://ecocrop.fao.org/ecocrop/srv/en/home>). Additional data from crop-related socioeconomic research and spatial analysis of determinants of livelihoods will complement the basis for priority setting.

1.2.3 Aligning research objectives to the needs of farmers and users

The impact of the research conducted on RTB is highly dependent on how its products (e.g., varieties and technologies) are adopted by next- and end-users to translate into improved food security and nutrition (Gibson et al. 2008). Thus research objectives must be based on a thorough understanding of the production and consumption patterns of RTB and on needs of different users along the delivery chain, with particular attention given to the needs of women and men. Users also must be strongly involved in priority setting, recognizing important differences in needs and preferences regarding traits (e.g., taste, consistency, timing, or ease of processing), production management systems, or value chain participation associated with gender or other cultural factors. In addition, end-users will need to actively participate in the evaluation of the products and outputs of RTB research, ensuring an effective feedback mechanism to the CRP-RTB.

Another important consideration is that production and consumption patterns change over time. For example, there has been a rapid shift in the use of RTB from food to animal feed in China, Thailand, and Colombia. Rising income levels tend to lead to higher potato consumption (particularly as fast food) and decreased consumption of cassava or banana. Rapid increase of urbanization, greater participation of women in the labor force, and increased exposure to advertisement of new food commodities can also affect consumption patterns and demand. Cultural factors may play a role—for example, rituals associated with yam explain its importance in the diet in West Africa (Bricas and Attaie 1998).

Policy-oriented analyses at regional and national levels consequently necessitate a disaggregated assessment that takes into account not only per capita income, but also other factors like existing use levels, relative prices, availability of substitutes, and gender-differentiated tastes and preferences.

Active participation of stakeholders in the development and implementation of research activities—and in the evaluation of research outputs and products—is paramount for validating, informing, or redirecting the research agenda and for the success of the CRP-RTB. The capacity to align research objectives to the needs of farmers and users depends on the quality of the delivery system and the capacity to build active and highly participatory partnerships and communication linkages. Working through dynamic networks of stakeholders, including donors, partners, and beneficiaries, will stimulate innovation and information sharing and ensure that end-users can provide input into the design of the strategy and the definition of research objectives. It will provide an opportunity for partners to be active in the development and implementation of the research activities, and allow participatory evaluation of products. The collaborative, user-driven approach and assessment will allow ways to identify needs and strategies that are more adapted to gender, cultural, knowledge sharing, or capacity-strengthening needs. Involving RTB partners in productive interactions is how future research can help them realize the maximum impact for improving food security and livelihoods of the poor.

1.2.4 Mitigating climate change

Threats from climate change are expected to increase, including extreme climate events; increases in outbreaks of pests and diseases; and associated impacts on soil fertility, biological function, and agricultural biodiversity. Africa and Asia, where most of the target RTB systems exist, are the most vulnerable to climate change (IPCC 2007, Ramirez et al. 2010). A recent study by the International Food Policy Research Institute (IFPRI) using the IMPACT partial equilibrium model linked to crop growth and other models indicates that under climate change, by 2050 severe negative impacts on yield and production for all root and tuber crops with sharp price increases can be anticipated (Rosegrant 2009).

Most RTB systems predominantly rely on rainfall, and increases in temperature and changes in rainfall patterns are already affecting some traditional RTB-based systems. Farmers are shifting locations to adapt to these changes, thus incorporating rangelands, forests, and other natural carbon sink locations into agriculture contributing to a greater release of greenhouse gases (de Haan and Juarez 2010, Segnini et al. 2010). For potato, for example, global warming is likely to lead to changes in the time of planting, the use of later-maturing cultivars, and a shift in the location of potato production (Hijmans 2003). New genetic material with high phenotypic plasticity to temperature acclimation can circumvent this problem by producing more potato in areas where temperature and pest and diseases pressures are increasing. However, the presence of large sinks for assimilates in RTB make these crops good candidates for yield response to rising CO₂. Several studies confirmed that RTB are more responsive to elevated CO₂ than other C₃ crops (Miglietta et al. 1998).

A review of the impacts of climate change on banana (Ramirez et al. 2010) suggests that future climates (2020s) are expected to be less suitable for banana production in more than 70% of the global land areas (mainly tropical areas), but that there could be gains towards the subtropics (ibid.). If well managed, these could even increase production and expand cropped lands, though the latter should only be done when environmentally sustainable and equitable.

The CRP-RTB, in close collaboration with CRP 7, will generate a portfolio of information sources, guidelines, and germplasm available for using genetic and species diversity to enhance adaptation and resilience of RTB-based systems to changing climate. These joint CRPs will not only seek aggressively the adoption and up-scaling of the technologies generated, but will also provide systematic technical and policy support for farm- to community-level agricultural risk management strategies that buffer against climate shocks and enhance livelihood resilience.

1.3 RTB Crops Lessons Learned

Over the past decades, the four Centers that make up the RTB alliance have amassed broad-ranging lessons learned that offer invaluable insights concerning salient R4D issues, obstacles, and opportunities to maximize the CGIAR's programmatic investments and impacts. Although many of these lessons are crop-specific, important larger themes or trends emerge:

1. **Breeding and Genetics.** The Centers have developed unique, global strategies for breeding RTB crops and have accumulated vast amounts of genetic variability and information to demonstrate that RTB breeding and genetics can be as efficient as for other crops if proper approaches are taken and new tools adopted. Germplasm conservation and exchange are particularly difficult for RTB and the process remains expensive, slow, and limited. Long-term, strategic population improvement under endemic pressures in target agro-ecologies is a reliable means to accumulate appropriate trait complexes to serve as excellent sources for varietal extraction in each RTB system. Breeding methods that incorporate diversity and maintain heterozygosity, and phenotyping/genotyping procedures that maximize trait

heritability, have been established. Where RTB are an important *food security crop* in subsistence farming and for traditional markets, participatory breeding/evaluation plays a key role. Where varieties are needed *to supply industrial markets*, conventional, more centralized breeding approaches can be very successful. There are major opportunities for exploiting the diversity of RTB for improved health and nutrition, linked especially to alleviating VAD. Such demands highlight the need for reliable information on the traits and agronomic performance of the accessions conserved in global collections of RTB.

2. **Pests and Diseases.** Because of vegetative propagation of RTB crops, pests and diseases play a major role in limiting productivity. Strong plant protection research is fundamental for diagnosis and control. Dynamic populations, emerging pests and diseases, climate change, and global crop movement require constant monitoring of risks to RTB production. RTB breeding is complex and addressing production constraints through pest- and disease-resistant hybrids requires long-term commitment and adequate resources. Advances in the understanding of genes and genomes should accelerate resistance breeding. The dynamics of pests for long-cycle crops such as yams, bananas, or cassava are different than for short-cycle crops where most research has been conducted. In RTB we have access to adequate sources of resistance to many pests and diseases, but resistance sources are still lacking for others. Biocontrol agents (both microorganisms and arthropods) have a larger role in crops with a longer growing cycle, and the threat posed by epidemic pests and diseases is best addressed through global efforts that bring together partners from affected as well as nonaffected countries. These efforts are often constrained by restrictions in international movement of biocontrol agents.
3. **Planting Materials.** Access to quality planting material is one of the factors limiting the adoption of both locally selected and introduced varieties. In addition, quality of planting material affects productivity from one cropping cycle to the next. Private sector investment in seed systems of most RTB crops has been minimal. Nonetheless, innovative public-private alliances are succeeding with tissue culture and related rapid propagation methods to provide supplies of large numbers of high-quality plants to smallholder farmers at affordable prices. Demand creation and innovative schemes such as the use of vouchers and communication through school gardens have shown promise as effective means to stimulate the production and exchange of planting materials for targeted dissemination of new varieties, and productivity gains from reduced pest and disease load.
4. **Sustainable Productivity.** RTB are frequently cultivated in degraded soils and low-input systems, especially in SSA, but these low-input systems cannot adequately address productivity constraints. Without attention to fertility and nutrient mining, crop production will lead to further deforestation and soil degradation. Efforts to overcome these constraints should involve a number of strategies, such as selecting cultivars for better responsiveness to application of nutrients or higher nutrient-use efficiency, developing management practices that enhance efficiency of nutrient use, and developing practices to conserve soil and improve its structure and fertility.
5. **Value Chain Development.** In many parts of the world, RTB crops are moving from subsistence to commercial systems. Product development, processing technologies, and markets need to be expanded and strengthened. Links with different industries and joint development of alternative products have proven to be very useful. Areas where this approach has been successful range from the promotion of traditional potato landraces in the highlands of Peru to the development of a waxy (amylose-free) starch for cassava in Thailand. In Africa, farmers' storage and marketing are vital requirements to increase their bargaining power, concentrate product supplies, and reduce transaction costs. During the last few decades, the bulkiness and short shelf life of RTB, which have long hampered their

wider marketability, have been gradually attenuated. As alternative approaches for processing RTB are developed, stronger markets for these products are developing. Strong markets for these crops, in turn, are key to promoting the adoption of technologies and to reducing poverty. RTB processing tends to be done in small facilities close to the areas where the crops are produced, which in turn favors local rural development. Diverse markets and products are critical requirements for long-term commercial success in RTB processing. The importance of focusing more on demand and working backwards to link to supply has proved to be a more sustainable way to smallholder productivity growth than initial focus on supply. Experiences across the RTB have shown that successful R4D requires an integrated approach that takes into account the entire system of production, processing, and marketing. Attention to any one of these elements of the value chain in isolation of the others will not lead to sustainable development.

6. **Partners and Stakeholders.** As the R4D effort has grown in size and complexity, new partnerships have been formed with a broader range of organizations, moving beyond the CGIAR's conventional partnerships with agriculture research institutes (ARIs) and NARS, to engage with diverse nongovernmental organizations (NGOs) and community-based organizations (CBOs). Fostering functional linkages and partnerships among research, farmers' associations, service providers, NGOs, processors, industrialists, and traders was essential. The trend to implement larger projects that cost less to administer presents the challenge of linking numerous countries in a single framework that also addresses local needs. Mapping and characterizing production systems and market chains are an increasingly important activity to undertake to help set priorities, target interventions, and share experiences across countries. The private sector and fellow CG Centers provide valuable partnerships for developing, testing, and scaling up and out of technologies. The involvement of stakeholders from regional networks and expert networks in the Centers' priority-setting process has lent credibility to their agenda, especially when it seeks to promote other actions such as the implementation of a conservation strategy or a policy on safe movement of germplasm. Donors also seem to appreciate when proposals for research or other actions have received clear support from an identifiable stakeholder group or subject matter specialists.
7. **Gender.** RTB crops are typically labor intensive in traditional production and processing systems. In most situations, women provide critical input—from planting, weeding, and harvesting to peeling, pounding, baking, or other kinds of processing activities. However, in more commercial kinds of processing activities, women's involvement may be reduced with potentially adverse consequences. Gender-aware interventions to improve the production, processing, or marketing systems can help ensure that new technologies bring equitable benefits right along the value chain for women, their children, and men.
8. **Next-Users and Capacity Building.** Networks of national program researchers; academic and practical researchers; and farmer training, capacity building, knowledge sharing, and participatory methods have enhanced capacities for innovation in the use, improvement, and production of RTB. Multi-country field trials have proved an important mechanism for NARS to identify cultivars that meet local requirements. Experience has shown that existing capacity tends to be self-reinforcing in that a few countries, which already have some capacity, tend to be the recurrent partners in project development. There is a challenge to reach out and use these countries as centers of excellence to transfer this capacity to countries where project execution requires additional investment of effort. Consultations with scientists and practitioners in RTB-producing countries have identified difficulties in accessing and navigating the growing body of work on these crops as a major constraint to their work. With the development of information technologies, synthesizing and integrating

research results into knowledge products—to which users could also easily contribute their own experience—show promise as a potentially effective solution to this problem. Sustainable technology transfer necessitates addressing issues such as intellectual property rights, technical know-how of manufacturers, environmental risks, gender influence, and flexibility of equipment use and adoption rate, and quality hazards.

9. **Statistics.** Because RTB crops are often managed on small plots and do not enter formal markets, the quality of the statistics on these crops is generally very poor. This deficiency reduced the visibility and perceived importance that RTB have in the economy of tropical and subtropical countries and in the livelihood of their people. Improved survey methods and reporting systems are needed to correct this deficiency.

1.4 An Innovative Program for the RTB Crop Research and Development Effort

The CRP-RTB's goal of increasing the food security, nutrition, and income of poor populations that depend on RTB for their livelihoods is an ambitious one. To meet this challenge, Bioversity, CIAT, CIP, and IITA are bringing together their extensive collective experience and lessons learned as premier agricultural research organizations at all stages in the R4D cycle for their respective crops.

1.4.1 Building a broad-based, integrated research for development in RTB

In collaboration with their partners, the four Centers will build on their experiences and expertise to develop a strong, integrated R4D agenda. The collaboration is unprecedented and has already begun to yield a firm foundation, further strengthened by the active and growing involvement of a wide range of partners and stakeholders who have taken part in stakeholder workshops, interviews, surveys, and informal conversations associated with the development of this proposal. Their input has been fundamental for ensuring that the program will be user-driven, establishing priorities, and identifying *what* services the CRP-RTB can deliver as well as *how* to maximize that delivery.

CRP-RTB will explore new ways of working together to take advantage of complementarities and synergies between crops and partners and to improve delivery pathways for ensuring a higher impact of products (discussed further in section 3). In this effort, the CRP-RTB will continuously integrate partnership, issues of gender and vulnerable populations, communication and knowledge sharing, and capacity strengthening into vision and action.

To meet its objectives, the CRP-RTB must first provide clear strategic focus and add value to the current Centers and programs in order to:

- Enhance the role of RTB in diversified global food security systems to reduce risk of food shortages and nutritional shortfalls.
- Assess and exploit RTB genetic resources to contribute to resilient food and farming systems.
- Assess and improve RTB productivity through breeding for adaptation to stressful environments, higher quality of planting material, and crop/resource management (including biological control and good agricultural practices).
- Better position RTB as market crops to increase incomes and reduce poverty.
- Develop a global RTB partnership to ensure knowledge sharing and technology delivery.
- Empower women and small farmer organizations through innovation systems.
- Improve efficiency and impact of RTB R4D through exploitation of synergies among crops and collaboration among CGIAR Centers and partners.

More attention will be given as part of the CRP-RTB to underused and neglected roots and tubers; their diversity and potential uses also constitute part of the innovative research this CRP. Some “minor” tropical tuber crops are being cultivated in different parts of the tropics to a limited extent. For example, IITA is focusing on tropical minor root crops—mainly cocoyam, taro, and other aroids—for their importance in food security in the humid tropics, particularly in Africa and South Asia (a focus of CRP 1.2). CIP has begun an emergency program to rescue wild and domestic ARTC threatened by biological extinction or severe genetic weakening. These crops are of great economic and nutritional importance to subsistence farmers and have important potentials along the impact pathway (see section 4).

1.4.2 Implementing an effective, comprehensive strategy to achieve objectives

The CRP-RTB strategy centers on seven themes and their respective product lines (Table 1.7). The themes, which garnered stakeholders’ support in the workshops and surveys held in 2010, reflect the major scientific and programmatic entry points across the R4D continuum designed to maximize the impacts that will achieve this CRP’s objectives (Annex 1 presents the results of the workshops, interviews, and surveys). Each theme is built around several product lines and products for RTB crops with cross-cutting research and the individual milestones and linkages to their anticipated outcomes and impacts (see the product line description tables in Annex 2). Section 2 expands on the CRP-RTB impacts; section 3 describes the program framework; and section 4 provides more information on each theme and product line, including linkages to other CRPs. The remaining sections describe arrangements for management and governance (section 5), monitoring and evaluation (M&E) (section 6), risk analysis (section 7), and budget considerations (section 8).

Table 1.7 Themes and Product Lines

THEME/PRODUCT LINE (PL)
<i>Theme 1. Conserving and accessing genetic resources</i>
PL 1. Ex-situ and in-situ conservation methodologies optimized
PL 2. Increased coverage of gene pools in global genebanks
PL 3. Collections of RTB phenotyped and genotyped for important traits
PL 4. Collections of RTB documented and information freely accessible to users
PL 5. Safe exchange of RTB genetic resources
<i>Theme 2. Accelerating the development and selection of varieties with higher, more stable yield and added value</i>
PL 1. Breeding tools, strategies, and approaches
PL 2. Trait capture and gene discovery
PL 3. Population development and pre-breeding
PL 4. Variety development
PL 5. Aligning research with farmers’ and end-users’ priorities
<i>Theme 3. Managing priority pests and diseases</i>
PL 1. Detection, surveillance, and mapping
PL 2. Ecology, biology, and epidemiology of pests and diseases
PL 3. Ecology and management of beneficial organisms
PL 4. Specific management strategies
<i>Theme 4. Making available low-cost, high-quality planting material for farmers</i>
PL 1. Policies, strategies, and decision support tools to improve effectiveness of seed systems
PL 2. Lower cost, more effective mass propagation methods
PL 3. Farmer-based quality seed production and management methods
<i>Theme 5. Developing tools for more productive, ecologically robust cropping systems</i>

THEME/PRODUCT LINE (PL)
PL 1. Ecological and physiological understanding of RTB crops and cropping systems
PL 2. Increasing productivity in RTB cropping systems through nutrient/water/light management practices
PL 3. Integrated decision and management tools for RTB crops
Theme 6. Promoting postharvest technologies, value chains, and market opportunities
PL 1. Postharvest approaches to improve food security
PL 2. Improving linkages to markets for environmentally friendly income generation activities
PL 3. Marketing strategies and policies to add value and promote RTB consumption
Theme 7. Enhancing impact through partnerships
PL 1. Targeting and setting priorities
PL 2. Building effective partnerships
PL 3. Communication and knowledge sharing
PL 4. Capacity strengthening
PL 5. Outcome and impact assessment

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2.0 IMPACT PATHWAYS

The CRP-RTB will promote a strong impact culture amongst all scientists. As discussed in section 5, the Management Committee will ensure that research is clearly oriented to achieve impacts and use evidence of outcomes and impacts to guide allocation decisions. To ensure a focus on impact, all research will be guided by and located within a set of impact pathways. Impact pathways are best-bet descriptions of how the partners in the CRP-RTB envisage that the planned outputs will contribute to outcomes and impacts. We differentiate *research outcomes* with next-users (where there is a degree of control by the CRP) from *development outcomes* with end-users (where the CRP's direct contact is limited), which are different from *impact* understood as the changes in livelihoods of the target beneficiaries of the CRP-RTB. Impact pathways for agricultural research are relatively complex and depend upon many actors. The timeframe for achieving impacts, even after products are available, is quite long because of adoption lags.

The outputs, outcomes, and impacts of the CRP-RTB are shown in Figure 2.1 at the most general level as seven themes. Each theme includes product lines and products with linkages to different research outcomes. These research outcomes feed into development outcomes that in turn contribute to improved food security, income generation, improved gender equity, and reduced environmental footprint as impacts.

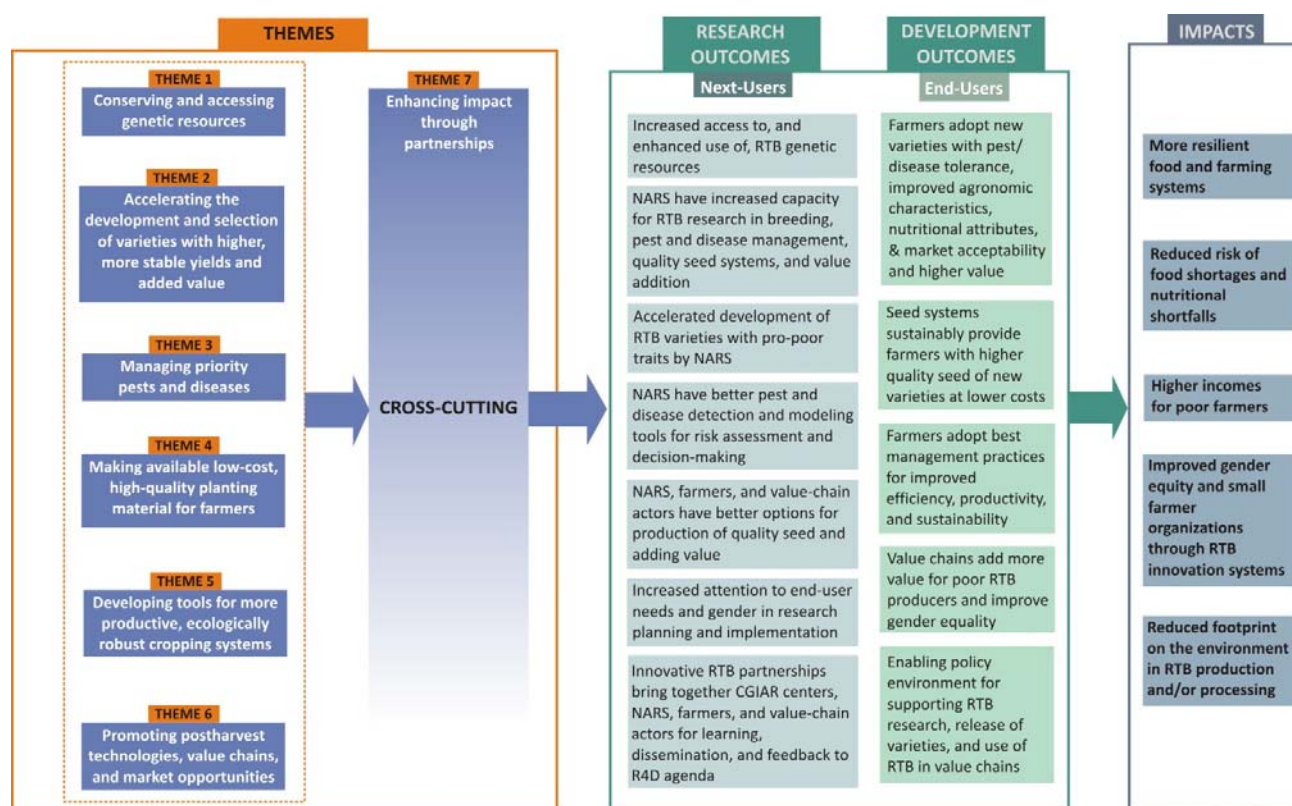


Figure 2.1 CRP-RTB themes and their anticipated outcomes and impacts.

The products and outcomes are linked and mutually reinforcing. Improved capacity of partners for RTB research and innovation generally increases the probability that products lead to relevant outcomes. Better availability of genetic resources contributes to more efficient breeding programs, and improved varieties. Improved varieties will give greater benefits where pests and diseases are better managed and where they are disseminated through improved seed systems. Further gains

may be expected when market linkages are more favorable. Improved access to markets and the engagement of value chain actors can drive change in seed systems and create new demands for varieties and other technology in a feedback loop from Theme 6 to Themes 1–5. Theme 7 facilitates knowledge sharing and linkages across themes amongst partners, contributes to a more favorable policy environment, and keeps the whole CRP on track. Figure 2.2 illustrates schematically this mutual reinforcement and feedback loop.



Figure 2.2 The CRP-RTB builds on R4D linkages that can cut across and reinforce other themes and CRPs.

An even broader set of impact pathways includes the other CRPs. Improved varieties, pests and disease management practices, better seed systems, and integrated nutrient management are important innovations that allow RTB systems to be intensified for greater production and productivity (CRP 1). The CRP can also contribute to a more diversified portfolio of crops available to farmers in more marginal areas to reduce food insecurity (e.g., cassava in SSA as a safety net crop for years with low rainfall) and provide more nutrient-dense cultivars (e.g., pVAC-rich bananas and sweetpotatoes) for improved nutrition (CRPs 1 and 4). In each case, there would be an incremental impact beyond that which the CRP-RTB could achieve on its own. Similarly, CRP-RTB could be a more downstream part of the impact pathways of other CRPs—for example, as methodologies for improved value chain functioning developed in CRP 2 contribute to Theme 6 or sustainable natural resource management practices developed in CRP 5 can contribute to improved RTB cropping systems.

More detailed elements of the impact pathways are described in each of the themes. Milestones to achieve products as well as their linked outcomes and impacts can be found in the product line tables (Annex 2). These will be the basis for monitoring progress in developing products and in achieving research outcomes underpinning the M&E system described in section 6.

Some of the products are cross-cutting and relevant to two or more of the RTB crops; others are crop specific. Cross-cutting products enhance synergy and add value by creating additional outcomes to those that could have been achieved by each of the Centers working separately. The product line tables (Annex 2) include the cross-cutting products and their linked outcomes and impacts separately.

A very large number of producers and consumers can potentially be reached through the CRP-RTB research. CRP-RTB researchers made an initial estimate based on FAOSTAT area data and assumptions about numbers of poor (under \$2/day) and overlap of crops. This analysis suggests that there are at least 180 million poor beneficiaries who could potentially be reached (Table 2.1).

Table 2.1 Estimated Number of Potential Beneficiaries from RTB Crops (in thousands)

Crop	Africa	Asia	LAC	Total
Potato	11,126	41,185	3,381	55,693
Cassava	55,813	34,751	12,465	103,030
Sweetpotato	60,716	22,549	1,713	84,979
Banana	55,893	28,517	3,600	84,410
Yam	54,228	0	0	54,228
Total*	84,023	81,043	16,378	181,085

Source: FAOSTAT.

*Based on estimated adding together the figures for potato and cassava beneficiaries and 10% of the rest of the crops to assume overlap in same production systems.

Theme 7 will include a rigorous priority-setting exercise to estimate actual numbers of beneficiaries and return on investment (ROI) across all crops and RTB product lines. The six different crops in this CRP, the diversity of agroecologies, and adoption domains and institutional differences in approaches to measuring impact make this a very sizeable undertaking for which time and resources were not available during the period of proposal preparation. We used conventional ex-ante economic analysis to provide a preliminary estimation of the ROI and net present value (NPV) of benefits, with a sampled subset of seven technologies that are linked to the products described in Themes 1–6. The technology parameters were specified by eliciting expert opinion. Because of the adoption lags, a 25-year project timeframe was used together with a set of standard assumptions (see Annex 3). Table 2.2 shows that the NPV of the economic benefits produced by this set of technologies for the 25-year period considered as the project duration is almost US \$15.4 billion (at 5% discount rate). This amount is equivalent to an annual aggregated payoff (annuity) from all technologies of \$1 billion. Since the technologies that will be developed are mainly tackling production, processing, and marketing constraints that affect poor farmers, adoption by these poor farmers is expected to take a large portion of the area. Therefore, most of these benefits will accrue to poor farmers and their family members.

Table 2.2 Returns on Research Investments on the Development of RTB Technologies

Theme	Product Line	Crop/Technology	NPV of Total Surplus Change (Million US\$)		Annuity (Million US\$)	
			Discount Rate			
			5%	10%	5%	10%
2, 3	2.2.3, 3.4	Cassava: productivity improvement in Africa	2,987	1,263	194	134
4	4.1	Banana & Plantain: BBTV clean planting material in Burundi, Malawi, and DRC	1,268	553	82	59
5	5.2	Plantain: improved resource use efficiency in Ivory Coast, Ghana, and Nigeria	1,947	994	127	105
2, 3	2.2.3, 3.4	Banana & Plantain: productivity improvement in the rest of Africa	5,782	2,182	376	231
2	2.2.3	Potato: Late blight-resistant varieties (world)	1,757	814	114	86
2, 3	2.2.3, 3.4	Yam: productivity improvement in Africa	1,079	443	70	47
2	2.2.3	Sweetpotato: virus and weevil resistant varieties in Africa	676	279	44	30
TOTAL—all crops			15,495	6,529	1,008	693

Comparing the stream of benefits to the projected research and technology dissemination costs yields an ROI of 32.3%, which is comparable and within the range of returns on other investments in agricultural research (Alston et al. 2000). Although the benefits are high relative to the projected investments, the long period until the technologies are released and the maximum adoption rates are reached reduce their present value.

As these crops are mostly for domestic consumption, the benefits are shared between consumers, producers, and traders, with consumers sharing a larger portion of the benefits (61.5%) than producers (38.5%). Besides the fact that many of the consumers are the rural households themselves and their members, this is also an indication that consumers in rural and urban areas beyond the farms may benefit from reduced prices of critical staple foods and increase real

incomes. This situation mostly benefits the poor as major consumers of the staple foods, which are the mandate crops of the proposed research program on RTB.

Sensitivity analysis shows that halving the expected maximum adoption rates leads to an NPV of benefits of \$7.7 billion (at 5% discount rate), with the corresponding annuities reduced to \$0.5 billion. The rate of return on the same investments is reduced to 24.8%. Additional estimates, based on an assumption of a 50% simultaneous cut in yield changes and maximum adoption rates, result in an NPV of benefits of \$2.6 billion (at 5% discount rate) and an ROI of 14.8%. The corresponding annuities are further reduced to \$0.17 billion. The sensitivity analysis shows that projected research benefits are reasonably robust to large changes in expected adoption and productivity improvements. Whilst this is still a preliminary analysis of a subset of all RTB technologies, it is indicative of the potential of the CRP-RTB. More rigorous priority setting is still needed, with more careful analysis of poverty weights and the use of alternate metrics to capture health and environmental benefits which are not factored into the ROI figures.

Reference

Alston, J.M., C. Chan-Kang, M.C. Marra, P.G. Pardey, and T.J. Wyatt. 2000. A meta-analysis of rates of return to agricultural R&D: *Ex Pede Herculem?* Research Report N° 113. International Food Policy Research Institute, Washington, D.C.

3.0 PROGRAM FRAMEWORK

3.1 Building Complementarities and Synergies

The rationale for a CRP on roots, tubers, and bananas is that synergies and complementarities specific to these crops and the Centers working on them are greater than the synergies and complementarities that might accrue across all crops. Exploiting these synergies and complementarities will improve outputs in the generation of new knowledge and materials. This will be achieved through an enlarged critical mass of researchers, improved contacts with partners, more comprehensive needs and opportunity assessment, shared policy advocacy to raise the profile of RTB, more interactive communication and knowledge management, strengthened capacity building, and a shared framework for outcome–impact evaluation. Efficiency might also be gained through more rapid spillover of global public good research across RTB (e.g., where a novel research strategy is shown to be successful in one crop, a related strategy could be more rapidly applied to similar problems or opportunities in the other RTB crops).

The CRP-RTB considers two broad types of synergies and complementarities: those that accrue across all the crops involved due to common characteristics, and those that result from work by more than one Center on a given crop (Fig. 3.1).

CENTER	PRIMARY CROP EXPERTISE					OTHER ROOTS AND TUBERS	
	BANANA	CASSAVA	POTATO	SWEETPOTATO	YAM	AROIDS	ANDEAN
Bioversity							
CIAT							
CIP							
IITA							

Figure 3.1 The CRP-RTBP alliance of Centers and the respective crops they work on.

3.1.1 Exploiting commonalities across RTB crops

The crops involved in the CRP-RTB (bananas, cassava, potato, sweetpotato, yam and other minor roots and tubers) are all vegetatively propagated crops whose main commercial product is a starchy root, tuber, or fruit with high water content, in contrast to seeds of grains or legumes. The bulky and perishable nature of vegetative seed, the starchy and perishable features of the main commercial product, and the sensitivity to inbreeding depression are the fundamental common features that distinguish these cross-pollinated, often polyploid clonally propagated crops from other groups. As discussed below, a set of common characteristics can be consequently identified among RTB for conservation, propagation, breeding, and postharvest technologies that suggest a range of research priorities that are unique to this group. In all those disciplinary areas, the Centers bring together specialists to exploit these commonalities.

Clear opportunities exist to gain efficiencies by sharing knowledge, experience, and best practices for RTB genebank management, including the use of standard description tools, genebank management software, and platforms and procedures for data management. A validation exercise for conservation methods will be done between the four Centers, and collaborative identification of geographic priorities for joint exploration will rationalize collection missions. The challenges that RTB have in common for seed system improvement are numerous. They include high volume of

planting material, low multiplication rates, transmission of pests and diseases, and perishability of planting material. In developing countries, RTB are also far behind cereals in terms of relevant regulatory mechanisms or structures and the involvement of private seed companies in the seed sector. The scope of these challenges suggests that a cross-crops approach, such as the development of “centers of excellence” for diagnosis of primary RTB pathogens and pests in planting materials, and a common framework for the interaction with private seed or processing companies could have efficiencies in terms of cross-learning and more rapid progress to achieve impact.

In the area of postharvest, bulkiness and perishability have traditionally limited RTB use to on-farm and local markets; specialized storage and transport or postharvest processing are required to extend use beyond harvest periods and for more distant markets. There is a space, common to all RTB, for cross-commodity research aiming to better understand the role of physicochemical, functional, and organoleptic properties that relate to consumer and industry preferences. There is also considerable scope for exploiting synergies for repositioning RTB crops as added-value cash crops through expanding their use for processing into food, feed, and industrial products. In the field of biotechnologies, new tools and techniques are generated very fast and it is very difficult for an individual Center to stay abreast of the advanced techniques and/or have experts or capacities in ever-mushrooming disciplines like omics and informatics. Indeed, it is often not cost-effective to build such capacities at each Center where they would be underutilized. Finally, the RTB crops have biological similarities that can be investigated by similar techniques. Platforms such as molecular breeding, databases, comparative genomics tools, and a cross-cutting bioinformatics toolbox to enable functional genomics studies, genotyping and accurate phenotyping, and methodologies for participatory crop development in a value chain context can be cost-effectively developed as shared resources, facilitating synergies and complementarities of skilled manpower that are now spread in different Centers.

3.1.2 Improving collaboration for shared-mandate RTB crops

Complementarities and synergies are especially high in the case of shared crop mandates. For these shared crops, a full set of production, processing, and marketing research outputs needs to be developed, and their development can be optimally shared so that each Center does not need to develop the critical mass for all activities. Nearly every aspect of the crop improvement program benefits from close collaboration among the relevant Centers.

Among the RTB crops, three Centers share mandates for cassava and bananas. CIAT and IITA have worked together on multiple aspects of cassava since the founding of the two programs in the mid-1970s. This collaboration has intensified in recent years with better communication and greater stakeholder demand for products that can be provided best with joint efforts, such as high vitamin A cassava. Likewise, in banana, IITA, Bioversity, and CIAT have been using the different capacities of the respective Centers to enhance research synergies (e.g., in the framework of the Consortium for Improved Agriculture-based Livelihoods in Central Africa). Banana research at CIAT is relatively recently established.

The CRP-RTB does not anticipate changes initially in the crop mandates across Centers. These have evolved for a number of reasons, especially including regional specificity of some research and the restrictions on germplasm movement between continents (particularly for cassava between Africa and either the Americas or Asia). But the CRP will reinforce existing linkages and create new ways of working together, including joint project development, collaborative training, and sharing capacity (e.g., laboratory services) to avoid duplication of efforts and investments. These linkages will move from the informal or specific-project basis of the past to a jointly planned and executed basis within the CRP.

3.1.3 *New ways of doing business*

The CRP-RTB is the first opportunity to fully rationalize how the Centers will ensure optimal outputs through coordinated efforts. Its collaborative nature and innovative features will prevent silos of knowledge and information that too often limit broad R4D programming. As described in section 5, a formal governance structure will broadly ensure the optimal alignment amongst Centers and harmonization of RTB activities while reinforcing a higher level of synergy through supporting more frequent and intense interaction. This set-up and structure provide the opportunity for the Centers to work as an organic whole in delivering on the research outlined in this CRP.

At the Center, crop, and project levels, there are many ways that the new model of working together will provide new synergies and efficiencies (see Box 3.1).

Box 3.1: Examples of new ways of doing business to optimize synergies across Centers

- Coordinated work plan development in areas of synergy
- Frequent formal and informal communication of progress in project implementation
- Joint project proposal development where synergies are strong
- Inter-center task forces, planning conferences, and symposia on new research topics (e.g., DNA banking; heterosis/population improvement; pathogen elimination)
- Collaborative research for learning from crop diversity—for example, comparative gene discovery toward pathway improvement, engineering (e.g., carotenogenesis) across crops; models and systematization of experiences on in-situ conservation of clonal crop genetic resource
- Shared platforms for germplasm exchange and health testing
- Shared training courses (e.g., on principles and practice of clonal crop breeding methods and germplasm management)
- Sharing of facilities (e.g., experiment stations for access to target agro-ecologies)
- Shared platforms for information sharing and knowledge management
- Shared positions, joint appointment, or job sharing in cross-cutting areas such as biometrics, GIS, plant physiology

The Product Line Description Tables, presented in Annex 2, are organized by the seven themes and within these by crop. But in each theme an additional set of cross-cutting products is included that are common for two or more of the crops. This creates a formal planning and reporting tool for organizing research in a way that captures cross-crop synergies. For example, in Theme 1, cross-cutting products include:

- 1.1.1.1 Improved and validated medium-term storage procedures (slow growth in-vitro protocols)
- 1.1.1.2 Methodology for germplasm integrity assessment during in-vitro storage
- 1.1.1.3 Improved and validated long-term storage procedures (cryopreservation).

In addition to the formal structure of the CRP, the interpersonal relationships, goodwill, and individual motivation among scientists will remain, at a fundamental level, as the primary forces for productive collaboration. The Centers need to have effective communication at all phases of planning and research; the formal planning and operational structure will further encourage this. Priority research areas for each Center will be agreed based upon existing strengths, experience, and capacity, along with regional comparative advantages for certain types of research. The four Centers will fully coordinate the development of a range of product lines by participating and contributing according to their specific expertise in different crops (Fig. 3.1 and Annex 2).

The CRP-RTB will take full advantage of the Centers' diverse locations to address specific local needs of farmers and communities. For example, the broad germplasm diversity of cassava in the Americas (the crop's evolutionary homeland) cannot be easily transferred to Africa due to phytosanitary and political concerns. In addition, resolving the unique local problems in Africa, Asia, or the Americas is only possible through on-site research. Hence the CRP-RTB model takes into account a combination of exploiting synergies while recognizing the need for each institution to contribute within its unique comparative advantages. For their research activities the partners will also share infrastructure, platforms, and outsourcing opportunities to reduce costs and enhance impact.

This integrated arrangement will build on the strengths and comparative advantages of the different Centers, allowing us to complement each other across and within crops. Inter-Center communities-of-practice will be established within research themes, which will be coordinated by one of the four Centers. Functional work teams will be established within and across crops that build cooperation rather than competitiveness among the Centers. The model for inter-Center and across-crop collaboration will focus initially on the areas of highest synergy and/or efficiency gains. As the model is developed and tested, it is expected that the areas of collaboration will evolve. The Program Management Unit includes a monitoring and evaluation (M&E) component to develop an understanding of changes required over time and to monitor such changes.

3.2 Developing Motivated and Efficient Partnerships

The efficiency and impact of RTB R4D will be enhanced through increased collaboration among CGIAR Centers and with partners. However, different kinds of partnerships are appropriate for addressing different outputs and outcomes within the CRP and the participating CGIAR Centers have their own experiences in this regard, and their own existing partnerships. In some cases, different personnel in the same national research organization will partner with different Centers in this CRP (e.g., sweetpotato and cassava in Africa). Rapid network mapping of the different Centers' partnerships, analysis of the key characteristics of different partnership "types" (up-stream with ARIs, "horizontal" with NARIs, private sector, universities, etc.; down-stream outcome-oriented partnerships with NARDs, CSIs, private sector, etc.), and identification of "collaboration gaps" will be undertaken under the leadership of PL 2, Theme 7, but fully inclusive of the diverse perspectives that partners often have of the same partnership. This characterization and analysis will be input to the different theme teams as they develop their partnership strategies further. These strategies are expected to include strengthening and streamlining of collaboration with public sector organizations and civil society (including farmers) and to lead to novel and nontraditional partnerships with the private sector and civil society to address identified "collaboration gaps." This collaborative innovation should, as one of its goals, increase the rate of return in public research without compromising the pro-poor focus of CRP-RTB research. These partnerships will be designed to widen technology dissemination; create synergies between public and private capabilities; and generate income through corporate social responsibility (CSR) schemes, temporally or spatially ring-fenced exclusivity, and intellectual property mechanisms. Moreover, the increasing importance of processing opens an array of possibilities for public-private partnerships (PPP), for which guidelines will be developed. We will take advantage of institutions that have a proven ability to work with poor populations in the delivery of new technologies and, in particular, link with organizations with a demonstrated expertise in gender. We will consider including as strategic partners those organizations that are interested in integrating their RTB research programs into the CRP, as described in section 5 of the proposal.

First steps in this process of network mapping and partnership characterization and development began early in the conceptualization of the CRP-RTB amongst its alliance Centers. In August 2010, workshops, meetings, and interviews were organized and conducted in Africa, Asia, and LAC to a

broad cross section of stakeholders in order to introduce this CRP and engage each attendee in thoughtful discussions about its themes and framework. A Web-based survey (Survey Monkey) expanded the reach of these consultations to capture an even wider audience and diversity and depth of opinion (Box 3.2).

Box 3.2: Using Survey Monkey for CRP design—capturing stakeholders’ needs (sample feedback)

- “Retrieve ‘lost’ information that is scattered in journals that are not accessible to many workers.”
- “Set up a virtual library that would, among other opportunities, give incentives for publications relevant to families, women and children – stories, legends and recipes connected to RTB crops.”
- “Conduct a systematic mapping of the architecture of regional/sub-regional structures and initiatives to identify key communications/partnership entry points.”

The invaluable feedback—more than 100 pages of stakeholder comments, concerns, and preferences—have been synthesized from over 255 stakeholders, representing approximately 200 different institutions (see Annex 1). Open questions received replies from as many as 150 out of 228 survey respondents, many of them extremely detailed, novel, and thoughtful. Respondents also assessed the importance of several methods for building effective partnerships among people and institutions (see Annex 1, section 4). A separate, comprehensive review of stakeholder priorities for R4D in roots and tubers was also carried out (see Annex 4). Results of this survey enriched the conceptualization of this CRP’s strategies and ensured alignment with stakeholder perspectives.

Particular attention will be given to engaging partners through regional fora, including the Forum for Agricultural Research in Africa and the organizations linked with it, the Asia Pacific Association of Agricultural Research Institutions, and Forum for the Americas on Agricultural Research and Technology Development for Latin America and the Caribbean. This will be especially important during the priority-setting process envisioned for the first year of the program.

3.3 Strategic Results Framework and Systemwide Livelihood Objectives

The CRP-RTB is aligned with the Systemwide Results Framework (SRF) in its focus and design (CGIAR 2011).

The SRF proposes four system-level outcomes (SLOs):

1. Reducing rural poverty
2. Improving food security
3. Improving nutrition and health
4. Sustainable management of natural resources.

The CRP-RTB contributes most directly to the first two SLOs. By developing, testing, and making available varieties with improved micronutrient availability (including high yields of nutritious leaves for use as vegetable in cassava and sweetpotato), it will also contribute to SLO 3, and linkages are envisaged and described with CRP 4 to further leverage this type of SLO. Similarly, by making available varieties with tolerances to abiotic stress or higher efficiencies in water and nutrient use, and developing tools for more productive, ecologically robust cropping and nutrient management systems, it will contribute to SLO 4. Linkages to improve this contribution are envisioned and described with CRPs 1, 5, and 7.

The CRP proposes a rigorous priority-setting exercise in the first year of implementation to align research activities with SLOs. The CRP-RTB encompasses six different crops. These crops are grown across a very wide range of agroecologies and face markedly different market opportunities in

diverse value chains ranging from an almost exclusively subsistence orientation to a highly vertically integrated crop supplying a processing industry. In the Philippines, for example, both these contexts can be found for sweetpotato in neighboring geographical areas. Data on area and yields are often of more dubious quality than for cereal crops, particularly in SSA. Several crops have shared mandates. Each of the Centers has hitherto taken different approaches to priority setting and impact evaluation and has different—if overlapping—partners. This diversity of crop contexts, issues of data quality, and institutional environments has meant that prior to CRP-RTB start-up, time and available human resources were not sufficient to describe fully and prioritize the activities within each crop that would best contribute to meeting the SLOs. Participating Centers are committed to developing this understanding of the differences between the RTB crops by ecology and market opportunity, in a unified analytical framework in terms of variable impact of research and differences in yield growth rates. Furthermore the process of working back from SLOs to research outputs and activities, as proposed in the SRF, needs more engagement of partners than was possible in the time frame provided for the preparation of the CRP.

3.4 Introduction of Novel Research Components and Priority Setting

Much of the research presently carried out by the different Centers and planned within the CRP-RTB is funded bilaterally under existing research contracts. As the SRF points out, most Center staff will be committed to delivering on these contracts over the next two or three years. The CRP-RTB will provide a vehicle for improving the coherence and integration of this work. The CRP-RTB will also promote novel cutting-edge research to address the relevant SLOs. As new funding becomes available, novel research components, exploiting complementarities and synergies, and consistent with inter-Center priority setting will be progressively introduced.

Table 3.1 shows examples of novel components considered in each theme (detailed description is provided in the relevant themes of section 4).

Table 3.1 Novel Component by Theme

Theme	Novel Component
1	Red list of genotypes and wild species under risk of extinction; production and conservation of botanic seeds and/or somatic embryos of vegetatively propagated crops; and full exchange of cassava germplasm between Africa and the Americas
2	Treat RTB in breeding as highly heterozygote hybrids and aiming at systematic heterosis exploitation; concerted efforts to induce flowering in RTB as a way to speed up the breeding process
3	Characterization of microbial communities in vegetatively propagated crop planting material; modeling of climate change effects on potential pest and pathogen distribution and severity for RTB
4	Quality declared seed to build on strengths of scientific knowledge with low cost of informal seed system; modeling the systems where "clean seed" systems have an economic advantage over conventional farmer systems
5	Cross-crop analysis of plant nutrition in RTB to better understand the role of potassium, which is needed in high amounts in most RTB; minimum or no-till management systems for erosion control, soil water retention, and reduced energy inputs
6	Comprehensive genebank phenotyping for novel starch traits and for genetic diversity of other potential value-added market traits; cross-crop strategies for extending shelf life (management and genetic)
7	Partnership learning cycle and CRP-RTB partnership strategy; cross-Center and commodity targeting and priority setting; RTB web portal; multiple communications and media options for stakeholder input into developing RTB research agendas

Table 3.2 summarizes funding by theme across product lines and crops and helps understand what groups of activities are new, since new activities by definition do not currently have funding. It also includes a few areas where there has been funding in the past but this is now no longer available (e.g., because this was exclusively covered by core funding until 2010). For most themes, cross-cutting activities to exploit commonalities across all crops are new and therefore mostly unfunded. Other novel components largely unfunded shown here include breeding activities for banana, and much of Theme 5 on robust cropping systems.

Table 3.2 Novel Component by Theme

	Crosscut	Banana	Cassava	Potato	Spotato	Yam	Other
Theme 1. Conserving and accessing genetic resources							
PL 1. Ex-situ and in-situ conservation methodologies optimized	●	●	●	●	●	●	●
PL 2. Increased coverage of gene pools in global genebanks	●	●	●	●	●	●	●
PL 3. Collections of RTB phenotyped and genotyped	●	●	●	●	●	●	●
PL 4. Collections of RTB documented	●	●	●	●	●	●	●
PL 5. Safe exchange of RTB genetic resources	●	●	●	●	●	●	●
Theme 2. Accelerating the development of varieties							
PL 1. Breeding tools, strategies, and approaches	●	●	●	●	●	●	●
PL 2. Trait capture and gene discovery	●	●	●	●	●	●	●
PL 3. Population development and pre-breeding	●	●	●	●	●	●	●
PL 4. Variety development	●	●	●	●	●	●	●
PL 5. Aligning research with farmers' and end-users' priorities	●	●	●	●	●	●	●
Theme 3. Managing priority pests and diseases							
PL 1. Detection, surveillance, and mapping	●	●	●	●	●	●	●
PL 2. Ecology, biology, and epidemiology of pests and diseases	●	●	●	●	●	●	●
PL 3. Ecology and management of beneficial organisms	●	●	●	●	●	●	●
PL 4. Specific management strategies	●	●	●	●	●	●	●
Theme 4. Low-cost, high-quality planting material for farmers							
PL 1. Policies, strategies, and decision support tools	●	●	●	●	●	●	●
PL 2. Lower cost, more effective mass propagation methods	●	●	●	●	●	●	●
PL 3. Farmer-based quality seed production and management	●	●	●	●	●	●	●
Theme 5. Robust cropping systems							
PL 1. Ecological and physiological understanding	●	●	●	●	●	●	●
PL 2. Increasing productivity in RTB cropping systems	●	●	●	●	●	●	●
PL 3. Integrated decision and management tools for RTB crops	●	●	●	●	●	●	●
Theme 6. Promoting postharvest technologies							
PL 1. Postharvest approaches to improve food security	●	●	●	●	●	●	●
PL 2. Improving linkages to markets	●	●	●	●	●	●	●
PL 3. Marketing strategies to add value and promote consumption	●	●	●	●	●	●	●
Theme 7. Enhancing impacts through partnerships							
PL 1. Targeting and setting priorities	●	●	●	●	●	●	●
PL 2. Building effective partnerships	●	●	●	●	●	●	●
PL 3. Communication and knowledge sharing	●	●	●	●	●	●	●
PL 4. Capacity strengthening	●	●	●	●	●	●	●
PL 5. Outcome and impact assessment	●	●	●	●	●	●	●

● Existing PL (i.e., already funded)
 ● Expanded PL (i.e., partially funded)
 ● New PL (i.e., not currently funded)
 ● No PLs planned

The transition to a new agenda with the introduction of novel components will be based on the prioritization process begun during year one. It would be premature to reassign this funding without a clear and agreed set of priorities and sufficient information to do it appropriately and equitably. In addition, time is needed to wrap up existing activities with partners and transition to new arrangements.

For the first year of the CRP-RTB, given this need for continuity, we propose funding activities according to their distribution by crop and Center in the 2009 audited budget. One exception will be to fund an inter-Center priority-setting and targeting exercise as described in Theme 7, with wide engagement of partners. From the second year of implementation, funding allocations would be reconsidered taking into account the priority setting exercise, and agreed by the Steering Committee. As the CRP-RTB accumulates experience and develops a shared framework for decision making, evaluation of success in terms of adoption of technologies and impact, will support prioritization and the identification of new research components.

The prioritization exercise will also contribute to the analysis of where to concentrate critical mass. Involvement of non-CGIAR partners in achieving critical mass will be considered. Cost structures will be taken into consideration with regard to concentration of critical mass and locations of hubs. Specific attention will be given to sharing facilities, phasing out old expensive structures, seeking partners interested in shared efficient hub structures (e.g., key national universities in strategic locations). Some rationalization might eventually be necessary in the placement of scientists by Centers in key target regions. By putting in place an institutional framework for working and planning together there will be natural evolution towards sharing facilities—for example, for propagation, GIS, and a shared statistician.

3.5 Implementing a Gender Strategy

The cultivation, use, and processing of RTB are often in the hands of women. Nevertheless, the extent of women's control over resources and benefits from selling these crops varies in different cultural and economic settings. Several characteristics of RTB favor their use as food security crops in multiple systems frequently managed by women. Enhanced productivity and nutritional characteristics of these crops, and their integration into well-balanced local food systems, can have a major impact on family food and nutritional security, especially for children and pregnant/lactating women. RTB are perishable, which is why their processing—often the woman's domain—is so important. There is also evidence that as RTB-based production systems become more commercial, they are disproportionately managed by men. Examples include sweetpotato in the Philippines (Campilan et al. 2002) and potato in the Andes. The CRP-RTB recognizes the role of women as producers and as guardians of family nutrition, and the importance of gender-based differences regarding needs, preferences, and opportunities.

The gender strategy involves mainstreaming throughout the CRP-RTB. Priority setting and impact assessment, for example, will explicitly analyze gender-specific roles in the RTB cropping systems, taking a value chain perspective to include seed systems, production, harvesting, processing, home consumption and storage, and marketing. Such information allows targeting not only for the potential poverty impact of interventions, but also the potential for achieving positive impact on women and their children. As part of outcome and impact assessment we will include tools for the measurement of changes in the food security and nutritional status of pregnant and lactating women and young children in response to RTB technologies.

Needs assessment will detail the roles, knowledge resources, and capacities of men and women. On the basis of needs assessment, we will prioritize research interventions in terms of their likely

contribution to improving food security of women and children. One tool we will explore is a comparative gender audit of the design and milestones of different research areas to pinpoint which interventions are showing effectiveness in achieving gender equity. This audit would itself build on another element of the gender strategy which involves mainstreaming gender within each of the seven CRP-RTB themes and their product lines. A separate subsection on gender strategy in each theme describes specific gender-linked issues that will provide the basis for designing gender indicators with the M&E system (see section 6).

Gender will also be mainstreamed within the governance and management of this CRP (section 5). Capacity strengthening in gender issues and analysis is proposed for the program director, research theme leaders, and scientists.

3.6 User-Driven Communications and Knowledge Sharing

The CRP-RTB takes a user-driven approach to communications and knowledge sharing that differs from previous CGIAR practice. This includes not only traditional information dissemination and public awareness building, but also recognizes that the communication needs of stakeholders includes such things as connecting partners through interactive tools and platforms; the development of capacity-building materials and tools; or presentation of information through diverse methods such as brochures, e-seminars, stories, theater, or impact briefs.¹ Framing communications and knowledge sharing this way will help link producers to markets and channel feedback from end-users to the RTB partners. The judicious use of stories, statistics, and briefs can also communicate social or economic impact and policy recommendations in ways that resonate with policymakers directly in support of evidence-based policy dialogue.

Development of any activity that involves communications and knowledge sharing will start from an in-depth assessment of the needs, preferences, capacities, and practices-behaviors of identified target audiences. The end result will often be a judicious, effective mix of methods, including face-to-face encounters, print and Web-based products, or other media. This CRP will also take advantage of advances in information communication technology/knowledge management (ICT/KM) developed within the CGIAR, across CRPs, or by other partners.

The CRP-RTB communications and knowledge-sharing strategy targets diverse audiences to meet the objectives of the CRP and promote dynamic communications to enhance research and development (R&D) uptake, outcomes, and impacts. Its aims include:

- Strengthening the multidirectional exchange of knowledge for translating RTB science to practice and informing the research agenda and giving greater voice to users, keepers of traditional knowledge, and partners.
- Capitalizing on the cross-cutting and interdisciplinary communication synergies already taking root in the CRP-RTB.
- Supporting the partnership and capacity-strengthening aspects of the program.
- Building global awareness of the role and potential of RTB crops, particularly among donors and decision makers.
- Highlighting the findings, outcomes, and impacts of CRP-RTB research and activities.
- Increasing access to RTB information resources and knowledge sharing among partners/stakeholders.

¹ Examples recommended by stakeholders through consultative meetings and survey.

- Reaching next-users and broader end-users with validated information to influence attitudes, knowledge, and behaviors for promoting change and achieving impact objectives.
- Linking the CRP-RTB to the proposed CGIAR e-platform for knowledge on gender tools and experiences.

The RTB's user-driven communications and knowledge-sharing approach is an iterative process that was launched with the August 2010 stakeholder consultations and survey implemented for the preparation of this proposal.² The process will continue to guide the overall CRP communications/knowledge-sharing strategy as well as the development of tools and approaches for specific programs and activities.

Direct engagement with end-users can radically change the course of the research agenda and help keep scientists on track.

Stakeholder comment

3.7 Strengthening Capacity of Partners

Capacity development is the ability of program partners and stakeholders to perform—that is, to deliver target outputs and outcomes, as well as the continuing use of improved capacities beyond and outside the CRP. Capacity strengthening encompasses joint adaptive learning processes (not just by individuals but, more importantly, by organizations and partnerships and networks) that take place as the CRP-RTB delivers its target outputs/outcomes along its impact pathway, and the continued use of improved capacities (i.e., performance) beyond and outside this CRP.

The CRP-RTB aims to enhance partner capacities, better reach potential end-users, and support strategic, innovative learning approaches and investments to achieve significant and measurable development impacts. Indeed, on the basis of the stakeholder meetings, there is strong support for building capacity at levels in different contexts and priority areas, but with a clear preference for delivery platforms and methods.

Stakeholders were consulted for their perspectives on capacity strengthening in R4D (Annex 1, section 7). They agreed as to the types of institutions that most need formal capacity strengthening for their staff in this CRP—ranging from NARS to farmer organizations and/or individual farmers to seed growers and national development institutions. The high ranking of need for capacity building of farmers and extensionists presents a dilemma about how far the responsibilities of the CRP-RTB should extend. Several comments highlighted the need for the whole range of partners to be strengthened, but acknowledged the limitations of research investment.

The current RTB research and impact capacity in many partner countries varies greatly. Some countries have been quite successful in improving the access of poor farmers to high-quality planting material of a specific RTB crop, while others have lagged in the face of this challenge. A central challenge is to better understand existing capacities and needs of our partners. This capacity must be focused on impact with a clear gender orientation that targets the poorest and most vulnerable populations where RTB crops already are commonly used or have high potential for greatest impact. The CRP-RTB will actively seek opportunities for organizing hands-on training courses and workshops, and for RTB student and professional fellowships. It will disseminate outputs and publications and stimulate partnerships and research and learning networks.

As a cross-cutting component, capacity strengthening is a joint responsibility of the Centers, with partners, and other stakeholders. There are natural synergies with communications and knowledge

² Feedback from stakeholders has been incorporated into the thinking behind the communications strategy and, more specifically, into communication/knowledge-sharing tools and strategies elaborated under each CRP theme of this proposal.

sharing for delivery tools and methods. Capacity-strengthening activities are embedded in specific product lines in Themes 1–6 and are fundamental to building more effective impact pathways. However, capacity building is also a cross-cutting activity of Theme 7 and provides technical and professional support to all other themes through partnerships and shared capacity strengthening services and common product lines.

3.8 References

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4. PROGRAM PORTFOLIO

4.1 Theme 1: Conserving and Accessing Genetic Resources

4.1.1 Rationale and objectives

The four CRP-RTB Centers play a leading role in the global conservation of RTB genetic resources, preserved primarily as clonal crops and mainly, but not exclusively, conserved in vitro. These Centers bring together community-of-practice specialists managing international RTB genebanks and collaborating as the “Clonal Crop Task Force”—as part of the Inter-Center Working Group on Plant Genetic Resources (ICWG-GR)—to preserve, add value, and safely distribute these crops.

Over 30,000 accessions of RTB crops are maintained by global collections. Bioversity’s *Musa* germplasm collection has 1,298 accessions of banana; CIAT 6,592 accessions of cassava; CIP 6,948 accessions of potato, 8,108 of sweetpotato, and 1,564 of ARTC; and IITA 2,783 accessions of cassava, 290 of banana, 3,360 of yam, and 41 of cocoyam. Depending on crop and Center, germplasm is maintained in field-, in-vitro, and cryobanking conditions as plants, plantlets, or seeds. Clear opportunities exist to gain efficiencies by sharing knowledge, experience, and best practices for the management of RTB genebanks.

Theme 1’s overall objective is to build upon the existing competencies of the four CGIAR Centers involved in clonal crop conservation in order to implement global conservation strategies for RTB crops in close collaboration with the Global Crop Diversity Trust (GCDT) and regional and national genebanks. These strategies strive to put genebanks at the forefront of efforts to conserve, increase, and better exploit the diversity of RTB genetic resources conserved and to better document the germplasm. This will permit researchers and farming communities to make faster and better use of the germplasm, to address biotic and abiotic stresses faced by RTB, mitigate the effects of climate change, improve nutrition, and supply new and expanding markets.

Ex-situ strategies, however, tend to be labor intensive and expensive. In-vitro plantlets, for example, require frequent culturing and need to be rejuvenated at regular intervals to prevent the accumulation of deleterious mutations. These strategies also “freeze” genotypes, preventing plants to adapt to changing conditions (Reed et al. 2004, Panis, Piette, and Swennen 2005). On-farm management of crop genetic resources and in-situ conservation of their wild relatives in their natural habitat provide a complement to genebank or other ex-situ repository approaches.

Taken together, in-situ conservation and on-farm management of genetic resources has become a well-established approach. It involves conceptually diverse R4D strategies to support the dynamic, ongoing use of cultivated agro-biodiversity by farmers and long-term survival of crop wild relatives in their natural habitat (Almekinders and de Boef 2000, Bellon 2004, de Boef 2000, Maxted et al. 2002). While it is beneficial to monitor in-situ reservoirs of species, cultivars, and genes, and ultimately prevent genetic erosion, on-farm conservation is additionally valued for its dynamic contribution to the ongoing evolution of genetic diversity and support of rural livelihoods of farmers in centers of crop origin (Bretting and Duvick 1997, Brush 2004). Many innovative approaches and concepts have been developed and are potentially replicable among the different RTB. Examples include landrace repatriation and bio-cultural heritage sites (CIP 2000, GRAIN 2005), GIS tools for biodiversity analysis and farmer-driven conservation (Prain, Fujisaka, and Warren 1999; Prain, Schneider, and Widyastuti 2000; de Haan 2009), in-situ catalogues (CIP 2006), market-based approaches, and training materials (CIP 2003).

Specific objectives of Theme 1 are:

- To ensure that the ex-situ conservation of RTB crops is efficient, relevant, and cost effective.
- To strengthen and better understand in-situ conservation and on-farm management towards resilient livelihoods.
- To improve the coverage of in-trust collections.
- To stimulate the use of RTB germplasm through characterization, description of agronomic features, reaction to pests and diseases, abiotic stresses, and nutritional and technological traits.
- To promote the use of germplasm by facilitating access to information.
- To strengthen the global system for the safe exchange of germplasm.
- To advocate proactively for the value of genetic resources to policy makers and donors.

4.1.2 Impact pathway

The four Centers work together and with regional and national partners to develop and implement global strategies for RTB germplasm conservation of and access to the existing diversity for users. Partners will be encouraged to develop their own strategies at regional and national levels. This includes the development of technologies that will ensure, in perpetuity, conservation and safe movement of the entire RTB gene pools and use of germplasm worldwide. Although the next-users of the practices to be developed are mainly genebank curators (in-vitro or field genebanks), the knowledge products aim for a broader impact: to benefit researchers, breeders, and, ultimately, farmers.

One of the key products generated by Theme 1 is germplasm, mainly as virus-free plantlets, but also as seeds, of diverse germplasm (wild species, landraces, cultivars, improved material) that will be available for use by RTB breeders (linking with Theme 2) to conduct improvement of cultivars in the best conditions. The challenge is to build efficient partnerships with national actors to reach the end-users (farmers). An excellent example of such a joint approach is the catalogue of native potatoes (Box 4.1.1).

Box 4.1.1: Catalogue of native potatoes

It is inefficient to support and research on-farm management of genetic resources without a good baseline of what is actually present in diversity hotspots, which cultivars do communities grow, and how abundant and endemic these cultivars are. The collective knowledge system surrounding on-farm management genetic diversity should be documented with previous informed consent from indigenous communities and in accordance with (inter)national laws that aim to protect traditional knowledge. The local participation, explicit recognition of indigenous knowledge, and ownership and co-publication with a regional farmer's union were essential for succeeding in the production of a catalogue of 144 native potato landraces from Huancavelica, in Peru (CIP 2006). This publication has led to increased indigenous self-esteem and pride concerning farmer knowledge, an interest from external institutions to use local genetic resources, and the incorporation of agro-biodiversity issues in regional curricula of education. In the longer term, this pilot experience is expected to result in the maintenance of nutritious food systems and risk avoidance strategies (e.g., mixed landrace stands), the development of marketing options, more resilient households towards socioeconomic and environmental change, more diversified diets, creation of new diversity, and its incorporation in ex-situ collections.

Sharing experiences across RTB crops, the four CGIAR Centers and partners will collaborate to improve standard description tools (e.g., molecular markers, comparative and functional genomics in novel systems, protocols for evaluation) and will encourage their use in characterization and evaluation research. Data and results analyzed using bioinformatics tools will be synthesized into a form directly accessible to users (who may be breeders or alternatively development professionals wishing to deploy available diversity in its present form). The reinforcement of information systems serves to disseminate this knowledge and facilitate and encourage the use of a broader range of genetic resources of these RTB crops. These activities will impact model initiatives for strategy and

policy development, but also increase incomes, food security, and livelihood options for smallholder farmers in the long term. Figure 4.1.1 shows the impact pathways envisaged for Theme 1.

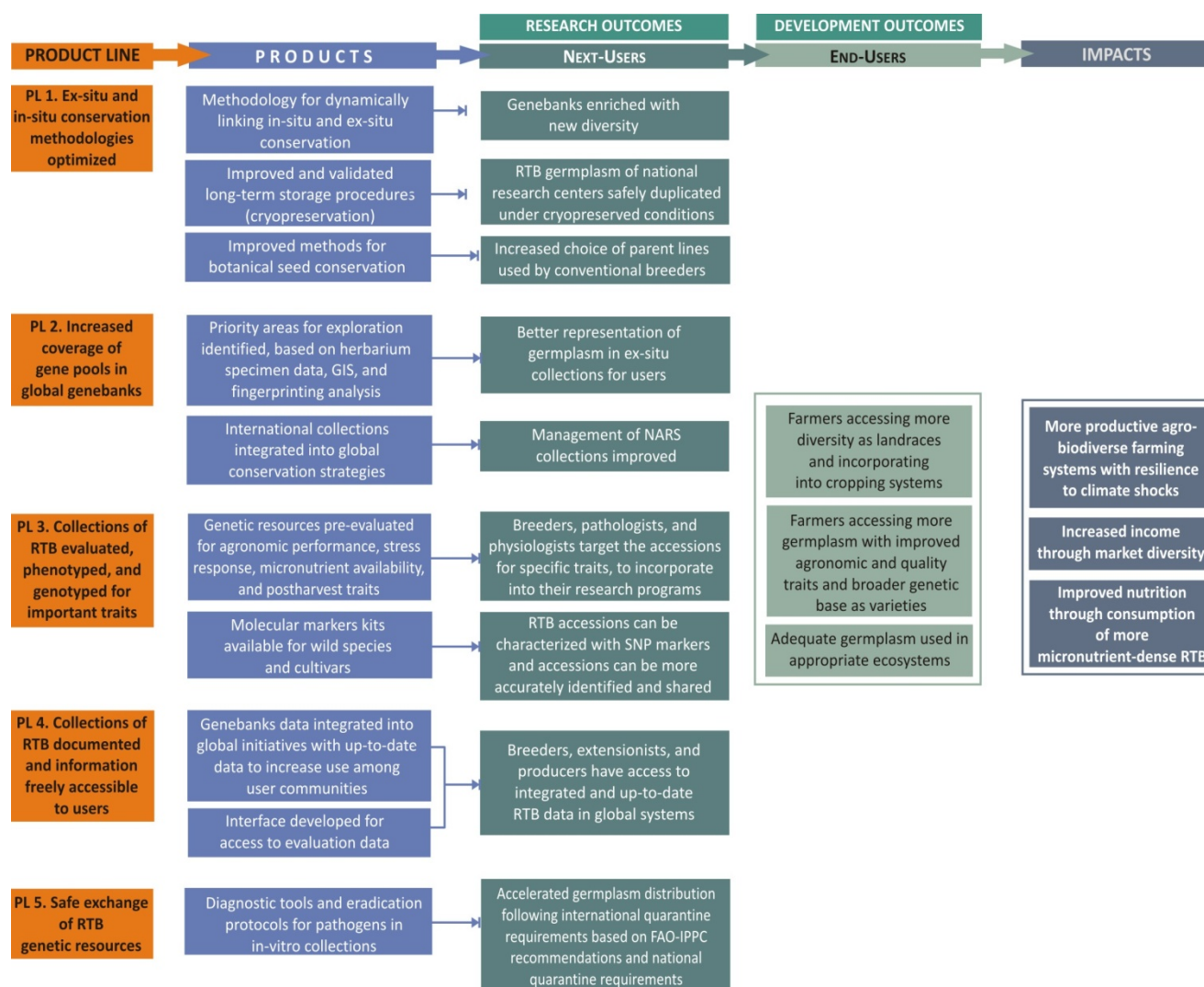


Figure 4.1.1 Theme 1 product lines, products, outcomes, and impacts.

4.1.3 Product lines

There are five product lines (PLs) associated with Theme 1. Annex 2 contains the product line description tables (research products, outcomes, milestones, and key partners) for Theme 1.

PL 1: Ex-situ and in-situ conservation methodologies optimized

PL 1 will bring together the Centers' strong knowledge base, diverse partnerships, and innovative science to ensure the conservation of threatened germplasm or identifying traits of interest for farmers and breeders.

Ex-situ conservation and safe exchange of clonal RTB germplasm rely on in-vitro culture and cryopreservation. During the last three years, CIP, CIAT, IITA, and Bioversity, under the ICWG-GR, jointly produced and tested protocols for the in-vitro conservation of cassava, potato, yams, bananas, and sweetpotato. These methodologies will be transferred to regional institutions acting as transit facilities and multiplication centers for breeders, farmers, and other end-users.

The Centers' genebanks will optimize the cost-effectiveness of protocols (e.g., use of slow-growth medium for potato and cassava in-vitro conservation) and will continue to develop strategies for a user-oriented conservation of the gene pool through a mix of (1) medium-term storage, maintaining working collections for accessions of frequent use, and (2) long-term storage (cryopreservation) for less often needed accessions. Methods of cryopreservation will be improved and standardized for banana, potato, cassava, and yam and developed for the long-term conservation of sweetpotato and ARTC. Model practices will be shared so that all collections of RTB will eventually be handled according to International Organization for Standardization standards (already in force at CIP's genebank). Rejuvenation and combined molecular and morphological approaches will be used as necessary to check that the genetic integrity (trueness-to-type) and quality of the germplasm are maintained during storage. Partnerships will be strengthened with key field collections to ensure safety back-up of the unique germplasm they hold.

Even when seed collections of RTB crops exist (for potato, sweetpotato, and cassava), ex-situ RTB germplasm collections consist largely of clonal germplasm of landraces and improved material, which exhibit most of the morphological variation and traits of interest to farmers but share a relatively narrow genetic base. Novel genetic diversity can be found within their wild relatives. Studies will be carried out to optimize the protocols for producing, storing, and monitoring the viability of their seeds expanding the use of this cost-efficient method of conservation (e.g., *Manihot esculenta* and related species, *Solanum* species of the *Petota* section). We will develop protocols for the seeds of wild banana accessions, for which no reliable method for long-term storage exists. Seed-based collections of wild relatives will be set up for the crops for which none currently exist to prevent irreversible loss of genetic diversity due to various factors such as climate change or habitat loss.

Conserving RTB germplasm and their wild relatives ex situ does not allow them to evolve in response to their natural environment, including pests and diseases. On-farm genetic resources management provides the opportunity for crop biotypes (e.g., resistant variants) to emerge, thus strengthening the resilience and adaptation of farmer management of agro-biodiversity in the face of climate change. Benchmark sites will be established for long-term research to enable effective conservation and critical learning that will reinforce the scientific basis of in-situ conservation. Research methods will be applied or developed to understand biodiversity hotspots, and vulnerable habitats will be identified using geographic mapping tools. "Memory banking" techniques will be applied to explore local uses, preferences, and evaluation criteria of existing and past varieties and methods for conserving this knowledge also in situ (Nazarea 1998). We will also explore the use of a simplified version of trade-off analysis (www.tradeoffs.oregonstate.edu; Claessens, Stoorvogel, and Antle 2010) to better understand the drivers of in-situ maintenance or loss of crop genetic diversity. The research will support efficient strategies that build up ongoing farmer-managed conservation and scale-up successful and replicable externally driven interventions (see Box 4.1.2). New methods for in-situ conservation of wild relatives will also be developed as part of this product line. This requires a long-term perspective and therefore institutional commitment beyond project life cycles.

In-situ conservation of both cultivars and crop wild relatives is recognized as offering different kinds of environmental services that benefit rural and urban populations and ecosystems and contribute to global food systems via breeding programs. Yet despite international agreements about sharing the benefits provided by these services, there has been little practical implementation of benefit-sharing arrangements. Through the partnerships involved in Theme 1 and the benchmark sites, alternative benefit-sharing arrangements will be tested in practice.

Box 4.1.2: Banking on ex-situ and on-farm management strategies to conserve native potatoes

CIP's Ruta C ndor project aims to restore and conserve the genetic diversity of native potatoes in their centers of origin. The cultivars were collected from Andean farming communities 20–40 years ago and conserved in CIP's genebank. The objective is to restore lost native potato cultivars and improve diversity, which has been affected by frost, drought, crop pests and diseases, human migrations, and poverty. CIP ensures that the planting material that is re-introduced is high quality and disease-free, thus increasing yields. CIP started repatriating native potatoes in 1998. Since then, it has reintroduced over 3,600 samples of more than 1,200 cultivars of native potato in 41 Andean farms and has worked with potato farmers to find commercial outlets and marketing opportunities for native potatoes. Similarly, CIAT initiated the shipping to Colombian farmers interested in growing traditional landraces of rooted cassava plantlets certified virus-free from the collection.

PL 2: Increased coverage of gene pools in global genebanks

PL 2 focuses on increasing germplasm diversity in international collections by collecting germplasm of interest, threatened by genetic erosion and under-represented in the global collections. This requires analyzing the extent of diversity held in genebanks (using morphological and molecular characterization to understand the diversity) and developing priority-setting mechanisms for collecting missions based on eco-geographic information (geo-referenced data from past missions) and risks of extinction (such as adapting the International Union for Conservation of Nature Red List approach, developed for wild species to identify cultivars at risk of extinction). Collection missions are also based on the definitions of traits of interest like tolerance to diseases, adaptability to harsh conditions, and nutritional qualities. This will allow us to not only fill gaps in collections and collect germplasm that might be at risk of extinction, but also to move towards "traits-based collections" (see Box 4.1.3).

Box 4.1.3: Strategy to collect the wild ancestors of bananas

Several of the 70 or so described species of wild bananas exhibit a wide range of intra-specific variation, little of which is represented in collections. Meanwhile, molecular analyses have revealed that several of the alleles observed in cultivated bananas are not present in the accessions of wild species held at Bioversity's International *Musa* germplasm collection. A search for the closest living relatives of the main cultivars of bananas would start with the development of markers specific to these cultivars. These markers would be used to screen wild species in their native habitat. In the mean time, arrangements could be made to introduce in collections the material with the most interesting characteristics for breeders and other users.

Networking with taxonomy experts and custodians of genetic resources at national and regional levels will be necessary to develop a community-of-practice and reach consensus on joint actions to consolidate collections. Moreover, urgent taxonomic review of several RTB genera (i.e., *Ipomoea*, *Dioscorea*, and *Manihot*) is needed to answer many questions, such as defining the number of wild relatives in the primary and secondary gene pools, and to generate information about their distribution and conservation status. To conserve a significant part of the RTB gene pools in the public domain, it will also be necessary to deploy policies that facilitate the acquisition of collecting permits and exchanges between collections.

PL 3: Collections of RTB phenotyped and genotyped for important traits

PL 3 focuses on adding value to the genebanks by documenting the main traits and characteristics of the germplasm held there. This information is invaluable to help breeders, biologists, and other users select the germplasm that will best meet their needs. This activity is also important to produce information useful for highlighting the importance of genetic resources, even from an economic point of view. Studying the morphological variations of germplasm (standardized characterization guidelines, sets of core accessions) and protocols for phenotyping different traits will be developed when not available (e.g., yams for improved "poundability" or potato and sweetpotato screening for abiotic stresses). Traits that are influenced by the environment will require interactions with Theme 2 to tease out genotype-by-environmental effects. There is a clear

connection between this work and Theme 2's PL 3: population development and pre-breeding. Here, the evaluation would be made by curators of germplasm collections. In other cases, it is the breeder doing the pre-breeding evaluations. Because many relevant traits are related to biotic or abiotic stresses, the work described in this section also has direct connection with Themes 3 and 5.

Collection optimization is of considerable interest in genetic resources management (van Treuren et al. 2009). An optimization strategy for RTB collections will be to build upon the concept of core collections. The proposed strategy relies on hierarchically structuring the crop gene pool and assigning a relative importance to each of its different components. This strategy has been applied to potato (ibid.) and could be extended to other RTB crops. This will help the rationalization, and ultimately reduce conservation costs, by eliminating duplicates and misidentified materials.

Different strategies for characterization will be combined for genotyping the collections—simple sequence repeat (SSR) markers, single nucleotide polymorphisms (SNP), and others (Risterucci et al. 2009, Hurtado et al. 2008, Ghislain et al. 2009). With costs of genotyping technologies declining, surveys are possible that can be equally broad and whole, genome oriented, or target specific genes of suspected function (Varshney et al. 2009). The evolution and diversity of crops can then be analyzed and better understood (Hurtado et al. 2008). Such new information will enable an efficient gain in insight into domestication while identifying the main historical benchmarks and biological drivers (Glaszmann et al. 2010). To understand the history and diversity of RTB crops, a mixed technological innovation and traditional knowledge will require skills and technologies of a global alliance of multidisciplinary partners (see Box 4.1.4).

Box 4.1.4: Understanding the evolution of clonally propagated crops

In the face of rapid global change, we must understand how the adaptive potential of clonal crops can be maintained. Clonally propagated crops can provide model systems for studying a different, collectively much larger, set of ecologically important traits than seed-propagated crops on which most evolutionary research has focused (McKey et al. 2010). Yet, the genetic diversity of clonally propagated crops is bound to erode if no mechanism generates new diversity. In roots and tubers, the frequency of sexual reproduction and its impact on genetic diversity in clonal propagation has often been underestimated. In such crops, a mixed clonal-sexual system exists. However, still much needs to be known about the ecology and genetics of this system, as well as the influence of farmers' practices on the continued domestication of wild yams (Scarcelli et al. 2006a, Scarcelli et al. 2006b). Will these crops be able to maintain their capacity to generate diversity? Perhaps the most fragile component of systems maintaining the evolutionary potential of clonally propagated crops is the local knowledge of "traditional" farmers about the sexual reproductive biology of these crops. Several factors endanger this knowledge. For instance, farmer's specialized knowledge may not travel along with the plant. A better understanding of this process will help maintain the adaptive potential of crops having mixed-clonal sexual systems.

PL 3 will take advantage of the recent (or soon expected) availability of the RTB genomes (i.e., potato, cassava, and banana) to carry out gene discovery and markers detection, to characterize the allelic content of particular germplasm, and to better understand gene-trait associations. For instance, Bioversity and the Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) have developed a tool for plant comparative genomics that predicts the function of genes based on their evolutionary relationship with genes of known function (Conte et al. 2008, Rouard et al. 2010). In including these three new genomes, PL 3 will support orthology prediction and gene candidate detections for important traits such as biotic stresses, nutritional qualities, and processing and postharvest characteristics, especially those of value to the poor (see Box 4.1.5). This product line will be fostered by strong interactions with other themes and other CRPs, such as CRP 4 on nutrition or CRP 7 on climate change, and stimulate the sharing of germplasm information among partners within the different RTB networks.

Box 4.1.5: Screening for vitamin A in RTB

OFSP and yellow cassava roots are good sources of beta-carotene (precursor to vitamin A) and offer promising potential as a food-based approach to combating VAD. VAD is widespread in half the world's countries, especially in Africa and Asia, and is a leading cause of preventable blindness, disease, and premature death, particularly affecting young children and pregnant women. CIP recently used new near infrared reflectance spectroscopy (NIRS) calibrations to measure levels of beta-carotene and other micronutrients (Fe, Zn, calcium, and Mg) in the CIP sweetpotato germplasm collection. On the basis of a sample of 1,195 clones, CIP was able to recommend 78 OFSP clones with high beta-carotene (≥ 150 ppm) that grow in rich or poor environments for dissemination and evaluation in other regions of the world. CIAT is developing, with CIP support, a similar system but based on the analysis by NIRS on fresh root samples. Recent screening of *Musa* fruits has shown that there is a remarkably high degree of variability in *Musa* fruit for pro-vitamin A carotenoids contents (Davey et al. 2009), with levels approaching those found in the best-performing sweetpotatoes and carrot varieties. In contrast, fruit pulp mineral micronutrient contents (Fe and Zn) were low and showed limited inter-cultivar variability, even for genotypes grown under widely differing environments and soil types.

PL 4: Collections of RTB documented and information freely accessible to users

PL 4 aims to improve existing structures, disseminate information held and produced in genebanks to reach the users of germplasm, and therefore facilitate the exploitation of genetic resources.

Experiences of data management will be shared among researchers across RTB, and the storage and exchange of genetic resources information will be standardized. Passport, morphological, and genetic characterization data; information from evaluations; and pictures of key morphological characteristics of accessions in the global collections will be integrated into the restructured existing databases. We will implement digital herbaria, virtual catalogues, and tools for identification in user-friendly and globally accessible databases. Genebank management systems, such as the *Musa* Genebank Management System (MGMS), used by Bioversity's banana collection, and the CIP in-vitro Genebank and Tissue Culture Laboratory, will be maintained and further developed to accommodate new functionalities (e.g., online ordering systems). In addition, we will maintain data from significant national and regional collections as Web portals as is already the case for potato and banana—for example, Inter-genebank Potato Database (2000) and *Musa* Germplasm Information System (MGIS 2003).

The four CGIAR Centers and partners will work together to develop tools, such as common crop registries standards and data dictionaries, to allow cross-reference checks between the crops they have in common with CGIAR Centers in order to expand to other crops and significant national and regional collections. Through these activities, a wider range of data, combined with better accessibility of information, will reach a wider range of users. The RTB information systems will also be linked to global multi-crop information portals (such as the GCDT/CGIAR/USDA-GIGA project) for optimum management and dissemination of materials.

A special effort will be made to adapt socioeconomic methods to document indigenous knowledge of native cultivars (Jarvis 1999, Prain and Hermann 2000, CIP 2006) to integrate this type of knowledge into existing databases.

PL 5: Safe exchange of RTB genetic resources

PL 5 focuses on reinforcing the global system in place for the safe exchange of germplasm worldwide. It involves working with specialists to define disease threats, develop when necessary diagnostic and pathogen eradication tools, and shape these into coherent and workable guidelines for the safe exchange of RTB germplasm. Promoting the use of the system involves advocacy and consensus-building with decision-makers at national level and in international statutory bodies to encourage the adoption of such guidelines. There are close linkages of PL 5 with other product

lines, particularly from Themes 3 and 4. Regional platforms for virus-indexing, sanitation, multiplication, and distribution will be set up to support the global system (Box 4.1.6).

Box 4.1.6: Novel approach for conservation and shipment of genetic resources through botanical seeds

Often, there is interest in a particular accession because it is the source of a specific trait (e.g., tolerance to abiotic stress or to herbicides, resistance to pest or disease, particular anatomical or morphological characteristic, or enhanced nutritional or commercial value). The genetic background in which the trait is contained is of minor importance. Currently, exchange of germplasm source of useful traits is typically as *in vitro* plants. This is expensive, time consuming, and does not deliver the best type of material to be used as source of these traits. CIAT and IITA have initiated a process to develop partially inbred genetic stocks in which the locus or loci responsible for the trait will be homozygous. Homozygosity will be determined by the use of molecular markers, or after conventional genetic studies. The partially inbred genotype will be self-pollinated (or crosses for the same trait crossed) to produce botanical seed that will then be stored and shipped as needed. In addition to the speed and reduction of costs, the value of this partially inbred genotypes will offer twice the breeding value compared with the original (heterozygous) sources. Self-pollinations in landraces from the germplasm collection have also been initiated as a back-up to the *in vitro* conservation and also as an alternative to ship botanical seed. These seeds would not reproduce the genotype of the parental clone, but will carry (safely, quickly, and inexpensively) a sample of the genes present in it. End-users of accessions from the collections are often more interested in particular genes rather than in the genotypes themselves.

4.1.4 Critical Assessment of Methods

PL 1: Ex-situ and in-situ conservation methodologies optimized—Conservation of RTB genetic resources for future generations through cryopreservation

Cryopreservation, or freeze-preservation at ultra-low temperature (-196°C ; i.e., the temperature of liquid nitrogen), is a sound alternative for the long-term conservation of plant genetic resources. Under these conditions, biochemical and most physical processes are completely arrested, and biological material can consequently be safely stored for the next generations for unlimited time. Cryopreservation is especially valuable for those species that produce recalcitrant (difficult-to-store) seed and species that are vegetatively propagated (because specific gene combinations can only be preserved through clonal propagation) such as cassava, potato, banana, sweetpotato, yam, and edible aroids.

Until 10 years ago, research on plant cryopreservation was mainly the subject of academic studies involving only a few, sometimes not even representative, genotypes. With the development in the early 1990s of “new” and simplified cryopreservation protocols, based on the prevention of intra- and extra-cellular ice crystals by means of cell vitrification and direct immersion of explants in liquid nitrogen, the cryostorage of genetic resources has become a realistic target for many plant species, among them RTB crops.

For many of the RTB, suitable cryopreservation protocols are already developed and they are now in different stages of application. For example, almost 70% of the available *Musa* accessions are now safely stored in liquid nitrogen. The experience with banana, for example with (1) management of large cryopreserved collections, (2) differentially responding accessions, (3) transportation of cryopreserved material, and (4) management of a safe back-up (“black box”), can be shared with other collections; thus securing the continuous availability of RTB genetic resources for future generations.

PL 3: Collections of RTB phenotyped and genotyped for important traits—Comparative genomics, including clonal crops genomes for gene candidate prediction

Genome sequencing efforts provide a comprehensive access to the gene set, to regulatory elements of genes, and to a very high number of markers for a given organism. The increasing number of

draft genomes available in crops (e.g., rice, sorghum, maize, and soybean) paved the way to comparative genomics and translational biology. Global research on *Arabidopsis thaliana* triggered by the sequencing of its genome unraveled basic mechanisms in plant development, tolerance to abiotic and biotic stresses, and adaptation. It was demonstrated that many pathways are common to all plants, which facilitates the discovery of candidate genes. The identification of target genes makes it possible to directly access and use the existing allelic diversity and to derive specific molecular markers that will contribute to breeding techniques as well as high-throughput methods for the development of molecular markers, such as SSR and SNP. Concepts and practical applications in crops (e.g., rice) have been discussed in numerous publications (Zhang et al. 2004, Rensink and Buell 2004, Kuzniar et al. 2008, Fukuoka et al. 2010, Kumar et al. 2010, Varshney et al. 2010).

With the recent availability of the banana, cassava, and potato genomes, the CRP-RTB will enter in the post-genomic era. We believe that a better understanding of genome evolution will contribute to elucidating the genetic basis of important agronomic traits and therefore facilitate ongoing plant breeding efforts.

A few of the advantages of genomics and comparative genomics in RTB include (1) the transfer of information from well-studied genes in other crops reduces research time and costs; (2) robust methodologies are established for other crops at a cheaper cost; and (3) breeding programs can benefit from high number of markers and a better understanding of genome structure that may hinder genetic mapping studies.

PL 4: Collections of RTB documented and information freely accessible to users—Information systems linked to global platforms

Genetic Resources Information Systems were initially designed for recording passport and characterization data from accessions in collections. In 2001, a list of Multi Crop Passport Descriptors was released to standardize the recording of passport data. During the second phase of the Global Public Goods project, an initiative was launched to cross reference accessions between collections managing the same crop, which eventually led to the creation of crops registries. All these activities have helped to collect and harmonize data from different sources. They have also helped to feed global systems, such as the System-wide Information Network for Genetic Resources and now Bioversity's GENESYS, and to improve the quality of data.

Nevertheless, analyses performed during data uploading in global systems have highlighted some discrepancies in data, especially for name, taxonomy, and geo-references. Even if data have been corrected at the global level (GBIF 2005 a,b), no real feedback mechanism to alert the originator of the data has been put in place.

It is also becoming clear that passport and characterization data alone are not sufficient; evaluation data are critical, especially for research of traits of interests. Apart from the International Crop Information System (ICIS), very few accession-level information systems are able to provide these data, and a range of different systems are in use for managing such evaluation data. For banana, for instance, three different databases exist: MGIS (*Musa* Germplasm Information System), compiling passport and characterization data from currently 22 collections (www.crop-diversity.org/banana/); MGMS, for daily data management of the International Transit Center collection (communication MGMS exists between MGIS and MGMS); and the International Musa Testing Programme to record multilocal evaluation data.

Existing systems thus need to be harmonized. The arrival of GRIN-Global, which is able to manage the data from accession level to sample level in evaluation trials, is one of the solutions to

standardize the data and the mechanisms to publish and exchange data. Another option is to develop standards for communication and protocols for the exchange of data between different systems. Within CRP-RTB, we have a framework to develop these standards and protocols for vegetatively propagated crops.

4.1.5 Partnership

Theme 1 relies on strong partnerships to achieve the CRP-RTB's goals and deliver the expected impact. Both a clear division of work and a strong interaction between the CGIAR Centers and with national and regional partners will be crucial to exploiting the synergies fostered by this CRP.

Every step of the research and of impact delivery depends on a successful partnership: collection and conservation of genetic resources relies on the readiness of countries, donor collections, and host organizations to share genetic resources and commit resources to a long-term undertaking. Safe exchanges of germplasm depend upon a reliable statutory framework of quarantine and other regulations. Evaluation of germplasm for specific traits is a great enterprise that needs the involvement of several partners (different growth conditions, regions of the world) in order to be conclusive. To enable these partnerships, the RTB Centers will undertake advocacy activities to explain the value of germplasm exchange and long-term investment in conservation to policy-makers and donors (linked to CRP 2 and other CRP 3s).

A great number of institutions already have a vested interest in collaborating with the four Centers to conduct the proposed research. These include other international centers (e.g., IRRI, ICARDA), universities (e.g., KUL, Tokyo University of Agriculture, University of Kisangani), ARIs (e.g., CIRAD, Japan International Research Center for Agricultural Sciences), NARS (field verification of accessions stored in vitro), private companies (DArT, Syngenta), or individuals. Box 4.1.7 illustrates an example of this kind of partnership in the global *Musa* genetic resources network. Through the systematization of the *MusaNet* and other partnership experiences that will be supported through Theme 7, PL2, this theme will receive guidance to strengthen its partnerships strategy.

Box 4.1.7: Global *Musa* genetic resources network (*MusaNet*)

The agenda for *MusaNet*—the network for the conservation and use of *Musa* genetic resources—is guided by a global conservation strategy document developed by Bioversity International, in close collaboration with partners inside and outside the CGIAR. The global *Musa* collection at the International Transit Center, held “in trust” by Bioversity under the auspices of the FAO, provides the foundation for conservation efforts. The function of the network is to mobilize diverse expertise and different perspectives, define priorities and build consensus around an agreed agenda for joint action. Specialist expertise is provided by the “*MusaNet* expert committee” acting as an advisory group, while much additional expertise is mobilized through the participation of national banana programs and the activities of the regional banana networks. Networking is vital to the implementation of a global strategy of conservation, both as a means for sharing out the multidisciplinary characterization as for reaching consensus on joint actions to expand the coverage of collections or rationalize them. A key element in understanding the diversity held in collections, managing them efficiently and making the diversity available for use by breeders and other clients, is an efficient genetic resources information system.

The collaboration of our partners throughout the product lines is key to realizing Theme 1's impact pathways (see Table 4.1.1).

Table 4.1.1 Roles and Responsibility of Partners in Impact Pathways

Product Lines	Representative Key Partners		Roles and Responsibilities
PL 1. Ex-situ and in-situ conservation methodologies optimized	▪ NARS ▪ Genebanks ▪ ARIs ▪ Universities ▪ Millennium Seed Bank ▪ Collection networks	▪ Global Crop Diversity Trust (GCDT) ▪ Private companies ▪ Farmers' communities ▪ Partners involved in conservation	Genebanks, in close collaboration with NARS, private companies, universities, and ARIs, and with support from GCDT, carry out research towards optimized methodologies for long-term conservation of GR. Partners in ex-situ conservation dynamically link with in-situ conservation actions by farmers' communities.
PL 2. Increased coverage of gene pools in global genebanks	▪ NARS ▪ ARIs ▪ Genebanks ▪ Collection networks ▪ Seed banks	▪ Germplasm users ▪ Farmers ▪ CGIAR-CSI ▪ GCDT	Genebanks, collection networks, and NARS work with CGIAR-CSI to identify priority areas for collection of new GR. Genebanks work closely with GCDT to integrate collections in global conservation strategies. Users' needs considered in prioritization.
PL 3. Collections of RTB phenotyped and genotyped for important traits	▪ Breeders ▪ STB scientists ▪ Professional associations ▪ ARIs	▪ NARS ▪ Genebanks ▪ Collection networks ▪ Farmers ▪ GCDT	NARS and genebank scientists, with support from GCDT, pre-evaluate GR for agronomic traits, biotic/abiotic stress reaction, and postharvest qualities. Molecular marker kits are developed in collaboration with ARIs.
PL 4. Collections of RTB documented and information freely accessible to users	▪ NARS ▪ Genebanks ▪ Collection networks ▪ ARIs ▪ Producers ▪ Private sector	▪ GCDT ▪ GBIF ▪ SINGER ▪ NGOs ▪ Farmers	NARS and genebank information managers work closely with global initiatives such as GCDT, GBIF, and SINGER to provide access to up-to-date information on GR, as such encouraging increased use of the collections.
PL 5. Safe exchange of RTB genetic resources	▪ NARS ▪ ARIs ▪ Genebanks ▪ Quarantine officers ▪ NGOs	▪ Universities ▪ Private sector ▪ Seed multipliers ▪ Farmers' communities ▪ Virus indexing centers	NARS and genebank scientists develop diagnostic tools and eradication protocols in collaboration with ARIs, private sector, virus-indexing centers, and quarantine officers. Closely link with actors in the seed system such as private and public seed multipliers, NGOs, and farmers' communities.

4.1.6 Gender strategy

Existing genetic diversity of the different RTB crops derives to a large extent from cultural beliefs, livelihood needs, and practices of women and men who produce, store, and manage plant material in a wide range of agricultural systems in different parts of the world. Because of the clonal propagation of these crops, much of their conservation and use is closely tied to the domestic sphere where women play a decisive role in storage for food and seed, food preparation, and seed selection and preparation for planting. In particular, women often make the final decision on selecting the best cultivars in terms of value for processing, cooking qualities and taste, and suitability for home consumption or for local marketability. Men and women are involved in the production of the crops and in selecting landraces that better tolerate biotic and abiotic stresses or which have preferred agronomic characteristics such as earliness or short or long dormancy. A gender strategy will be most relevant to PLs 1 and 2.

A gendered understanding of indigenous knowledge and practice will be a key output of on-farm conservation strategies. Prain, Schneider, and Widyastuti (2000) have reported the selection by New Guinea women of introduced sweeter, yellow- and orange-colored sweetpotato as baby food. It is also known that on the eastern slopes of the Andes, short-maturing *chaucha* cultivars of potato

are planted to provide an early food supply for families. This kind of detailed information will contribute to the characterization and documentation of native germplasm and will guide plans for repatriation of this germplasm.

4.1.7 Communication and knowledge sharing

Communication and knowledge sharing will focus primarily on strengthening communities-of-practice to respond to the diverse and evolving needs of present and future germplasm users. Policy makers, donors, and the general public will also be informed about the importance of conserving and documenting genetic resources and the bottlenecks that affect these activities.

We will make protocols and guidelines available to users, who in turn will be encouraged to provide feedback on their applicability. Modifications made to protocols to adapt them to local conditions will subsequently be shared with the RTB community through crop-specific knowledge-sharing platforms. Links will be made to existing platforms, like the Crop Genebank Knowledge Base (CGKB), a portal of best practices for crop genebank management developed collectively by the CGIAR. Using this portal, researchers can discuss topics that affect the conservation, collection, and movement of genetic resources.

Databases will be made available and feedback on their user-friendliness will be encouraged. The involvement of experts in validating the information in databases will be especially important to make RTB products relevant and up-to-date. Users may elect to subscribe through regular email updates to alert them when either new germplasm or information becomes available.

4.1.8 Capacity strengthening

Capacity strengthening in Theme 1 involves a wide range of actors and next-users: RTB curators, conservation biologists, molecular biologists, breeders, and NARS program scientists. Many of these organizations will have a dual role as an intermediary organization that will adapt and extend research results to a wider group of stakeholders. The capacity of genebank curators to conserve, characterize, and document RTB genetic resources to promote their greater use will be strengthened.

Partners' capacity for research will also be strengthened through focused skills-based training on topics such as cryopreservation technologies, laws, and policies for exchange and transfer of germplasm. E-learning modules will be developed to help next- and end-users access and use technologies and protocols, such as slow growth in-vitro protocols. For example, an e-learning module on seed handling already exists and another on germplasm enhancement is under development with the Global Initiative on Plant Breeding Capacity Development-FAO. The material developed through the research of this theme will be made available on the CGKB (<http://cropgenebank.sgrp.cgiar.org/>) for immediate access to users (SGRP 2010). This includes protocols for genebank management and protocols for crop characterization and evaluation.

Capacity strengthening is also achieved through genetic resources networks—for example, *MusaNet* and the Latin America and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA)—that gather specialists to work on specific research related to the conservation, documentation, and use of genetic resources. The Vavilov-Frankel Fellowship encourages the conservation and use of plant genetic resources and innovative research in areas such as gene discovery in crop wild relatives, use of climate and environmental data to add value to genebank accessions, or policy research in support of the implementation of the International Treaty. It and similar competitive grant schemes can be implemented to strengthen capacity and deliver Theme 1 outputs.

4.1.9 Links with other themes and CRPs

Theme 1 activities are complementary to those carried out in the framework of the program dealing with the conservation and management of collections in the genebanks. While this program will include activities related to introduction, conservation, characterization (morphological and molecular), and evaluation of germplasm, Theme 1 will focus on the improvement of conservation methodologies and the development of tools helping to define gaps in collections and increasing coverage of gene pools. Theme 1 will also analyze the genetic diversity structure of collections and evaluate them for traits of interest. It will finally enhance access to germplasm and related information through the improvement of databases and the implementation of pathogen eradication methods that guarantee safe exchange of RTB genetic resources.

Theme 1 aims to provide access to RTB genetic resources, which are the foundation of most of the themes developed in this CRP. It conserves the germplasm, explores new regions, and collects germplasm of interest. It provides general information on cultivars and species, and it ensures the safe distribution of germplasm. Links with the focus of other themes are shown in Figure 4.1.2.

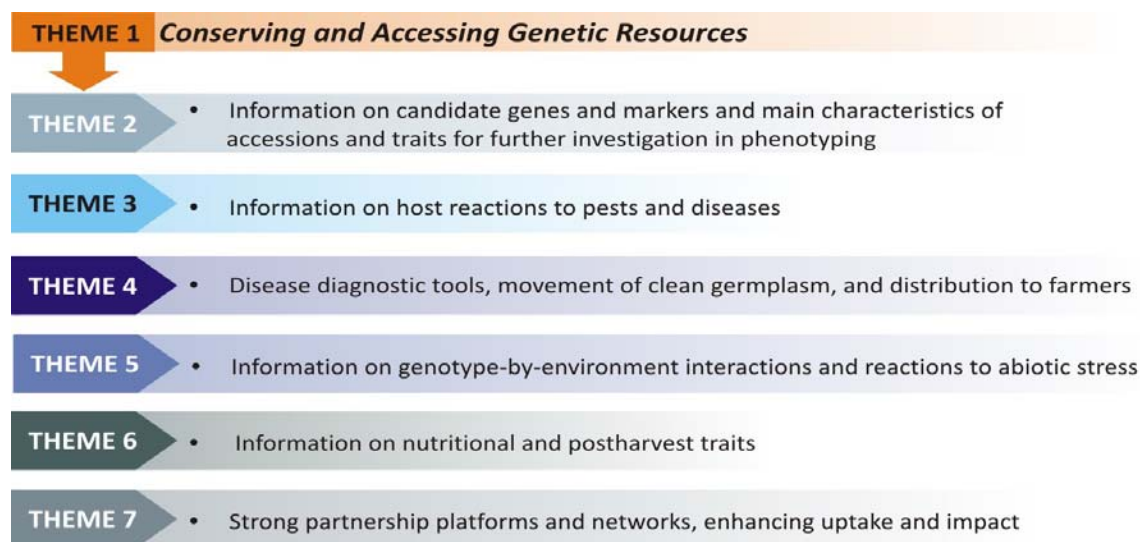


Figure 4.1.2 Theme 1: Links with key features of other CRP-RTB themes.

Theme 1 links up with other CRPs as follows:

- CRPs 1.1–1.2: Interaction of genetic resources with agro-ecosystems
- CRP 2: Policy issues on exchange of germplasm mainly, but also marketing new RTB diversity
- Other CRP 3s: Exchange of knowledge on conservation, characterization, evaluation, and global information management about and access to genetic resources
- CRP 4: Provision of information about diversity of nutritional traits to facilitate access by CRP 4 to more diverse and nutritionally dense germplasm. CRP 4 to contribute to improved targeting of distribution of accessions for improved access by farmers
- CRP 7: Climate change effects on genetic resources adaptability, distribution, and risk of extension.

The CRP-RTB Centers will undertake advocacy activities to promote the value of germplasm exchange and long-term investment in conservation to policy-makers and donors (linked to CRP 2 and other CRP 3s).

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4.2 Theme 2: Accelerating the Development and Selection of Varieties with Higher, More Stable Yield and Added Value

4.2.1 Rationale and objectives

The goal of Theme 2 is to exploit the genetic resources of RTB to improve productivity, enhance stability of production with particular consideration of the impact of climate change, and increase nutritional and commercial value. More productive and resilient RTB varieties are targeted at emerging markets for fresh and processed products, simultaneously addressing farmers and household needs. This will help guarantee food availability and increase income generation of households that grow and handle RTB. Women, who often have critical roles in RTB production and processing, will particularly benefit.

New RTB varieties are often cumbersome to develop. As many are polyploid and all yield best as highly heterozygous hybrids, their complex genetics and sensitivity to inbreeding complicates simple trait amendment. Moreover, strong type preferences require intensive quality breeding and limit new variety adoption. Owing to their vegetatively propagated nature, RTB exhibit relatively low multiplication rates and are subject to high disease load in their bulky and perishable propagating material. Therefore, variety delivery and farmers' uptake are challenges, especially where infrastructure is poor. Vegetative propagation, however, is an advantage for variety development and use, including rapid selection schemes. Successful hybrids from a crossing program are genetically fixed by clonal propagation; and while disease load may result in yield decline, genetic integrity from breeder to farmer is easily maintained through different multiplication alternatives.

Breeding objectives in RTB are multiple but essentially seek to contribute to sustainable productivity gains and enhanced nutritional and market value (Table 4.2.1). The recent intensification and expansion of cultivated areas for cassava, potato, sweetpotato, banana, and yams, together with the spread of introduced and endemic pests or pathogens in Africa and Asia in the absence of appropriate resistant varieties, have increased crop losses. This development requires consistent efforts on resistance breeding to help reduce chemical use, provide yield stability, and increase the profitability of farming. Climate change will affect the dynamics of pests and diseases and the character of RTB environments, increasing the need for varieties that tolerate heat, drought, and water-logging. RTB will be differentially affected by these constraints, and modeling is needed to predict the impact of climate change and anticipate its challenges and opportunities (Ceballos et al. 2010, Ramirez et al. 2010) (see Theme 5). Existing models predict that drought and heat tolerance will become more important to potato. Tolerance to low P and acid soils will be needed to maintain productivity of sweetpotato and cassava (Hijmans 2003).

Table 4.2.1 Priority Breeding Objectives in RTB Crops

Objective	Bananas	Cassava	Potato	Sweetpotato	Yam	Others
Resistance to diseases	Fusarium wilt; Sigatoka leaf spots (<i>Mycosphaerella</i> spp.); banana bunchy top virus; banana streak viruses, <i>Xanthomonas</i> wilt; <i>Ralstonia</i> strains	Cassava mosaic disease; cassava brown streak disease; Frog Skin Disease; Bacterial blight (<i>Xanthomonas</i> sp.); African root and tuber scale	Late blight; potato virus, and potato leaf roll virus; bacterial wilt	SPVD complex, particularly sweetpotato chlorotic stunt virus; <i>Alternaria</i> storage root; leaf spot and stem blight (<i>Alternaria</i> spp.) (tropical highlands)	Anthraxnose; yam mosaic viruses (e.g., yam mosaic Potyvirus, Yam badnavirus); tuber rots	For Ahipa: <i>Meloidogyne</i> spp.) For Cocoyams: Corm rot (<i>Pythium</i> sp.), Leaf blight (<i>Phytophthora</i> sp.); Dasheen mosaic virus

Objective	Bananas	Cassava	Potato	Sweetpotato	Yam	Others
Resistance to pests	Nematodes (<i>Radopholus similis</i> and <i>Pratylenchus</i> spp.); banana weevil and banana aphid	Whiteflies, particularly <i>Bemisia tabaci</i> ; mealybug (<i>Phenacoccus manihoti</i>); different mite species	Potato tuber moth	Sweetpotato weevils (<i>Cylas</i> spp. and <i>Euscepes postfasciatus</i>) for regions with a pronounced dry season; nematodes (in temperate regions)	Nematodes (<i>Scutellonema bradys</i> and <i>Meloidogyne</i> sp.)	
Tolerance to abiotic stresses	Drought, dwarf plant architecture for tolerance to wind, early rationing, and fast cycling	Drought, low temperature, excessive rains (soil erosion)	Drought, heat, salt	Salt, drought, heat	Drought, heat	Drought
Quality of harvested organs	Extended shelf life (delayed ripening); thicker peel; palatability; enhanced pro-vitamin A carotenoids; cooking ability (starch and fiber quality), new flavor-color combinations for new markets	High and stable yield of leaves and root dry matter; starch quality; cooking quality; low cyanogenic potential; enhanced carotenoids content and proteins increased shelf life	High bio-available Fe, Zn, vitamin C, high dry matter, low reducing sugars; appearance and shape for market and processing flavor	Starch and other desired quality attributes (i.e., bio-ethanol exploitability); enhanced nutritional quality (carotenoids)	Thermally stable starch; enhanced nutritional quality (profile of amino-acid contents), vitamin C and carotenoid content); color; flavor; tuber shape for market and ease of harvest long dormancy	Cooking quality, flavor

Several features distinguish RTB from other major staples and weigh into breeding approaches and objectives. Their direct use in human consumption implies many preference and quality traits that differ among cultures and communities. The underground nature of roots and tubers enables very high harvest indices and consequent high yields, whereas the perennial nature of banana/plantain enables greater carry-over of reserves from one generation to the next. Their vegetative propagation brings unique constraints and opportunities, as do the multiple uses of leaves and root/corms of cassava, sweetpotato, and cocoyams in Africa. Their heterozygous nature makes population improvement and application of marker technologies more complicated. Finally, polyploidy brings opportunities and challenges for breeding many RTB crops. However, the genetic constitution and structure of RTB lead to great potential for the exploitation of heterosis to enhance productivity. Successes registered in the past for traditional breeding (in relatively isolated RTB programs) and the advent of new technologies to assist in breeding indicate that new collaborative efforts across CGIAR Centers, NARS, and ARIs will yield greater successes.

Population improvement is among the major contributions of the CGIAR institutions with crop mandates for agricultural R4D. In the process of variety development, genotypes are fixed and do not change genetically from the first to the final selection steps. But tropical conditions and poor infrastructure in developing countries make RTB management a challenge. Meanwhile, commercial

breeding, seed trade, and marketing sectors for RTB are much less developed, leaving impact from this crop group much more dependent on public efforts compared to cereals.

Genetic improvement and the development and diffusion of varieties in the RTB crop group face similar problems and entail many of the same techniques, so that working across CGIAR Centers will lead to synergies and economies of scale. A few categories of traits for crop improvement to benefit the poor are common across RTB and influence priorities, schemes, and methods in global breeding efforts. The clonal nature of RTB “seed” (planting stock) or perennial plants, which build up pathogens, compel resistance breeding and influence selection schemes. Efficient accumulation of carbohydrates (particularly under stress) and improved shelf life are needed to enhance productivity and reduce postharvest losses of market and nutritional quality of RTB. These crops can reduce malnutrition in food-based approaches because of the potential to increase micronutrient contents. Processes of micronutrient acquisition and redistribution to storage organs may be similar and similar approaches to biofortification might be successful.

Considering both the unique comparative advantages of each crop species, and shared opportunities for research, Theme 2 research will convene expertise from the CGIAR and key NARS and ARIs to build long-term, multidisciplinary efforts to develop improved RTB germplasm and advance the frontiers of clonal crop breeding. A major departure from the past is that in addition to collaboration in different disciplines, there will be intense interaction among people working in different crops.

4.2.2 Impact pathway

Theme 2 is central to securing impact in the CRP-RTB. It builds RTB populations with improved productivity, biotic and abiotic stress tolerance, and nutritional and end-use quality. This contributes to improving food security, health, and income generation while reducing environmental and economic risks encountered by smallholders in developing countries.

New breeding approaches enable the full exploitation of the genetic potential of RTB. Target evaluation of genetic resources and their use in pre-breeding will include new sources of needed traits for crop improvement programs. Novel gene constructs facilitate the efficient combination of attributes from within and beyond crop gene pools. Trait capture will improve breeders’ ability to select and improve on RTB for complex traits, including drought and heat tolerance. Real-time analysis of performance data and integration of analytical tools will support the targeting of populations to RTB cropping systems. Participatory evaluation and communication with multiple end-users of new varieties will ensure that preferences of farmers, consumers, and processors are maintained and enhanced in breeding populations. New screening methods and selection schemes will accelerate the rate at which new varieties become available.

Knowledge products combined with capacity strengthening and pilot testing will speed the screening, release, and multiplication of new varieties. Accelerated and participatory selection, effective promotion, links with seed programs (Theme 4), and farmer-to-farmer dissemination will increase dissemination. Adoption of improved varieties leads to yield increases, added-value, loss reduction, yield stability, and lower costs of inputs, particularly pesticide sprays and expensive seed. This contributes to increased RTB revenues and increased farmer income. Greater food security from RTB should lead to reduced hunger and better family nutrition.

Figure 4.2.1 shows the impact pathways envisaged for Theme 2.

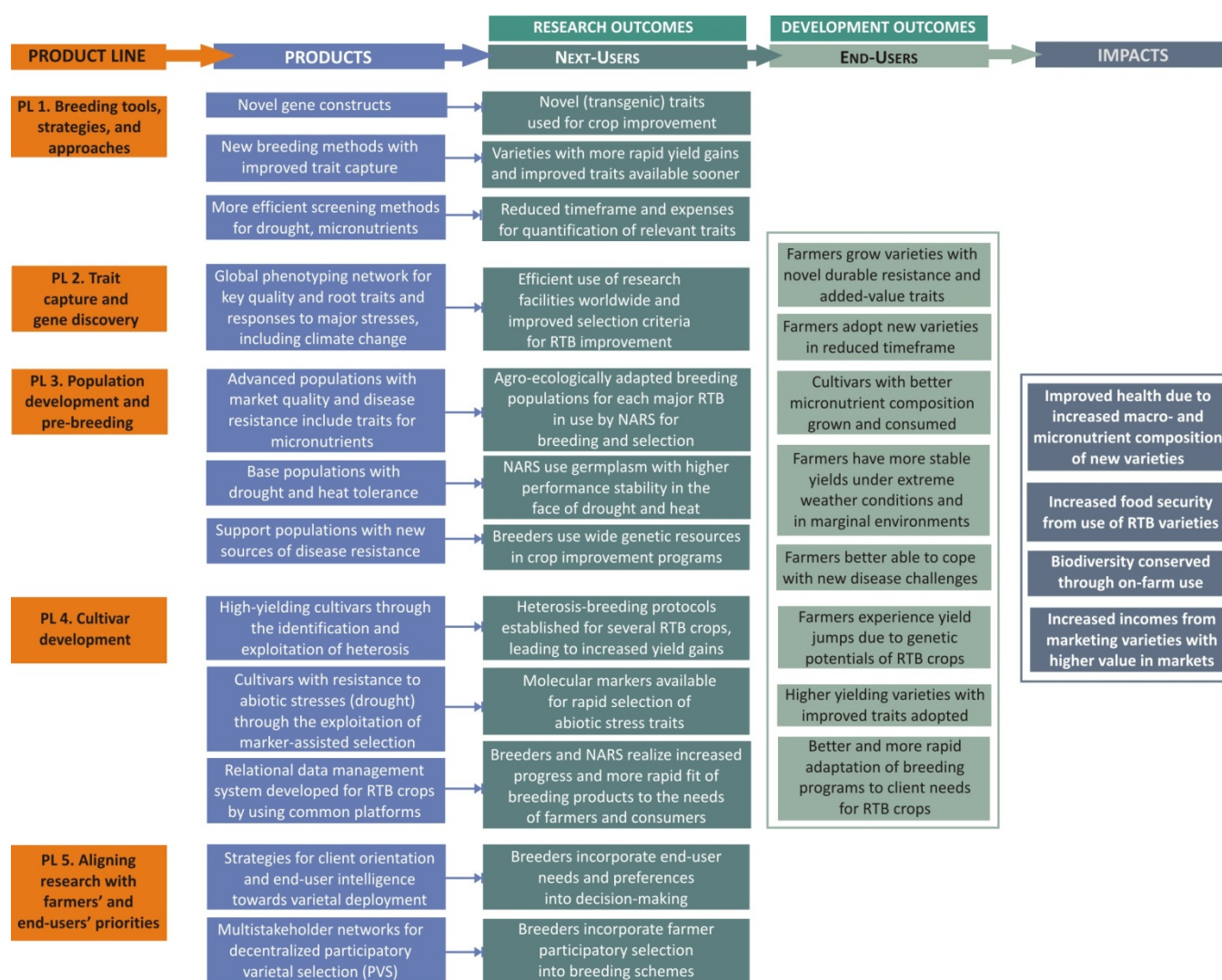


Figure 4.2.1 Theme 2 product lines, products, outcomes, and impacts.

4.2.3 Product lines

There are five product lines associated with Theme 2. Annex 2 contains the product line description tables (research products, outcomes, milestones, and key partners) for Theme 2.

PL 1: Breeding tools, strategies, and approaches

Screening tools for nutritional quality

Enhancing the nutritional quality of RTB contributes to improving food security (Meenakshi et al. 2007). Enhanced nutritional quality and better cooking quality of RTB are highly relevant factors, particularly for women both in rural and urban areas. In Theme 2 we will identify the genetic factors controlling the synthesis and accumulation of Fe, Zn, vitamin C, and/or carotenoids in RTB crops, and effective strategies to deploy biofortified varieties. Approaches will follow from the recent discovery of banana varieties rich in pro-vitamin A (Davey et al. 2009), potatoes rich in Fe (Burgos et al. 2007), and the successful development of OFSP and high-carotene cassava. Considerable collaboration has already taken place in the work to develop varieties with high pro-vitamin A carotenoids. Common efforts will continue in this CRP to improve screening techniques using near infrared reflectance spectroscopy (NIRS) (see Box 4.2.1). NIRS will also be used to help

reduce anti-nutritional factors (e.g., glycoalkaloids in potato, cyanogenic glucosides in cassava) and to evaluate and improve starch and protein quantity and quality for diverse end-uses.

Box 4.2.1: The NIRS Quality Network

NIRS provides simultaneous analysis of several macronutrients, micronutrients, and other important traits (e.g., dry matter content, individual carotenoids, protein, amino acids, individual sugars, individual polyphenolics, glycoalkaloids, anthocyanins, starch, carbohydrate quality) online. NIRS increases from 8- to at least 30-fold the number of samples analyzed per day for several traits simultaneously at reduced cost. A worldwide established NIRS networks will help in rapid and highly efficient quality breeding and adoption of biofortified varieties in all relevant crops. The NIRS Quality Network will share expertise, capital investment, and capacity-building methods and events. Helping in faster and more efficient quality breeding of biofortified varieties is particularly relevant for improving the health of women of reproductive age and for infants and children (<http://www.cipotato.org/qnlab>).

Improved flowering of parental lines

Except in potato, RTB frequently encounter limitations for rapid and efficient production of botanical seed that are likely related to their long-term vegetative propagation. Sexual crosses of cassava, bananas, yam, and cocoyam are inefficient, with large variation in the number of seeds obtained and lengthy periods to produce seed from desirable crosses. The CRP-RTB will address the issue of flowering in these crops and develop systems for the induction of flowering and improvement of seed set through exogenous application of phytohormones (Pinto da Cunha 2005, Trivellini et al. 2007, Wilson 1990). In addition, in the case of banana and, to some extent, cassava, seed production is location specific. Most-suitable breeding locations and management methods will be identified. This research will greatly accelerate the production of recombinant seed and considerably reduce the cost of population improvement and genetic research for breeding. New knowledge of the impact of genes that control flowering in model and seed crop plants may help develop alternative methods for promoting earlier flowering in RTB crops. These flowering and photoperiod genes may also play a role in shortening vegetative cycles (earliness) and promoting wider adaptation.

Heterosis breeding

Another promising way to increase breeding efficiency in RTB is by taking advantage of heterosis. Although the phenomenon of heterosis is still not well understood, the effect of hybrid vigor for yield and adaptive traits is well proven in many crops, but under-investigated in clonal ones. CIP, IITA, and CIAT will set a new research emphasis on heterosis breeding of RTB. Exploitation of heterosis in RTB requires an inter-population approach based on the identification and/or development of heterotic patterns. Two (or more) populations are gradually bred to better complement each other and maximize hybrid vigor of their cross products.

Inbreeding for RTB improvement

Most RTB breeding is based on the use of non-inbred progenitors (or only partially inbred due to recombination of more closely related clones). The use of more inbred progenitors might offer advantages such as more efficient exploitation of heterosis; the possibility of implementing backcross schemes; and a very effective way to reduce genetic load (undesirable alleles) and identify useful recessive traits (see Box 4.2.2). However, production of inbred germplasm in RTB is difficult. Therefore, different approaches ranging from the more conventional use of anther, ovule, or microspore culture or wide crosses and the new “centromere alternative” (Ravi and Chan 2010) will be investigated for RTB. An *S* locus inhibitor gene (denoted *Sl*) identified in diploid wild potato species (Phumichai et al. 2005) may be useful for generating highly homozygous lines for a hybrid breeding scheme at this ploidy level, enabling subsequent incorporation of new diversity into tetraploid breeding populations. In banana, homozygous lines based on double-haploid plants have

been recently developed, but their application is yet to be scaled up (Bakry, Assani, and Kerbellec 2008). This diversity of approaches illustrates the relevance of inbreeding for RTB.

Box 4.2.2: Inbreeding and heterosis in RTB

Inbreeding can facilitate germplasm enhancement in several ways. Once an outstanding hybrid is identified, inbreeding of its parents could enable further improvement of specific combining ability to produce a better hybrid. Inbreeding therefore allows a step-wise, systematic improvement of heterosis as has been done in maize for almost a century. High-value traits such as disease and pest resistances, special quality traits, or tolerances to abiotic stresses can be introgressed into inbred germplasm through the backcross scheme, which allows predictable recovery of the original inbred. Inbred progenitors allow designing good hybrids, rather than finding them just by chance. Inbreeding also allows the elimination of undesirable alleles, the identification of useful recessive traits, and the recovery of hybrids by botanical seed. Heterosis can be exploited without inbreeding through reciprocal recurrent selection (see above) and inbred progenitors can then be extracted from each population (Duvick 2009).

Accelerating selection

Research will develop and quantify the efficiency of quick-breeding strategies. There is an urgent need to develop more rapid-breeding schemes for RTB. It takes on average 12 years from a cross until variety release. Needed traits may arrive too late and donors are reluctant to invest in breeding when concrete outputs take so long. Research across Centers for RTB will take multiple approaches to shorten the time from cross to variety release. Accelerated selection schemes and marker-assisted selection will be applied in both CGIAR population improvement and NARS variety selection schemes. The successes in the accelerated breeding schemes can be enhanced by complementary use of rapid propagation techniques to increase the number of plants at early stages, participatory selection at local and regional levels, and effective manipulation of tuber dormancy in the case of yams. Rapid cycling recurrent selection can be implemented for high-heritability traits (i.e., high carotenoids) where selection and recombination can be done at the seedling stage.

Biotechnology tools

There are many potential synergies in the area of biotechnology. Molecular markers and genetic engineering techniques cross the bounds of different species as already proven for many cases. The future breeding activities of RTB will make efficient, targeted use of these technologies to further improve the genetic contributions to improve productivity, protection, and utilization traits of RTB. The possibility of sharing some resistance genes and cassettes across RTB will also be considered. Molecular genetics, genomics, and bioinformatics underpin molecular marker-assisted breeding and will speed up gene discovery and trait improvement in the complex RTB crops. Genome sequences are already available for potato and cassava, and their availability for banana is scheduled this year. Bioinformatics, mutants, conventional genetic stocks, and comparative genomics will be applied in crop-specific and systematic functional analysis to better understand physiology, development, and host-pathogen interactions.

Marker-assisted selection

Much effort has been placed in trying to improve RTB for target traits using marker-assisted selection following linkage mapping and quantitative trait loci (QTL) identification. However, given the heterozygous nature of the crops, the high degree of epistasis seen in complex traits, and the difficulty in transferring marker utility across genetic backgrounds, little progress has been made compared with conventional selection. For some traits, such as disease resistance, fine mapping or positional cloning of significant regions is required to enhance utility of this approach. For more complex traits, alternative strategies described below offer greater ROI.

Association mapping

Incorporating new traits by traditional breeding methods is difficult, time consuming, and with a low chance of success. New genetic knowledge, alternate breeding strategies, and improved genomic tools may help bypass many of the inherent problems of conventional breeding approaches. Improvements to breeding programs can be implemented through incorporation of genomics data into selection methods. Association mapping (linkage disequilibrium) is an approach that searches for functional variation in a broad germplasm context, enabling the use of modern genomic technologies to exploit natural diversity. Association mapping has been successfully applied to map genes in several plant species, including potato (Gebhardt et al. 2004, Simko, Haynes, and Jones 2006). However, low heritability, small population sizes, confounding population structure, and arbitrary significance thresholds found in current association mapping efforts in different RTB resulted in identification of only a few markers with overestimated effect. Collaborative research is needed to overcome some of these problems. For example, the estimation of linkage disequilibrium and marker-based relative pair-wise kinship coefficients in outbreeding polyploids are proposed as cross-cutting research of relevance across RTB.

Genomic selection

Genomic selection is a new approach for improving quantitative traits in large plant-breeding populations that uses whole genome molecular markers (high-density markers and high throughput genotyping). Genomic prediction combines marker data with phenotypic and pedigree data or kinship in an attempt to increase the accuracy of the prediction of breeding and genotypic values. This strategy will be implemented for the calculation of genomic-estimated breeding value for complex traits. Molecular genetic markers covering a large portion of the genome, along with candidate genes linked to regions contributing to these complex traits, need to be recorded in wide genetic base breeding populations for applying genomic selection. Best linear unbiased prediction or any other suitable statistical approach can be used for calculation of genomic-estimated breeding value in a similar manner as traditional breeding values, reducing the requirement of phenotyping subsequent generations and thus shortening cycles of selection in a breeding program.

Genetic modification

Genetic modification (GM) approaches are particularly important for RTB as they represent virtually the only means of adding or silencing a specific gene(s) to improve the phenotype of an accepted variety whose constitution could not be recovered by conventional breeding due to its inherent heterozygosity. Genetic transformation is also important for the introduction of traits not present in RTB gene pools.

Most RTB have been successfully transformed with genes for pest and disease resistance, herbicide and drought-tolerance-related traits, enhanced nutritional and commercial value, and/or postharvest traits. As it has been proven with other crops, these technologies offer clear advantages for overcoming the problems they address. There are many problems in RTB that have not been overcome through conventional technologies; GM will allow for breakthroughs. The case of potato LB is a good example of where GM can have a major impact in overcoming the fungicide dependency. Another example is genetically modified banana resistant to banana *Xanthomonas* wilt, a new-encounter disease for which suitable host-plant resistance is not available. It has become the most devastating disease of banana in the Great Lakes region of Africa (Tripathi et al. 2009). GM also offers great potential for nematode resistance in banana and yams and resistance to the sweetpotato weevil.

The relative low interest of the large GM companies in RTB allows the public sector to access key proprietary technologies associated with GM approaches for global RTB uses. Yet GM varieties of

RTB remain to be commercialized by the public sector in and for developing countries through partnership with the CGIAR Centers and NARS. Major efforts will be directed towards establishing adequate biosafety regulations, contributing with NARS in the development of suitable regulations, developing a better understanding and handling of intellectual property rights, and expanding the current ongoing work to analyze pollen/gene flow in clonal crops in the tropics, which has an entirely different dynamics than for grain crops in temperate regions.

Mutation induction enhanced breeding

The application of induced mutations, coupled with somaclonal variation and new tools of functional genomics, offers means to improve traits that may otherwise be difficult to improve in RTB crops. Mutation induction shows promising aspects in RTB due to its ability to change only very few characters of an otherwise good variety without altering the remaining, and often unique genotype (Broertjes and van Harten 1988). Recent advances in plant genomics, especially large-scale genomics sequencing, have opened new possibilities for application of mutation techniques in crop improvement (Maluszynski et al. 2009). Using the reverse genetic strategy called TILLING (Targeting Induced Local Lesions In Genomes) and high-resolution DNA melting, it is possible to identify mutated alleles in a target locus even in heterozygous state. This is a major advance because scientists can identify carriers of the desired mutation without the need for its expression, which is particularly relevant for polyploid species. TILLING relies on precise knowledge of the sequence of the target locus (McCallum et al. 2000) since homologous sequences have proven to be inadequate. The sequencing of genomes from different RTB will significantly enhance the power of this technology. A research program, coordinated by the FAO and the International Atomic Energy Agency, already works with cassava and banana and will become important partners in this activity.

Unraveling host-pathogen interaction

Innovation on molecular tools provided new information on pathogen diversity and evolution, pathogenicity, and resistance genes. These new approaches provide a rationale for global strategies for the development and deployment of (more) durable resistance at crop, farm, and systems scales. In particular, new science approaches (the 'omics) offer the insight needed for research to be able to solve recalcitrant challenges. Bacterial diseases of RTB provide such a challenge as good host-plant resistance has not been identified in cultivated or wild crop relatives. *Xanthomonas* spp. cause devastating yield losses of cassava and banana. Similarly, species of *Ralstonia* cause bacterial wilt of potato and banana. Genome sequences reveal similar disease strategies across the pathogens, suggesting a common approach to discovering resistance genes in the RTB crops they affect. The Institut de Recherche pour le Développement (IRD), CIRAD, the National Institute for Agricultural Research (INRA), CIAT, IITA, CIP, and NARS of Africa and LAC will collaborate on *Xanthomonas* and *Ralstonia* pathogenesis and host-plant resistance to identify and use mechanisms, including type III effector proteins and plant resistance genes in RTB breeding.

PL 2: Trait capture and gene discovery

An urgent and ultimate practical aim of RTB plant breeding is to better target genetic diversity toward likely climate change scenarios. Phenotypes at the crop level are extremely complex, particularly for adaptive traits, and regulated by multiple interactive genes whose effects and expression may be highly dependent on environmental conditions and developmental stages. Information on attributes and traits that contribute to complex processes, knowledge of genetic variability, parameters and trait correlations, and efficient methods for selecting on available diversity are needed for successful improvement of any crop. Much of the work discussed below will find synergy in research described for Themes 3 and 5 that provide tools for evaluating biotic resistance and abiotic tolerance traits.

Plant architecture

Plant architecture and harvest index determine yield. Harvest index is associated with yield stability and is a favored trait in early stages of selection (Grüneberg et al. 2005). It has a considerably higher heritability than yield, and indirect selection for high harvest index might provide an elegant and efficient approach to breed for yield stability (Kawano 2003). The stability of plant architecture might reflect on tolerance to abiotic or biotic stresses. One of the problems that root and tuber scientists have faced in the past is the limited knowledge about events occurring underground. Research in the CRP aims to develop nondestructive techniques to study complex dynamics of partitioning, as well as monitoring corm, root, or tuber growth through the season. Research on magnetic resonance imaging (MRI), through a partnership between CIP and Embrapa (Empresa Brasileira de Pesquisa Agropecuária), is an example of a non-invasive and nondestructive approach to study potato tuber onset that may be informative for studying other underground storage organs of the RTB. Collaborative research with Theme 5 will take advantage of the possibility to monitor partitioning to the sink to help breeders adjust crop cycles and enhance the productivity of RTB crops and cropping systems. A nondestructive technique is also important for RTB breeders to identify early bulking genotypes, which so far has remained an elusive trait.

Drought and heat

Tolerance to drought and heat has been a key trait for many RTB in spite of the recognized tolerance of some of these crops to these stresses. Cassava in particular can survive extended periods of drought that would cause cereal crop failure, and then take advantage of subsequent favorable growth conditions to produce acceptable yield. However, it is important to enhance productivity under stress conditions. Water is the main limiting factor for much banana/plantain production, reducing yield by about 50% on East African highland bananas. Similar situations can be observed for other RTB and regions of the world. Key issues will be defined in relation to drought/heat tolerance:

- Type of stress (i.e., timing or intensity, relative importance of water and temperature)
- Clear understanding of the type of tolerance sought
- Development of reliable rapid, accessible, and robust phenotyping tools (such as the spectral reflectance and isotope discrimination approaches described in Theme 5)
- Screening of diverse germplasm taking into consideration information defined above
- Once influential component traits are identified, genetic parameters and the genes underlying them can be determined in breeding populations.

Trait capture strategies

There is a vast amount of information that will be shared among RTB as research evolves, allowing synergies among the different crops and regions. As genes underlying tolerance to drought/heat are implicated in one RTB crop, information can be transferred to related species, owing to the evolutionary conserved gene order that may be retained in chromosome blocks or even in chromosomes to inform gene discovery in other crops.

A particularly fruitful approach to the description of useful genetic variation for complex traits is the use of transcriptomics and other tools that report on gene response to challenges. These technologies are capable of identifying genes that differ in expression when genotypes are exposed to contrasting growing conditions.

Related to Theme 1 dealing with conserving and accessing genetic resources and taking advantage of the large genetic diversity available to the CRP-RTB, systematic screening of germplasm will be conducted in search of novel traits. An implicit fact is that novel traits can be identified only after

new screening methods are implemented. There is therefore an opportunity to jointly learn about innovative phenotyping approaches for the identification of new traits (in addition to those molecular strategies already described in PL 1). An example is the systematic evaluation of self-pollinated progenies in cassava that has led to the identification of natural tolerance to herbicides such as ammonium glufosinate (Basta; Finale) and atrazine. Herbicide tolerance is a key trait that has had many beneficial outcomes for other crops. It allows for minimum tillage practices, which in turn favors reduced soil erosion, improved water use efficiency (WUE), conservation of soil fertility, and reduction of production costs. It also offers a particular advantage for women who are typically responsible for weeding RTB in many regions of the world. The relevance of this experience is that identification of such a trait requires not only the expression of a (putatively) recessive trait, but also specific criterion on timing and dosages of herbicides to be applied. Another trait of interest for many RTB is apomixis, which allows for the exact reproduction of the mother genotype through botanical seed (Savidan 2000). As desirable as apomixis is, little progress has been made so far to identify and exploit it in RTB. As for many other traits, the main reason is the inadequacy of proper phenotypic techniques, and progress in improving them will be enhanced through the collaboration within the CRP.

Pre-breeding affords special opportunities to identify useful germplasm and traits that may be masked in collections of the heterozygous RTB. For example, in the case of cassava after several years of screening accessions from the germplasm collection, pre-breeding has led to the identification of starch quality traits and extended shelf life (Ceballos et al. 2007, Ceballos et al. 2008; Sánchez et al. 2009). Different starches have also been identified in banana (Eggleston, Swennen, and Akoni 1992) but need much more in-depth studies. Phenotyping close wild relatives and landraces of different crops will be a key activity in this CRP. Partners will share experiences, equipment, and evaluation facilities, including phenotyping platforms (see Box 4.2.3). The sharing of testing sites (e.g., for drought tolerance) will make this process much more efficient. In banana and potato, several candidate genes for drought tolerance have been identified, which could be considered candidates for similar role in other RTB.

Box 4.2.3: Phenotyping—a crucial and challenging issue

A crop's phenotype results from the expression of its genes, the influence of environmental factors, and the interaction between the two. Phenotyping is a complex process, which happens at different levels and involves close collaboration between actors from different disciplines. Accurately measuring traits of interest is widely recognized as a major bottleneck for breeding and selection. A substantial portion of the increased efficiency of modern breeding is due to progress made in rapid, accurate, large-scale phenotyping. Good phenotyping is consequently essential for reducing the genotype-phenotype gap, especially for quantitative traits (e.g., drought tolerance).

Phenotyping of RTB will be done across the different CRP-RTB themes. For example, curators describe the accessions in their collection to promote their use (Theme 1), plant pathologists look for the host reaction of RTB crops to different strains of major pathogens (Theme 3), crop physiologists and agro-ecologists are interested in unraveling the crop's response to the environment (Theme 5), nutritionists and biochemists look at the physical, chemical and nutritional properties of the harvested organs (Theme 6), farmers evaluate how certain varieties fit in their production systems under the local conditions (Theme 5), taking into account market factors as well (Theme 6), and consumers are concerned about taste and potential for processing (Theme 6). To respond to the end-users' needs for new varieties in target environments, breeders (Theme 2) will need to closely interact with all those actors in the development of protocols and tools, the standardization of methods, the selection of parent material, the design and set-up of replicated multilocation trials, the characterization of environmental conditions, and the analysis and interpretation of results. Such interaction will help them to continuously adjust their breeding strategy to respond to the new insights gained.

Within the CRP-RTB, this broad collaboration will be organized in a “virtual phenotyping platform.” Phenotyping platforms and trait capture approaches can enable the dissection of complex objectives, like more crop per drop, into measureable components that facilitate selection and breeding.

Notwithstanding that good phenotyping is a critical issue for any kind of trait, investigating the effects of drought is particularly challenging. A sound interpretation of the results of a drought-stress experiment requires a good characterization of the soil-plant-atmosphere continuum, which in turn relies on accurate (1) monitoring of the soil and plant water status and (2) measurement of drought tolerance-related traits. The collaboration within this CRP and between the CRP-RTB and its partners will be intensified to face this challenge around three components:

- Characterization and comparison of target and testing environments, using GIS tools (through a close collaboration between CIAT and CIP)
- Development and sharing of approaches, methods, and protocols for drought tolerance evaluation
- Development of access to new technologies (digital image analysis, NIRS and spectral reflectance, MRI, stable isotopes, and modeling and simulation of virtual phenotypes).

Gene Discovery

A genotyping platform or shared use of service providers may be envisaged as a base for the search for association of genetic and trait variation within germplasm and breeding populations. Similar to the reverse genetic technologies described above for mutation induction, a method called *ecoTILLING* has been used to identify natural alterations in specific gene sequences (e.g., Till et al. 2010). Collaboration with Theme 1 (conserving and accessing genetic resources) will highlight natural genetic variation between RTB types, which will help significantly speed up current breeding programs as genome sequence, gene index information, and candidate genes for key traits become available. Advances and approaches to the application of molecular tools for the screening of potentially useful RTB populations will be readily shared within this CRP.

There is a need and an opportunity for collaboration in basic research for the identification of root- and tuber-specific genetic sequences that act as promoters in the expression of genes in these organs. This activity will allow for a better understanding of genetics and gene expression in tissues (roots or tubers) not well studied. Identifying efficient promoters has a direct linkage with activities described above for genetic modification and will allow the development of varieties with enhanced expression of desirable traits in roots and tubers such as enhanced nutritional quality or extended shelf life.

PL 3: Population development and pre-breeding

Broadening the genetic base and trait introgression

Breeding of vegetatively propagated crops may lead to a narrow genetic base of breeding populations and/or released varieties, and consequently, vulnerability to new pathogen variants and limited prospects for genetic gain.

In addition to access to genetic variability and knowledge about useful traits that can be extracted, there is a need for efficient means to introgress these traits into breeding populations. But this is frequently hampered by a diversity of problems that are common to many RTB. Genotypes in the RTB gene pools vary from diploid to hexaploids. Reproductive barriers challenge the use of crop gene pools (differences in ploidy, pollen viability, stylar and endosperm barriers, gametophytic self-incompatibility). Ploidy manipulation and natural formation of $2n$ gametes (or gametes with the sporophytic chromosome number) have been effective in overcoming genomic imbalances in hybrids between species with different chromosome numbers.

Pre-breeding strategies

Efficient pre-breeding strategies, however, require the development of special stocks and support populations that have merit for trait incorporation into breeding programs, and help minimize

negative consequences of trait transfer from within the species, from different species, from different genera, and from outside the immediate gene pool. Research conducted by this CRP will implement innovative and proven approaches to transferring new traits from non-adapted sources into well-adapted backgrounds through cross-breeding.

Several approaches are possible for the efficient introgression of new genetic variability into breeding populations. The long reproductive cycle and lengthy time required to introgress useful genetic variation into breeding populations often discourages the use of wild species in most conventional cassava breeding programs. However, the use of molecular markers to monitor introgression of a single target region of the genome can save between two to four backcross generations (Frisch, Bohn, and Melchinger 1999). Indeed, it has been shown in several crops that the “tremendous genetic potential” locked up in wild relatives can be released more efficiently through the aid of new tools of molecular genetic maps and the advanced back cross-QTL mapping scheme (Tanksley et al. 1996). This approach has been implemented in RTB (Blair et al. 2007). The scheme entails generating BC₁ crosses and carrying out QTL mapping followed by selection of genotypes carrying the genome region of interest with minimum segments of the donor genome. More important, it has been adapted to the heterozygous nature of all the segregating materials involved in the process.

Pre-breeding populations

New base populations must be developed to cope with diverse agro-ecological constraints and climate change. Effective breeding schemes such as the evolutionary approach proposed for bananas (Ortiz 1997), or inter-population hybridization for potato and sweetpotato, will maximize heterozygosity in order to produce high-yielding hybrids. However, heterosis is not expressed in backgrounds of susceptibility to prevailing plant diseases, such as black sigatoka in bananas and virus diseases in potato or cassava. Marker-assisted selection will play an important role in preserving or incorporating durable resistance into breeding populations in a more systematic way (i.e., pyramiding resistance genes).

Enhancement of diploid germplasm prior to its incorporation into a polyploid breeding scheme must be considered in RTB crops such as potato and bananas since they are sources of different useful traits. A scheme for hybrid breeding in potato using highly homozygous diploids (pure lines) generated by means of introgression of *Sli* genes (mentioned above in PL 1) from other sources or by identification of individual *Sli* variants within donor species would boost prospects of successful pre-breeding to mainstream new traits and needed diversity into bred populations.

The development of support populations through pre-breeding facilitates testing of gene combinations and upgrading of agronomic type (enhancement) of trait donors. For example, a diploid pre-breeding population is under development to introgress new types of resistance to potato LB identified in distant wild relatives. Embryo rescue was required to overcome interspecific reproductive barriers, and an open backcross scheme will use a pool of diploid bred lines and landraces as recurrent parents to combine resistance and agronomic traits. The pyramiding scheme will be supported by disease assays, gene tags, and expression analyses that will allow early testing of the impact of individual and combined genes or QTL to resistance phenotype. Multi-trait selection for agronomic attributes, cooking quality, frequency of extreme resistance to potato virus Y from the diploid recurrent parent pool, and the functioning of unreduced gametes (2n pollen) will enable transfer of enhanced resistance sources to the tetraploid level.

The examples above illustrate the diversity of alternatives that can be applied in different RTB. Sharing experiences and learning from each other will be a valuable contribution to the genetic enhancement of RTB that, up to now, was conducted with little interaction amongst the CGIAR partners.

Population improvement

RTB breeders consider continuous improvement of at least a few widely adapted (including client needs and environmental conditions) breeding populations as absolutely vital to fulfill their global tasks. Medium- to long-term-oriented population improvement requires significantly greater capacities, both human and financial, than many NARS variety development programs can afford. RTB breeders will ensure through these widely adapted populations that a broad range of countries can be supplied with material for the release of varieties with pro-poor attributes. In addition, these populations must be able to cope with future challenges (productivity gains, biotic and abiotic stresses, new quality needs, climate change, etc.). An important breeding objective will be biofortification (i.e., the breeding of new varieties of RTB with increased mineral and vitamin content and bioavailability). This will be realized by coordinating quality analysis facilities (e.g., NIRS) available across the Centers, and collaboration on the optimization of breeding methods and schemes for mainstreaming micronutrient traits into RTB populations that meet productivity, protection, and utilization needs. Strong linkages will be built with CRP 4, especially in the development and standardization of methodologies, and for the targeted delivery of biofortified crops.

Strategies of enhancing RTB breeding populations

The CRP-RTB will deliver breeding populations, as international public goods, and continuously improve them in collaboration with NARS. Although methods will change with new knowledge and tools, a general outline can be given for the population management of RTB in the CRP system, which is quite different from approaches used in the past century (Grüneberg et al. 2009). Attention is given to detect the existence of genetic correlations among traits, because such correlations can rapidly result in tradeoffs of one or more traits, as described by Wricke and Weber (1986), making whole breeding populations useless for variety selection. Multi-trait selection procedures are available to avoid negative tradeoffs. In addition to the clone performance of parents per se, we will use additional information about parents such as molecular marker information about likelihoods of resistances and the off-spring performance of parents (breeding value of progenitors). An important shared objective is to validate and implement reciprocal recurrent selection schemes to maximize heterosis, which is ultimately one of the most ambitious steps to be taken by this CRP.

Data management for breeding populations

Data management for breeding populations will be supported by electronic field books for RTB linked into statistical software that facilitates analysis by multiple evaluators as a cross-cutting product. It will provide outputs of parameters needed to estimate the value of genotypes and potential parents in RTB breeding populations. We will develop appropriate statistical analysis and software for association mapping studies in outbred and polyploid species. These statistical tools will implement new findings from PL 1 to improve the efficiency of population development, thereby relieving the bottleneck of RTB population improvement. IITA and CIAT will gradually merge their cassava database and coordinate the way variables are measured in the field and analyzed using the statistical tools developed by this CRP. Looking forward, these statistical and software products will also facilitate the access of partners and collaborators to the information generated in each RTB crop improvement program through Web pages. Moreover, a common data management framework will facilitate exchange of ideas and debate among plant breeders of the CGIAR, NARS, and dedicated ARIs. Testing, validating, and implementing optimal strategies for improving populations of open pollinated vegetatively propagated crops will thus be more efficient. For example, reciprocal recurrent selection schemes informed by tests of combining ability and implementations to untap heterosis in polysomic polyploid RTB will be tested in potato, sweetpotato, and banana.

Dissemination of breeding populations

Dissemination of material from breeding populations to national variety development programs is standard practice entering the most successful clones into in-vitro and quarantine conditions. However, in the CRP-RTB, we will establish new shortcuts, such as maintaining breeding populations under sterile or isolated conditions while reducing the number of genotypes in parallel with field selection. This procedure has been tested in sweetpotato and banana, and clones in seed nurseries in 2007 became available as advanced breeding clones for dissemination to NARS in 2010. This requires investment for in-vitro or screen house facilities. Another channel for the dissemination of breeding populations to evaluators and breeders worldwide is via true seed from controlled crosses among superior progenitors. This program aims to use this dissemination channel on a large scale. In the past, such exchange has often been made via polycross seeds or untested parents that had the disadvantage that partners benefited only partially from the breeding progress achieved for RTB in the CGIAR. Capacity will be built to produce, receive, and evaluate germplasm as true seed progenies. Information on progeny performance during selection will be applied to predicting value for similar regions. Repeating the most successful parental combinations on a large scale will streamline the infusion of large amounts of germplasm with high variety ability into partners' breeding and variety development programs.

PL 4: Variety development**Participatory variety selection**

Participatory approaches will enable farmers, buyers, processors, consumers, and support institutions (e.g., NARS, NGOs) to participate in and benefit from crop improvement. Variety development for RTB is heavily supported by bred-germplasm, training and capacity building, and the approaches outlined in PL 5: Aligning research with farmers' and end-users' priorities. Efficient strategies for the deployment of improved populations to targeted production regions underlie decision-making and are essential to ensure that available genetic diversity meets variety needs.

Targeting varieties to environments

New statistical methods are being implemented to study and interpret the genotype-by-environment interaction in stability tests. These methods allow for improved identification and recommendation of new clones with specific or broad adaptation. The combination of GIS with an analysis of variance of additive main effects and multiplicative interactions (AMMI) models, sites regression model, and partial least squares regression offers a novel combination of tools to predict potential performance of bred germplasm and populations across divergent environments. These tools entail the multilocal trial of "training sets" of germplasm at strategic locations across diverse environments and can be used to map adaptation domains for further exploitation via modeling of crop performance. This results in information about the likelihood of adaptation of new varieties to locations in which they have never been tested. The integration of GIS with models, including AMMI, is already helping to orient strategies for the efficient deployment of broad-based populations of potato from South America to variety development targets in Southwest Asia and SSA, where diversity is low.

Accelerated variety selection

Fortunately, in contrast to population improvement, variety development in RTB is relatively straightforward. It can be easily linked into NARS breeding and selection programs—provided the transfer of genetic material from population development to variety development across borders is made more efficient. Good overall performance across a range of traits, stability, and genotype-by-environment interactions are primary concerns for the identification of successful varieties.

Highly accelerated variety selection schemes are possible for vegetatively propagated crops, which can result in variety releases after 2–3 years of evaluation in properly designed selection schemes. However, national systems require data from several years of multilocation trials and on-farm data in large plots before considering variety release. National programs are usually well beyond the short 3–4-year window before they have evaluated advanced clones adequately enough to make a release decision. There are some exceptions, such as the National Institute of Agrarian Innovation in Peru for sweetpotato variety releases, which managed to release new biofortified OFSP (600 ppm pro-vitamin A) in three years with backstopping by CIP. Similarly, the use of rapid propagation techniques to increase the number of plants at early stages and participatory selection contributed to the success of reducing time to release a cassava variety in Colombia between CIAT and the national institution from 14 to 8 years. Backstopping national breeding programs, along with value chain actors' participation, has significantly reduced the time to release a new improved variety.

NARS breeding components, or “collaborative breeding systems,” are suggested in this CRP for each crop, to facilitate adaptive breeding and ensure that such linkages of CGIAR and NARS breeding can serve as models for training and research for articulation of population improvement and variety development phases of RTB crop improvement.

Maintenance and dissemination of varieties

In principle, maintenance and vegetative production of planting material RTB selections and varieties should not be difficult because genetic changes do not occur by recombination and mutations are rare. However, in practice, maintaining clonally propagated varieties is much more difficult and expensive in RTB than in cereal crops. The main reason is that many more diseases can be transmitted through vegetative seed than through botanical seed (an issue addressed by Theme 4). RTB crops share similar requirements, as distinct from cereals, for maintenance, multiplication, and exchange among evaluating programs:

- A new variety can easily be lost without a system that maintains and provides at least some healthy planting material in vegetative state.
- Numerous viruses, bacteria, and fungi are more easily transmitted; viruses are particularly important because they cannot be controlled chemically.
- Protected areas and greenhouse facilities to maintain varieties and to provide healthy starter material are much more important.
- Healthy seed production in fields depends much more on healthy environments.
- The need to maintain germplasm in vitro is much more important.
- Dissemination of clones across countries and regions are more complex due to quarantine regulations and the higher risk of transfer of associated pathogens that may harm crops.

RTB breeders wish to support dissemination of released varieties by NARS programs across countries and regions, especially when these varieties were developed on basis of breeding populations delivered to NARS. However, the successful exchange of bred germplasm and varieties across countries and regions is a significant challenge that needs to be addressed. The International *Musa* Testing Program is evaluating selected hybrids and elite varieties in multilocal trials to assess their adaptation to a range of environmental conditions and their adoption potential in different production or consumption systems (Molina, Escalant, and Van den Bergh 2007). The activity is scaled up by NARS-led field trials for yield and other agronomic traits evaluation and adoption (Molina 2005).

The CRP-RTB will encourage the private sector to invest in RTB variety development. With few exceptions (i.e., potato), there is little interest by the seed industry to get involved in breeding RTB crops. However, the processing sector is gradually learning about the need and potential benefits of breeding RTB to better fit its needs. For example, the recent discovery of amylose-free (waxy) starch in cassava (Ceballos et al. 2007) has prompted the starch industry from Thailand to invest in the development of a waxy starch variety. In record time and with adequate financial resources, the mutation was introgressed into germplasm adapted to Thai conditions and by 2010 waxy-starch clonal evaluation trials had already been planted in Thailand. Involvement of private processing sector (animal feed, starch, bio-ethanol, processed food) can be through the initiation of its own germplasm programs or through the financing of existing programs. Both approaches will ultimately benefit RTB farmers.

PL 5: Aligning research with farmers' and end-users' priorities

Obstacles to the rapid testing and delivery of RTB populations and candidate varieties constitute an impediment to realization of the benefits of pro-poor traits. Up to the (official) release of a new RTB variety, there are numerous needs and opportunities to actively involve next- and end-users in order to address specific bottlenecks for the crop and for the release system.

Farmer participatory variety selection and development are fundamental approaches for achieving a more focused germplasm enhancement process. International and national evaluation and release processes involving farmers have proven to be an efficient way to deliver products that farmers are more likely to accept and adopt. This CRP's component on research with end-users specifically prioritizes action-research at the pre-variety release phase. The use of electronic field books and statistical tools facilitate the collection and interpretation of information from end-users' varietal preferences on a large scale, as feedback to plant breeders for the identification of desired traits as well as promising genetic materials with high variety potential. This is valuable information for the planning of new crosses that will better target farmers' needs.

Approaches to be used in PL 5 include:

- Participatory evaluation of varietal traits and of acceptable tradeoffs between desired traits as feedback on populations in early stages. This includes analysis of the convergence or divergence between plant breeders' selection criteria and those of other actors who determine acceptability and adoption of new varieties.
- Hedonistic price analysis, or contingent valuation of willingness to pay, can be used to value attributes of candidate varieties (Ockowski 1984, Chowdhury et al. 2009).
- Use of molecular marker-assisted breeding (whenever it is possible and offers advantages), to detect and understand the genetic parameters of users' preferred traits.
- Establishment of long-term evaluator networks for specific agro-ecological regions and/or particular end uses.
- Clonal catalogues such as CIP's Potato Catalogue to collect end-users' information generated during the evaluations process toward variety selection and development.
- Information management and knowledge sharing to build and use global databases on producers' desired traits and to determine correlations between preferences of farmers and consumers and other measures of these attributes.
- Models and GIS analysis for analysis and prediction of acceptability and identification of recommendation domains that incorporate data on agro-ecological and gender-differentiated user preferences.

- Use of end-user participatory plant-breeding schemes with appropriate representation of men and women to reduce, if possible, the time taken from cross to variety and improve probability of adoption. A range of methods will be used to establish these schemes entailing social science support for disaggregating user preferences across and within households, engaging farmers, and documenting impact pathways (Ashby 2009, Bellon 2002, Lilja and Dixon 2008).
- On-farm trials that allow the farmer to participate in the technology development by providing feedback to the researchers on perceived benefits and constraints of the tested technologies. A range of tools for farmer participatory technology development can be used in this process—for example, focus group discussions and farmer field schools (FFS).

Attention at the pre-variety release stage aims to provide early information to end-users about what breeders have available. It provides feedback to breeders and consequent incorporation of previously gathered intelligence to realign/adapt breeding programs. But, perhaps most importantly, it implies the involvement of end-users in the actual selection of new varieties. At the same time, this approach will also address post-variety release issues through interdisciplinary research streamlined with Theme 4 (seed systems). Examples include enhanced strategies, capacities, and communication for the more efficient and innovative dissemination and adoption of new varieties from public breeding programs; specific activities that address the wide diffusion and uptake, such as marketing (posters, printed materials), variety catalogues, seed systems work (up and out-scaling), and identification of constraints to variety uptake and change; and attention to bottlenecks in delivery pathways (such as variety protection). The interaction with farmers also provides an opportunity to learn or share knowledge on agronomic practices (Theme 5) and postharvest processing approaches (Theme 6). Agronomists have observed that varieties often serve as the entry point for innovation and transfer of other technologies and capacity building such as in seed or ware crop management.

There are some cases in Africa where there is not a formal (official) release system—in such cases, there is an additional bottleneck that needs to be overcome. Through participatory varietal selection (PVS)/breeding, this bottleneck can be addressed. Entries in farmer fields undergo an informal variety release through farmer selections. For many countries, PVS becomes an important product in the reaching end-users' product line (Bishaw and van Gastel 2009, Dixon et al. 2007, Ntawuruhunga et al. 2006). During the August 2010 stakeholders meeting held in Cali for the LAC region, there was a strong request to find alternatives to the release process of varieties. This approach, together with backstopping the national system to enhance policy of the release system, will help reduce the time and costs to release improved varieties.

Within this product line, the CRP will validate and quantify the efficiency of such breeding schemes (i.e., determine correlations between visual screening of attributes by farmers and “true” values of these attributes). Gibson et al. (2008) has shown for sweetpotato in Uganda—and this is significant end-user information—that farmers use more criteria and characters to select sweetpotato than do breeders in formal plant breeding programs. In this context there is a risk that important end-user attributes remain unconsidered, which can make whole breeding populations useless for variety development. More such studies as those carried out by Gibson and colleagues will be conducted across countries. For cassava in Colombia, Lopez and Marin (2007) found a contrasting case with a strong association among men and women farmers, breeders, and middlemen selection criteria and preferred characteristics for cassava for both food and feed.

The food security role of RTB to be achieved through enhanced nutritional quality needs to distinguish between visible quality (i.e., color and pro-vitamin A) and invisible quality (i.e., Fe and Zn). Both attributes in RTB varieties need to be addressed in different pathways in reaching end-users.

In addition to productivity, there are two key factors for end-users: (1) dry matter content (which can vary widely in RTB crops) and (2) the need to widen the availability of RTB through the year. This demand is driven by the need of year-round operation in processing facilities. There has already been significant progress in different RTB to identify special traits that affect their quality and offer great advantages for different industries. For the starch industry, the identification of mutations that affect starch quality traits (amylose-free starch, high amylose) has already proven to have huge economic advantages in temperate regions of the world that will now be exploited by the CRP-RTB in less-developed regions.

We foresee the emerging trend for a departure from “generic” varieties that can be used more or less successfully for different end-uses to more specialized varieties that better fit specific end-use needs. This is linked into a closer interaction between the production and processing sectors. The advantages and risk (i.e., certain cases of farmers becoming captives of a certain industries) for the entire system to be sustainable needs to be studied and quantified.

4.2.4 Critical Assessment of Methods

PL 1: Breeding tools, strategies, and approaches—Potential for genomic selection in RTB crops

Decreasing costs for obtaining DNA sequence information has created new opportunities for use of molecular data to improve the efficiency of selection for RTB crops. Molecular markers have been most useful for traits determined by relatively few genes with high heritability. Identification of QTLs has had limited success for traits affected by many genes with small effects. Genomic selection offers a new opportunity to use DNA sequence data to estimate breeding values. Markers spread through the genome will be linked to QTLs for traits of interest with all markers contributing to estimation of breeding values (Meuwissen, Hayes, and Goddard 2001). Training populations associate genomic data with phenotypic data with a statistical model developed to estimate breeding values (Heffner, Sorrells, and Jannink 2009; Jannink, Lorenz, and Iwata 2010). Successive rounds of phenotypic evaluations can improve the prediction models from training populations. Using genomic selection, it will be possible to complete cycles of selection and recombination without the need to phenotype in each generation. This results in reduced time needed for each cycle of selection and reduced costs (Heffner, Lorenz, and Jannink 2010).

Advantages of genomic selection in RTB crops include:

- Increased gain from selection
- Reduced cycle time
- Reduced cost
- All markers used to estimate breeding value to capture small and large effects
- Historical phenotypic data especially useful in clonal crops
- Index selection used to target multiple traits environments.

Genomic selection needs to be rigorously tested in RTB crops especially for complex farmer-preferred traits subject to strong genotype-by-environment interaction. For clonal crops, genomic selection based on genotyping of seedlings will allow immediate rapid multiplication of selected genotypes for use in crosses and replicated trials.

PL 1: Breeding tools, strategies, and approaches—Near-infrared reflectance spectroscopy

Studies of nutritional and anti-nutritional characteristics should combine chemical analysis. Tools such as high-performance liquid chromatography, gas chromatography, and inductively couple plasma allow analysis of RTB in their natural, modified, and processed forms at a high level of precision. On the other hand, NIRS is a rapid and inexpensive technique that facilitates the analysis of several traits simultaneously. It is hazard free as there are no toxic or corrosive reagents (Osaki, Christy, and MacClure 2006, Marck et al. 2002). A critical issue for reliable, robust, and precise NIRS calibrations is the selection of “calibration samples” to span variation (different cultivars/genotypes, regional differences, environments, etc.) of the target population.

RTB breeding programs need high-throughput techniques to estimate simultaneously the concentration of nutritional and anti-nutritional characteristics in thousands of genotypes in the short time between harvest and sowing, because breeders need high selection intensities that result in significant gains, especially if several quality traits are considered. NIRS is commonly used to estimate the main macronutrients like oil, protein, and carbohydrates in agricultural products and even in the complex matrices of processed foods (Shenk and Westerhaus 1993, Zum Felde et al. 2007). NIRS has been successfully applied to estimate carbohydrates, protein, total and individual carotenoids, and minerals in potato, sweetpotato, and bananas (Bonierbale et al. 2009, Davey et al. 2009). The technology can probably be applied to evaluate stress tolerances in RTB as plants subjected to different biotic and abiotic stresses develop metabolites that can be detected and evaluated by NIRS.

PL 2: Trait capture and gene discovery—Targeting Induced Local Lesions IN Genomes

Lack of sufficient genetic variation in RTB crops is exacerbated by the biology of these crops, which favors vegetative propagation rather than propagation by sexual seeds, thereby limiting recombination. Innovative techniques such as TILLING (McCallum et al. 2000, Colbert et al. 2001) provide a non-GM organism approach to the improvement of desired traits through creation of allelic variation. TILLING is a robust, low-cost, and high-throughput functional genomics assay that combines mutagenesis with sensitive mutation detection (Gilchrist and Haughn 2005, Comai and Henikoff 2006, Till et al. 2007, Waugh et al. 2006). A wide spectrum of assays, ranging from heteroduplex analysis with high-performance liquid chromatography, electrophoresis, microarray, to direct sequencing, are developed to detect nucleotide variations—induced or natural (Gilchrist and Haughn 2010; Waugh et al. 2006; Tadele, Mba, and Till 2009). Screening of mutants with IRDye-labeled primers assayed on Li-Cor platform is the most well established and commonly used technique in TILLING (Till et al. 2006). Recent advances in sequencing hold the potential to be high throughput, cost-effective mutation detection system by resequencing the gene of interest in mutagenized plants (Gilchrist and Haughn 2010, Weil 2009, Talame et al. 2008).

The challenges to routine application of induced mutagenesis include handling of the propagules, which makes it expensive, laborious, and time-consuming (Mba et al. 2009, Waugh et al. 2009). Another drawback is the formation of chimera, which necessitates careful management so as to generate genotypically homogeneous plants and standardized techniques are available (IAEA 2010, Mba et al. 2009, Datta 2009).

A common challenge that needs to be mitigated in RTB crops is polyploidy. Work in other polyploids have demonstrated that TILLING provides a targeted method for developing phenotypes that may not be obtainable in using forward genetic strategies (Slade et al. 2005). TILLING can be harnessed as a complementary tool in double haploidy to fix mutation. The DNA sequences of putative genes can also be converted into useful markers for screening associated traits through marker-assisted selection (Lübberstedt et al. 2005, Slade et al. 2005). The availability of genome

sequences (cassava, potato, and banana) and comparative methods offer the opportunity to select target genes involved in the biosynthetic pathways of traits of economic importance.

PL 4: Variety development—Participatory variety selection

Breeding and selection of RTB crops have become increasingly market and farmer oriented (Grüneberg et al. 2009). This allows breeding to address diverse problems and accelerate the availability of varieties that meet farmers' particular needs for specific environments and markets. It complements the conventional linear process of research and extension in which breeders first develop, then test and release new varieties, with the limited involvement of farmers and the extension services that promote these varieties.

Farmer-centered plant breeding concerns the entire breeding process (participatory plant breeding), while farmer-centered PVS is limited to testing of finished varieties (Gonsalves et al. 2005) or fixed lines (released, advanced lines, or landraces) by farmers in their target environments using their own selection criteria (Witcombe et al. 1996). Success in PVS involves (1) situation analysis (e.g., through community meetings) to identify, prioritize, and document farmers' needs and preferred traits in RTB cultivars; (2) search for suitable varieties for testing; and (3) trials on acceptability of varieties in farmers' fields plus visits with farmers, scientists, and extension personnel during crop growth and at harvest. PVS offers a direct way of using multiple traits to assess the value of a variety to farmers who trade off the traits against each other in their selections. While traditional on-farm trials are sometimes considered similar to PVS when they involve farmers, they typically give farmers a limited choice of varieties preselected by breeders. Moreover, trials are managed with a package of practices determined by scientists and often do not use powerful techniques, such as matrix ranking, for discriminating among varieties.

Tools have been developed for participatory evaluation of various RTB crops, statistical analysis of subjective criteria from farmers and other value chain actors, ranking systems analysis, multiple correspondence analyses between value chain criteria and ranking systems, and regression analysis for unbalanced data.

PVS programs often use some form of mother-and-baby trials in which scientists manage a small number of "mother" trials, which include all of the test entries. Farmers run a larger number of "baby" trials, each of which includes only a couple of the test entries. The programs have been particularly successful in marginal areas with low-resource farmers, but their advantages are less in productive environments where on-station trials are representative of the situation in farmers' fields. Uptake of farmer-preferred varieties may be limited by the conventional protocols for statutory release that may not yet recognize data from PVS trials.

4.2.5 Partnership

The four Centers implementing Theme 2 already have built up a wide range of partnerships through which they have been implementing activities in crop improvement. These include collaboration with ARIs like the French institutions CIRAD, IRD, and INRA; the Agriculture and Agri-Food Canada; CIMMYT; and the Generation Challenge Program (GCP) through its Molecular Breeding Platform. In conjunction with Theme 7, PL 2, this theme will review these existing partnerships and seek to harmonize and streamline collaboration across the different crops.

This process will also allow us to identify "collaboration opportunities" (e.g., linking multiple crop activities with the same ARI) and "collaboration gaps" (e.g., where no clear "next-user" partners exist for reaching outcomes along the impact pathway). The partnership strategy for this theme will use this information to develop innovative and collaborative platforms to accelerate the uptake and

dissemination of novel germplasm, from the breeding “pipeline” to client smallholder farmers. Expectations that national programs, or other partners, automatically receive, evaluate, register (as new varieties), and effectively disseminate novel RTB germplasm depend very much on respective national capacities and often lead to the common problem of technology remaining “on the shelf.” We will develop novel partnerships and platforms to accelerate evaluation and uptake of promising RTB germplasm to both better exploit existing material in the short term and to develop more efficient systems going forward with future material under development. To this end, we propose better targeting of germplasm (based on receiving agro-ecology), multiplying seed as selection takes place (rather than a simply linear process), and working with subregional organizations such as the Association for Strengthening Agricultural Research in Eastern and Central Africa and the Common Market for Eastern and Southern Africa. Working with subregional partners will facilitate policies that favor neighboring countries to recognize each other’s national performance trial data, for similar agro-ecologies, negating the need to continually repeat trials with the same germplasm. Our collaboration with CRP 4 in relation to breeding and dissemination of biofortified varieties of CRP-RTB target crops will enable us to access new networks of nutrition and health professionals to support increased demand for—and more efficient—varietal dissemination. Our own consolidated partnerships of national researchers involved in RTB crop improvement will in turn contribute to strengthening the platform for developing and disseminating biofortified crops, which is the objective of CRP 4, Component 2 on biofortification.

Also, regional platforms such as the Red LatinPapa network, which seeks to enhance the pro-poor impact of breeding technologies through collaborative research on and development of advanced potato germplasm, strategies for dissemination, seed systems, and information management, will be actively involved. The development of sustainable and more effective seed systems (described in Theme 3) is also critical. For example, the Bangladesh Agricultural Research Institute developed and effectively manages a low-cost tissue lab for dissemination of outstanding potato varieties. Farmer groups in San Jacinto and Toluviéjo, Colombia, produce seed of improved and local varieties of cassava, yam, and bananas also through a low-cost tissue culture lab. Maruku, an ARI in Tanzania, multiplies and distributes millions of banana plants. The GCP Cassava community-of-practice can considerably contribute to the dissemination of virus-resistant and drought-tolerant cassava varieties.

The example of involvement of Thai private sector mentioned above (now expanding to Colombia and Brazil) in the development of specialty varieties is largely a novel situation for RTB that this CRP will encourage as a way to guarantee impact of the products to be developed, but also sustainability of the process for years to come.

The collaboration of our partners throughout the product lines is key to realizing Theme 2’s impact pathways (see Table 4.2.2).

Table 4.2.2 Roles and Responsibility of Partners in Impact Pathways

Product Lines	Representative Key Partners		Roles and Responsibilities
PL 1. Breeding tools, strategies, and approaches	▪ NARS ▪ ARIs	▪ Universities ▪ Private sector ▪ Farmers	ARIs and private sector share experience with partners on breeding tools and strategies, and adapt breeding technologies to NARS. NARS, universities, and private sector assist in validation of screening methods. NARS facilitate the adoption of new cultivars through farmers participatory approach.
PL 2. Trait capture and gene discovery	▪ NARS ▪ ARIs ▪ Universities	▪ Seed industry actors ▪ Private sector ▪ Farmers	NARS, ARIs, and universities collaborate for laboratory services for phenotyping technology development. With actors in the private sector, they conduct analyses of agronomic and quality traits of genotypes, and collaborate toward identification of novel trait to accelerate plant breeding and better exploitation of genetic resources. The different partners work together on introgression of major gene in commercial varieties.
PL 3. Population development and pre-breeding	▪ NARS ▪ ARIs ▪ Universities	▪ Private sector ▪ National, regional, and international networks	Private sector will better exploit specific traits and heterosis. Access to suitable population available to start breeding program.
PL 4. Variety development	▪ NARS ▪ ARIs ▪ Universities	▪ Private actors ▪ NGOs ▪ Farmers ▪ Consumers	NARS, ARIs, universities, and private sector collaborate toward shortening breeding cycle. They support and enhance capacity of variety release by NARS, and facilitate access to different sources of disease resistance genes. Successful promotion and uptake of biofortified crops to enhance nutrition.
PL 5. Aligning research with farmers' and end-users' priorities	▪ NARS ▪ ARIs ▪ NGOs ▪ CBOs	▪ FBOs ▪ Universities ▪ Farmers ▪ End-users	Provide early access to information about source of supply of elite genotypes. Develop strategies for client orientation, gender preferences, and end-user knowledge. Enhance interest in use of RTB as food and income for farmers. Facilitate farmer and end-user participation in research design through surveys, planning meetings, visits to experimental sites, FFS, etc. Train scientists in participatory strategy and techniques. Develop information management systems that incorporate farmer and end-user information.

4.2.6 Gender strategy

Breeding goals need to be balanced between agronomic traits/productivity and quality characteristics on the one hand, and food and nutrition security and income generation on the other (Table 4.2.3). Theme 2 intends to move beyond breeding “generic” varieties and towards specific varieties for different uses. There will unavoidably be tradeoffs and gender implications of targeting (e.g., nutritional versus processing quality). It is important to understand the tradeoffs involved and how, for example, intensifying the generalized or specialized commercial potential of RTB will affect decision-making and resource control between men and women and the nutritional well-being of households. The gender strategy will be especially important for PLs 2–5, but can also help guide the elaboration of methods and tools in PL 1.

Table 4.2.3 Matrix of Gender Implications of Breeding Goals

	Food Security	Income
Agronomy/Productivity	More subsistence food available to women for household provisioning. Risk that women lose control over food from crops that shift from predominantly subsistence to	More production for generalized commodity markets favoring conventional gender roles in marketing. Risk that women lose control over income from crops that shift from predominantly subsistence to commercial scale, with negative impacts on child welfare.

	Food Security	Income
	commercial-scale production. Risk that women's family labor burden may increase if cropping systems intensify.	Men's income increases from sales of previously women's subsistence crops that are being commercialized. Increased demand for labor as cropping systems intensify may increase wage earning opportunities for landless women and men.
Quality	Better nutrition of household members; specific nutritional targeting of young children.	Increased volumes for specialized markets, favoring new involvement of men (e.g., in linking to industry with processing varieties) and requiring special strategies supporting women's involvement in enterprise development (link to Theme 6).

The RTB will draw on tools and instruments developed through participatory research and gender analysis work on participatory plant breeding (Farnworth and Jiggins 2003). These tools not only enable adequate gendered diagnosis of end-user needs, they also support adequate monitoring of the deployment of these technologies and, where necessary and when possible, propose adjustments or additional actions (e.g., the promotion of woman's associations to enable them to better exploit marketing opportunities of the specialty varieties that will be generated). Seeking equity in income benefits accruing to women and men from commercial crops can also have a broader positive impact on the farming system and on gender roles if it offers an economic alternative to male migration to urban centers, with its associated increase in labor burdens on rural women and youths. This theme will involve capacity strengthening among team members and local partners in gender-aware participatory plant breeding and PVS.

4.2.7 Communication and knowledge sharing

The primary focus for communication and knowledge sharing will be on establishing feedback mechanisms between RTB breeders and end-users (farmers, consumers, and processed food producers) to set breeding objectives and evaluate the suitability of the material being developed. Communication with scientists developing molecular tools, as well as access to comprehensive information on the germplasm available to breeders, will also be crucial in expediting the breeding process. In addition, communication with scientists working on other aspects of RTB crops and cropping systems will be ensured to allow for feedback loops across disciplines. Consultations, participatory evaluations, attendance at conferences, information and knowledge platforms, and discussion fora are among the communication and knowledge-sharing tools and strategies that will be deployed to achieve the objectives of this theme.

Outreach material will also be produced in collaboration with other themes to facilitate access to germplasm and remove other bottlenecks to breeding. Breakthroughs and achievements will be publicized through timely channels (such as websites and media).

4.2.8 Capacity strengthening

Most developing countries are struggling to maintain, rehabilitate, or initiate meaningful plant breeding programs in the face of trends towards reduced funding and decreased capacity to produce new, adapted varieties of essential crops. Even when national breeding programs are in place, their short-term goals do not often prioritize sustainability, and a paucity of trained plant breeders is recognized at the highest levels. At the same time, investment in biotechnology infrastructure has been largely insufficient to allow national researchers to fully take advantage of molecular biology and genetics.

Capacity strengthening includes assessment of training needs; identification of opportunities; and a range of approaches to develop and transfer knowledge, expertise, and skills. The CRP-RTB has a unique role in this sense, as private sector and developed-country breeding initiatives generally pay little attention to RTB crops and their performance under marginal conditions. Specific objectives are:

- To train new developing-country scientists in modern technologies of plant breeding and upgrade the skills of practicing breeders in classical breeding and biotechnology.
- To develop and share tools, methodologies, know-how, and facilities to help find genetic solutions to crop productivity constraints.
- To innovate in plant breeding and communication methods, including participatory research methods to shorten timeframes for the development of new varieties that deliver pro-poor traits.

Capacity building in Theme 2 will engage CGIAR centers, universities, NARS, professional societies, NGOs, farmers, private sector, and other partners who participate in setting breeding objectives and in practicing breeding or selection. International efforts and regional centers of excellence in research and plant breeding will be critical partners. We will engage policy-makers as well.

Expected outputs and outcomes are:

- Enhanced knowledge of NARS breeders of molecular techniques and their application in plant breeding.
- New learning materials for building capacity in developed and developing countries on breeding vegetatively propagated crops.
- Website and knowledge bank on breeding capacity assessments data and analyses.
- Expanded corps of active, competent breeding programs that address different needs and opportunities for sustainable RTB improvement in a complementary and dynamic fashion.
- Increased impact of RTB breeding programs in responding to user-needs.

4.2.9 Links with other themes and CRPs

For an efficient exploitation of diversity for sources of resistance to pests and pathogens, breeders will take advantage of the activities already described in Theme 1 (conserving and accessing genetic resources). This includes enhancing knowledge of policies and practices for improved access to and use of international genetic resources.

Theme 2 will also interact with Themes 3 and 5 that address biotic and abiotic stresses. For host-plant resistance to main pathogens, our strategy does not only rely on breeding resistant germplasm, but also on producing the clean planting materials described in Theme 4. The development of herbicide-resistant varieties will require extensive research in the area of minimum tillage in Theme 5. The development of varieties with special quality characteristics (i.e., starches that are better for the starch industry, roots/tubers that are better fit for ethanol industry or products with enhanced nutritional quality) will require close interaction with Theme 6 that aims at promoting postharvest technologies, value chains, and market opportunities. Linkages with Theme 6 will ensure articulation with value chain actors (industry, consumers, and smallholders in the process of delivery products) that will ultimately improve food security and alleviate poverty. For example, RTB's role in food security is limited by their relatively short shelf life. Little progress has been made from the genetic point of view. This CRP will address this issue more aggressively. Extending the shelf life of RTB would offer an important advantage to women selling these crops.

Theme 2 also links with Theme 7 in addressing partnership and impact analysis to ensure competence and appropriate focus of breeding efforts to adequately meet user-needs. Close interaction with CRP 1 will ensure that livelihood options identified have a direct bearing on the breeding and selection process of RTB.

Interaction with end-users has provided valuable insight of their particular needs when RTB are to be processed. The CRP-RTB intends to gradually develop special germplasm to satisfy the particular needs of different value chains (which has important links with Theme 6 and CRPs 2 and 3.7). For the animal feed industries, enhanced nutritional quality (vitamins and proteins) and starch quality are key traits to be exploited. In addition, the possibility of exploiting foliage requires the development of double-purpose varieties and the implementation of new cultural practices (a connection with Theme 5, CRPs 1.1, 1.2, and 3.7).

Collaboration with CRP 4 is envisaged for the targeting of and increased access to improved RTB varieties with enhanced micronutrient availability (e.g., combining increased nutrient density in the raw material, high nutrient retention during processing, and low levels of antinutritional factors). This will occur primarily with *Component 2: Biofortification, which has the objective to “develop and test biofortified nutrient-dense staple crops to make these novel crops available to the poor and undernourished.”* CRP 4 will help orient the outputs and scale up the outcomes of CRP-RTB by helping to identify and specify requirements and opportunities for biofortified RTB, and to reach vulnerable populations with biofortified varieties and identify how they can contribute to increased dietary diversity and a more balanced diet of these populations. CRP 4 will contribute to the CRP-RTB through characterization of food systems with the goal of improving RTB populations to a level at which they can make a significant contribution to improving nutritional status amongst vulnerable groups. In particular, CRP-RTB will contribute to addressing the research question raised by CRP 4 as to whether plant breeding and modern agricultural biotechnology techniques can increase the nutrient density of food staples to target levels that can potentially have a measurable and significant impact on human nutritional status. It will do this by identifying and exploiting genetic diversity and improving knowledge of the effects of environment and management on the micronutrient density of RTB to validate expectations for genetic gains in the concentration of specific micronutrients in each RTB through plant breeding.

Close collaboration with CRP 7 is envisaged to consider the best available predictions of climate and define what would be the most relevant traits to enhance the suitability of RTB as food security crops worldwide.

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4.3 Theme 3: Managing Priority Pests and Diseases

4.3.1 *Rationale and objective*

Pests and diseases have multiple negative effects on small-scale and resource-poor RTB growers in developing countries. When no efficient control measures and preventive tactics are used, direct pre- and postharvest losses can be very high. Pests and diseases of RTB crops include some of the most devastating biotic agents known, including diseases such as the viruses of cassava that threaten food security in parts of Eastern and Central Africa and the potato LB organism, which causes losses estimated at \$12 billion in developing countries (Haverkort et al. 2009). Reduced productivity further leads to inefficient use of soil and water resources, while use of pesticides can be costly, lead to development of pest resistance, and harm human health and the environment. Furthermore, pest and disease problems are likely to exacerbate due to agricultural intensification and climate change and will continue to strongly contribute to the challenges RTB farmers will face in the future.

Theme 3 aims to generate knowledge and novel technologies, build communities-of-practice, and strengthen capacities that will better enable farmers to manage RTB pest and disease problems of the near future—and be prepared to tackle those of the not-so-near future. On the basis of current, comprehensive information on the biology and life cycles of pests and their interaction with the environment, activities will be carried out using IPM approaches to achieve sustainable increases in food production, counteract the impacts of climate change on pests' distribution and damage potential, reduce contaminants in the food chain, increase agro-ecosystem resilience through a better understanding of biological interactions in agro-ecosystems, and improve farmers' access to decision-making tools that support specific IPM practices. These approaches are based on series of pest management evaluations, decisions, and controls. In combination with available pest control methods, they will be used to manage pest damage by the most economically efficient means and with the least possible hazard to people and environment. Products of this theme include innovative technologies for crop health management, like remote sensing surveillance and early detection, precision crop protection, pest risk assessments through process-based pest phenology modeling, and risk mapping using GIS under current and future climate change scenarios, early disease detection tools (e.g., diagnostic kits, DNA bar-coding), use of biological control (parasitoids, predators, beneficial microorganisms) that regulate densities of pests as well as the development and use of biorationals (e.g., pheromones, attract-and-kill strategy), or physical control based on the understanding of pests' migration capacities and spatial dispersal. IPM technologies include the effective use of pest- and disease-resistant RTB varieties, but also have to act independently where adequate host-plant resistance does not exist to keep pests and diseases under the control threshold. The theme identifies four product lines, which serve as major components in the logical framework for both cross-cutting and crop-specific activities.

Vegetatively propagated crops have similar disease issues. For example, viruses are transmitted in similar ways either via vegetative seed or vectors such as whiteflies or aphids, which are common across crops. This limits rapid exchange and dissemination of planting material of improved varieties, and reduces the quality of farmer-produced seed. Therefore, exploiting the synergies among Centers will help develop common and more efficient vector control strategies as well as effective low-cost virus (and other pathogens) detection methods for use across RTB for screening in breeding and seed programs. Better standardization of resistance phenotyping (measuring and describing resistance) will improve efficiency of selection for new resistant varieties.

We will develop improved and robust detection and monitoring methods and surveillance platforms for detecting and mapping existing, emerging, and resurgent molecular pests and pathogens of RTB.

This work will be supported by joint efforts on pest and disease modeling and risk assessments under changing and uncertain scenarios (e.g., globalization; climate change; increased human mobility; pest, pathogen, and vector evolution; intensification and diversification of agro-ecosystems). The developed methods will facilitate the safe movement of germplasm that is essential for introducing, assessing, and deploying new varieties and will provide information useful for IPM strategies, such as location of pesticide-resistant pest and pathogen populations.

Diversity of high genetic crop and cropping systems, diversified landscape structures, and appropriate agricultural practices are important to maintain long-term agricultural productivity and sustainability. Conservation agriculture and the strategic use of natural enemies to keep pest populations under the control threshold are major elements in the crop health management approach developed and used in RTB. We will develop, integrate, and adapt innovative pest management technologies to the different RTB agro-ecologies and experiences shared and synergies exploited among partners. Theme 3 also contemplates characterization and use of beneficial insects and microbial communities to take better advantage of their positive role in RTB productivity.

4.3.2 *Impact pathways*

Pests and diseases pose severe constraints on sustainable production of RTB for several reasons: direct yield loss, economic loss, and health and environmental risk due to pesticide dependency and poor use of soil and water resources. Thus, reduction in the severity of pests and diseases or pesticide dependency will lead to greater economic return and overall more sustainable production. Impacts can be direct or indirect, as better management of pests and pathogens born on planting material can lead to increased multiplication rates and more rapid diffusion of resistant materials. In addition, generating tools to anticipate or prevent the spread of pests and diseases and give sufficient time to prevent such a spread—or to be prepared to respond—will lead to significant savings in terms of losses and control costs, also in the face of climate change. Figure 4.3.1 shows the impact pathways envisaged for Theme 3.

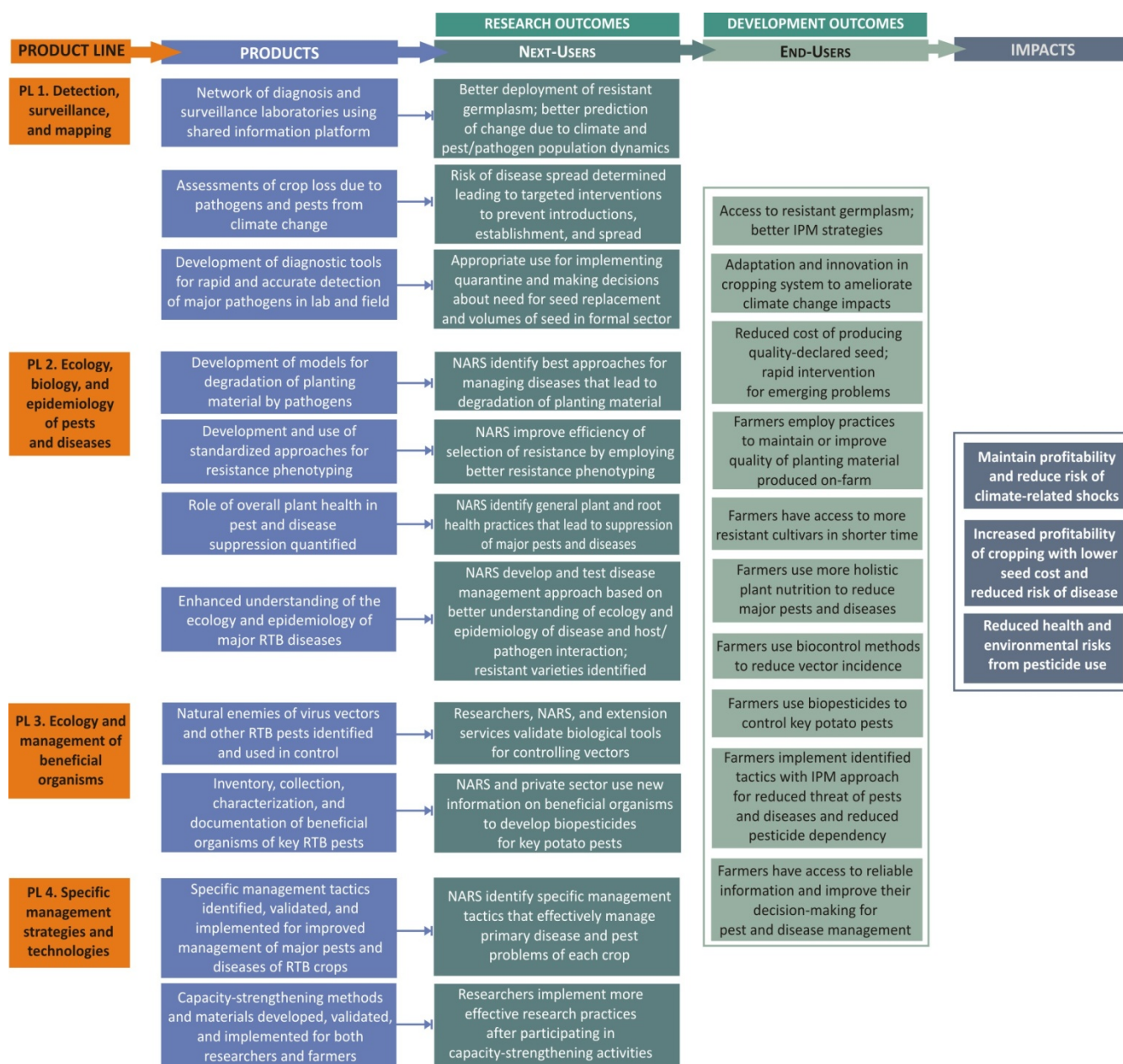


Figure 4.3.1 Theme 3 product lines, products, outcomes, and impacts.

4.3.3 Product lines

The general structure of the product lines represents a logical sequence of R&D from basic to applied research. Annex 2 contains the product line description tables (research products, outcomes, milestones, and key partners) for Theme 3.

PL 1: Detection, surveillance, and mapping

Pest and pathogen detection and monitoring units for RTB will be established in regional laboratories (e.g., West and East Africa, Central and Southeast Asia, and Central and South America), sharing highly skilled human resources and up-to-date laboratory equipment and technologies. This will provide both the adequate infrastructure to develop novel detection tools as well as the services for phytosanitation of germplasm and breeding material prior to cross-country movement

and capacity strengthening and training to regional stakeholders. We will establish and preserve for the long term core collections of pathogens (and RTB-associated beneficial microorganisms) based on existing and new collections. A centralized computing and database management facility will analyze data produced from next-generation detection methods such as siRNA sequencing in a rapid and accessible way (see Box 4.3.1).

Box 4.3.1: Pathogen detection tools

Ensuring phytosanitation of germplasm and breeding material prior to cross-country movement is a serious bottleneck for all clonally propagated crops. Several pathogen detection tools based on molecular biological methods have been under development in recent years, one of the most promising of which is siRNA sequencing technology. The method, generic and extremely sensitive, identifies viruses infecting plants through defensive “siRNA” molecules produced in response to infection. The current cost is estimated at about US \$100 per sample (down from about \$1,500 two years ago)—already well within the acceptable limit for germplasm indexing. Other platform technologies that may be considered are generic microarray-based pathogen detection chips, which when produced at large scale (all clonally propagated crops) can achieve very low per-unit costs.

Regular monitoring and surveillance of emerging pests have been shown to be critical to take early actions for eradication, if still possible, and to develop and communicate adequate control measures to farmers in a timely fashion. In the case of banana, the alarm raised by the new occurrence of *Fusarium* wilt Tropical Race 4 epidemics in Asia (Molina et al. 2009) has prompted global stakeholders to prioritize actions to mitigate the threat of this disease. Continental action plans to limit the movement of *Fusarium* wilt pathogen and to prevent the entry of Tropical Race 4 into Africa and the LAC need to be developed or further refined, then supported by reliable diagnostic methods and strict quarantine policies and procedures. A very aggressive cassava mealybug species was inadvertently introduced to Asia, and CIAT, in close collaboration with IITA, is providing key expertise to establish a promising biological control agent to suppress it. Similarly, leafminer fly has been identified as an emerging pest in potato in Africa (Kenya, Rwanda) and Nepal, where farmers did not know leafminer fly or mistakenly attributed its damage to fungal disease.

Surveillance data will be important and used for risk assessment of the severity of existing pests and diseases and the expansion of their range in the future, as well as new pests and diseases related to climate change. This will be supported by pest phenology modeling and risk mapping using GIS as innovative tools to assess and understand how pests may spread across regions. We will build strong partnerships with CRP 7 Agriculture and Climate Change and other partners to improve aggregation and down-scaling of modeling results for risk assessments on regional scales.

Risk assessment and modeling of the spread of pests and diseases linked to an ex-ante (and eventually ex-post) assessment of potential losses will be carried out to orient priority setting of research activities and for cost-benefit analysis of pest control measures. Risk assessment will include the analysis of national and international phytosanitary regulation and economics of quarantine policies (Breuker et al. 2008, Olson and Roy 2002) as well as household- and community-level analysis of impacts on income and food security (Karamura et al. 2010; Abele, Twine, and Legg 2007).

In PL 1, the cross-cutting product emphasizes development of facilities and expertise, establishment of global data structures, and risk assessment that can best be done by a common GIS facility. Specific-crop product lines focus on the detection and monitoring needs of the primary pests and pathogens of the respective crop. There is a strong link between cross-cutting and cross-specific in that the latter will also be done in the facilities of the former. This would enable ongoing detection and surveillance activities to be continued and improved by exploiting synergies, and particularly will permit initiation of new activities in research groups that may have not yet delved into this kind of research.

PL 2: Ecology, biology, and epidemiology of pests and diseases

Several products under this product line clearly demonstrate a potential for synergy among Centers and other partners. The first product consists of predictive models and approaches through better understanding of the epidemiology of plant pests and pathogens for improved management interventions (e.g., threshold action-based disease management tactics, inoculum reduction) of pests and diseases. The study of changes in the population dynamics of virus vectors and key pests will be essential. It is highly likely that models can be used across crops with proper parameterization—work that can build on some theoretical work that has been done by strong laboratories in Europe (Chan and Jeger 1994). There will be very strong interaction with Theme 4 on planting material as knowledge developed here can feed directly into implementation of seed systems, both by specialized seed producers and on-farm.

PL 2 is also where we envisage a very important area of potential synergy: development and use of common approaches for evaluating the host plant for resistance to pests and pathogens (resistance phenotyping). For example, the development of rapid and reliable methods for virus screening is important, in particular, for breeders who need to be able to evaluate thousands of genotypes each year. Here we propose to identify tools needed by partners to accurately assess, analyze, and store data related to host-plant resistance in a way that will permit subsequent meta-analyses. In conjunction with development of these tools, we propose training of partners for sustained use and input of data into standard database structures. Given the current and growing interest throughout the research community for data quality, standardization, storage, management, mining, and so on, this work could have many partners within and outside of the CRP.

PL 2 also houses work on general principles related to the role of plant and root health in disease expression. We plan to conduct comparative studies involving a few key systems to determine the potential for improved disease management via better overall root and plant health and to look at the potential of disease-suppressive soils (see Box 4.3.2).

Box 4.3.2: Soils suppressive to *Fusarium* wilt

There are indications that some soils are associated with higher incidence of banana *Fusarium* wilt (*Fusarium oxysporum* f. sp. *cubense*) or Foc, while others have lower incidence of the disease. Organic farms in Taiwan monitored for 10 years had an average incidence of *Fusarium* wilt of 25% as compared to 67% for the conventional farming system (Chao 2009). The lower incidence of *Fusarium* wilt in the organic banana was believed to be associated with a positive change in the properties of the soil, notably higher organic matter, pH, P, K, and Ca soil content, and possibly microbial populations. There is now an increasing interest in carrying out epidemiological studies that will clarify the roles of key environmental, soil, and host factors that influence the incidence, development, spread, and survival of Foc to diversify the options to manage this important disease. The Australian Centre for International Agricultural Research, through Bioversity, is currently supporting research in Indonesia looking at Foc-suppressive soils and their organic matter, soil amendments, soil antagonists, and other microflora. This will be linked to optimization studies to improve the efficiency of suppression and the exploitation of biological control agents identified in previous studies in Asia and LAC that were effective in the screen house but less successful in the field.

Under this product line, there will be crop-specific focus on the knowledge gaps related to their major disease and pest problems. For example, banana work will focus on *Fusarium* wilt, in particular Tropical Race 4, bacterial wilts, Banana bunchy top virus (BBTV), and weevils; cassava on Cassava brown streak virus, frogskin disease, root rots, cassava burrowing bug, and cassava lace bug; potato primarily on LB; sweetpotato on viruses, root rots, whitefly, and sweetpotato weevil; and yam on yam internal brown spot disease and anthracnose. Knowledge gaps need to be filled to improve the design of IPM approaches, development, and selection of resistance both classically

and via genetic modification. The study of ethno-ecology and ethno-biology of pests and diseases will facilitate the understanding of the effect of social and ecological factors on these biotic constraints.

PL 3: Ecology and management of beneficial organisms

The research in this product line will focus on understanding and using agro-ecosystem resilience as an approach to sustainably control pests and diseases. Ideally, the agro-ecosystem has to be developed to function in a largely self-regulating manner to counteract a range of pests and diseases. Maintaining and promoting the natural antagonistic potential should become one of the major elements of crop health management to stabilize RTB agro-ecosystems and reduce the incidence of pests and diseases. This will include research on soil management for specific soil pests and diseases. For RTB, a large number of entomophagous species are important as natural biotic limiting factors of pests. Their abundance and efficacy depend on various factors (e.g., farmers' agricultural practices and pesticide use; temperature and climate change; limitations in food, shelter, and alternative hosts due to landscape fragmentation or monocropping) that might limit their contribution in balancing pest populations. In the Andes, for example, the heavy use of pesticides over decades has reduced resilience of potato agro-ecosystems to major pests and would require the recuperation of beneficial insects in an IPM program. Hence, our joint research will generate important knowledge and information on the underlying drivers of (natural) pest control and how their efficacy can be effectively augmented using the potential of conservation, augmentation, or classical biological control approaches (see Box 4.3.3). By bringing technologies to farmers, biological control has often been instrumental in increasing agricultural productivity and reducing pesticide misuse in developing countries such as the introduction and release of an exotic wasp to control successfully the exotic and invasive cassava mealybug in Africa (Neuenschwander 2003).

Box 4.3.3: Fighting the sweet potato weevil with pheromones

CIP and international partners are working with farmers in Uganda and the Philippines to adopt and test the use of attract-and-kill technology to combat three species of sweetpotato weevils which can reduce crop production by as much as 60–100% in Africa and Asia. The efficacy and costs of this innovative technology will be compared with previously used mass trapping devices. Attract-and-kill technology relies on an insecticide–pheromone co-formulation: male moths are attracted by the pheromone and killed through contact with the applied insecticide. This strategy is consistent with the aims of IPM and environmental sustainability because only the target pest is affected, significantly reducing the amount of insecticide needed and thereby avoiding deleterious effects on beneficial and other non-target organisms.

Microbial organisms associated with pests, plants, and soils serve multiple functions: biopesticides, stimulation and strengthening of plant growth, and pest and disease suppression (Berg 2009). An important group of beneficial organisms are entomopathogens (nematodes, bacteria, baculoviruses, and fungi) of pests that will continue to play an important role in pest management. New isolates will be identified, characterized, and developed into biopesticides. Vegetative planting material represents an important risk for the transmission of pests and diseases. It can also be associated with beneficial microbial organisms supporting plant growth (e.g., in yams, see Tchabi et al. 2010), in addition to suppressing pests and diseases. These organisms could be isolated to develop microbial treatments stimulating plant growth and defense functions. The microbial communities associated with RTB are made up of those that can be readily isolated and cultivated and those that have only been discovered with the use of molecular fingerprinting and other novel techniques (Berg and Smalla 2009). Both of these groups will make up an important R4D program that will be explored and exploited in this product line. All of the CRP-RTB centers have ongoing R4D activities on the use of beneficial microbes that can be cultivated and used to inoculate planting material or soils (Sikora et al. 2008). This will provide the initial basis for a cross-crop product and shared

knowledge base on the collection of beneficial microbes, formulation methods, and delivery systems for their use in pest and disease management by small-scale farmers.

Synergies generated by collaboration among participating Centers will be used in many ways in species identification with classical taxonomy or novel molecular tools to characterize microbial communities. In collaboration with ARIs, we will work in the long-term preservation and data bank of microorganisms; the facilitation of shipments of biocontrol agents; and in the formulation, production, and promotion of biopesticides through collaborations with the private sector and others.

PL 4: Specific management strategies

PL 4 does not have cross-cutting activities. However, a number of common principles could be shared, particularly on how to implement, assess, and learn from integrated pest and disease management programs. Crop-specific management strategies and technologies will be developed and shared among the Centers involved in the CRP-RTB, but also will be provided as input to those CRPs (1.1 and 1.2) dealing with system approaches. Some of these include:

- Strategies for soil and nutrient management to improve plant health and enhance plant defense mechanisms
- Sanitation measures for inoculum reduction and eradication of pathogens in farmers' fields
- Use of varieties with single or multiple resistance to RTB pests and diseases, including genetically modified RTB
- Best-bet cultural practices to reduce the incidence of pests and diseases
- Strategies to enhance natural biological control
- Integration of bio-rationals (e.g., attract-and-kill), biopesticides, botanicals, and other innovative technologies.

IPM will often entail a judicious mix of different methods, supported by farmers' decision-making tools. Our research will emphasize multifunctional management tactics, seeking to integrate pest and disease control in the context of agro-ecosystem management. Agro-ecosystem modeling, based on information systems to streamline the collection of farm record metadata, will guide the optimization of pest and disease management, balancing interventions with an enhanced recruitment of ecosystem services (link with Theme 5).

The development of IPM for key pests and diseases will be accompanied by socioeconomic research on adoption of knowledge-intensive versus chemical input-extensive pest control strategies. Cost-effectiveness as a driver of adoption of control measures for pests and diseases will be studied. Issues such as participatory research and training methods as well as farmer perceptions of pests and the risks of yield loss versus risks of pesticide use will be addressed (Rola, Jamias, and Quizon 2002; Norton et al. 2005; Hashemi and Dalas 2011; Daniel et al. 2011).

We will continue to contribute to the sustainable management of whiteflies, a key pest complex that directly and indirectly affects roots and tubers. Emphasis will be on host-plant resistance, as CIAT has commenced promising work to identify and potentially clone whitefly-resistant genes from cassava to facilitate an eventual transfer to other crops. More innovative work in CIAT's pipeline includes the identification of obligate whitefly symbionts as targets of control efforts.

Participants of the RTB stakeholder workshops stressed the importance of cross-regional learning for scaling-out proven technologies of pest and disease management. For instance, previous experience of managing similar bacterial wilt diseases in LAC and Asia enabled countries in East

and Central Africa to respond quickly and effectively to a rapidly spreading epidemic of a new disease, banana *Xanthomonas* wilt.

4.3.4 Critical Assessment of Methods

PL 2: Ecology, biology, and epidemiology of pests and diseases—Development of diagnostic tools for rapid and accurate detection of major pathogens in lab and field

More rapid, sensitive, and generic methods need to be developed to identify and monitor emerging diseases and support seed quality improvement programs in the developing world. This is particularly critical in clonally propagated crops, which are prone to build up of seed-borne diseases through successive generations. Diagnostic microarrays (Frey et al. 2010, Engel et al. 2010) and next-generation sequencing approaches (Kreuze et al. 2009, Adams et al. 2009, Roossinck et al. 2010) both have the potential to detect multiple pathogens simultaneously, including to various levels of unknown ones. Next-generation sequencing methods are ideal to rapidly diagnose novel diseases and survey pathogen variability; however, they are still quite expensive. Microarrays on the other hand can achieve very low per-unit cost if printed in big volumes, which is achievable if pathogens (e.g., for all RTB or CGIAR crops) are included on the array generating a one-for-all concept. Direct field testing is dominated by the serologically based lateral flow devices, which are rapid, easy to use, and interpret. Generic lateral flow devices can be produced to detect any pathogen DNA amplification products, thus combining the ease of use and interpretation of these devices with the sensitivity and specificity of isothermal amplification methods (Tomlinson, Dickinson, and Boonham 2010). An added benefit of isothermal amplification is that it can be applied in the field as it does not require bulky and sensitive thermal-cycling equipment like polymerase chain reaction (PCR)-based methods (Gill and Ghaemi 2008).

PL 3: Ecology and management of beneficial organisms—Inventory, collection, characterization, and documentation of pathogenic and beneficial RTB-associated organisms

Only through comprehensive living reference collections of correctly identified and well-maintained strains, representing the genetic diversity of a target organism, can robust, specific, reliable, and efficient diagnostic and detection tools be developed. Constraints and opportunities to better organize diagnosis of plant diseases through the links of networks, in both developed and developing countries, is addressed by the review of Miller, Beed, and Harmon (2009).

Pathogen population research has been very active in *Phytophthora infestans*, causal agent of LB in potato and tomato. To date, a large array of markers has been developed for phenotypic and genotypic characterization (Cooke and Lees 2004) and a regional database in Europe now houses information on more than 20,000 isolates (Hansen et al. 2007). The European consortium, EUCABLIGHT (www.eucablight.org) has developed procedures and tools for standardized data input and storage. The EUCABLIGHT developers have now joined forces with the Borlaug Global Rust Initiative (www.globalrust.org/) to develop new portals where knowledge on crop constraints can be managed. A portal for cereals will first be developed, then subsequently one for potato that can be used in the CRP-RTB. Similar technology could eventually be applied to other vegetatively propagated crops.

Biocontrol of plant pathogens and arthropod pests based on naturally occurring antagonists offers promising perspectives for RTB crop protection. Genetic analyses provide an accessible and highly informative means to examine predator-prey interactions and identify key natural control agents (Symondson 2002, Garipey et al. 2007). PCR-based gut content analysis is used as a novel tool to assess predation on soil-borne pests (Juen and Traugott 2005). Recently, this approach has helped identify predators of multiple important cryptic insect pests such as the coffee berry borer or the

western corn rootworm (see Jaramillo et al. 2010; Lundgren, Ellsbury, and Prischmann 2009). Aside from using regular PCR to record predation, predator importance can be determined through prey detectability half-life and quantitative PCR assays (Greenstone et al. 2010, Weber and Lundgren 2009). PCR-based gut content analyses can shed light on resident natural enemies of multiple cryptic RTB pests, such as the banana weevil, potato weevil, cassava burrowing bug, or sweetpotato weevil. They thus could constitute an invaluable tool in the development of eco-efficient pest management programs in a broad range of crops and geographical settings.

PL 4: Specific management strategies—Methods for studying degenerative diseases of vegetatively propagated crops

Degeneration (i.e., the increased frequency of disease-affected individuals within a crop over successive cycles of propagation) is a major problem of vegetatively propagated crops. In the past, capacity to optimize management of these diseases has been hampered by a lack of coordination among related disciplines: plant breeding, plant virology, and plant disease epidemiology (Jeger, Dutmer, and van den Bosch 2002). Plant disease modeling would appear to be one way to incorporate perspectives from these disciplines to design the best control strategies (Jeger et al. 2004). Research done in this CRP will build on a strong body of literature related to virus epidemiology.

A number of models have been devised to evaluate different control measures for degenerative diseases such as African cassava mosaic virus (Holt et al. 1997; Jeger et al. 2002; van den Bosch and Jeger 2001; Jeger et al. 2004; van den Bosch, Jeger, and Gilligan 2007) and sweetpotato virus disease (ibid.). In contrast, there are some diseases that are most noteworthy for their lack of attention, including those causing degeneration of potato, and in particular, non-virus diseases such as bacterial wilt (bacterial) or black scurf (fungal) of potato.

One modeling study aimed at deciphering the complexity of potato seed degeneration in developing countries was done by Bertschinger, Keller, and Gessler (1995) working in Peru in the 1980s. These workers developed EPIVIT, a PC-based model that predicts degeneration by major virus diseases utilizing temperature (related to altitude) as a driving variable. On the other hand, the use of insect vector phenological models (Gamarra et al. 2009), in combination with virus transmission models, can enable the prediction of risk of virus spread and their contribution to seed degeneration as affected by changing climate. Such models can help in predicting future changes in speed of degeneration in crops and, when combined with previously mentioned models, provide recommendations for control measures to maintain seed health at an acceptable level.

4.3.5 Partnership

Different components in this theme depend on different kinds of partners. For example, detection, monitoring, and surveillance will rely on access to cutting-edge technologies acquired through partnerships with leading research institutes. Some of these partnerships are in place for the different implementing Centers, but as part of the network mapping and characterization process of existing partnerships to be undertaken with support from Component 7, PL 2, these will be harmonized and streamlined. Other kinds of “partnership types” relevant to this theme will be further refined through the systematization process. It is expected that the CGIAR Centers’ role will be important in the participatory development of learning materials and methodology, in conjunction with the participation of governmental agencies, NGOs, and farmer organizations that are involved in farmer capacity building. The Centers can play a facilitator role aiming at North-South and South-South associations that frequently do not occur. For example, an existing partnership with the Food and Environment Research Agency (Fera) will be strengthened to help in areas of pest risk analysis, surveillance strategy, and technical support to diagnostics lab and field. A good example of the support that Fera is currently providing is with the Great Lakes Cassava Initiative (see

<http://www.glc.fera.defra.gov.uk>). Other partnership opportunities will be explored with Global Plant Clinics. We will continue to build on the existing partnership with the Euroblight Network (<http://www.euroblight.net/EuroBlight.asp>) designed to monitor LB of potato; technology and methods developed by the network will be employed in target areas.

In further collaborations, CIP participates in two European Union Framework 7 funded projects (Q-BOL and Q-DETECT) in which CIP has a key role in validating advanced diagnostic and surveillance technology, developed by leading advanced European research laboratories, for quarantine pests and diseases and transferring this technology to NARS on a global basis. The Q-BOL project looks at applications of DNA-barcoding technology to facilitate and simplify identification of any quarantine pest or disease. This technology will benefit not only European countries through reduced import of quarantine pests, but also Southern countries through increased capacity for pest identification, development of World Trade Organization-required national and regional pest lists, and facilitation of intra-regional trade. The Q-DETECT project has similar aims but looks at modern methods of pest surveillance through technologies such as remote sensing, acoustic detection, and electronic noses.

A strong collaborative effort led by CIP has been established between IITA, the International Centre of Insect Physiology and Ecology, the University of Hohenheim, Germany, and NARS in Africa. Researchers are developing and applying innovative phenology modeling and risk mapping to understand the effects of rising temperatures caused by climate change on the distribution and severity of major insect pests on important food crops in Africa. This collaboration is part of the research framework implemented by the Systemwide Programme on Integrated Pest Management.

Product lines related to epidemiology and biology, as well as that of specific management activities, represent areas where the historical approach of only “on-station” research should be avoided. Hence, we will ensure that CRP-RTB research is demand driven, which is most effectively achieved in a participatory manner with both next- and end-users. For this purpose, interactions with system-oriented CRPs such as those dealing with dry areas and humid/sub-humid tropics will be essential.

The collaboration of our partners throughout the product lines is key to realizing Theme 3’s impact pathways (see Table 4.3.1).

Table 4.3.1 Roles and Responsibility of Partners in Impact Pathways

Product Lines	Representative Key Partners		Roles and Responsibilities
PL 1. Detection, surveillance, and mapping	- NARS - Universities - Global plant clinics (CABI) - FAO - Farmers	- Fera - Regional and international networks and crops societies - Protection agencies - Quarantine services	Leading research institutes develop technologies for detection, monitoring, and surveillance. Diagnostic and monitoring networks help in pest risk analysis, surveillance strategy, and technical support. Local farmers' systems for surveillance collaborate with quarantine services and CABI.
PL 2. Ecology, biology, and epidemiology of pests and diseases	- ARIs - NARS - Universities - Primary industry	- Mycothèque - Farmers - NGOs - Systemwide Program on Integrated Pest Management	ARIs, NARS, and universities join forces to enhance understanding of and develop models for pathogen ecology and epidemiology. Partners develop tools for phenotyping for biotic stresses. Collection holders assist in collection and characterization of pathogen diversity.
PL 3. Ecology and management of beneficial organisms	- ARIs - NARS - Universities - Science academies	- Mycothèque - Private sector - Insectarium - Farmers	Collection holders assist in collection and characterization of natural enemies and beneficial organisms. NARS and extension services develop biological tools for controlling pests and diseases. Private sector involved in developing biopesticides.

Product Lines	Representative Key Partners		Roles and Responsibilities
PL 4. Specific management strategies	▪ NARS ▪ ARIs ▪ Networks ▪ NGOs	▪ Associations ▪ FAO ▪ Government agencies ▪ Private sector ▪ Farmers	Develop specific management techniques for major RTB pests and diseases. Government agencies, NGOs, and extension agencies will be involved in training and capacity building.

4.3.6 Gender strategy

The gender strategy for Theme 3 underscores the importance of understanding and, where appropriate, building on existing pest and disease knowledge of local farmers, differentiated by gender, and providing well-targeted new learning experiences that can provide information, generate knowledge, and teach skills for the sustainable management of these biotic stresses in specific regions, systems, and crops.

As stated elsewhere in this proposal, women are often the principal cultivators of RTB and are faced with dealing with pest and disease problems, though the exact role of women and the level of pest and disease pressure vary across different regions and production systems. The importance of particular pests and diseases and their appropriate management also vary depending on whether the main objective of the production system is for household consumption or for market sale. The theme will factor in the role of women and the relative contribution of the different RTB crops to food security and income in determining priorities and actions.

Until quite recently, men have tended to have a leading role in pest and disease control, primarily through the application of pesticides, which are acquired through commercial and social networks they tend to control (Arce, Prain, and Maldonado 2009). However, with increasing migration of men to urban centers and for other reasons, this appears to be changing. More women are becoming directly involved in preparation and use of pesticides, which increases health risks to themselves and their children. At the same time, there is evidence that women have greater concerns about agriculture-health linkages—both positive and negative—and are receptive to IPM messages (Norton et al. 2005). Thus there are strong arguments for involvement of women in alternative forms of pest and disease management. Capacity strengthening in Theme 3 will pay special attention to women's needs for information and methods that can facilitate their understanding of biophysical information, which is frequently complex and not related to local or indigenous knowledge.

The research approaches to be adopted will involve a gender audit of systems and regions where pests and diseases of global importance are prevalent. This will draw on existing general tools for gender analysis in agriculture (Feldstein and Jiggins 1994, Fernandez 2009) as well as more specific approaches focusing on gender and IPM. FFS will continue to be used as a key methodology for both research and farmer learning about detection, risks, ecology, and biology of pests and diseases and about options for sustainable management.

4.3.7 Communication and knowledge sharing

Because of the involvement of stakeholders from different perspectives (e.g., R&D), defining clear and user-friendly communication and knowledge-sharing tools, according to the focus of each product line, will be an important element of success of this theme. The idea is to link specialists from different disciplines—for example, plant pathologists with partners working with farmers at field level.

Platforms for pathogen and pest surveillance and risk assessment will be built on effective content management and communication tools. One example could be the tools used in Europe for pathogen monitoring of the pathogen *Phytophthora infestans* within the Euroblight network

(www.euroblight.net). The CRP-RTB could also link up with initiatives like the Global Plant Clinics, now embedded in PlantWise (<http://www.cabi.org/default.aspx?site=170&page=3057>), or other participatory networks such as Global FFS. On the basis of farmers' queries, and advances from CGIAR scientists (e.g., resistant varieties), the Global Plant Clinics can help clinic and CRP staff write fact sheets about new disease-resistant varieties and management issues, which can be used in extension programs and in mass media (Bentley et al. 2009). Through a system of plant doctors linked up with diagnostic services, new RTB pest and disease observations could be entered into a global database and mapped (see Box 4.3.4).

Box 4.3.4: Blue Sky communication mechanisms

The rapid progress in information communication technologies (ICT) will facilitate communication among RTB stakeholders. For example, images sent by partners on the ground will help build a global image bank of RTB pest and disease symptoms organized by crop and region. This database, combined with a set of step-by-step questions on observed symptoms, could further be exploited for the development of an electronic diagnostics key, making use of image recognition tools. Linked to a cell phone application tool, this methodology would allow farmers to obtain a rapid identification by simply taking a picture and a few key observations, and submitting this information to the global databank. A similar tool could also be developed for variety recognition (Theme 1), as is currently being done for several crops by PI@ntNet (<http://www.plantnet-project.org/page:technologie?langue=en>).

The kind of communication activities among different stakeholders contemplated here was recently highlighted as needs for management by a group of international LB experts (<http://sites.google.com/site/bellagiolbnov2009/home>). The success of the proposed pest and disease detection platform will also depend upon implementation of an effective Web application that makes the information readily available for users. This will also be essential for communicating results of surveillance and mapping and risk assessment of pests and diseases, which will have to be communicated to decision-makers through appropriate means, particularly ICT.

4.3.8 Capacity strengthening

Integrated pest and disease management is knowledge intensive. Farmers need to know about the pest and disease biology, sources of infestation or infection, dissemination mechanisms, and interaction with external factors such as weather conditions. Researchers and other decision makers (e.g., from regulatory or plant health organizations) need access to up-to-date information about existing and emerging pests and diseases, risk management and forecasting, and management technologies (e.g., the management of beneficial organisms).

Capacity needs of NARS needs to be strengthened in new areas of research such as modeling, GIS, risk management, use of beneficial organisms, and assessment of pest and disease management programs. Given the progress in ICT, methods for long-distance training could be assessed in terms of effects on learning and cost effectiveness. ICT or cross-learning visits will promote North-South and South-South learning. Cross-learning, through the formation of communities-of-practice among CGIAR Centers, is important in order to share information, experiences, and training materials.

We will use standardized methodologies to compile and revise existing CS learning resource materials or to develop new ones and IPM activities common to RTB crops. The CS process for next- and end-users will focus on identification of necessary capacities, from which appropriate learning experiences will be developed. The CRP-RTB will interact closely with partners for building capacity of both next- and end-users, including governmental agencies and NGOs (Ortiz 2008).

A second level that requires methodological research is how to strengthen the capabilities of field workers (extension workers, technical advisers, facilitators) to access and use up-to-date

information regarding the management of RTB pests and diseases, and how to facilitate farmer learning of pest and disease management principles and practices. In the same way, different options could be explored to reach as many field workers as possible with at least three types of information: biology and behavior of pests, control methods, and participatory training methods.

A third level that requires methodological research, which could be conducted in linkage with Theme 5 and in interaction with CRPs 1.1 and 1.2, is how to strengthen farmer decision-making regarding RTB pest and disease management. This focus on capacity strengthening would build on existing pest and disease knowledge of local farmers and involve users in the assessment of alternative forms of pest and disease management. A number of methods have been tested with different degrees of success—for example, FFS, plant health clinics, farmer-to-farmer, and radio to provide technical advice. Therefore, the methods should be adapted and assessed in terms of contribution to cost-effective scaling-up and -out of technologies to control RTB pests and diseases.

4.3.9 Links with other themes and CRPs

This theme will work closely with Themes 1 and 2 to share diagnostic and screening tools for specific pests and diseases, and identify and test the potential of tolerant or resistant germplasm for pest and disease management. Similarly, close linkages will be necessary to ensure the multiplication of clean planting material in Theme 4. We will explore interaction between pest and disease and crop management practices, together with Theme 5, and impacts on postharvest losses and food safety with Theme 6. This theme will rely on input from Theme 7 to develop effective partnerships, capacity strengthening, and communication approaches related to pest and diseases.

There are natural links with other CRPs that will be developed early in the implementation process. For example, bananas and cassava are important components of many of the lowland humid tropical ecosystems, and disease and pest work should be coordinated with CRP 1.2. Ready-to-use pest management technologies could be validated and adapted through CRP 1, assessing how technologies perform within a broader agro-ecosystem (e.g., potatoes in systems where other *Solanum* species are grown may be at greater risk of being affected by LB or other common pests or diseases). We also anticipate a close link with the wheat component of CRP 3 because of development and use of a common platform for cereal rusts and the LB pathogen, *Phytophthora infestans*. This platform involves a number of partners, including European laboratories, the FAO, and The World Vegetable Center. We will also establish an important linkage with CRP 7 to look into changes in and implications of the spread and severity of pests and diseases as a result of climate change.

4.3.10 References

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4.4 Theme 4: Making Available Low-Cost, High-Quality Planting Material for Farmers

4.4.1 Rationale and objective

The quality and availability of planting material are a recurrent concern of small farmers in developing countries, particularly for those who grow RTB crops. Organizations dealing with plant health issues are also concerned about planting material because it is often an important carrier of new or existing pests and diseases. Planting material is a key component for reducing the “yield gap” and allowing the expression of the genetic potential of improved or native cultivars in terms of productivity. The quality of seed depends on several biophysical factors: (1) *physiological*—germination rate and initial vigor, (2) *genetic*—heritable traits and purity, and (3) *health*—presence of pests and diseases. This is equally the case for the vegetatively propagated crops (see Table 4.4.1), although the concept of seed quality and seed systems was originally developed for true or sexual seed crops.

Table 4.4.1 Clonal Crops—Some Characteristics of Planting Material

Crop	Planting Material	Planting Density (plants/ha)	Planting Material (kg/ha)	Yield (t/ha)	Major Seed-Borne Pests/Diseases
Banana and plantain	Non-edible corm. suckers	1,000–2,000	500–1,600	10–70	BBTV, BSV, BBrMV, CMV, BMMV, BVX, <i>Cosmopolitus sordidus</i> , nematodes, <i>Fusarium oxysporum</i> pv. <i>cubense</i> , <i>Xanthomonas campestris</i> pv. <i>campestris</i>
Cassava	Woody stem section with 5–7 nodes	8,000–16,000	500–1,000	10–30	<i>Colletotrichum gloeosporioides</i> , <i>Xanthomonas manihotis</i> , EACMV, ICMV, ACMV, EuCMV, CBSV, Frog-Skin disease, super-elongation disease
Potato	Edible tuber, true potato seed	25,000–50,000	1,500–3,000	10–40	PLRV, PVY, <i>Ralstonia solanacearum</i> , <i>Pthorimaea operculella</i>
Sweetpotato	Vegetative shoot	15,000–40,000	100–200	8–30	SPCSV, SPFMV, SPMNV, SPCFV, SPLCV, <i>Cylas</i> spp., <i>Alternaria</i> spp.
Yam	Edible tuber piece, aerial tuber	8,000–12,000	2,000–3,000	10–30	DAV, CMV, DbBV, DaBV, YMV, <i>Colletotrichum</i> , <i>Erwinia amylovora</i> gloeosporioides, <i>Planococcus</i> sp., <i>Aspidiella hartii</i> , <i>Meloidogyne</i> spp., <i>Scutellonema bradys</i>

Currently, more than 95% of RTB planting material used by small farmers originates from the farmer’s own field or a neighbor’s field, except for the case of potato and banana in a few localities with a very high market orientation. Locally produced planting material is extremely low cost, especially for out-of-pocket expenses, although in certain cases such as yam, costs may be high. Low cost—an important feature for small farmers in marginal environments—the relatively high volume of planting materials needed, and the perishability of planting material are just some of the many challenges to increased use of quality planting material by small, poor, and women farmers, particularly from off-farm sources. (See for example FAO 2010 for an analysis of the issues with planting material in cassava in SSA.) In only very few instances have private sector suppliers been able to develop a steady market for high-quality planting material. This has resulted in a heavy dependence on public sector initiatives to develop clonal crop seed improvement initiatives, either based on new cultivars or disease-free planting material. Lack of access to quality planting material appears to be the single most important limiting factor contributing to the observed yield gap seen in developing countries for all of the RTB crops. Furthermore, the lack of effective seed systems holds back the rapid and wide-scale adoption of new cultivars, with their associated pro-poor traits,

and thus we fail to exploit and benefit from the substantial investment in CGIAR and other partner pro-poor breeding programs. In addition, seed stocks are at increased risk due to the more frequent extreme climate events (droughts or floods), which can reduce dramatically the amount of planting material from one season to the other.

The challenges that RTB have in common for seed improvement initiatives are numerous. They include high volume of planting material, low multiplication rates that slow scale-up of new germplasm, transmission of pests and diseases from field to field and season to season, perishability of planting material, and, frequently, the lack of an organized seed system. The scope of these challenges suggests that a cross-crops approach could have efficiencies in terms of cross-learning and more rapid progress to achieve impact for poor and women farmers. In addition, an increase in production and volumes of supply would enable farmers to take advantage of emerging market opportunities at local, regional, and national levels.

Priorities for improving impact are national policy and planning frameworks that address clonal crop issues, infrastructure and human resources for quarantine, multiplication of both healthy and improved germplasm, and strategies to link the incipient formal system with networks for traditional locally produced planting material and to reach poor clients. Such an approach must build on public sector capacity, but quickly move to mobilize both private sector and civil society entrepreneurs as well as farmer-based organizations to increase farmer use of higher quality planting material.

The global objective of Theme 4 is that poor farmers and rural communities use clean (or at least higher quality), low-cost, genetically adapted, high-performing RTB planting material through the use of tools, methods, and frameworks developed by CGIAR Centers and public and private sector partners. The challenge is not to convert all farmers to the use of commercial planting material or new cultivars, but to target actions and zones where improvements in the diverse components of quality have the highest impact on poverty reduction through productivity, income, and nutrition (see Box 4.4.1). This impact will particularly benefit women, who have an increasingly important role in RTB management and, in some areas, are fully in charge of taking care of the planting material from one season to the other.

Box 4.4.1: Vouchers for cultivars

The Sweetpotato Action for Security and Health in Africa project is testing a novel proof of concept for project beneficiaries. This initiative links integrated OFSP agricultural-nutritional intervention to a health service delivery system serving pregnant women at five health facilities in Kenya. Women who make pre- and postnatal visits at the clinic receive vouchers worth 6 kg of OFSP vines of two new cultivars: 150 cuttings of Kabode and 150 cuttings of Vita. The vouchers have either a nutrition message on OFSP consumption or an OFSP planting message in Kiswahili printed at the bottom.

The CGIAR Centers of the CRP-RTB, since their inception, have engaged in seed system R&D. This focus has expanded in recent years with an increasing emphasis on impact, especially for poor and women farmers. For example, IITA employed quality management protocols to effectively mobilize virus-resistant cultivars of cassava to millions of farmers in SSA, has simplified the use of boiling water to clean banana planting material of weevils and nematodes, and has established clean seed yam systems in Nigeria that use both traditional and novel propagation techniques. IITA's national partners in Ghana and Nigeria have also developed effective rapid propagation techniques for cocoyam (*Xanthosoma* sp.).

Bioversity has teamed with private sector laboratories to develop innovative systems for BBTV-free planting material in Asia (Molina et al. 2009) and Africa and has also collaborated in simple, low-

cost approaches to produce highly uniform planting material for high-density, frequent replanting. CIP has developed multiple strategies to enhance farmer access to improved, healthy planting material for sweetpotato and potato based on aeroponics (rapid multiplication technique), innovative PPPs, diffused light storage, and farmer roguing of diseased plants with application to conditions of Africa, Asia, and LAC. CIAT has pioneered rapid, continuous media recycling for large-scale cassava multiplication with adaptations for decentralized rural infrastructure applicable in LAC, Africa, and Asia. Cross-center approaches to seed systems have occurred in specific contexts—for example, the Consortium for Improving Agriculture-based Livelihoods in Central Africa in Central Great Lakes Africa (www.cialca.org), FAO-led cross-center development of quality-declared seed protocols for vegetative crops, GPG2 Safe Movement of Germplasm best practice for clonal crops, SP-IPM collaborative research (Markham et al. 2007), and IITA-CIAT collaborative agreements for Africa.

The proposed thematic area on access to clean, high-quality planting material for RTB offers a unique opportunity to develop a more innovative cross-crop approach that brings both efficiencies and synergies to improving the quality of planting material used by poor farmers for clonal crops. Theme 4 is a key element in farmer access to new germplasm with disease resistance and greater yield potential as well as planting material free of pests and diseases. In the regional RTB stakeholder workshops held in August 2010, seed systems were identified as a priority for collaboration between CGIAR Centers and country partners (Annex 1). Participants emphasized that innovative approaches to improving the quality of planting material used by marginal households can have a high return.

4.4.2 Impact pathway

Achieving impact with poor and especially poor women-headed households in the CRP-RTB depends on effectively linking all thematic areas. Theme 4 is of particular importance, as seed systems link efforts in genetic resource conservation and characterization, breeding, and pest and disease management with the use of these materials and knowledge by poor households. Since planting material of higher quality may also require additional investment by the farm household, in many cases upgrading market access and prices through a value chain approach may be central to improving the quality of planting material. Tripp (2003) proposed that a commercial seed sector can only arise with demand from market-oriented farmers who are willing to pay for quality planting material (as was the case in Shandong, China, when adoption of virus-tested sweetpotato planting material accompanied a transformation in the use of the crop from a subsistence one to a commercial fodder crop).

Targeted approaches to impact pathways and capacity building for improving farmer access to quality planting material need to consider the specific context of each country and the locality, taking into account supply and demand for seed (Pray and Ramswami 1991). The interface between an often incipient formal system for vegetative seed material and the informal vegetative seed system is the primary focus for analysis and possible action in Theme 4. A more effective impact pathway should respond to a number of key questions:

- What are important cultivars for market and local food?
- What are major disease threats and what infrastructure is appropriate to respond to them?
- What are the opportunities to improve marketing?
- What infrastructure and human resources are currently available to engage in improved farmer access to or use of planting material?
- Is there a role for private sector investment?
- What are the specific needs and opportunities of the poor, poor women, and other marginal households in terms of accessing improved planting material?

For example, a recent survey by CIP found that 14 out of the 19 countries in SSA had at least some experience of in-vitro multiplication, although many of the facilities are in poor condition and not currently active. About half are capable of virus detection through Enzyme-Linked ImmunoSorbent Assay methods (very few PCR), but currently only two—South Africa and Kenya—carry out thermotherapy and virus indexing.

Figure 4.4.1 shows a generic description of the impact pathways envisaged for Theme 4.

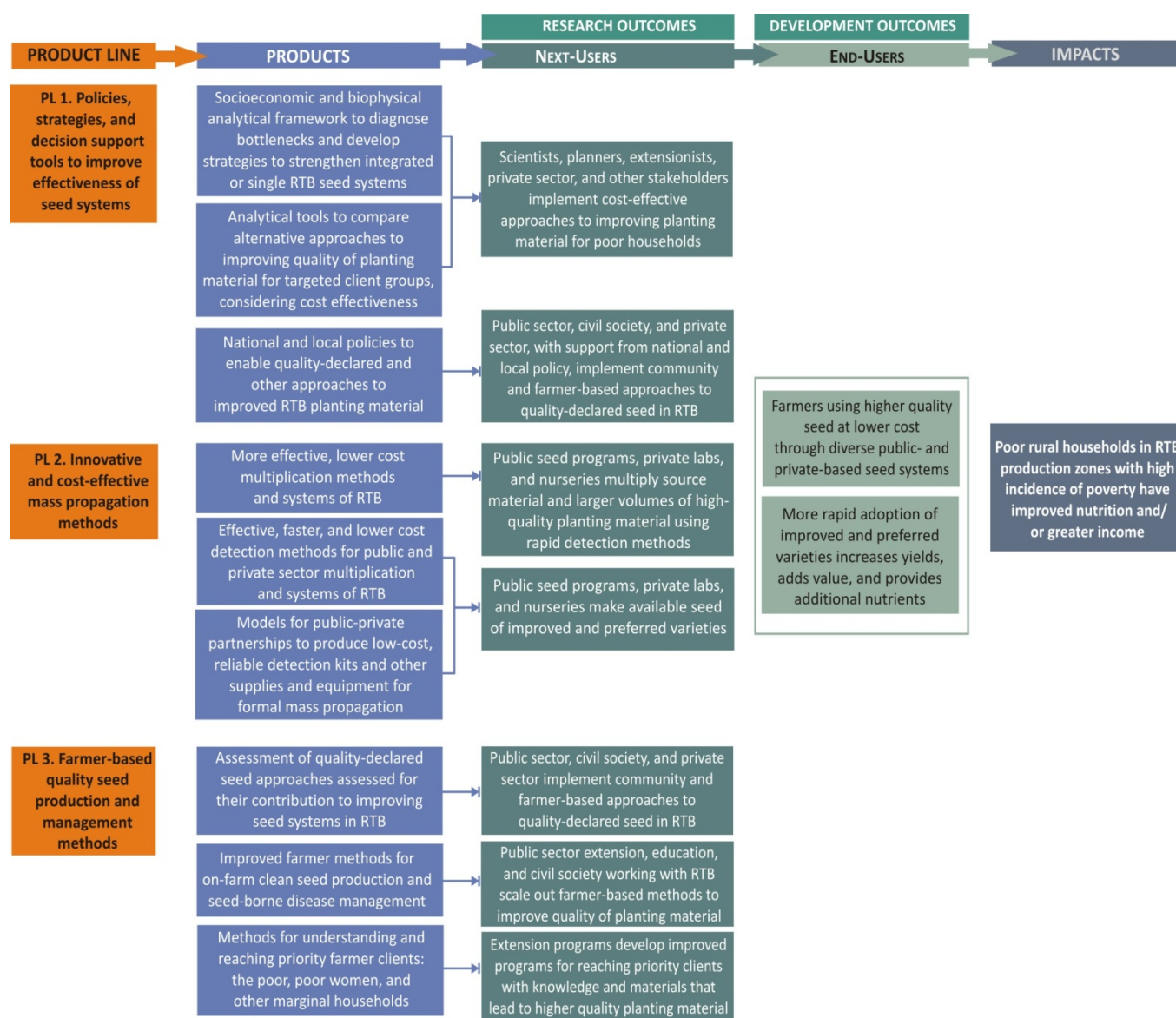


Figure 4.4.1 Theme 4 product lines, products, outcomes, and impacts.

More context-specific impact pathways will be developed. When responding to pest and disease threats involves on-farm practices (PL 4), and farmers are market oriented with functioning access to sources of information, a simple impact pathway can be visualized based on training (printed, audio, and audiovisual) documentation. The application of tools from PL 1 may be useful to design and monitor these actions. In other cases, responding to pest and disease threats may require off-farm action (e.g., breeding a resistant cultivar and then multiplying planting material, organizing a

supply chain of virus-free planting material, establishing internal quarantines to reduce the spread of a disease through planting material). BBTV is a common disease that threatens food security and income from bananas in Central Africa. In such cases, the three product lines in Theme 4 contribute to an improved impact pathway. Initially, a general diagnostic is needed using the socioeconomic and biophysical framework for bottleneck identification and development of strengthening strategies (PL 1). On the basis of these results, the analytical framework to compare alternative delivery systems and other strategies (PL 1) can be applied in combination with approaches for characterizing priority client farmers (PL 3).

Multiple products from diverse themes, including Theme 4, will be needed—rapid diagnostic tools, low-cost methods for multiplication of clean source material, value chain building, and farmer training. Building awareness (and creating the demand for quality planting material) of the benefits of investing in quality planting material will be critical, as are demonstration trials and participatory yield trials. We will explore more innovative approaches such as the widespread distribution of affordable, small packs or quantities of healthy planting material. Understanding why and when smallholders will invest in quality seed is also important as is investigating mechanisms to increase access to capital (such as Savings and Internal Lending Communities and internal loan communities) and reducing and managing the risk of investing in quality seed (input insurance schemes, seed credit, seed banks, etc.).

4.4.3 Product lines

We have identified three key R&D areas (product lines) related to seed systems for the delivery of products by the CGIAR centers in the CRP-RTB and their advanced research, national research, and field partners. This builds on current efforts for greater efficiencies and expands into new areas to attain more impact-oriented outcomes. Annex 2 contains the product line description tables (research products, outcomes, milestones, and key partners).

PL 1 addresses the need to find institutional and action frameworks to target priority interventions according to current country capacity, pest and disease threats, and consumer preferences given the predominance of farmer-based seed systems. A more robust framework for learning and action is proposed to facilitate the identification of policy issues, partnership approaches, and strategies for alternative delivery channels for the use of high-quality planting material by farmers.

PLs 2 and 3 address specific bottlenecks for more effective approaches by public and private sector partners as well as farmer organizations. These include lower-cost and more effective methods for rapid multiplication and storage of elite, market-preferred, and clean material as basis for organized seed system; and farmer-based seed production and management methods to improve the genetic, health status, and physiological quality of vegetative planting material.

PL 1: Policies, strategies, and decision support tools to improve effectiveness of seed systems

Plant breeders of RTB have ambitious plans to exploit further the genetic potential of RTB in terms of overall yield, quality, and biotic and abiotic stress tolerance. Pathologists of RTB have built a substantial base of techniques for detecting seed-borne diseases, developing strategies for maintaining source material free of pathogens, and for enhancing planting material with microbial organisms. Biotechnologists are improving the effectiveness of mass multiplication techniques of high-quality planting material. These are central elements to a successful formal seed system. Poor rural producers of RTB, on the other hand, obtain more than 95% of their needs for planting material from the farmer-based or traditional seed system. In PL 1, the CRP-RTB addresses the issue of the configuration of policy, institutional, and action frameworks to increase poor farmer use of high-quality RTB planting material. The priority regions where CRP-RTB will contribute to

poverty reduction vary widely in their current capacity to achieve this end (see below). The research challenge is to develop frameworks and models to ensure effective access and to extrapolate strategies according to the current capacity and bottlenecks of each region and country. The characterization by Trigo (2003) of country capacity to access and use biotechnology was used as a model by Staver et al. (2010) to characterize country capacity to improve farmer use of higher quality planting material. Three categories of capacities were proposed:

- Minimal: limited capacity for quarantine, virus detection, and research on multiplication, incomplete collections, limited extension coverage, and very little market for seed and agricultural inputs (DRC, Central African Republic, Haiti, Guinea, and Papua New Guinea).
- Moderate: small-scale, semi-commercial and commercial tissue culture, more extensive germplasm collections, greater quarantine and research capacity, and an incipient market for improved quality planting material (Uganda, Cameroon, Nicaragua, Peru, and Sri Lanka).
- High: large-scale commercial tissue culture labs, more fully implemented quarantine procedures, and a commercial market for improved quality planting material (Ecuador, Costa Rica, Brazil, India, China, and South Africa).

Such a scheme can be applied differentially to regions and crops (i.e., certain region/crop could have minimal capacity, while in others—within the same country—could have high capacity) and needs to be expanded for application to the priority regions with poor households depending on RTB for food and income. Pilot work will be targeted to developing successful delivery mechanisms for germplasm and knowledge based on local capacities. Extrapolation will be based on agro-climatic as well as institutional and market similarities. Similarly, pilot work will be targeted to leveraging infrastructure for successful delivery of one crop to the improvement of use of clonal crop planting material in other RTB crops.

The following research questions can be asked, for cross-crop products and gender approaches:

- What are primary bottlenecks to farmers' use of higher quality planting material? How do these vary from country to country and what alternatives are most effective in addressing them?
- What are alternative approaches to develop a formal component to more effective farmer-based seed systems? How do these vary for countries of different capacities?
- Under what conditions and how much are farmers willing to pay for improved quality planting material?
- What measures can be taken to reduce the risk to smallholders when investing in quality seed (e.g., input insurance or seed credits)?
- How can the different clonal crops be piggybacked for more effective delivery systems?
- How to ensure that stakeholders in public and private sector adopt standard protocols that improve production and distribution of high-quality planting material?
- How do successful delivery systems need to be modified to serve poor women-headed households?
- What actions can be done so that the current legislation and universities accepts and promotes the informal and combined systems (formal/informal)?
- How could the standards for seed certification be more realistic for RTB?

Cross-crop products for the period 2011–2013 will focus on cross-commodity lessons and advanced hypotheses.

Key reviews (Venkatesan 1994, Thiele 1999, Louwaars 2007, Barker 2008, Staver et al. 2010) have proposed that improved farmer access to quality seed is better served by a combination of formal and informal mechanisms. However, for clonal crops, a conceptual framework to analyze ex-ante alternatives to bottleneck identification and alternatives for system strengthening is not yet available. This was highlighted by stakeholders in the August regional workshops who emphasized that RTB are generally absent from government rural development strategies.

We have identified four cross-crop products:

1. A socioeconomic and biophysical model for diagnosing bottlenecks and developing strengthening strategies of integrated or single RTB seed system will bring together CIP, IITA, CIAT, and Bioversity with advanced research partners.
2. Tools for the design of targeted dissemination mechanisms to farmer use of higher quality planting material based on the compilation and analysis of past and ongoing work. Special emphasis will be on cases in which poor and women farmers are the priority beneficiaries. The components of self-financing delivery systems are expected to depend on current country capacity, degree of market orientation of RTB growers, disease threats, and crop biodiversity.
3. An assessment of the potential for exchange of source materials and commercial lots of seed through the development of harmonized country-level legislation.
4. Since the farmer-based and combined seed systems are not accepted or promoted in current legislation, the CRP-RTB could influence decision makers and act at a policy level, including suggesting realistic standards for certification of planting material such as the adoption of the FAO's quality-declared seed standards recently developed for RTB crops through CGIAR collective action with the FAO.

Capacity development and communication activities and tools will be targeted to policy makers; research and extension directors; and leaders and planners of rural development from civil society, farmer organizations, private investors, and the public sector. We will use participatory multistakeholder planning and prioritization tools applied to the analysis of farmer use of higher quality planting material, policy briefs, and case studies of successes and failures to ensure uptake by next-users. For example, tools for achieving official recognition of quality-declared seed as an intermediate approach between certified seed and informal seed systems has already been piloted by CIP and national partners. This should lead to the design, monitoring, and evaluation of investment strategies, policies, action plans, and capacity building derived from the integrated framework for seed system diagnostic.

PL 2: Lower cost, more effective mass propagation methods

The provision of improved planting material for clonal crops has a proven track record in poverty alleviation. Its efficacy has been through recovering crop yields after catastrophic disease spread and raising crop productivity, both as a result of improved phytosanitary quality and the dissemination of improved cultivars with their associated pro-poor traits. Successful cases have been documented for viruses—for example, in sweetpotato in Shangdong Province, China, and Zimbabwe, Uganda, and Malawi; in cassava throughout SSA; and for BBTv in Philippines and other countries in Asia. Cavatassi et al. (2009) documented the use of these techniques to improve potato seed quality for accessing high-value markets in Ecuador. In the case of sweetpotato in China, national authorities adopted CIP technology of virus indexing and tissue culture that ultimately boosted incomes of 7 million smallholders and improved yields by 30%. The key components in these successes include the capacity for multiplying small amounts of high-quality germplasm through several stages, maintaining preferred germplasm free of serious disease threats and available for multiplication, and monitoring the quality of material at each different stage. There is

an ongoing need to develop more effective and lower cost methods. For example, CIP has recently adapted aeroponics to multiply elite potato cultivars that reduces the generations in multiplication from 5–7 to only 3, with considerable cost savings (see Box 4.4.2). Although this represents a considerable breakthrough, the technique can only be applied to countries with a moderate to high capacity to improve farmer access to quality seed. Successful work in this product line will be manifested by a menu of methods for mass propagation and cleaning for RTB, which can be applied in a wide diversity of country contexts from those with both low and high capacity and for individual as well as multiple crops.

Box 4.4.2: 3G—Rapid multiplication of quality potato seed and public private partnerships

Potato is an important staple crop in Kenya. National yields remain at 7 t/ha whilst the progressive farmers exceed 25 t/ha. CIP trials have demonstrated that the single most important component of this yield gap is access to quality planting material. Public and parastatal bodies struggle to produce even 1% of the national seed needs. CIP has increased access to quality seed through an innovative partnership of public, parastatal, and private organizations and the introduction of new rapid multiplication technology (aeroponics), which lowers costs. This limited (three) generation, or “3G,” strategy has seen the development of a nascent but thriving private sector seed sector. High-grade seed is further multiplied through a network of over 65 decentralized small private entrepreneurial seed multipliers, trained through the project who are starting to earn a good income from seed sales. To date, the project has trained 12,000 smallholder potato growers through the “select the best” training program, with participants recording average yield increases of 30% by simply marking and harvesting next year’s seed from healthy plants.

Several research questions can be asked, considering cross-crop products and gender approaches:

- What is the role of public and private sector actors in using mass propagation methods for making new cultivars available and in cleaning useful cultivars for market-oriented and home consumption farmers?
- Can efficiencies be gained through a common infrastructure for multiplication of several clonal crops in the same facility?
- What are efficient and effective monitoring strategies for both public and private approaches to mass propagation of elite materials?
- How can current and promising methods be further modified to lower the cost, to reduce the infrastructure demands, and to reduce the degeneration rate? How can virus screening be done both at a lower cost and with lower risk of virus presence? Are beneficial microbes present that need to be conserved rather than cleaned?

Two cross-crop products are proposed initially:

1. A platform for enhanced knowledge sharing about methods for mass propagation and rapid pathogen detection and the varying contexts for their successful deployment. Although PL 2 is crucial for farmer access to high-quality planting material, we do not anticipate that methods will have any particular gender bias. During the compilation of methods, we will gather information on possible gender implications. We will develop and validate a framework to evaluate cost effectiveness and identify gaps in approaches for maintenance and multiplication of clean source material.
2. Models or approaches for PPP to produce low-cost, reliable detection kits and other supplies and equipment for formal mass propagation, an important service link for functional and effective public and private organizations. We will review our experiences and identify key successful elements. Follow-up will be based on successful cases and a review of opportunities for expanded action by country capacity.

Capacity-strengthening activities and communication tools will be targeted primarily to technical and managerial staff in public and private laboratories, quarantine departments, and universities. These are key next-users whose work will link formal multiplication, cleaning, and monitoring activities with key nodes in informal, local farmer networks. Manuals and guides, training courses, in-service training, and graduate student research will build on existing programs, taking a cross-center and cross-crop approach for greater effectiveness. The cross-crop products from PL 1 will provide the framework for identifying the appropriate capacity-strengthening and communication activities according to country capacity, crop biodiversity, market orientation, and the threats of diseases.

PL 3: Farmer-based quality seed production and management methods

The improvement of seeds has been a key component of increasing agricultural productivity. Improved yields can come from more uniform and vigorous crop stands, clean planting material free of pests and diseases, and cultivars with greater yield potential or resistance to key pests and diseases. The challenge for breeders, agronomists, and rural development planners is not to convert all farmers to the use of commercially acquired planting material—especially under conditions where very few farmers use commercial planting material—but to facilitate farmer access to planting material of ever increasing quality (physiological, genetic, or phytosanitary). For poor farmers of RTB, under many circumstances this may mean improving the quality of farmer-saved seed; in fact, partners in LAC considered the most important action that the CRP-RTB can make is to improve the quality of planting material (see Annex 1). The partner centers in the CRP-RTB have been pioneers in this area. For example, CIP’s “select the best” promotes the selection of healthy potatoes that improves the yield potential of the remaining saved as seed by an average of 28% (Gildemacher et al. 2007). Although now expanded to include 12,000 smallholders in East Africa, the initial progress only serves to highlight the potential. Much work is still to be done.

Several research questions can be asked, considering cross-crop products and gender approaches:

- What seed quality problems can be addressed by farmers (differentiated by gender)?
- What are current farmer practices for the selection and exchange of planting material that favor and disfavor the maintenance and improvement of quality?
- Do the resource level of the household and the gender of the household head affect the capacity to implement farmer-based seed production and management methods?
- What are the returns on farmer-implemented quality measures versus other approaches?
- What are key factors in improving access to quality planting material among poor households? What seed technologies are more suitable for non-market-oriented farmers?
- What upstream links to informal community networks are most effective to provide clean foundation stocks of farmer-preferred landraces and improved RTB planting materials?

Three cross-crop products are proposed initially:

1. A platform for enhanced knowledge sharing about methods for on-farm clean seed production and on-farm seed-borne disease management. Successes and failures with improving farmer selection, including a review of the capacity building and scaling-out dimensions, will be compiled.
2. Strategies and methods for characterizing and reaching high-priority rural clients: poor rural households, women in poor households, women-headed poor households, and other marginal households will be consolidated from the experiences of RTB CGIAR Centers and other initiatives in agriculture and health.
3. Guidelines for quality-declared planting material in RTB draws on the results of a workshop in 2007 held by the CGIAR centers in collaboration with FAO to prepare It will be improved

through pilot testing of decentralized and farmer-managed approaches based on declared quality for their contribution to improving seed systems in RTB.

Tools for capacity strengthening and communication will be targeted to those working in scaling-out strategies to rural households—training of trainers, extension staff, nutrition and rural health workers, farmer promoters, and diverse members of farm households. Through improved teaching materials and field exercises for technical high schools, universities, and extension training programs, farmers will receive technical assistance in quality planting material (Gildemacher et al. 2007). Model materials that can be translated into local languages will be made available electronically in resolution for easy reproduction (see examples under extension at the site: <http://platforms.inibap.org/xanthomonaswilt/>).

4.4.4 Critical Assessment of Methods

PL 1: Policies, strategies, and decision support tools to improve effectiveness of seed systems—Analytical tools to compare approaches to improve the quality of planting material for targeted client groups

For RTB in the tropics and the subtropics, more than 95% of farmers source their planting material from their own or their neighbors' fields or from the local market. The seed system work in the CRP-RTB seeks strategies to improve the timeliness, quality, and production potential of planting material that will make the largest overall contribution to food security and poverty reduction. Responding to this challenge requires a set of complementary methods from the level of policy and prioritization to applications of advanced multiplication technologies to farmer skill-building based on the identification of critical knowledge.

Key reviews (Venkatesan 1994, Thiele 1999, Maredia et al. 1999, Louwaars 2007, Barker 2008, Staver et al. 2010) have proposed that improved farmer access to quality seed is better served by a combination of formal and informal mechanisms. The focus on the quality of planting material, including phytosanitary aspects and timeliness, dictates a perspective beyond the classic formal seed system, which looks at the supply of improved varieties. On the other hand, this CRP also recognizes that improved cultivars will form an important component of pro-poor impact, especially through virus resistance, improved vitamin and mineral contents, and yield potential under abiotic stress. Analyzing farmer access to quality planting material with an innovation system framework as proposed by Weltzien and vom Brocke (2000) and Lal (2008) suggests a focus on information access and multiple stakeholders in the generation of new economic and social value. Theme 4 has summarized these different issues in its proposal to develop a socioeconomic and biophysical model for diagnosing bottlenecks and developing strengthening strategies of integrated or single RTB seed systems. The importance of both the biophysical as well as the socioeconomic dimensions of such a model are illustrated by Staver et al. (2010), who highlighted the importance of cultivar diversity, disease threats, and current country capacity. Hirpa et al. (2010) as well employed a procedure to analyze within-country differences and identify priority actions for different client groups.

PL 2: Lower cost, more effective mass propagation methods—Platform for enhanced knowledge sharing about mass propagation methods and effective use of detection tools and cleaning procedures

For the diverse vegetatively propagated crops in CRP 3.4 the pipeline of new cultivars is relatively well stocked (Theme 2) and technologies for cleaning current cultivars of problem diseases, particularly viruses, are well established. This CRP, through Theme 4, proposes to emphasize a key step that increases the impact of improved varieties and the value of cleaning technologies: lower cost mass propagation techniques. Each of the RTB has biological particularities that require different mass propagation techniques, and the RTB Centers have made leading contributions in

this area. We propose to develop a platform for enhanced knowledge sharing about methods for mass propagation and rapid pathogen detection. This platform will emphasize cost effectiveness, the identification of gaps, and the varying contexts for their successful deployment. Corrêa et al. (2007) compared propagation methods of potato tubers, incorporating not only technical criteria but also costs and multiplication ratios. The proposed platform will provide both technical information and document the services and inputs required for different methods, thus allowing for more informed planning and implementation of mass propagation in different contexts. The need for simple and low-cost mass propagation is especially great in those countries that have more limited service capacity for low-cost laboratory, greenhouse, and nursery technologies. Work by CIAT with continuous media recycling techniques, CIP with hydroponics, and IITA provide initial models. Hamill, Moisaner, and Smith (2009) demonstrate the role of micro-propagation in Australia in clean planting material supply chains and highlights the potential for cross use of facilities among crops. This type of comparative approach is proposed to be central to the knowledge-sharing platform.

PL 3: Farmer-based quality seed production and management methods—Quality-declared seed approaches assessed for their contribution to improving seed systems

Quality declared seed is an attempt to bridge the gap between the opportunities represented by improving seed quality to farmers with the diversity of farming systems and cultivars and the predominance of local planting materials. FAO (2006) provided an updated version of guidelines for a concept that originated in the 1980s for true seeded crops. In 2008 it convened a workshop to develop quality seed standards for vegetatively propagated crops and was published in 2009. The CRP-RTB will build on this initial collaboration among the CGIAR Centers and FAO to develop specific applications of the principles of quality-declared planting material for RTB crops.

4.4.5 Partnership

To implement Theme 4, a large diversity of partners at multiple levels will need to be drawn on, both upstream and for action research. ARIs have an important role in formal research as well as in the extrapolation of successful seed system programs with clonal crops. The CRP-RTB Centers have all undertaken multipartner initiatives to improve farmer access to quality planting material. We will use the systematic review of the lessons from this ongoing research to be undertaken with input from Theme 7, PL2, as proposed in the cross-crop products. This will include network mapping and evaluations of collaborative arrangements to provide guidelines for future partnership building, particularly through platforms that bring together a wide diversity of partners from the private and public sectors, civil society, and CBOs (see Box 4.4.3). New kinds of partnerships for infrastructure planning and development, particularly laboratory capacity with a cross-crop focus, will be needed as well as partnerships for institution building for quarantine and seed system governance and effectiveness. Action research partnerships involving PPP; private enterprise promotion; and capacity building with scientists, laboratory and field technicians, and trainers and extensionists will also be established. Through partnerships based in specific countries, we will pilot useful models that can then be scaled-out both through South-South partnerships and regional networks such as the banana regional networks.

Box 4.4.3: Small farmers benefit from public-private partnerships

BBTV, caused by a virus and spread by an aphid vector, *Pentalonia nigronervosa*, is a major disease that affects important local cultivars grown by small-scale farmers in Asia and Central Africa. Infected plants become stunted with narrow leaves, chlorotic, and unproductive. Suckers taken by farmers from infected but symptomless plants are an effective means of spreading the disease. In the Philippines, Bioversity worked with public sector universities and research agencies to understand disease epidemiology and identify key management strategies (INIBAP 2004). Private sector commercial tissue culture companies diversified their product line normally centered on export bananas to include local cultivars used by small farmers. State universities trained small local nursery operators in key weaning and hardening practices for tissue culture banana. As a result, small farmers in the Philippines within reach of large urban markets have recovered an important income-generating option.

The collaboration of our partners throughout the product lines is key to realizing Theme 4's impact pathways (see Table 4.4.2).

Table 4.4.2 Roles and Responsibility of Partners in Impact Pathways

Product Lines	Representative Key Partners		Roles and Responsibilities
PL 1. Policies, strategies, and decision support tools to improve effectiveness of seed systems	▪ NARS ▪ ARI ▪ Universities ▪ Planners ▪ Extensionists	▪ Private and public sectors ▪ Civil society ▪ Industries ▪ NGOs, FBOs, & CBOs ▪ Farmers	NARS will help gather and analyze information on experiences from local, national, and regional systems for RTB seed systems. Conduct policy analysis to understand limitations to seed uptake. Conduct analysis of research needs with stakeholders.
PL 2. Lower cost, more effective mass propagation methods	▪ NARS ▪ Public seed program officers	▪ Private labs ▪ Nursery officers ▪ NGOs, FBOs, & CBOs ▪ Farmers	NARS will help compile experiences at local, national, and regional levels on mass propagation systems. Private labs, nursery officers, NGOs, FBOs, and CBOs will contribute to the development of locally adapted and effective propagation systems.
PL 3. Farmer-based quality seed production and management methods	▪ NARS ▪ Local leaders ▪ Extensionists	▪ Public sector officers ▪ Private sector actors ▪ Civil society ▪ NGOs, FBOs, & CBOs ▪ Farmers	NARS, public and private sector officers, and NGOs, FBOs, and CBOs apply farmer participatory methods to understanding best practices for seed production and management. Align for-profit private sector expertise and experience with on-farm seed systems. Develop coordination among farmer seed producers to optimize the overall system. Farmers will be trained on seed production and management methods through farmer field schools and other methods.

4.4.6 Gender strategy

As women often play an important role in the production of RTB for food and other uses, they have a particular need for access to quality planting material of their preferred cultivars. In many cases, however, women and men have differential access to formal and informal seed systems. An important cross-crop product for this theme will be to understand the seed needs of key end-users, including different household members, which will provide the starting point for developing more effective access to quality planting material, especially by women in poor male-headed households. This will synthesize the experience of the CGIAR Centers and their partners.

Starting in 2011, we will also develop a biophysical and socioeconomic framework for identifying bottlenecks and for developing CS strategies for single- and multi-crop systems. This framework will incorporate gender analysis, building on such experiences as documented by Conlago et al. (2009). The proposed analytical tools for comparing alternative CS systems will also examine gender-specific

delivery systems. On the basis of the results of the application of these and other tools, more effective approaches will be incorporated into RTB research with partners. Applying a gender perspective to analyze and improve seed systems will help to overcome or at least reduce existing biases in access to, availability of, and use of adequate seed.

4.4.7 Communication and knowledge sharing

Cross-crop products will be the primary focus for communication and knowledge sharing in Theme 4, although crop-specific communication and knowledge sharing will also continue both through ongoing mechanisms and through Theme 7. The cross-crop products will capture many of the relevant crop-specific experiences. During 2011–2012, CGIAR scientists will compile and analyze RTB crop-oriented experiences and lessons that will contribute to the formulation of the tools, methods, and frameworks to strengthen farmer access to improved quality planting material. Communications with policy makers and planners will focus on informing them and strengthening their vision of the specifics of farmer access to improved planting material. The tools, success stories, and case studies will be documented in concise formats and complemented with proposed discussion formats on identifying bottlenecks, evaluating alternative policy approaches, and developing targeting strategies for poor households. For example, an innovative method called horizontal evaluation (Thiele et al. 2007) will be used for fostering knowledge sharing and program improvement among CGIAR Centers and their main stakeholders. Knowledge products will derive from the initial workshops mentioned above. The knowledge products will be oriented for use by diverse stakeholders in countries with different current capacities as explained in PL 1. We will generate improved versions and additional case studies based on the initial use of tools. These will be shared through network workshops, electronic media, and printed material.

4.4.8 Capacity strengthening

For the CRP-RTB Centers, capacity strengthening for increased use of high-quality planting material has been an ongoing concern. These efforts will be redoubled and sharpened in focus for a greater impact on poverty reduction through this proposal. Initially, our first priority will be to consolidate the tools, methods, and frameworks applicable to clonal crops and to identify cross-crop complementarities. This effort will include building a greater understanding of how to strengthen seed systems in the context of differing country capacity and of differing threats to and opportunities for higher quality planting material. A greater understanding is also needed about how to reach marginal clients, poor and female, either with planting material or appropriate training for on-farm improvement of planting material quality. Specific CS activities are described in each of Theme 4's proposed product lines at the level of multistakeholder, institutional, and policy frameworks. Other areas of capacity strengthening include technical training in conjunction with infrastructure improvement for the public and private organizations in the incipient formal seed system and materials, and training adapted to highly local circumstances for creative, farmer-friendly scaling-out approaches for improving the use of high-quality planting material. For this last category, capacity strengthening will extend beyond conventional agricultural extension to include rural health workers, CBOs, farmer marketing groups, and primary and secondary schools.

4.4.9 Links with other themes and CRPs

Theme 4 is central to CRP-RTB and will link with all other themes (see Fig. 4.4.2). Theme 4 draws on CRP 2 outputs for improving the tools and action frameworks for better farmer access to quality planting material—an important example of input supply chains—for client characterization and targeting, and for policy analysis and change. We will also establish links with CRP 1 where prototype formal and informal seed systems can be validated and adapted further. Functioning seed systems will be critical to make desired planting material available within the nutrition component of CRP 4 and within the adaptation context of climate change presented by CRP 7.

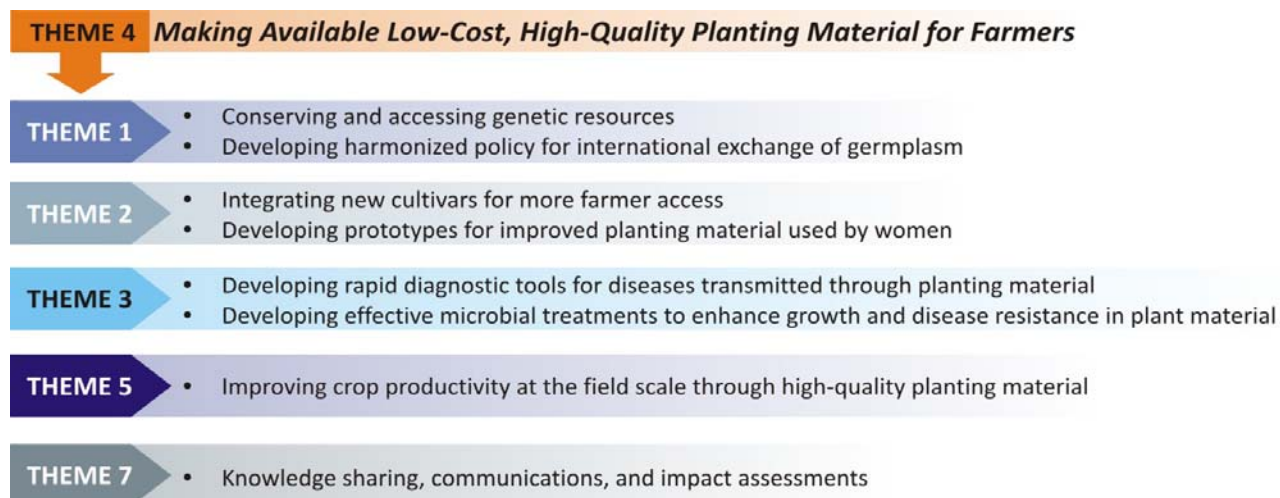


Figure 4.4.2 Theme 4: Links with key features of other CRP-RTB themes.

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4.5 Theme 5: Developing Tools for More Productive, Ecologically Robust Cropping Systems

4.5.1 Rationale and objective

RTB are grown in many different climatic regimes across the tropics and subtropics and on soils varying in nutrient supply capacity. Rural households in developing regions often grow RTB with few inputs beyond their own labor, land, and rainfall. What they produce is mostly used for subsistence consumption. However, market-oriented production opportunities are expanding, and traditional strategies to maintain crop and land productivity are increasingly complemented with purchased fertilizers and, in some cases, irrigation, especially for potatoes and bananas.

Although some RTB crops (e.g., cassava and yam) are perceived as being more robust (i.e., less sensitive to adverse biotic and abiotic stresses) than most crops, others such as potato and banana are extremely responsive to improved crop management and can produce exceptionally high yields. Cassava has gained importance over the past decades owing to its ability to yield under marginal soil conditions where most crops will fail (FAO 2010).

There are tremendous new opportunities for the intensification and diversification of RTB cropping systems, for which managing abiotic stresses related to water, temperature, and soil fertility is essential. Abiotic stresses of RTB cropping systems must be understood and managed to create novel crop management systems that are resilient in the face of climate change and use agricultural resources more efficiently. To ensure that the advances in productivity and environmental sustainability reach resource-poor farmers, innovative crop management systems for RTB need to be developed with farmer participation to improve the probability of scaling-up and -out.

RTB management practices for intensification and diversification under a wide range of conditions can be more effective if built on an improved understanding of the crop physiology and at the field scale through an agro-ecosystem perspective. A thorough understanding of the crop's resource use efficiencies, opportunities, and constraints is needed in order to overcome potential shortcomings and ensure sustainable productivity of RTB cropping systems. With such tools as remote sensing and off-site monitoring we will analyze the suitability of decision support systems for improved management given diverse characteristics of households.

Ultimately, the synergy between variety development and crop management research, taking into account farmer decision-making processes, will allow resource-poor farmers to sustain and increase yield for years to come. Issues of cost and ROI also need to be taken into account for developing decision-making tools for targeting management practices to specific conditions of agro-climate, soils, and yield gaps. Tittonel et al. (2009) proposed that increasing household well-being through improved production requires not only increases in input use but also changes in the structure of production on the farm. This suggests changing technology and an evolving role of RTB as households move out of poverty. A focus on agro-climatic as well as household resource access and markets through the decision-making tools will bring these issues into greater consideration. This work needs to be coordinated closely with CRPs 1.1 and 1.2 for production systems in dry and humid areas, respectively.

The objective of Theme 5 is to develop decision support tools for more productive, less vulnerable, and more resilient RTB crop systems. Furthermore, it will focus on the development of tools to facilitate more efficient integration of different management components, related to biotic and abiotic constraints and different levels of resources and plant genotypes (species and cultivars) to produce RTB for particular end-uses or environmental benefits. Management practices involve making the growing environment and supply of resources (i.e., plant nutrients and water) more

favorable for the crop. Plant genotype determines the ability of the crop to withstand any hazards (biotic and abiotic stresses) and produce to the limits set by the environment and resources availability. Understanding crop management decisions according to household characteristics will be key to facilitate the expression of the genetic characteristics of the cultivar.

The integration of crop management to overcome biotic and abiotic constraints will be validated and improved through an assessment of current on-farm practices and farmer participatory experiments involving partner organizations. This will permit a fuller understanding of the decision-making processes for selecting the best management practices from the possible options that would be developed by Theme 3.

4.5.2 Impact pathways

The impact pathway of Theme 5 begins with an improved understanding of the plant and abiotic environment to the field, either in monocrop or mixed. This knowledge will generate alternatives for the optimal management of resources for plant growth and effective strategies for applying these alternatives and varieties in different agro-climatic zones, household typologies, and markets. The improved understanding of crop physiology and crop modeling will strengthen targeting of integrated crop management for diverse agro-ecologies, particularly those related to the management of abiotic factors (water and soil), and provide insights to integrate them with the management of key biotic factors. Although integrated crop management will be site-specific, guidelines and decision support tools will help partner organizations to select best prototype technologies for integration according to local conditions and the characteristics of farmer households. Theme 5 will establish links with other CRPs, particularly the system-oriented ones of CRPs 1.1 and 1.2, so that component technologies and integrated crop management approaches can be tested within system frameworks. Figure 4.5.1 shows the impact pathway proposed for Theme 5.

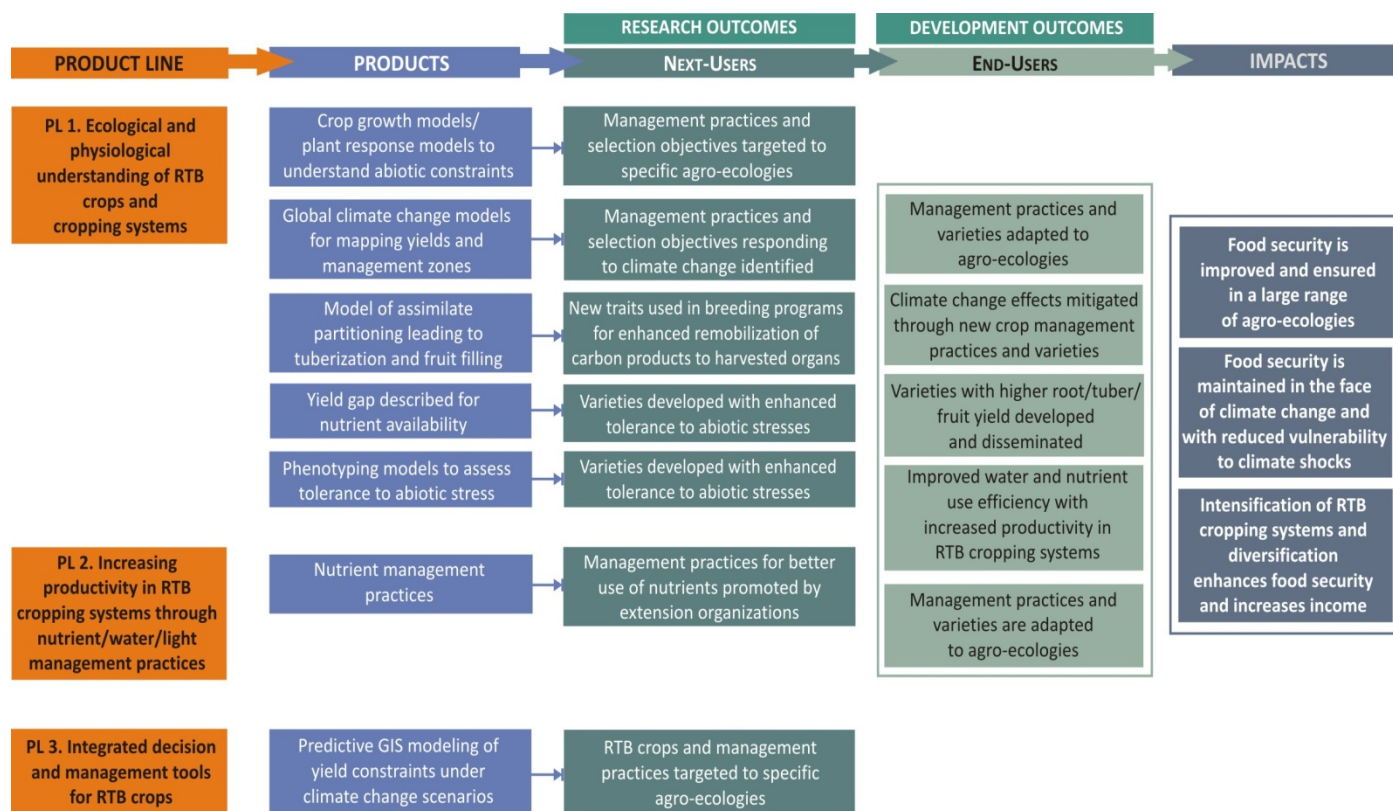


Figure 4.5.1 Theme 5 product lines, products, outcomes, and impacts.

4.5.3 Product lines

Theme 5 examines how the different RTB crops interact with environmental factors and how to apply this knowledge to sustainably increase productivity of diverse RTB systems. PL 1 focuses on understanding crop physiological processes and yield gaps and responses to some fundamental environmental factors and provides inputs for Theme 2. PL 2 looks at how to use this information to improve management practices for increasing RTB productivity. PL 3 explores the integration of diverse management components (i.e., varieties, pest and disease management, seed, soil, and water) to develop and validate decision-support and management tools for RTB crops. Modeling activities in PL 3 integrate information generated by PL 2 and by Theme 3. The three product lines are articulated and interdependent, with the level of integration increasing from PL 1 to PL 3 (Fig. 4.5.2).

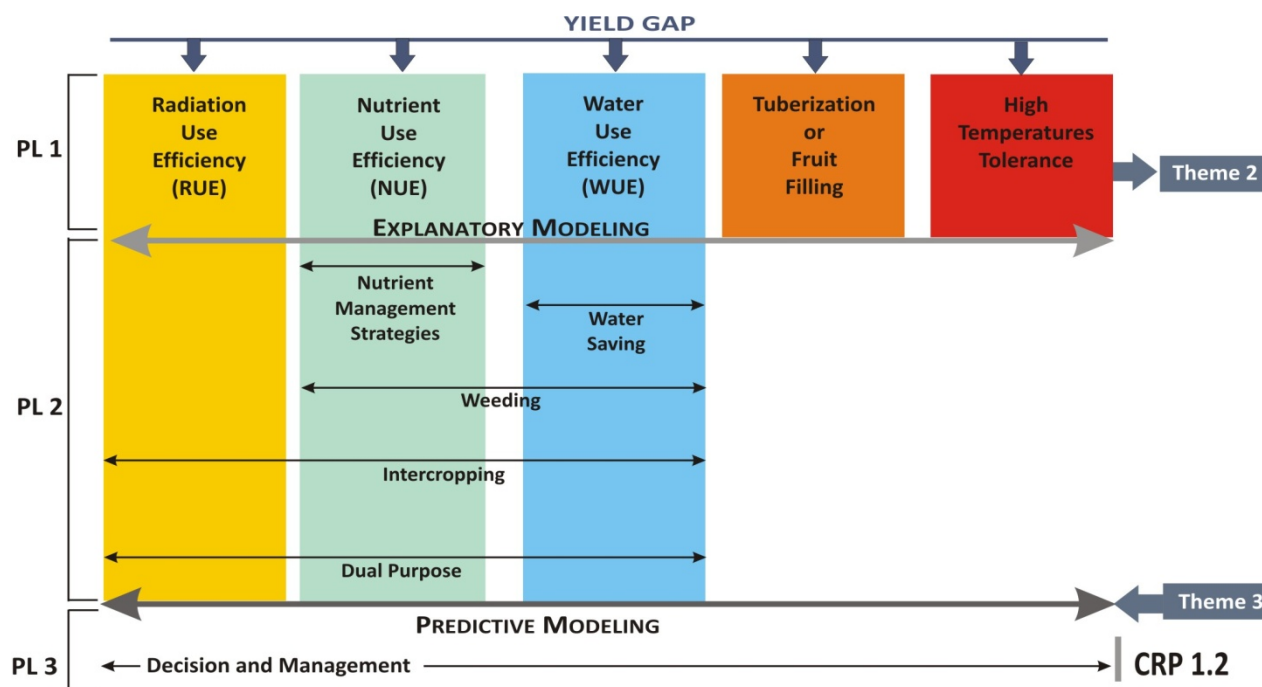


Figure 4.5.2 Theme 5's product lines link with Themes 2 and 3 and CRP 1.2 to address the yield gap.

Annex 2 contains the product line description tables (research products, outcomes, milestones, and key partners) for Theme 5.

PL 1: Ecological and physiological understanding of RTB crops and cropping systems

Radiation use

The quantification of radiation-use efficiency—the amount of dry matter produced per unit of intercepted photosynthetically active radiation—is important for the determination of yield potential in different environments and yield modeling. Light interception models are conveniently used for simulating crop development and growth. The light interception mechanism is generally approximated using canopy cover or leaf area index. Radiation interception alone is a good predictor of potato (*Solanum tuberosum*) total dry matter grown under different environments (Condori et al. 2010). CIP is testing the use of vegetation indexes as a reliable, low-cost alternative to parameterize tuber crops models (see PL 3) or to direct assessment of plant behavior. Data from experiments conducted both in a growth chamber to generate the parameters and in the field for validation were used to prove the concept (Barreda, Gavilán, and Quiroz 2009). The use of vegetation indices shows great value in assessing potato genotype responses to stress and thus might become a useful selection tool, with potential for application to other RTB.

Some RTB crops like cassava, sweetpotato, and yam require high solar radiation for efficient photosynthesis. Shading is frequently a major yield constraint for these three crops in intercropping systems (Lebot 2009). In cassava, shading has a significant effect on growth and production; root bulking starts later and the number of roots per plant is reduced (Okoli and Wilson 1986). Bananas are frequently grown in partial shade in perennial crop mixtures in LAC, Asia, and Africa. Certain cultivars are more shade adapted, persisting and producing in an environment of partial light; tropical aroids are shade tolerant. Little research has been conducted on shading tolerance, although RTB are frequently intercropped. The main approaches are based on artificial shading and estimation of the modifications of photosynthetic activity and pigments concentration (particularly the Chla/Chlb ratio) induced by low radiation.

Nutrient use

As RTB crops are often grown on highly weathered tropical soils, the deployment of sound nutrient management practices is key to maintaining and improving RTB production. Smallholders often use little or no fertilizer inputs in most RTB crop systems. However, RTB generally require substantial amounts of potassium (K), moderate amounts of nitrogen (N), and relatively small amounts of phosphorus (P), among other nutrients. Understanding nutrient acquisition, use, and relative impact on productivity will be essential to developing sustainable management practices for productive RTB systems.

Soil nutrient management and fertilizer applications are often not based on the temporal nutrient requirements of the crop during the cropping season and the site-specific determination of soil nutrient status. This has led to low nutrient-use efficiency (NUE), low yield response of the crops, and negative impacts on the environment as a consequence of nutrient leaching and run-off. For instance, recovery of applied N by crops in field experiments ranges from 40% to 60% for most crops (Mosier, Syers, and Freney 2004). The application of current and further knowledge in plant and crop physiology, root biology, soil-plant rhizosphere interactions, and crop-growth modeling offer interesting opportunities for improving NUE by RTB crops.

In collaboration with Theme 2 we will develop, through breeding, varieties able to absorb and use nutrients more efficiently in producing roots, tubers, and fruit of commercial and food value. The fertilizer-use efficiency could be expressed by different indicators. Agronomic efficiency—calculated as production of tuber/commercial root/fruit per unit of applied fertilizer nutrient; nutrient uptake per unit of applied plant nutrient; and crop quality parameters such as minerals, vitamins, and protein content are all examples of indicators of fertilizer-use efficiency.

Water use

Despite the fact that RTB crops such as cassava seem more resilient to drought stress than most cereal and/or legume crops (Sakai et al. 1994), current changes in climatic conditions (e.g., drought and heat) are likely to impact productivity. There is increasing evidence to suggest that several major RTB production areas in the tropics are experiencing levels of drought severe enough to adversely affect yield potential (Wairegi and van Asten 2010).

Drought is a major constraint for most crops. RTB present different levels of drought tolerance yet are often grown in marginal areas more likely to experience insufficient water. Long crop duration for most RTB means that many will experience a dry season between planting and harvest. Cassava and yam are tolerant (Lebot 2009), but bananas are extremely susceptible to water shortage because of their high leaf area index and shallow root system (Robinson 1996). Potato is also a water-demanding crop, and the critical period to water deficit is from tuber initiation to maturity.

Even short episodes of water stress during this period can significantly reduce yield and quality (Kumar et al. 2004). Aroids also have high water requirements (Lebot 2009).

We will conduct research to define the factors that condition response to drought with RTB crops, improve efficiency of breeding for this important abiotic constraint, and develop improved management tools. Tolerance to abiotic stress is afforded by a combination of morphological, physiological, and biochemical traits expressed at different stages of plant growth and periods with respect to the stress encountered. For instance, cassava can withstand short dry spells as well as prolonged periods of drought for up to 4–6 months. It responds to drought episodes mainly by rapidly closing stomata to reduce transpiration and maintain high water potential in order to prevent dehydration (El Sharkawy 2004). Thus, cassava would greatly profit from improved phenotyping methods to assess RTB tolerance to abiotic stress tolerance in selection schemes. A list of drought-tolerance-related traits has been established for potato, based on metabolite analysis (Schafleitner et al. 2007). It shows that changes in carbohydrate and amino acid metabolism, osmotic adjustment, induction of lipid metabolism genes pointing to membrane modifications, as well as anti-oxidant defense systems confer improved tolerance to drought.

We will focus on drought-tolerance-related traits that can be assessed across RTB and on phenotyping methods that contribute to a better understanding and can eventually further be used in selection schemes. We will test, for example, as a cross-cutting approach potentially applicable further in selection, the $^{12}\text{C}/^{13}\text{C}$ carbon discrimination method (Δ) (see Box 4.5.1). The relationships between Δ and WUE, measured in dry-down experiments (Sinclair, Tanner, and Bennett 1983), will be explored in different RTB crops. The research will be carried out in collaboration with FAO/IAEA, which played a driving role in the use of Δ in wheat and rice (FAO/IAEA 2008).

Box 4.5.1: Carbon isotope discrimination

The capacity of a plant to discriminate between the two stable isotopes of carbon (^{12}C and ^{13}C) has been proposed as an indirect selection criterion for drought tolerance and WUE. In C_3 crops, carbon isotope discrimination allows an integrated measurement of stomatal conductance and can reflect the capacity to accumulate carbon products in storage organs. This technique provides information about stomatal behavior over the plant life cycle and allow estimating WUE components (Misra et al. 2010). The relationship between Δ , yield under drought, and WUE has been particularly well analyzed in C_3 cereals. (This modern tool already contributed to the release of two drought-tolerant wheat cultivars in Australia, but it has been poorly explored in RTB.) El Sharkawy and De Tafur (2007) reported significant correlations between Δ and storage root yield across cultivars. The CRP-RTB Centers plan to take advantage of preliminary results to select for improved drought tolerance and WUE in potato and banana and expand the idea to develop and use this physiological tool in all RTB crops.

Tolerance to high and low temperatures

Little is known about the response of RTB crops to heat. Potato is a heat-susceptible crop: high temperatures reduce tuberization (Stol et al. 1991), decrease photosynthetic CO_2 fixation, alter carbohydrate partitioning to tubers, and reduce overall plant yield (Timlin et al. 2006). Conversely, photosynthesis in cassava has a high optimum temperature (35°C) (Lebot 2009). CIP has developed an in-vitro microtuberization assay for early generation selection for heat-tolerant families. In the present CRP, this assay should be validated in the scope of field trials and subsequently be implemented for heat-tolerance screening in different RTB.

In potato, the use of the chlorophyll fluorescence technique based on an estimation of the thermostability of photosystem II allowed heat tolerance in potato to be predicted and revealed a large variation for this trait (Havaux 1993). This technique could be implemented for heat-tolerance screening in different RTB. Studies on model plants, as well as preliminary data on potato,

have shown that the response to a combination of drought and heat differs from the responses that occur when both stresses are applied individually (Rizhsky et al. 2004). Several drought-tolerance traits were found to be ineffective when heat was present as an additional stress factor. Thus, we will conduct research on response of RTB to drought and heat. This knowledge will help define the physiological factors that condition response to individual and combined abiotic stresses in order to improve efficiency of breeding for these important abiotic constraints and develop improved management tools.

Tuberization and sink strength of roots, tubers, and fruit

The establishment stage, particularly of the root system, is considered to be the most critical phase in the growing cycle of sweetpotato and cassava. Any stress during this period determines later growth and concomitant yield (Pardales and Yamauchi 2003). The moment of complete filling of RTB harvestable organs is generally not known, particularly in potato and sweetpotato. Practical tools to directly study tuberization and phenotype roots are not yet available. In spite of their crucial importance, root traits are not currently included in selection schemes for RTB.

At present, CIP and Embrapa are collaborating on methods that use MRI to monitor root development and water uptake in in-vivo potato growing system. Use of MRI in this application would improve our understanding of the adaptation of roots to drought and soil temperature conditions, and enable direct scoring of root traits in drought-tolerance screening. In cassava, this approach could be used to assess the essential processes involved in storage-root initiation and tuberization. After validation, the in-vitro microtuberization system developed by CIP could serve to establish hormone measurements in stolons, to investigate the interaction between high gibberellic acid levels, and tuberization inhibition under heat. Another way of analyzing the determinism of storage organ filling in RTB is through studying the effects of defoliation at different stages.

Explanatory models

Explanatory models will help explain plant response based on underlying physiological phenomena and sharpen our physiological understanding of how RTB plants respond to the environment. Potato crop growth models are being developed to simulate the expected behavior—growth pattern, development, and yield—of selected genetic materials under drought and heat stresses. Data collected either in greenhouse or in field trials will be used to develop, calibrate, and validate the model. We envisage fine-tuning methods to parameterize crop growth models with field-scale spectral reflectance data of plants under drought or heat stress to simulate responses at different scales. This adaptation will allow the model to simultaneously simulate plant response in large areas using satellite data.

These models can help researchers better understand the potential yield (as a function of light, water, temperature, nutrients) in several RTB. These activities will be developed in partnership with ARIs like CIRAD, Cornell University, and Wageningen Agricultural University, as well as with NARS such as Embrapa, the National Research Centre for Banana in India, and the Centro de Investigacion Cientifica de Yucatan in Mexico for bananas.

Understanding yield gap in field situations

The physiology-related knowledge of RTB developed with the activities described above will facilitate understanding the factors that influence yield gap with respect to plant physiology. Yield and yield constraints data on most RTB crop are lacking or at best of poor quality. As noted in section 1 the drivers of changes in yield over the past five decades (Table 1.4) are poorly understood. Standard yield determination methods such as those applied in cereal systems are often not available or are inconsistently or inappropriately applied in much of the RTB research.

For instance, the harvest index concept used mostly in grain crops could be less useful when calculated for roots and tubers (Hay 1995). On the other hand, expressing yields in unit mass per unit area and unit time (t/ha/yr) is often difficult for crops like banana and cassava. Their crop cycle durations often exceed one year and harvests may be piecemeal (harvest starts some months after planting a plot in a given date and can continue for several months according to food or cash needs) or continuous (planting can occur at different dates in the same plot, so too harvest). Activities under PL 1 will aim at developing novel approaches of determining and expressing RTB yields and the environmental conditions in which these were achieved, facilitating exchange and comparison of yield-related data between major RTB cropping regions.

New analytical tools for yield data have been developed and adapted over the past years to accurately quantify RTB's gaps in yield and to measure the relative importance of different yield constraints in farmers' fields. For example, a tool developed by IITA enables accurate estimation of annual banana yield via quarterly visits to collect data for a predictive equation. This information on yield, coupled with soil and foliar analyses of minerals and nutrients, could enable proper assessment of RTB productivity potential. Preliminary diagnosis of limiting nutrients can be made and then validated in the field.

Remote sensing techniques have been used to assess cropping areas and yield of sweetpotato (Zorogastúa et al. 2007). These techniques are based on the distinct spectral patterns of light reflectance of different plant canopies (Jensen 1996), allowing the crop of interest to be differentiated from other plant coverage and land uses and quantifying their respective areas.

Once available and validated, RTB scientists will need to exchange these novel approaches on how to quantify yield gaps and yield constraints among the RTB scientific community. Thus, such methodologies will simplify the task of identifying RTB production constraints and will be invaluable for assessing the accuracy of crop production statistics.

PL 2: Increasing productivity in RTB cropping systems through nutrient/water/ light management practices

Nutrient management strategies

Sustainably meeting the high nutrient (especially K) requirements of high-yielding RTB crops demands sound nutrient management practices, especially considering the weathered tropical soils where many RTB are grown. Traditional nutrient management for RTB varies widely, from mining adjacent communal land via manure or harvested mulch to basically nothing. Mineral fertilizer plays a significant role in intensified systems, especially in Asia and LAC. The impact of nutrient applications in terms of quantity, type, timing, and placement on RTB yield quantity and quality needs to be better understood in order to maximize returns on nutrient investments. Fertilizer use efficiency can be improved through combined application with organic nutrient inputs. In traditional farming systems, particularly in Vietnam, China, and Indonesia, smallholders apply animal manure to cassava with good results. Little is known, however, about the optimal doses and methods of application. There are some beneficial rhizobacteria that could also improve NUE. This will not only allow farmers to make best use of their locally available resources, but will also minimize environmental impact. The RTB program will also look at how soil fertility could enhance the nutritional characteristics of edible RTB parts.

Tools exist that can help manage fertilization and optimize NUE, including the QUEFTS model (QUAntitative Evaluation of the Fertility of Tropical Soils) developed by Janssen et al. (1990). By combining data from nutrient analyses of soil and plant parts with actual productivity in the field, accurate estimations of the respective impact of each nutrient can be made for a given recommendation domain.

Although most of the research results will be crop and site specific, common principles could be derived from the work on how to better use local sources of nutrients in response to production or market demands.

Water management techniques

Climate change may further increase drought stress when rainfall decreases and temperatures rise. Opportunities for affordable irrigation are often very limited for RTB crops, so it is important to understand if and when supplemental irrigation would be required. Use of locally available technologies to improve water availability also needs to be investigated. This can include the use of water harvesting and conservation technologies such as contour bunds and various types of micro-basins or the use of mulch (Kar and Kumar 2007). This could be particularly important for crops like bananas with very superficial rooting systems. Through the use of mulch, farmers can also reduce weeding and tillage practices that would not only lessen damage to the crop roots, but could also improve soil chemical and physical properties. The potential use of partial root-zone drying as a water-saving technique in potato, to be used in areas where water availability is becoming critical, will be tested on a larger scale. Preliminary results showed that reducing the irrigation water to one half did not affect fresh tuber yield, whereas WUE increased dramatically. The distribution of moisture in the soil improved and the potential evaporation due to the reduced evaporative surface decreased. Results also showed that under low precipitation and low water retention capacity, the use of plastic mulching and a variety selected for drought-prone environments can make the difference for maintaining high yield while reducing the wasteful use of water (Xie et al. 2010).

Intercropping management

RTB are often cultivated in combination with other food or cash crops—an association that minimizes risk, optimizes land use, and maximizes labor input per unit of area and time.

More than one third of the cassava grown in the world is intercropped (Lebot 2009). In the Philippines, 60–70% of the estimated 3.1 million ha of coconut is intercropped with bananas and cassava (Magat 2004). In this case, cassava and banana tend to suffer from shading and production can be very low. Small farmers in LAC, Asia, and Africa have, however, learned to grow bananas in partial shade in perennial crop mixtures. Certain cultivars are more shade adapted, persisting and producing in an environment of partial light (see Box 4.5.2).

Box 4.5.2: Innovative research—High banana productivity in partial light for carbon fixing, nitrogen-balanced banana agroforests

Small farmers in LAC, Asia, and Africa have learned to grow bananas in partial shade in perennial crop mixtures. CRP-RTB scientists and partners propose to use physiological and ecosystem field studies and modeling to optimize resource partitioning among shade-tolerant banana and carbon- and nitrogen-fixing trees to achieve yields of 15 t/year of banana, 5 t of fixed carbon in wood, and 1 t of fixed carbon in soil organic matter and no external nitrogen inputs. If greater banana photosynthetic efficiency is achieved, higher banana yields in lower light can also be realized with accompanying increases in carbon fixation.

Cassava is also frequently intercropped with upland rice, maize, and legumes in Indonesia; groundnut in Vietnam and China; and maize or bean in LAC. The association with legumes is particularly interesting because of their soil-improving (N fixing) characteristics. In Colombia, cassava, when associated with bean, often produces higher yield (Thung and Cock 1979). Cassava with erect growth, late ranching, and medium vigor, producing less shade, is the most suitable for intercropping with low-growing annual species. The shading effect of cassava decreases at the end of its growth cycle, which is often the best time to establish the other crop. This “relay” cropping system can also have positive impact on soil protection (Howeler 2001). Sweetpotato is less

frequently intercropped and generally with bean, maize, and cassava. In Uganda, the association of sweetpotato with maize resulted in good yield for both crops (Stathers et al. 2005). Sweetpotato, particularly the dispersing type, can contribute to weed control. In the case of the cassava/sweetpotato association, nutrients (K and Mg) seem to be the limiting factor of yield (Moreno 1982). Yam has proven to be very susceptible to intercropping (Agbaje et al. 2002).

Intercropping can also contribute to improved human nutrition (e.g., in the case of growing high-vitamin A banana varieties) with green leafy vegetables, which have high micromineral contents (Fe and Zn) that banana cannot provide.

Weed management strategies

Weeds compete with RTB for light, water, and nutrients. The early growth stage (before canopy closes) is the most critical period. Weeding is the most important labor cost. In cassava, the vigorous and early branching cultivars contribute to an earlier formation of cover and limit weed development. Fallow management and use of cover crops such as *Mucuna* or *Crotalaria* have provided excellent results in Ghana. Yam, because of its inability to shade the soil completely, is particularly susceptible to weed competition (Lebot 2009).

Reducing weed competition is especially required when direct planting is practiced. IITA and CIAT are developing herbicide-tolerant cassava germplasm, but there is also a need for additional research to understand how to manage direct planting for cassava. This work will have positive impact on reducing erosion, costs, and labor (particularly for women). These research activities should include an analysis of the impact of direct planting on control of termites in different regions of the world and the development of special machinery in the few areas where mechanical planting is already common (e.g., Brazil).

Managing dual purpose RTB crops

Besides abiotic yield constraints, humans also directly affect yields through harvests of different non-storage plant organs (mostly leaves) at different times and intensities. Leaves of cassava and sweetpotato in particular serve as nutritious food for humans; most RTB crops provide livestock fodder. Leaf pruning may also be required to improve the light availability and reduce water- and nutrient competition for crops that are planted within RTB fields. Although the timing and intensity of leaf pruning during the vegetative and reproductive stages of most RTB crops have not been properly studied, CIP has produced evidence on the use of dual purpose (feed and roots) sweetpotato based on the timely harvest and re-growth of leaves prior to the final crop harvest (León-Velarde et al. 2009). Research is also required to quantify the relationship between leaf-pruning regimes and harvested quantity and quality of storage organs, in order to provide recommendations on tradeoffs between leaf yield and storage organ yield.

Socioeconomic constraints

Social science research will be carried out to diagnose the causes of yield gaps in farmers' fields and experimental stations, constraints and bottlenecks to adoption of higher yielding varieties and improved practices, as well as to identify innovations with a significant potential to resolve the constraints. The specific lines of research will include systems and farm household characterization work (linked to CRP 1.2); farm decision-making processes; ex-ante impact assessment for priority setting; participatory technology development; farmer efficiency and adoption and diffusion of new technologies and practices over time and space; ex-post impact assessment to evaluate the impact of research and learning over time; and policy-oriented research.

PL 3: Integrated decision and management tools for RTB crops

This product line focuses on practical decision support tools to manage RTB crop production, make informed recommendations applicable to wide domains, and provide superior data on actual RTB production that can be used for improved statistical reporting and tracking impact.

Predictive modeling

Increasing productivity of RTB requires a good knowledge of the geographic and temporal distribution of actual yields, potential yields, yield gaps, and constraints contributing to yield gaps for potato, cassava, sweetpotato, yam, and bananas, which are produced in diverse agro-ecosystems and are facing different yield constraints. Potential yield can be estimated from climatic data (radiation, sums of temperatures) and can be easily mapped.

A better knowledge of the yield constraints will help research to explore how RTB crops and their associated crop management technologies can be adopted and adapted in different environments. Such models may sometimes need to be cultivar or cultivar-group specific. Multilocation trials in a wide range of agro-ecologies will help researchers study interactions of genotype-by-environment-by-management and understand how cultivar choice can help farmers use their (natural) resources better. Such trials can also help provide essential data for the crop growth simulation models and help select varieties that have higher nutrient and WUE.

Owing to the lack of reliable production data for some of the crops, actual yield and yield gaps are not always correctly estimated, and RTB scientists will need to exchange approaches on how to quantify them. The data collected on farmers' field yields will be invaluable for assessing the accuracy of crop production statistics. New data analysis tools have been developed and adapted over the past years to quantify yield gaps and the importance of different yield constraints in farmers' fields.

Geographical data on yield gaps, yield constraints, and resource availability, stored in common GIS databases, need then to be linked to agro-ecological data (e.g., soils, climate) to better understand the spatial relationships of these parameters. Such analysis, once extended and validated across RTB and regions, will permit us to accurately identify the main production constraints and estimate the relative importance of different yield constraints. Spatial information on existing abiotic constraints, which can include soil toxicity, drought, and heat, and superposition with maps of RTB cultivation will allow describing mega-environments for each crop and identifying target regions. For water availability, target populations of environments will be defined by combining modeling of water availability (e.g., Aquacrop software developed by FAO) and use of GIS. GIS teams of the four centers will work together to achieve this task.

Modeling can also be used to predict future RTB production in the view of climate change. In banana, the WorldClim dataset for current climate (Hijmans et al. 2005, available at <http://www.worldclim.org>) and Global Climate Models for future climates (www.ipcc-data.org) were used in combination with the Ecocrop model (<http://ecocrop.fao.org/>) to predict future suitability for banana production (Ramirez et al. 2010).

Household and value chain decision and tools for integrated RTB crop management

The improved knowledge on the geographical distribution of the yield gaps and constraints should be matched with maps of resources available to farmers and input/output market prices and infrastructure and information on household objectives and decision making. Combining these data should allow the identification of best-bet technologies. For example, in a study carried out in Uganda,

Wairegi and van Asten (2010) concluded that there is scope for increased input use in banana systems there, but that regional variations in crop response, input/output prices, and price fluctuations have to be taken into account. Modeling can provide further support (e.g., Homologue TM software, Jones et al. 2005) and software can be used to identify areas of environmental similarity (i.e., climates, soils), opening options for transfer of technologies between such homologous areas.

These technologies should be validated and adapted in the different regions before proceeding with out-scaling. Such validation exercises would require conducting a substantial number of on-farm trials to test technologies for their robustness and profitability in a wide range of farmer conditions. Participatory on-farm trials will not only allow the research to better understand the technology efficiencies, but will also enable the farmer to participate in technology development by providing feedback to researchers on perceived benefits and constraints of the tested technologies. A range of tools for farmer participatory technology development can be used in this process—for example, focus group discussions and FFS. The work to be conducted as part of this product line will be coordinated with CRP 1 because the decision and management tools will have to be validated under the conditions of dry, humid, and coastal/aquatic livelihood systems.

Systems and farmer characterization work will use bio-economic modeling approaches of cropping and livestock systems to determine development domains and household typologies. Ex-ante impact studies will be conducted using econometric modeling to evaluate the costs and benefits of new technologies and evaluate their likely impact prior to adoption by farmers. Farm decision-making analyses will apply partial, enterprise, whole-farm, and capital stochastic budgeting and mathematical programming methods to determine the profitability and competitiveness of new technologies and risk-return tradeoffs to investments in new innovations. Participatory technology development will use mother-and-baby on-farm experimental approaches to develop more relevant, practical, feasible, and profitable technologies tailored to varying farmer resource endowments. Studies of farmer efficiency will apply stochastic frontier efficiency techniques within a spatial analysis framework. Adoption studies will focus on qualitative and econometric modeling of adoption processes, factors distinguishing adopters from non-adopters, and factors encouraging adoption.

4.5.4 Critical Assessment of Methods

PL 1: Ecological and physiological understanding of RTB crops and cropping systems—Carbon isotope discrimination

The isotopic distribution of ^{12}C can reveal information about the physical, chemical, and metabolic processes involved in carbon transformations. The overall abundance of ^{13}C relative to ^{12}C in plant tissue is commonly less than in the carbon of atmospheric CO_2 , indicating isotope discrimination (Δ) in the incorporation of CO_2 into plant biomass. Because the isotopes are stable, the information inherent in the ratio of abundances of carbon isotopes is invariant as long as carbon is not lost. Carbon isotope discrimination (Δ) in plants was extensively reviewed by O'Leary (1981) and others.

In crop plants with the C_3 photosynthetic pathway, Δ has been used to assess genotypic variation in WUE and other performance features such as yield (Farquhar, O'Leary, and Berry 1982; Farquhar, Ehleringer, and Hubick 1989; White, Castillo, and Ehleringer 1990). Discrimination (Δ) against the naturally stable isotope ^{13}C occurs during photosynthetic CO_2 fixation (*ibid.* 1989), and this is reflected in the stable carbon isotope composition ($\delta^{13}\text{C}$) of plant tissue. In C_3 plants, Δ is largely dependent on the ratio of intercellular to atmospheric partial CO_2 pressure (p_i/p_a) prevailing when the leaf carbon is assimilated. This ratio represents a balance between the rates of inward CO_2 diffusion controlled by stomatal conductance (G_s) and CO_2 assimilation determined by photosynthesis (Evans et al. 1986).

Stable carbon Δ is a promising indirect selection trait for higher yield (Meinzer, Saliendra, and Crisosto 1992). Δ depends on the ratio of intercellular and atmospheric partial pressures of CO₂ and thus reflects the integrated relationship between Gs and photosynthetic rates (O'Leary 1981; Farquhar, O'Leary, and Berry 1982; Farquhar, Ehleringer, and Hubick 1989). Hence, selection for low Δ values would favor genotypes with higher photosynthetic rates, relative to Gs, and a higher WUE rate (*ibid.*, op. cit.). Selection for high Δ values would favor genotypes with a higher Gs (Condon et al. 2004).

PL 2: Increasing productivity in RTB cropping systems through nutrient/water/light management practices—QUEFTS model

Soil nutrient dynamics are important sustainability indicators for agricultural production systems (Smaling and Janssen 1993). Soil nutrient status in agricultural systems is determined by physical, chemical, and biological processes in the soil. In turn these are affected by climate, soil type, and topography (Janssen 1998) and by farm management practices, which play a role in the sustainability of agricultural systems (Stoorvogel and Smaling 1990).

Soil fertility is one of many factors influencing farmers' choices. To understand how different factors contribute to farmer's decisions on management practices, we need to accurately measure soil fertility. The QUEFTS model (Janssen et al. 1990), which predicts crop yields from chemical soil characteristics, can be a potentially good indicator of soil fertility for RTB. QUEFTS's predictions can be compared with actual RTB yields, as well as farmers' own estimates of soil fertility (Smaling et al. 1992, Smaling and Janssen 1993).

The QUEFTS model was designed for the quantitative prediction of maize yields on unfertilized tropical soils, but it can be adjusted for other crops and soils. The empirical relationships of the model published by Jansen et al. (1990) were estimated on the basis of results from field trials in two areas in Kenya and one in Surinam. Smaling and Janssen (1993) applied QUEFTS in an area of Kenya, other than the area for which the original empirical relationships were tested. Additional fertilizer trials allowed Smaling to calibrate QUEFTS and resulted in more empirically based relationships, improving the performance of the model. Smaling adapted the model so that it could be used to estimate yield response to fertilization with N, P, and K. In this way the model could contribute to a more efficient use of mineral fertilizer at both regional and farm level (*ibid.*). QUEFTS can be used to calculate optimal combinations of fertilizer from a crop physiological view (restoring an imbalance of nutrients in the soil), an environmental point of view (minimizing nutrient losses), and an economic point of view (what fertilizer application gives the highest net return).

PL 3: Integrated decision and management tools for RTB crops—Crop growth models

Several existing tools (and those under development) for crop growth models will be part of the toolkit used in the CRP-RTB. It is critical that the data used for crop growth models are of sufficient quality for the models to work. Hence, the methods developed in CRPs 7 and 5 will be used to refine data for RTB models so that the validity of results regarding the suitability and sustainability of alternative options designed for RTB systems is enhanced. Some tools that will be cross-checked with CRPs 7 and 5—and eventually integrated in to the modeling for RTB systems—include ways to generate daily climate data (Quiroz et al. 2010, Heidinger et al. 2011), soil organic matter and fertility (Segnini et al. 2010, Milori et al. 2006, Martin 2010), and water dynamics (Posadas et al. 2009).

The potential for the use of crop growth models can be illustrated from a few examples for RTB crops. Tixier, Malezieux, and Dorel (2004) developed a model to predict the timing of bunch harvest based on accumulated degree days for export bananas. Tixier et al. (2011) expanded on the same model structure to model light penetration and the potential for cover crops in perennial export

banana. Nyombi (2009) modeled yield potential for East African Highland bananas based on allometric growth relationships measured in factorial N, P, and K experiments in two rain-fed environments. On the basis of light and temperature, his model indicated a yield potential of over 100 mg/ha. Ramirez et al. (in press) used ECOCROP to project the effects of climate change on global suitability for rain-fed banana production, but also identified weaknesses in the model for use with a crop such as banana. Condori et al. (2010) showed that the genetic diversity of potato germplasm can be accurately approximated through crop modeling. In addition, crop models and geospatial robust climate data can be combined and used as tools to assess the expected impact of climate change on global specific crop production. Hijmans (2003) showed that climate change can seriously reduce potato production, yields, and food security.

4.5.5 Partnerships

The Centers recognize that other ARIs and NARS have done considerable work of relevance to Theme 5, have research skills which complement those of the Centers, and are often well positioned to contribute to the type of crop-specific modeling proposed. Hence for work in Theme 5, the Centers will pay special attention to identifying and bringing together a coalition of key partners amongst ARIs and NARS, development organizations, and farmers' associations, depending on the stage in the impact pathway. As with other themes, mapping of existing and future partners involving the four Centers and in relation to the impact pathway will be undertaken with support from Theme 7, PL 2. Theme 5 is relatively underfunded at present and particular attention will be given to joint problem analysis and proposal development with these key partners.

Partnerships for conducting basic research related to physiology understanding, model development, and yield gap analysis will be strengthened between CG Centers and ARIs (e.g., CIP and Embrapa's co-development of scanning methods for root development). Bioversity, IITA, and CIAT propose a working group to develop a banana growth model through partnerships with CIRAD and Wageningen Agricultural University as well as national institutes and other universities. These partnerships will access databases on crop growth in key climatic zones generated by field partners for model validation. This will be achieved by the definition of the minimum parameters needed for model validation.

Partnerships on nutrient and water management will require a broader range of partners, including other components of Centers leading this CRP, such as CIAT's Tropical Soil Biology and Fertility Institute mainly working in CRP 5, and other Centers such as the International Water Management Institute as well as ARIs, NARS, and field organizations. IITA, Bioversity, and the TSBF have set up such an approach with the Consortium for Improving Agriculture-based Livelihoods in Africa working with both cassava and banana. Numerous national and field partners are involved. CIP also operates in Central Great Lakes Africa on potato and sweetpotato. This overlap offers an opportunity for efficiencies in operations and learning through the CRP-RTB. In addition, we will establish partnerships with development-oriented organizations to conduct participatory research and validate the decision-support and management tools and to have feedback from different perspectives. As an example, CIP and the Papa Andina Initiative consists of a number of potato-related R&D and private organizations interested in using good agricultural practices to improve potato farmer competitiveness in emerging markets in the Andes.

A further avenue that will be pursued is the development of strategic partnerships—for example, with French research partners (CIRAD-IRD-INRA-CNRS) who have already mapped out where they would be able to add value to the RTB research agenda. Additional linkages will be sought with specific universities through whom we would also look to strengthen the capacity of national partners.

The collaboration of our partners throughout the product lines is key to realizing Theme 5's impact pathways (see Table 4.5.1).

Table 4.5.1 Roles and Responsibility of Partners in Impact Pathways

Product Lines	Representative Key Partners		Roles and Responsibilities
PL 1. Ecological and physiological understanding of RTB crops and cropping systems	▪ NARS ▪ ARIs ▪ NGOs	▪ Universities ▪ International cooperation ▪ Farmers	The partners complement or advance efficiently ongoing works on understanding of RTB crops and cropping systems.
PL 2. Increasing productivity in RTB cropping systems through nutrient /water/light management practices	▪ NARS ▪ ARIs ▪ NGOs	▪ Universities ▪ Professional associations ▪ Extensionists ▪ Farmers	A range of partners will be involved in testing and confirming the effectiveness, usefulness, and sustainability of technologies developed to increase productivity in cropping systems.
PL 3. Integrated decision and management tools for RTB crops	▪ NARS ▪ GIS specialists ▪ Ecologists	▪ Private sector ▪ Farmers ▪ Extensionists ▪ Ministries of Agriculture	Help develop tools in area where they have comparative advantages and help evaluate and disseminate the tools. Farmers will field test improved management technologies. Scaling up efforts by extensionists need to be supported by Ministries of Agriculture.

4.5.6 Gender strategy

A key challenge specific to Theme 5 is the effect that intensification of crop management and the likely associated capital investments will have on women's role in crop production. Key questions are: will women be able to access the technology and the capital required to invest in it? and will they benefit from increased income flowing from this intensification? The gender strategy will target these issues, particularly in PLs 2 and 3.

As part of an ecological and physiological understanding of RTB crops and cropping systems, PL 2 will pay particular attention to the gender roles in the different systems—for example, the importance of small-scale mixed plantings in home gardens or food security plots away from the house managed by women. It will also characterize abiotic constraints and cultural practices that have tradeoffs for yield in relation to men's and women's needs. For example, dual-purpose systems involve tradeoffs between food and feed, between harvesting roots for household consumption, or feed for animals that will later be sold. Increasing productivity in RTB cropping systems through nutrient/water/light management practices in PL 2 will involve assessments of the likely access of women, men, and children to productivity gains in different cropping systems. This is partly about increasing the capacity of women to manage household food security and the need to address problems of poor soils and water stresses often found in small-scale, women-managed plots in upland areas, home gardens, and peri-urban locations. But it is also about targeting systems where productivity gains can result in equitable access by women to increased income.

The aim of PL 3 to use integrated decision and management tools to identify wide recommendation domains has a strong gender dimension in both the design of the tools and in their scaling-up and -out. The mapping exercises planned in this product line will include a gendered understanding of the resources available to farmers in different systems and to ensure that women are well represented in on-farm trials to capture the "wide range of farmer conditions" required to validate technologies.

The research approaches to be used as part of the gender strategy for this theme will draw on generalized gender analysis tools for agriculture (Fernandez 2009) as well as methods that have

been more specifically used in relation to natural resources management and systems analysis (Njenga et al. 2010). These will support an adequate gender audit of the different types of systems where RTB crops are important.

4.5.7 Communication and knowledge sharing

Communication support and backstopping are important for the projects and activities in this theme involving various players, partners/collaborators, networks, and end-users. Emphasis will be on:

- Organizing, compiling, and building up knowledge resources and databases on crop-specific RTB systems, including directories of experts, modeling/decision support tools, GIS tools, communities-of-practice (e.g., among crop physiologists, modelers).
- Disseminating information to raise awareness, build support, encourage dialogue, influence decision-makers, expand networking and collaboration, and enhance adoption of technologies and solutions working in concert with Theme 7.
- Establishing communication lines and working relationships among various players, partners/collaborators, networks, and end-users covering the range from crop eco-physiology and modeling to specific management practices and decision support tools.
- Sharing and exchanging related knowledge, feedback, best practices, tools, and solutions.

4.5.8 Capacity strengthening

Theme 5 will focus on overcoming abiotic yield constraints and improving stakeholder decision-making for developing site-specific, demand-driven integrated RTB management. This requires thorough understanding of crop physiological processes and approaches. We will employ specific CS methods, tailored to the situation in target countries that can facilitate the access to and understanding of knowledge-intensive technologies.

Use of sentinel landscapes for multilocation trials to study genotype-by-environment interactions of RTB crops in a wide range of agro-ecologies will provide platforms to engage local and international graduate students on similar research questions and contribute to the development of global comparative research outputs. Content will be used for training of trainers and further adapted by intermediary partners and knowledge-transfer agents for uptake by smallholder farmers, communities, and other stakeholders.

Research on crop management practices to overcome abiotic stress for local food production and urban markets will be converted to contextually relevant guidelines, strategies, case studies, and best-bet recommendations that are tested and validated with knowledge transfer agents and end-users in appropriate formats and platforms. Training-of-trainers techniques will strengthen the capacity of farmer experimenters, local NARS researchers, extension service, and local and international NGOs to scale-up cropping systems management practices and integrated decision and management tools and models for RTB crops with end-users.

4.5.9 Links with other themes and CRPs

Themes 2 and 3 are expected to provide inputs to the predictive models developed in the present theme. Theme 5 will function as a link between the CRP-RTB and agro-ecosystem-oriented CRPs and will help to better understand how the crop management of a specific RTB can be inserted into a wider system and contribute to intensification or diversification. As mentioned above, the knowledge and tools developed in this theme will be validated within specific systems with CRP 1 partners. However, tools and methods will also be exchanged with CRPs 5 and 7 in terms of water/soil management and climate change factors, respectively.

Biotic yield constraints may also interact with abiotic constraints (e.g., root nematodes can reduce the functioning of plant roots, thereby hindering water and nutrient uptake). Although pests and diseases are extensively researched in Theme 3, it is important that interactions between various yield constraints are investigated, since interventions to overcome single constraints may be affected or benefit from interactions with other constraints and related interventions to overcome those. The results of this theme will be of great value in defining targets and ideotypes and tools for crop improvement in Theme 2.

The results of the research in Theme 5 will not only be of benefit to mono-crop systems, but will also help us to explore technology options in intercrop systems. Mixed cropping systems will require a careful study of the tradeoffs between increased complementarities in terms of resource (light, water, nutrients) capture on the one hand and resource competition on the other. Mixed cropping systems are dominantly found in RTB production areas and will also be studied in CRPs 1, 5, and 7. Close interactions between this CRP and others will be required to develop integrated and sustainable solutions for RTB cropping systems. Similarly, since sustainable systems will require some level of external inputs, coordination with Theme 6 and CRP 2 will be needed with regard to value chains. While not currently incorporated into this theme, expertise can be provided to Theme 6 with regard to postharvest physiology of RTB products.

The partnership, communication, and knowledge-sharing framework of this theme will be closely aligned with Theme 7.

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4.6 Theme 6: Promoting Postharvest Technologies, Value Chains, and Market Opportunities

4.6.1 Rationale and objectives

RTB are consumed as a staple or supplementary food by the rural poor across much of the developing world. They enter in the transition to more market-based food systems, especially through added-value products, both fresh and processed. Sweetpotato, cassava, yam, and banana trade in SSA is characterized by short and direct marketing channels with high rates of loss due to the bulky nature and perishability of these crops, lack of appropriate handling and storage technologies, and often coupled with an unfavorable policy environment (Crissman et al. 2007). Bulkiness and perishability have traditionally limited RTB use to on-farm and local markets, with specialized storage conditions, or postharvest processing required extending use beyond harvest periods and for more distant markets. In developing countries, postharvest crop losses are higher than the global average and impact more severely on already endangered livelihoods. There is considerable scope for repositioning RTB as added-value cash crops through expanding their use for processing and sales of preferred varieties to satisfy emerging markets in small and large cities (see Box 4.6.1). Market development research will complement the genetic enhancement described in Theme 2 and provide a strong demand pull. It will pay attention to issues of storage, transportability, and gaining market share through processing into diverse products.

Box 4.6.1: Applying the Participatory Market Chain Approach to unleash the potential of native potatoes in Peru

In the Andes of South America, potato is a key component for food security of small-scale farmers as food source and cash crop. In this region, as in many developing countries, the potato is often produced in poor, remote, and mountainous areas, on small plots; but potatoes generate more added value and employment per hectare than other staples. CIP/Papa Andina facilitated a joint innovation process (PMCA) engaging, private companies, farmers, chefs, and researchers to expand the market for native potatoes and add value for poor producers.

Early products opened new market niches and brought higher prices for farmers. Among these were T'ikapapa (bagged native potatoes) and Jalca Chips (multicolored native potato chips), sold at the Lima airport. As visibility and interest in native potatoes rose, Papa Andina facilitated further product development by small-scale farmers, NGOs, and large multinationals, while boosting the bargaining power and participation of local farmers. As a result, a supply chain has been created that gives farmers access to a stable market and a higher price. Export channels are opening, too, and there has been an increase in the overall demand and prices of native potatoes in niche markets in Peru with additional revenues for farmers. The emergence of a native potato market has fueled the research agenda. Scientists, along with NGOs and farmers, are working on ways to increase quality and yield while safeguarding the sustainable and natural production methods valued by consumers. An important aspect of consolidating the market is to position the native potato on the policy agenda. Interested stakeholders have formed lobby groups, leading to the creation of National Potato Days in Peru and Ecuador and the compilation of quality norms for potatoes and their processing (Devaux et al. 2009).

As incomes rise, there is a gradual shift to purchasing a more diversified, higher quality diet and more specialized food products rather than untransformed commodities. This shift is often correlated with urbanization, as town-dwellers demand foods that are quick to prepare or pre-cooked. Given that RTB are often produced by poorer farmers, they could gain significant benefits if they could capture value addition inherent in the transition from marketing undifferentiated commodities to differentiated commodities, and then to specialized products. For example, enhancing the functional diversity of RTB starch and other properties for industrial uses will add value for these value chains into the future.

The development of value chains driven by the private sector for added-value products—fresh and processed—for national and export markets is well advanced in some regions (East and Southeast Asia, LAC), but much less so in SSA and South Asia. Global production and trade systems in fresh

and frozen potato products and fresh sweet bananas are highly efficient value chains dominated by multinational companies. The expansion of demand seen during the last decade for some RTB (e.g., cassava in LAC and Asia) is due to improved competitiveness as a low-cost source of starch for multiple industrial uses. However, improving chain efficiency needs to be complemented by a focus on equity to ensure that the rural poor (either producers or processors) can participate fairly in these expanding value chains, if future income generation and livelihood aspirations are to be met. Equally, inefficient use of water and other inputs, process wastes, and sub-optimal use of residues reduce chain efficiency and result in environmental pollution. It is essential to develop and integrate specific technological innovations and also support improved efficiency (economic and resource use) and equity of value chains for RTB.

Although commonly considered as contributing mainly carbohydrate to diets, the importance—actual and potential—and diversity of RTB as sources of protein, vitamins, and minerals have been highlighted recently through germplasm screening and improvement programs, including use of protein-rich leaves/vines.

Theme 6 thus relates to overcoming the challenges linked to bulky and perishable crops, and unfavorable policy environments, and realizing the opportunities of RTB in postharvest systems. This objective needs technological, market, and organizational innovations, as well as strong linkages to policy development and PPP. This implies strong linkages with CRP 2 on Policies, Institutions, and Markets to Strengthen Assets and Agricultural Incomes for the Poor.

Theme 6 aims at promoting research to identify, develop, and promote diffusion of relevant technologies to reduce postharvest food losses and organizational models for value chain linkages to growing markets that enhance income generation and improve food security.

4.6.2 Impact pathways

The impact pathway will be through improved capacity of downstream users for research on postharvest and value chains, and through a more diverse and expanded use of RTB in food systems that together act to improve food security and market linkages that raise farmers' incomes. In addition, there will be a reduction in health risks and improved nutrition. It will also enable a more equitable access to knowledge, technologies, and opportunities for countries, institutions, disadvantaged groups—women in particular—in the developing world. Other impacts anticipated under Theme 6 include reduced need for imports and food aid, reduced drudgery for women, increased schooling for children, strong and diverse participation in value chains, and greater innovation by local companies. Figure 4.6.1 shows the impact pathways envisaged for Theme 6.

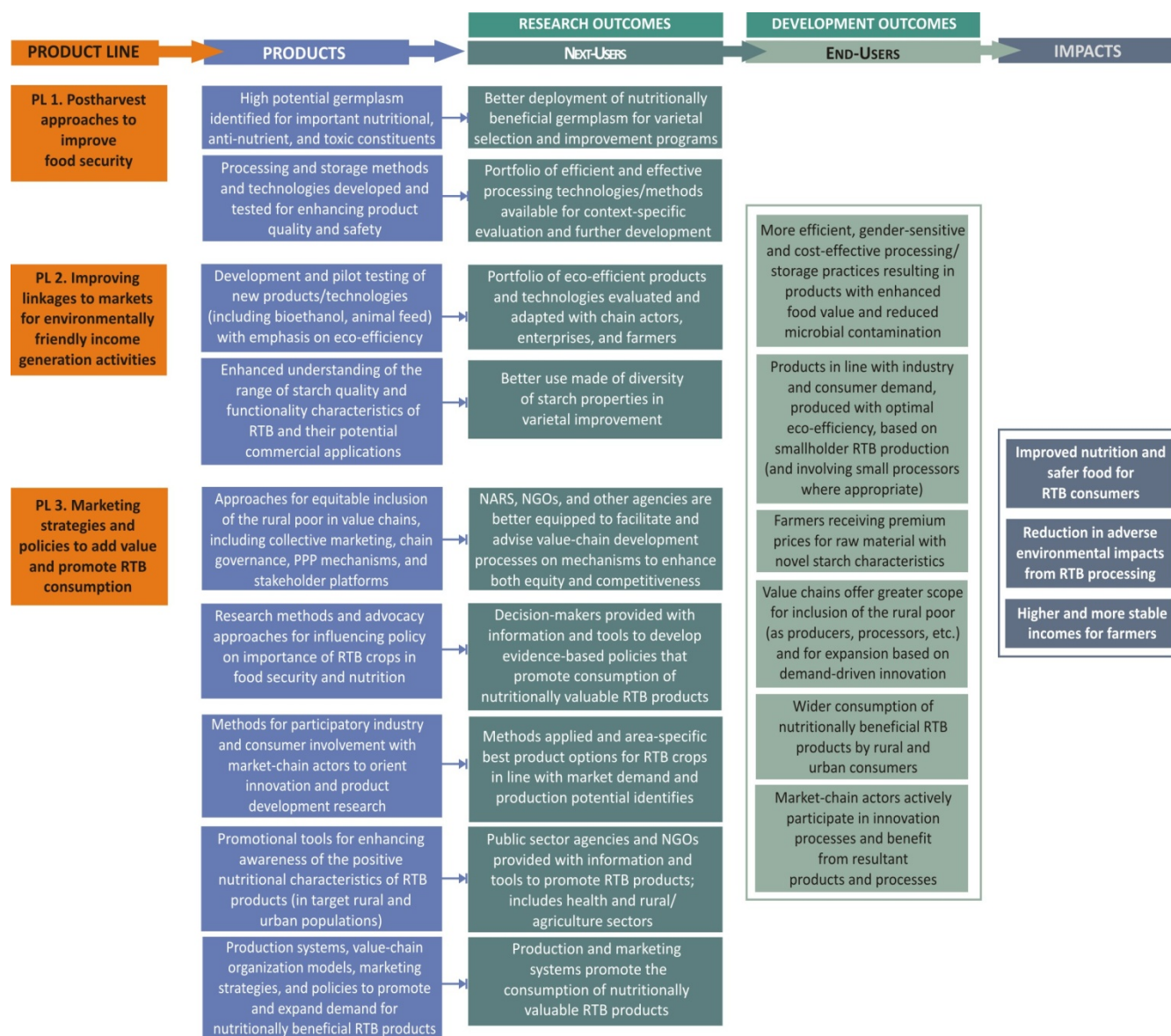


Figure 4.6.1 Theme 6 product lines, products, outcomes, and impacts.

4.6.3 Product lines

PL 1: Postharvest approaches to improve food security

This food security product line will aim to increase consumption and enhance nutritional value of RTB by developing products that enhance the availability, access, and consumption of RTB foods by the rural and urban poor (as well as richer consumers) through the introduction of new approaches that increase the range of food products, enhance food safety offset, postharvest losses, and prolong shelf life of perishable crops like RTB. This will include:

1. Postharvest research to improve storability and transportability of RTB to make them available for longer periods of time and over broader geographic areas. Special attention will also be given to the retention of micronutrients during storage and food processing.
2. Cross-commodity research to understand the role of physicochemical, functional, and organoleptic properties that relate to consumer and industry preferences for, and the

acceptability of, RTB varieties. This includes the carbohydrate profile and the energy-yield, protein, vitamins, and micronutrient contents, which largely determine their potential in food, feed, and industrial use.

3. Understanding food quality preferences of different categories of consumers.
4. Studies of nutritional and anti-nutritional characteristics of RTB (including native germplasm) as affected by production systems, including their retention/reduction during storage and processing, as well as their levels as raw material and in final products and their bioavailability in the human body. It should link to research on production practices (at pre-harvest), which significantly affect quality traits of interest at the postharvest stage (Themes 2, 3, and 5).
5. Investigating and minimizing qualitative and quantitative spoilage of RTB by physiological causes and microorganisms, including understanding the mechanism of action of storage systems, fungicides, plant extracts, and other biocontrol agents.
6. Developing and expanding efficient and nutrient-preserving postharvest processing and storage, and market outlets for RTB products, in line with these demands and preferences, so as to increase incomes and improve livelihoods in rural areas.
7. Reducing or eliminating anti-nutritional or toxic compounds through the application of food quality and safety management measures that prevent microbial and chemical contaminants, and optimizing processing methods for RTB.
8. Investigating the inherent beneficial nutritional, physical, and chemical traits found in RTB and promoting approaches that maximize the benefits, particularly from biofortified cultivars.
9. Developing knowledge on the potential impacts of climate change on nutritional quality and safety of RTB and how to avert any adverse effects expected.
10. Assessing and improving traditional processing methods and developing new techniques for making acceptable food products for new consumers.

PL 2: Improving linkages to markets for environmentally friendly income generation activities

Market-oriented products based on RTB crops produced by smallholder farmers serve the dual purposes of food security and income generation. Rapid urbanization of developing countries across Africa, Asia, and LAC—and export markets they serve—is creating demand for a wide range of RTB-based products for food and non-food industries. This demand is driving the significant increases in productivity, seen in cassava in Southeast Asia, for example. Product development research, in partnership with the private sector as appropriate, has potential to further increase demand for RTB, and thus the income generated for smallholder producers linked to these value chains. Improving the efficiency of resource/input use in RTB value chains is important. Life-cycle analyses of processes (e.g., starch extraction) will enable research to improve the efficiency of starch extraction and water use, and to optimize the economic value of, and reduce pollution from, biomass residues and wastes (e.g., biogas or wastewater treatment).

Increased understanding of physiochemical and nutritional characteristics of RTB foods and consumer preferences from PL 1 can contribute in this product line to expand the use of RTB in the growing range of food, non-food industrial, and feed markets across Africa, Asia, the Americas, and Europe. This opens up opportunities for smallholder producers and processors, mostly women, to access these growth markets. We will use this knowledge to develop and test new technologies with potentials to add value to RTB and so increase rural incomes and employment in the major producing regions of Africa, Asia, and LAC. Specifically, studies will be carried out to develop postharvest handling, processing, and value-adding technologies that enhance the priority

characteristics for a wide range of consumers and industrial end-users. Research will be linked with crop management in Theme 5, because some production practices can significantly affect the expression of quality traits of interest for processing (i.e., tuber skin setting, dry matter content, reducing sugar and polyphenol content, antioxidant activity, etc.). These interactions should be studied in the pre-harvest stage to improve competitiveness of the growers.

The studies will involve such areas as assessments of starch quality, functional characteristics, and modification of RTB starches to suit different end-uses. Value-adding technologies will be evaluated and refined to reduce drudgery, save processing time (mostly for women, at small-scale operations in many areas), and increase adoption in ways that increase rural incomes and employment. Improvements in the efficiency and cost-effectiveness of value-adding technologies for RTB, such as drying, brewing, and cooking, are expected to increase the commercial viability of agro-processing enterprises.

Technologies will be developed to improve the competitiveness of using RTB as an environmentally beneficial feedstock for production of liquid fuel/bio-energy and, by so doing, promote sustainable management of the environment due to the reduction of CO₂ buildup from use of RTB-based biofuel compared with hydrocarbon-based energy sources. Environmental sustainability will further be promoted through research in WUE, particularly for water-intensive RTB processing methods such as starch extraction, and solid waste management systems that benefit producers and processors. We will conduct life-cycle assessments of RTB value chains and products to understand the environmental impacts of production and processing, as well as policy and economic analyses to find approaches that reduce value chain transaction costs, waste, and storage losses.

Given the ongoing research agenda of the private sector in many of these areas, it will be important to work in partnership with them, and regional/national research agencies, to identify where the CGIAR Centers have a comparative advantage in this research agenda. This is likely to focus on the evaluation of germplasm in processing and product development and value chains with major roles for smaller scale processing.

PL 3: Marketing strategies and policies to add value and promote RTB consumption

In this product line we will develop and evaluate strategy models for the inclusive organization and governance of value chains, including social marketing approaches, which favor the more vulnerable smallholder producers or processors. These will be gender neutral, and will link with the private sector entities that operate within a framework of social responsibility.

We will employ a value chain approach that works with all RTB chain actors to identify constraints and weak links (and opportunities) along the RTB value chain, then test and evaluate innovations that aim to ensure competitive and market-led RTB development. Private sector partnerships such as “contract-processing” will be investigated as means of reducing the cost of coordinating many low-technology-dependent, small-scale processors and vertically integrating them into profitable RTB value chains. Market innovation involves the development of new products or services for specific market niches to add value to smallholders’ production. The framework of intervention will focus on promoting innovation by including social learning, social capital formation, and joint activities (Devaux et al. 2009). Based on the experiences and knowledge already available, studies will consist of implementing approaches that bring together research organizations and a wider range of partners to foster market innovation in RTB value chains, with special attention to inclusion of small-scale producers.

Deciding on which technologies to develop and which partners to engage with in order to capture the value added of RTB product development for the poor is context specific, but the CRP-RTB will share lessons learned and methods that increase the prospects for success. Given the critical role that the private sector plays in enabling any product to go to scale, successful efforts typically require a favorable policy environment and/or government subsidies, industries with CSR as part of their mandate, or specific socioeconomic conditions that have driven the industry to look for lower cost or locally produced ingredients for their operations. In value chain innovation processes, there is always a risk that the lion's share of the benefits will go to large commercial interests. CSR is an entry point for addressing the issue of small-scale farmers' interests with the largest players in the value chain. CSR refers to an ethical form of management that takes into account the expectations of a company's stakeholders in order to achieve sustainable development (Thomann et al. 2009). In a value chain, two important areas for CSR work are (1) developing a market segment willing to pay a premium price for a high-quality, environmentally, and socially sustainable product and (2) developing the competitiveness of supplier organizations to reduce asymmetries in bargaining power. We will implement studies to facilitate dialogue among large companies, NGOs, and farmer organizations on the application of CSR in the market chain.

PL 3 provides a platform for the integration of the CRP-RTB with CRP 2, particularly in selecting and refining different postharvest, processing, product development, and organizational models that contribute to link farmers to markets. If successful, the application of these organizational models should assist in the development of equitable chain linkages between low-technology-dependent, small-scale processors to advanced-technology-dependent enterprises, through the supply of partially processed intermediate RTB products. Small-scale processors would be unable to access these higher value markets directly. Approaches developed and validated through this product line will enhance income of women since in many rural areas and cultures they constitute majority of small-scale processors (see Box 4.6.2).

Box 4.6.2: Linking smallholders to the new agricultural economy—study of multistakeholder platforms in Ecuador

In the highlands of Ecuador, small farmers were struggling to enter higher value markets for processing potatoes. INIAP facilitated the implementation of multistakeholder platforms (MSP). MSP are alliances between farmers and suppliers of agricultural services, including research institutes, NGOs, universities, and local governments. The platforms, and subsequently the Consortium of Smallholder Potato Producers, have directly linked smallholders' organizations to higher value markets for their products, including fast-food restaurants and a company that produces potato chips. An important component of the platforms was training provided through FFS, where farmers learned about integrated crop management, especially in relation to weevils, late blight, and seed management. Participants in the MSP had higher potato yields and profits than did nonparticipants. Participants' yields averaged about one-third higher than those of nonparticipants, and their average selling price was about 40% higher and profits were approximately six times greater. MSP success can be explained firstly by their intervention along the whole value chain and by reducing transaction costs; secondly by the introduction of technological innovations to increase yields; and thirdly by an improvement in social capital that is expressed, among other things, as greater trust among the actors in the production chain, which enables small-scale producers to overcome the obstacles to entering more demanding markets (Cavatassi et al. 2009).

Significant experiences exist within the CGIAR Centers, and their partners, that can be leveraged to investigate and develop suitable arrangements for PPP that promote small-scale agro-processing industries and rural enterprise development. This includes establishing the lower and upper limits for the nutritive, physical, biochemical, and functional properties of RTB and safe levels for undesirable constituents and contaminants. This is fundamental to the design of quality assurance and safety limits for RTB crops. Such limits serve to standardize products for marketing purposes, to reward quality in the marketplace, and also to promote fair trade. This limit-setting activity of

RTB underpins the standards/certification aspects of, and serves as linkage opportunity to, CRP 2's objective of identifying best practices that promote effective quality assurance systems. We will assess the impact of those quality and safety limits on the market access and livelihoods of smallholder farmers, in relation to the tendency of smallholder farmers and processors for entrepreneurship innovations.

4.6.4 Critical Assessment of Methods

PL 1: Postharvest approaches to improve food security—Studies of nutritional and anti-nutritional characteristics of RTB (including native germplasm) as affected by production systems

Studies of nutritional and anti-nutritional characteristics combine chemical and biochemical testing of RTB in their natural or modified forms. They may include nutritional and animal feeding tests. The nutritional value of cassava leaves for dairy cattle feeding through ensiling was studied by Kavana et al. (2005). Chemical analysis of cyanide and crude protein after ensiling showed a reduction in hydrogen cyanide and an improvement in crude protein and dry matter. Other authors confirm the effectiveness of processing methods in the reduction of toxins in feeds made from RTB (Tewe 1991; Wanapat 2001; Wanapat, Petlum, and Pimpa 2000).

Safe storage of RTB is challenging for smallholder farmers. Understanding relationships between the occurrence of spoilage microorganisms, related mycotoxins, and length of storage period can help develop strategies for increasing the quality and safety of RTB products. A procedure to establish such relationships in traditional cassava and maize products sold in consumer markets in Tanzania and the DRC was adopted by Manjula et al. (2009). Assay for aflatoxin B1 and fumonisin B1 using a competitive direct enzyme linked immunosorbent assay was combined with identification of fungal contaminants. The approach established that processing and storage affect safety of both RTB and grains, but fumonisin contamination in grains is potentially a more serious risk to consumer health.

PL 2: Improving linkages to markets for environmentally friendly income generation activities—Assessment of starch quality for industrial, biofuel, and feed market

Assessment of starch quality, functional characteristics, to suit different end-uses for RTB-based products is very important (Dufour et al. 2009; Gibert et al. 2010). Native starch characterization of existing and newly developed cassava varieties have been reported by various authors (Onitilo et al. 2007; Eke et al. 2007; Sanchez et al. 2009, 2010; Ceballos et al. 2007). The waxy (amylose-free) starches recently discovered in cassava and yam, represent a new industrial opportunity. Roots and tubers waxy starches are a promising ingredient to formulate refrigerated or frozen products (*ibid.*, Sanchez et al. 2010, Perez et al. 2011, Zhao et al. 2011). Current research focuses on the characterization of RTBs for food (Ceballos et al. 2006, Dixon et al. 2007) with less emphasis on industrial and livestock uses. Screening of RTB varieties needs to assess starch quality from thin peel RTBs, conversion of varieties to chips, grits, pellets, and quality of animals fed with RTB blended feed stocks across the regions.

The usual mechanical method for starch extraction leads to starch losses of up to 20% and involves high use of energy and water and expensive machinery (Kallabinski and Balagopalan 1994). The settling of starch granules is often hindered by presence of components like mucilage and latex, leading to loss and reduced quality of extracted starch (Moorthy 2002). The use of commercial cell-wall-degrading enzymes has been used to address this. The treatment of ground cassava roots with pectinase and/or cellulase significantly increased starch recovery (up to 36% after a 3-h incubation). The results were also confirmed in experiments with sweetpotato. The reliable method for

determination of total starch is based on total conversion of the starch into D-glucose by purified enzymes specific to starch, and determination of the D-glucose released by an enzyme specific for it.

Differential scanning calorimetry has been important in studying starch properties such as gelatinization in roots and tubers (Moorthy et al. 1993 a,b). It is simple, fast, requires only small quantities of sample, and gives reproducible results. The advanced version, modulated differential scanning calorimetry, can give even more valuable information regarding gelatinization, glass transition, and starch-lipid complexes. Crystallinity of starch can be measured using X-ray diffraction (Moorthy 1982), and starch granule sizes can be measured using Image Analysis and Laser Diffraction Technology (Wilson et al. 2006). For directly observing changes related to the gelation process of starch, infrared spectra of starch in water while heating can be obtained by using Fourier transform infrared attenuated total reflectance spectrometry (Lizuka and Aishima 1999).

Viscosity of starch is important for its use in textile, paper, adhesive, and food industries, and it is measured using a Brabender viscographic or rapid visco analyzer (Hashim et al. 1992). Digestibility of starch by enzymes is important for evaluating nutritive value and also in industrial applications. This can be measured by both in-vivo and in-vitro methods (Moorthy 2002, Rocha, Carneiro, and Franco 2010). Starch modifications can be done by physical methods such as steam pressure treatment and blending with other starches. Chemical modification includes complexation with surfactants and derivatisations like esterifications, crosslinking, and oxidation.

PL 3: Marketing strategies and policies to add value and promote RTB consumption—Organization and governance of value chain approach

Developing countries have seen the reconfiguration of value chains presenting new opportunities for adding value and raising rural incomes (Gibbon 2001). Reardon and Berdegue (2002) describe how supermarkets and large-scale food manufacturers have transformed agri-food markets in much of the developing world. An extensive literature documents the effects of this new economy on the potential exclusion of small farmers, who produce small volumes on dispersed fields and struggle to meet demands for quantity, quality, and timeliness of delivery (Reardon et al. 2009).

Harper (2010) analyzes ongoing initiatives to develop more inclusive and equitable value chains favoring poorer farmers. Markelova et al. (2009) review options for promoting collective action for small farmer market access and the role of small farmer organizations in value chain upgrading. Thiele et al. (2011) critically examine the role of multistakeholder platforms in improving value-chain governance. There is a growing literature on approaches for stimulating collaboration among value chain actors and promoting improved governance, including the PMCA and the Territorial Approach for Agroenterprise Development (Devaux et al. 2009, Lundy et al. 2005). Recently, several authors (de Janvry and Sadoulet 2010, Manson 2010) have demonstrated that value chain analysis needs to be part of a more strategic and sustainable intervention, going beyond a single market. This may require addressing market failures as in the DrumNet scheme in Kenya (Ashraf, Gie, and Karlan 2009). A range of tools and approaches are under development for promoting CSR, which can contribute to improved governance and enhanced equity for small farmers (World Bank 2006).

On a cautionary note, Shepherd (2007) argues that business development is not synonymous with creating equity and prioritizing poverty goals may be at the expense of business sustainability. If the approach of “linking farmers to markets” is to be successful, its proponents need to accept commercial realities.

4.6.5 Partnership

Strategic alliances will be developed with organizations that possess core strengths in value chain work, including international NGOs (such as Catholic Relief Services, Oxfam, CARE, and Practical Action), institutes such as Natural Resources Institute (UK), universities, and private sector initiatives such as the Sustainable Food Lab. National RTB programs in NARS will be engaged for collaborative research in several disciplinary areas based on their expertise in local testing of technologies and close links with farmers and extension systems. NARS in several regions have already been involved in multidisciplinary collaborative research with the CGIAR Centers. Examples include CLAYUCA (see Box 4.6.3), in the Andes the Papa Andina regional partnership program (Box 4.6.1), and the Sweetpotato for Profit and Health Initiative (in SSA). Universities will collaborate with Theme 6 in research in various disciplinary areas. National NGOs (e.g., Bangladesh Rural Advancement Committee, PRADAN in India, Centro de Servicios Agropecuarias, PRISMA in Peru), and farmer organizations will play active roles in execution of capacity building and expansion of RTB utilization options based on their expertise, facilities, as well as close links with farmers, extension, and research agencies. Associations of farmers, processors, transporters, and marketers will also be important to the success of these activities through their capacity to organize their members and enhance efficiency of up-scaling the results. French research partners (CIRAD-IRD-INRA-CNRS), who have expertise particularly in postharvest quality and value addition, offer valuable collaborative potential. Within the CGIAR, and in collaboration with ARIs, Theme 6 will benefit from the strength in postharvest biology, value chain analysis and development, as well as in social sciences for M&E and impact assessment. The regional and subregional organizations will offer the umbrella that will put the theme in the regional and subregional context, and attract political support that will influence success of regional, subregional, and in-country efforts in advocacy.

Market-led innovation makes it necessary to look beyond the research community and build relationships with a broader range of public and private actors. Mechanisms, such as learning alliances and stakeholder platforms, to promote interaction, social learning, social capital formation, and collective activities involving diverse actors in innovation processes will have to be promoted and tested. Unlike conventional agricultural extension programs that “disseminate” technologies developed by researchers to selected individual farmers, learning alliances and stakeholder platforms tap into existing community institutions not only to disseminate technologies, but even to articulate their needs for research and technologies. Engaging with the private sector, especially small- and medium-scale agro-industries, and other actors of the value chain such as supermarket and culinary schools will be key to promoting innovations. Initiatives must consider consumers’ needs and interests and ensure that benefits flow back to small farmers through CSR arrangements (Thomann et al. 2009). New urban consumption patterns are increasing demand for quality and processed foods, along with health, environmental, and social concerns in modern society, thus creating market expansion opportunities for RTB. The involvement of public sector institutions at local and national levels is a key element for supporting institutional innovation processes when regulatory or specific legal frameworks need to be adjusted or modified to align the interaction between the value chain actors towards a more equitable and competitive status especially for the smallholders.

The collaboration of our partners throughout the product lines is key to realizing Theme 6’s impact pathways (see Table 4.6.1).

Table 4.6.1 Roles and Responsibility of Partners in Impact Pathways

Product Lines	Representative Key Partners		Roles and Responsibilities
PL 1. Postharvest approaches to improve food security	▪ Institutes of nutrition ▪ Processors ▪ Postharvest equipment manufacturers ▪ Public-private partners ▪ Consortia ▪ Public health agencies	▪ Private sector actors ▪ Universities ▪ NARS ▪ ARIs ▪ NGOs ▪ Farmers	The partners will conduct joint research on food quality preferences of different categories of consumers, and postharvest research to reduce waste and add value.
PL 2. Improving linkages to markets for environmentally friendly income generation activities	▪ NARS ▪ ARIs ▪ NGOs and CBOs ▪ Private entrepreneurs	▪ Public sector ▪ Producers ▪ Transporters ▪ Processors ▪ Marketers ▪ Farmers	NARS and ARIs, together with private sector partners and processors, will conduct joint research on starch quality and functional characteristics of RTB, value-adding, and bio-energy. Other actors will join in the evaluation of attributes of germplasm for processing and value chain development.
PL 3. Marketing strategies and policies to add value and promote RTB consumption	▪ NARS ▪ ARIs ▪ NGOs ▪ Decision makers	▪ Public and private sectors ▪ IT specialists ▪ Value chain officers ▪ Market-chain actors ▪ Small-scale processors ▪ Farmers	NARS, NGOs, private sector actors and other players along the value chain will identify new products to add value. Together with ARIs, they will test innovations to lower costs and improve quality with value chain actors.

4.6.6 Gender strategy

The gender strategy for this theme focuses on developing clear and sound pathways to enhance food security and improve income generation for poverty reduction. In many parts of the world, women play a major role as producers and processors of RTB. However, their access to resources and opportunities to be able to move from subsistence agriculture to higher value chains is often much lower than men's. In addition, as market opportunities for RTB improve, there will often be a shift to large-scale production systems. This transition is important to increase overall availability and food security, and make RTB crops cost-competitive compared to other ingredients for agro-processors. However, in such systems, there is a risk of displacing women from the production and/or marketing systems. At the same time, focusing uniquely on women—and excluding men—can backfire, undermining women's ability to participate. Gender analysis will focus on the opportunities and constraints facing women in actively participating in value chains, especially in the areas of value-added processing and enterprise development. Strategies will be developed on how to ensure market development with adequate gender equity (Rubin, Nichols-Barrett, and Manfre 2010). This will include analysis of institutional constraints on their participation, whether from the way that the R&D organizations engage with users, or the way that producer, trader, and processing organizations facilitate (or not) the involvement of women. Indicators will be developed to monitor progress in increasing women's active participation in commercialization activities (not just as sellers but as decision makers).

A gender strategy is relevant also for PL 3, policies and strategies to enhance consumption of RTB, at two levels. Policy development will emphasize the role of women in consumption choices and policy prescriptions for targeted nutrition education campaigns that work with women's groups and associations, and that can be delivered by extension services and health providers. Marketing and nutrition education efforts need to directly work with such groups.

Through the CRP-RTB we will encourage gender balance in RTB R4D teams and capacity development of core team members and local partners in gender-sensitive, value chain research. Work in Theme 6 will stimulate innovation, factoring in gender perspectives, and develop practical tools to foster women's participation in decision-making processes. It will favor the introduction of technologies that will be managed in ways that are not gender blind or do not affect women negatively in their traditional roles. We will give strong emphasis to collective action initiatives, such as enterprise associations with strong participation by women.

4.6.7 Communication and knowledge sharing

Responses from the stakeholder consultations and survey underscored the high value attributed to having access to examples of successful PPPs (see Box 4.6.3), promising methods, technological innovations, and lessons learned that can be adapted and applied across different crops, market value systems, and regions. For example, small-scale producers have developed marketing innovations and business plans to promote value-added products. But communication tools and activities (e.g., guides, stories, face-to-face interactions and site visits, community kits, videos, training materials) are needed to share methods, lessons, and ways for adjusting the approach to meet local needs, strengthen capacity, and further inform the R4D agenda (e.g., regarding processing, postharvest, or quality concerns). Development projects with a focus on building value chain and postharvest market opportunities can benefit greatly from having project information available on the Web. Where appropriate, we will explore mechanisms to use the CRP-RTB website to link agricultural markets to RTB producers in rural agro-enterprises for greater exposure.

Box 4.6.3: The CLAYUCA Partnership—engaging private sector partners to help set research agenda

CLAYUCA is a consortium operating from its base at CIAT in Cali, Colombia. It was formed in 1999 building on more than 20 years of cassava research at CIAT, developing and adapting the concept of cassava integrated development projects. CLAYUCA started as a response to a real demand from the private sector, that was seeking a new model for supporting cassava research and development in the region, which could give them more influence on the definition and management of the agenda, and more access to the benefits obtained. In exchange, the private sector was willing to participate in financing activities and sharing risks. The CLAYUCA model is based on the principle that producers in the private sector identify their priorities, and decide which technological improvements are needed. CLAYUCA then works to generate appropriate, efficient and sustainable responses. Most of the research for development activities of CLAYUCA in the last 10 years has focused on postharvest technology and mechanization of planting and harvesting, but positive demand for improved plant varieties and more upstream science can also be documented.

Another important role is reaching policy and decision-makers with research findings and information that can help valorize RTB and create a more favorable environment to recognize their value. Working with the media and other intermediary partners to generate public debate around research and evidence can also affect policy outcomes indirectly.

The combined communication experiences and capacities of our CRP-RTB centers, partners, and linkages to other CRPs offer a unique opportunity to create a dynamic and active process of information exchange that can boost the advances regarding postharvest technologies, value chains, and expanded market opportunities.

4.6.8 Capacity strengthening

The lack of knowledge decreases the potential of many crops to benefit smallholder farmers. Capacity will be strengthened in postharvest management technologies, product development, germplasm improvement, and infrastructure that will benefit farmers, processors, and other stakeholders along the value chain. This area of work will focus on next-users and end-users and

involves multiple actors from knowledge transfer agents such as NGOs, CBOs, community health workers, public and private sector researchers, and breeders to universities and ARIs. Wherever possible, we will work through partners to deliver capacity, collaborating with existing networks, centers of excellence and expertise, to strengthen others' capacity for learning and to avoid duplication of effort.

CS interventions will be different for each target group. For example, the capacity of young NARS scientists for research on postharvest products, technologies, and germplasm improvement will be strengthened through workshops, training courses, and individual training. Content will also be used for training-of-trainers and further adapted by intermediary partners for uptake by farmers, communities, and other stakeholders.

The capacity of small- and medium-scale processors to develop products or to fabricate processing machines will be strengthened through group training in collaboration with partner training centers of excellence in processing. Training-of-trainers interventions, working with intermediaries such as NGOs, CBOs, or ministries, will be used to strengthen the capacity of communities on food and product diversification or linkage to markets. Training-of-trainers will also be used to strengthen the capacity of farmers, local NARS researchers, extension service, and local and international NGOs to scale-up processing technologies with end-users. The staff of government agencies responsible for enforcing food safety and food quality standards will be trained in the application of CODEX standards in country specific workshops. Participating centers will facilitate the training, which is linked to getting products to the markets. Skills of all the value chain actors, including the research team and policy actors, in multistakeholder participation processes, will be strengthened at the outset of a project and learning alliances will be established.

To foster better understanding of the needs of the private sector, the CRP-RTB will support short-term exchange programs for researchers to be based with private sector enterprises and for private sector operators to visit other countries with specialized capabilities in RTB product development and marketing.

4.6.9 Links with other themes and CRPs

Theme 6 is an integration point of the different themes of the CRP-RTB. Considering the two aims of this theme—food security and income generation—it will:

- Serve the other members of the CRP as a platform to test the acceptability of new germplasm generated by the breeding programs and local landraces.
- Contribute to environmental sustainability by conducting life-cycle analysis of processing technologies.
- Allow evaluation of crops harvested under diverse environments to discriminate genetic from environmental effects on product quality.
- Promote the development of rural agro-enterprises through the development of new processing technologies that enhance product consumption.
- Provide healthier products to consumers.
- Generate income to farmers and communities.

There will be close interaction with Theme 2 for cultivar development, as postharvest attributes and market suitability are key determinants of cultivar attributes. Seed is a key component of value chains in Theme 4, and value in markets and postharvest are also linked to appropriate crop management practices in Theme 5. There will be significant linkages of postharvest work with CRP 4, because of

the contribution to improving nutritional quality and health impacts. There will be important linkages with the value chain work in CRP 2, which would help develop new methodologies for linking farmers to markets. These methodologies can be applied in the CRP-RTB with lessons learned to be shared across RTB and other crops. Feedback to CRP 2 on technological, market, and organizational innovations will contribute to develop policies and improve approaches for PPP. Experiences gained will also be incorporated within the livelihood context of CRP 1.

4.6.10 References

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4.7 Theme 7: Enhancing Impact through Partnerships

4.7.1 Rationale and objectives

The CRP-RTB strongly believes in the potential of formal and informal partnerships to mobilize complementary expertise and ensure that impacts are achieved in a cost-effective manner. To fully exploit this potential, the process of partnership building and management needs to be an integral part of program planning, drawing on a range of tools and experiences for “good partnering” (Horton, Prain, and Thiele 2009). The objective of this theme is to increase the potential of the program to achieve positive outcomes and impacts on vulnerable groups by setting priorities for RTB R4D, capturing users’ needs and perspectives, engaging the right partners, building capacity, and promoting continuous learning.

The CRP-RTB will use the partnership learning cycle (Fig. 4.7.1) as the “conceptual glue” that keeps the CRP on track. Five product lines are linked in a virtuous circle, each product line positively informing and strengthening the next, recognizing also that there may be positive overlaps between them.

Over the years, the RTB partner Centers have invested funding and human resources in different forms of partnerships. In a tightening budget environment, there is a risk of seeing this as a “luxury” that can be dispensed with. However, the investment of relatively modest resources can achieve a multiplier effect through effective partnerships. The importance of partnerships has been highlighted in GCARD and more generally in the CGIAR reform process. Partnerships play a key role both in generating products and in creating a favorable context for products to be translated into outcomes and eventually impacts. Often, consortia of partners will come together for particular “projects” within the CRP. The types of partnership and roles of partners change along the R4D continuum, and Theme 7 will play a steering and facilitation role with a relatively limited investment. It will constitute a space for learning more generally about how to engage in and manage partnerships, communications, and capacity strengthening across all areas. Most of the actual work in partnership mode will occur in Themes 1–6. Consistent with the philosophy of partnership, wherever possible, opportunities will be taken to make use of partnerships with other organizations to achieve joint products.

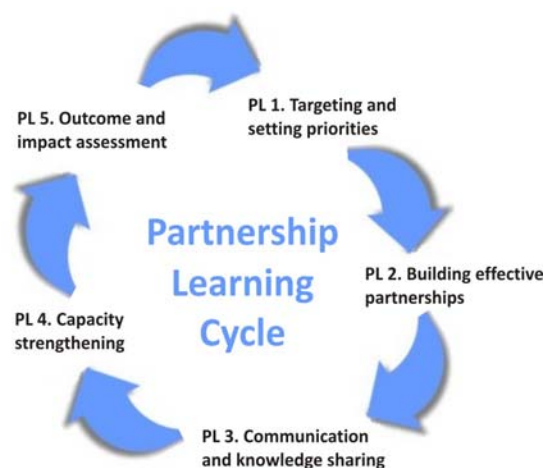


Figure 4.7.1 The partnership learning cycle.

Planning through partnerships captures input from key stakeholder groups, such as national agricultural research organizations and the private sector. Priority setting exercises and mechanisms that include scientists and other stakeholders outside the CGIAR provide a useful reality check and counterbalance to priorities identified within the Centers (see Box 4.7.1). The involvement of stakeholders in the RTB priority-setting process lends credibility to the program’s agenda. This is important in collaborative research, but is especially important to promote changes in policy, such as the implementation of a germplasm conservation strategy or a policy on safe movement of germplasm, and advocate concerted action, which can have broader impact on agricultural development. Donors are also likely to be favorably impressed when proposals for research or other actions engage strong partnerships because of synergies and possibilities of greater, more timely delivery and impact through niche knowledge domains and added resources.

Box 4.7.1: Banana Regional R4D Networks—helping set priorities and responding to partners

Around one-third of total global banana production comes from each of three regions: LAC, SSA, and Asia and the Pacific. Banana regional R4D networks were established on the basis that each of these regions has different technical needs and different levels of development in their R4D infrastructure. As informal associations of national banana research organizations, drawn together by Bioversity, which provides technical and logistic support, the steering committee of each regional network regularly comes together. Its members exchange ideas on priorities and opportunities for joint action as well as reporting back on research undertaken in each country. Over the years, each region has identified different research priorities and developed a distinctive research agenda, including also the market-oriented development of the banana sector. Each banana R4D network has aligned itself, at least to some extent, with the agenda of its respective regional agricultural research umbrella organization (e.g., the Association for Strengthening Agricultural Research in Eastern and Central Africa). The members also closely link with the Global Musa R4D Programme, ProMusa (www.promusa.org), which provides a platform for exchanging information, synthesizing research results into knowledge products, and delivering outputs to various user groups. Regional research areas provide valuable opportunities for inter-regional learning, despite differences in production systems and other circumstances. This process represents a tremendous increase in the effectiveness of the impact pathway for research and illustrates a vitally important way in which networking leverages research efforts.

In terms of *implementing* a collaborative research agenda, existing partnerships provide almost instant access to project partners, whether individuals with special expertise or organizations with a compatible agenda. Project consortia can be readily mobilized among partners who are already familiar with one another's strengths and weaknesses and among whom some level of mutual trust has already been established. This will mobilize more and more diverse resources than any partner could gather on its own and provide access to a vastly greater range of expertise (see Box 4.7.2).

Box 4.7.2: The Sweetpotato for Profit and Health Initiative—a long-term consortium for collaborative research

In 2009, CIP launched the Sweetpotato for Profit and Health Initiative (SPHI) focusing on reducing child malnutrition and improving smallholder incomes through the effective production and expanded use of sweetpotato in SSA. Breeding for resistance and improved nutritional quality, the release of new varieties, participatory breeding with local farmers for improved variety development and evaluation, and farmer training programs are just some of the components of the initiative that brings together a number of institutes. SPHI illustrates the powerful potential of establishing a collaborative research agenda with multiple partners as part of the program-planning process. The 10-year, multidonor initiative is expected to improve the lives of 10 million households and bring an annual value of \$241 million in additional production in 17 countries of SSA by tapping the unmet potential of sweetpotato to improve health, income, and nutrition. The design involved a 10-month planning process, including 10 in-country visits by teams of CIP scientists and partners, outreach to 300 potential partners through a questionnaire soliciting input and interest, and five workshops to establish program priorities and components. It also built the framework for a dynamic and sustainable base of partners of a scale necessary to meet the goals of this wide-scale initiative.

Once the research of a project consortium is complete and products are available, partnerships provide many key elements of a “ready-made” impact pathway, not necessarily the “classical” ones, leading through NARS to agricultural extension systems to farmers. Peer networking can rapidly spread the uptake of research products among fellow researchers and may even provide a platform for advocacy in different directions—for instance, when researchers from different organizations join in advocacy efforts directed towards investors and other decision makers.

However, leveraging significant outcomes will require new types of partnerships to tailor products more cost effectively to specific users, regions, or needs. For example, partners may offer particular expertise in such areas as the development of culturally appropriate training materials and communication tools, or in the use of webinar technology and networks to broaden the reach and uptake of new knowledge.

Certainly it is not necessary to carry out all R4D through complex, multipartner projects. Some research is best done by a single organization with clear comparative advantage—though, in such a case, partnerships still offer part of the impact pathway for encouraging the uptake of that organization’s results and for learning amongst organizations and across geographical and disciplinary boundaries. Partners can be engaged through learning alliances and partnership and information platforms (see Box 4.7.3).

Box 4.7.3: RedLatinPapa—dynamic communication to enhance germplasm exchange and variety development

RedLatinPapa—a network launched by 15 international and national potato research organizations—is both a partnership and communication platform. It is aimed at improving farmers’ access to improved potato varieties and new technologies to increase food security and incomes. Specific objectives include enhancing investments in potato improvement and dissemination, systemizing models for the uptake of new varieties, and exchanging experiences in PVS and seed systems by combining inputs and information from multiple disciplines, actors, and environments. The active collaboration and information sharing among members has stimulated new approaches and prevented unnecessary duplication of conceptual or methodological concepts. Germplasm exchange has increased, with 1,000 genotypes shared in three years, and concurrent trials throughout partner countries of Central America, the Andes, and the Southern Cone to test selected long-day and short-day varieties in differing environments.

4.7.2 Impact pathway

The impact pathway of Theme 7 will occur primarily through Themes 1–6; this is reflected in its location on the impact pathway diagram as “cross-cutting” in Figure 2.1 (p. 22). For example, capacity strengthening for improved breeding methods will be a part of Theme 2, but will benefit from the learning alliances. Figure 4.7.2 shows the impact pathways envisaged for Theme 7.

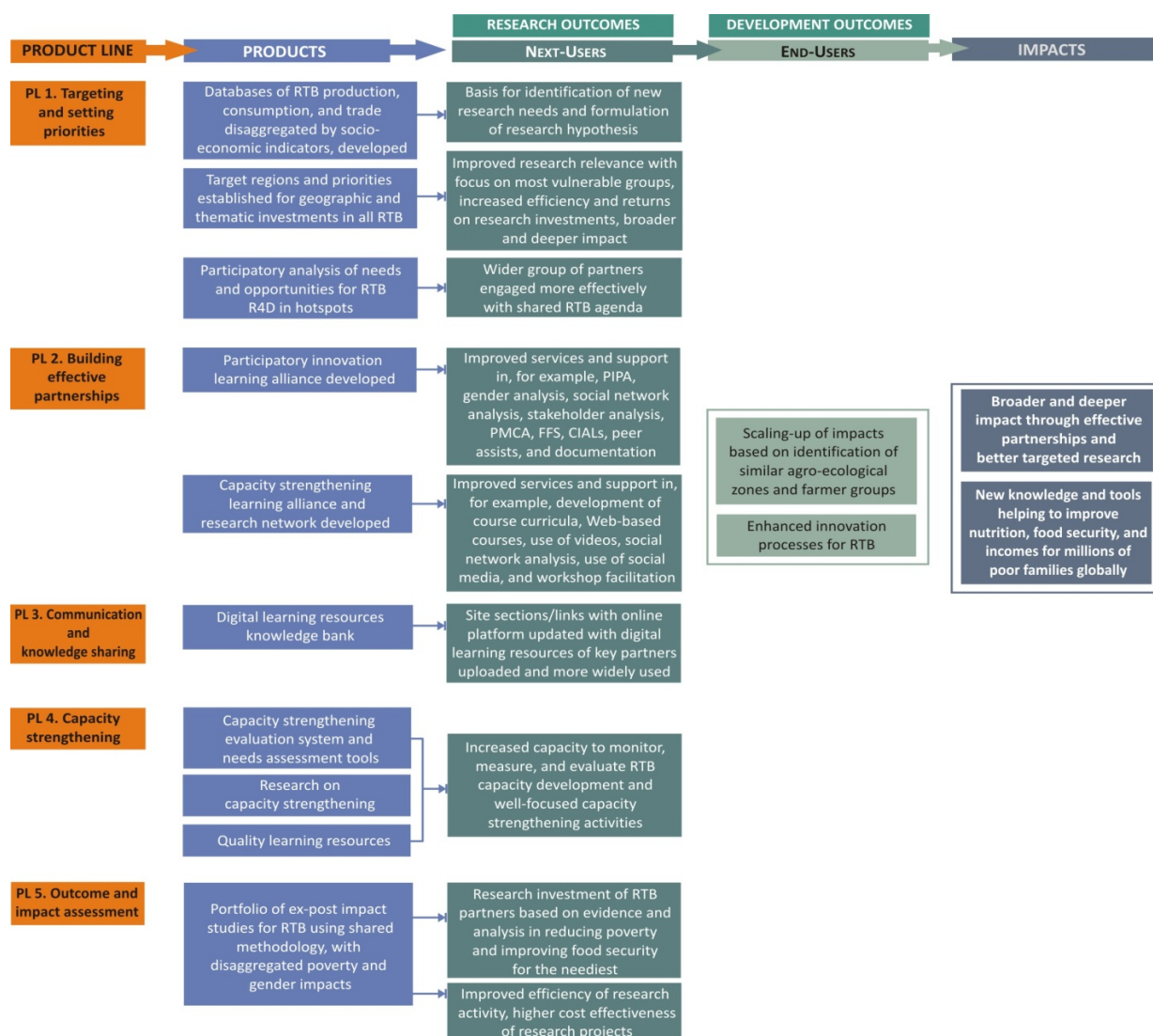


Figure 4.7.2 Theme 7 product lines, products, outcomes, and impacts.

4.7.3 Product lines

There are five product lines associated with Theme 7. Annex 2 contains the product line description tables (research products, outcomes, milestones, and key partners) for Theme 7.

PL 1: Targeting and setting priorities

Targeting

Poverty has clear geographical dimensions (Bigman and Loevinsohn 2003). Differences in the incidence of poverty in different geographical areas are linked to differences in agro-climatic conditions, natural resource endowments, road access, and availability of public services. Geographical distribution of RTB crops is also driven by natural resource endowments, climate, and socioeconomic factors, with wide differences in the crops grown in different regions and their farming systems. These different farming systems have different constraints and opportunities; they require different production technologies, different genetic material, and a different organization of research and extension services. *Targeting* will ensure that agricultural R4D is guided by the importance of the RTB crops in farming and food systems for addressing hunger and poverty.

Advances in GIS and availability of spatial data make feasible the mapping of a combination of agro-ecological and socioeconomic variables (Byerlee 2000). Making poverty mapping relevant for the targeting and development of agricultural technology will increase the impact of agricultural research on the poor, and may be particularly effective if regional disparities are large.

We will target R4D efforts based on the combined mapping of poverty indicators with agro-ecological variables of areas where the RTB crops are dominant (closely linked to CRP 1.2 action areas), actual crop or cropping system maps, pest and disease incidence maps, and the like (Theisen and Thiele 2008). This will lead to the identification of hotspots defined as geographical areas where high poverty incidence or vulnerability to poverty coincide with high importance of RTB target crops for subsistence and income generation.

Scientists from all four Centers, in collaboration with existing networks of researchers and organizations and new partners, organized by crop and region, and linking closely with CRP 1.2, will *identify priority* research needs for RTB and opportunities for up-scaling in the hotspots.

Geo-referenced databases for cross-regional analyses

The CRP-RTB will complement ongoing efforts in producing, managing, and using spatial information in individual Centers and the wider CGIAR community. It will integrate, share, and streamline these efforts through Web-based tools. Using these tools, partners, collaborators, and other stakeholders can find, display, download, and use spatial data related to RTB crops. Cross-regional analysis will play a key role in enhancing the understanding and strengthening of pro-poor impact pathways, which are of particular relevance to Theme 7. We envisage the following steps:

1. Improve maps of RTB production areas using both SPAM (Spatial Allocation Model, <http://mapspam.info> in collaboration with IFPRI/Harvest Choice) and crowd-sourcing approaches and overlay with agroclimatic data to identify global intersections for RTB and poor households.
2. Annex existing household survey results (cultivars grown, production technology used, external inputs, household wealth indicators, etc.) to production area maps to fine-tune understanding of limitations and opportunities for RTB to contribute to poverty reduction through income and food security. Global maps of poverty will be cross-referenced at this point. Typologies for key client household groups will be identified for RTB production and postharvest technologies.
3. Develop a cross-referencing approach to link germplasm, IPM techniques, and crop production technology to specific agro-climatic and socioeconomic homologue zones across continents.

Specific geo-spatial databases operating through CG-wide initiatives will contribute to other themes in this CRP, for example:

- *Theme 1: Conserving and accessing genetic resources.* The genetic resources documentation portal Genesys (<http://www.genesys-pgr.org>) compiles passport, characterization, and evaluation data of 22 crops with data shared by several CGIAR genebanks. The list includes RTB crops.
- *Theme 2: Accelerating the development and selection of varieties with higher, more stable yield and added value.* The GCP-IBP platform (<http://mbp.generationcp.org>; <http://cropinfo.org/icis>) is a “public database” for experimental results in breeding, from planning to analysis. Locations are geo-referenced to interpret GXE effects. All CG Centers are working on the ICIS databases for their mandated crops. This approach will be especially useful for RTB crops based at two different Centers.

- Theme 3: *Managing priority pests and diseases*. All four CRP Centers are mapping and modeling the principle pests and diseases of RTB using climate- and ecology-driven global distribution models, data from global cultivar trials, and spatially explicit models of disease incidence and severity (e.g., GeoBlightCast for potato LB).

Initiatives applicable to several themes in the CRP-RTB include:

- CRP 7 on Climate Change is building a CG-wide platform for mandate crops globally. Data from previous, ongoing, and new variety trials will be compiled into a single database to strengthen analogue/homologue approaches in the context of adaptation to climate change and variability.
- The Consortium for Spatial Information (www.cgiar-csi.org) links CGIAR scientists and national and international partners to apply geospatial science for sustainable agriculture development, natural resource management, biodiversity conservation, and poverty alleviation. Important data-sharing initiatives are the geonetwork (<http://geonetwork.cgiar.org>) and the agricultural development atlas (<http://mappr.info/atlas>). All four partner Centers in RTB are represented in this Consortium and new proposals will build on the broader initiatives and tools.
- Crop atlases have been developed for potato and sweetpotato using census data, poverty and health statistics, and expert knowledge (<http://research.cip.cgiar.org/confluence/display/wpa>, <http://research.cip.cgiar.org/confluence/display/wsa>).
- IITA has produced an electronic tool (WebGIS) to capture spatial data on banana production. Bioversity and IITA worked with local banana experts in Africa to map banana-growing areas and characteristics, incorporate them into GIS, and publish as the Banana Open Access Platform (<http://banana.mappr.info>). Bioversity and partners in LAC and Asia are using these tools to map banana production and overlay with agro-climatic data to identify homologue zones and sub-groups of growers based on resource endowment and market access. IITA is working on a geo-referenced dataset of production and yields of cassava and yam in Africa.

Priority Setting

A rigorous assessment of priorities for RTB investment at the global level will be planned and carried out as soon as the CRP-RTB is approved using current best practices (see Box 4.3.4, p. 93).

The CRP's overall objectives will be used to define an appropriate set of criteria such as the following:

- **Food security:** contribution of crops to sustainable food systems and environmental sustainability in different regions, share in consumption and marketing, share of rural and urban household expenditure in crop consumption, and gender participation in crop production.
- **Improved nutrition:** proportion of calorie intake from crop, contribution of crop to diet diversification, and contribution of crop and technologies to improved intake of micro-nutrients.
- **Income generation:** potential productivity increase of crops; yield gaps between current and potential productivity; crop share and value across different regions; and potential of crops (including minor crops) and technologies to reduce poverty across different income groups, including consumption and marketed share of crop and employment potential. This includes spatial criteria to assess the geographical dimensions of poverty and the link to agro-ecological conditions, natural and physical resource endowment, considering vulnerable agro-ecosystems.

These criteria will be refined during the planning phase of the exercise and agreed with the Management Committee (MC) and other stakeholders to ensure alignment between the portfolio of research activities and optimal resource use. The priority-setting exercise will draw on advice from well-known experts in the field, including gender experts, to plan the process, develop appropriate methods considering RTB complexity, and interpret results. An inter-center taskforce for priority setting (TFP) will conduct the exercise in four phases over a 12-month period (see Figure 4.7.3 and Box 4.7.4). The purpose is to develop an RTB investment portfolio composed of those products or product lines for which tangible benefits can be clearly identified and optimized.

PHASE	Months	Coverage	Participants
I Plan & Identify Criteria	1 2	Global	RTB MC, TFP, ARIs experts, selected global stakeholders
II Analyze Demands & Needs	3 4 5	Regional & National	Regional and national stakeholders, scientists, TFP
III Assess Crop & Technology Priorities	6 7 8 9 10	Global & Regional (Centers)	Centers' scientists, TFP, priority-setting experts
IV Communicate Results & Adjust Plans	11 12	Global & Regional	Centers' staff, RTB MC, global, regional, and national stakeholders

Figure 4.7.3 Timeline of phases to conduct the priority-setting exercises.

Box 4.7.4: Four phases of the 12-month priority-setting exercise for the CRP-RTB

Phase I: Plan and Identify Criteria—months 1–2

1.1 Set up inter-center taskforce (TFP) and assess current priorities against RTB objectives. We will review the relevant experience and results of prior priority-setting exercises and identify complementary resources to be drawn on for the exercise. The TFP will rigorously review methods and priorities set at each individual Center in the near past (5–7 years) to conduct a gap analysis of the current situation by crop and Center with respect to the objectives of the CRP-RTB.

1.2 Refining, selecting, and agreeing upon the criteria and methods to be used in priority setting. Criteria for priority setting will be selected and agreed upon by all involved Centers in consultation with key stakeholders. This will provide the basis for selecting appropriate methods and developing a detailed framework and timetable for the exercise.

Phase II: Analyze Demands and Needs—months 3–5

2.1 Spatial targeting and identification of hotspots. Advances in GIS and availability of spatial data make it feasible to map a combination of agro-ecological and socioeconomic variables. Making poverty mapping relevant for the targeting and development of agricultural technology will increase the impact of agricultural research on the poor, and may be particularly effective if regional disparities are large. We will target R4D efforts based on the combined mapping of poverty and livelihood indicators with agro-ecological variables of areas where RTB crops are dominant (closely linked to CRP 1.2 action areas), actual crop or cropping system maps, pest and disease incidence maps, and others. This will lead to the identification of *hotspots*—that is, geographical areas where high poverty incidence or vulnerability to poverty coincide with high importance of RTB target crops for subsistence and income generation.

2.2 Stakeholder consultation to validate and complement spatial targeting. The results of spatial targeting and the identification of hotspots will be reviewed with a broader range of stakeholders in order to ensure inclusion of regions where (1) agro-ecosystems might be particularly fragile and vulnerable and require innovative research to prevent degradation or (2) regions with high potential for fast development of technologies and for effective testing of approaches for out-scaling impacts to the poor.

Phase III: Assess crop and technology priorities—months 6–10

3.1 Consultation to identify best-bet technologies, probabilities of successful development, and adoption. At the crop and technology level, best-bet technologies will be identified and rated with respect to probabilities of successful development and adoption. Key stakeholders will contribute their assessment of relevance and probable research success and scale of adoption by target populations.

3.2 Application of sound methods to assess priorities at crop and technology levels. We will carry out quantitative and qualitative assessment of best-bet technologies in order to derive indicators such as comparing returns to investments between research programs, DALYs methods and optimization techniques, and estimation of gender-specific effects. Technologies can then be evaluated in terms of rates of return, numbers of farmers bootstrapped across a poverty line, and scored against criteria.

Phase IV: Communicate results and adjust plans—months 11–12

The results of rates of return, scoring, and number of farmers reached by technology and research areas in Phase 3 will be shared among Centers. Regional stakeholders will be consulted in order to review outcomes against the priorities and needs that were agreed during the earlier phases. Detailed feedback will be provided to all relevant stakeholders of results.

In the RTB hotspots, priority setting will be supported by Participatory Impact Pathways Analysis (PIPA) to build a theory of change with partners and form a basis for documenting outcomes and impacts (Douthwaite et al. 2009). Involving local, national, and international stakeholders in the analysis of impact pathways from the beginning will strengthen the impact orientation of research planning and implementation and form the basis of alliances between actors to facilitate the use of outputs in the development process. Targeting of the poor and vulnerable as well as addressing gender-specific roles will be supported by specific in-depth studies on the significance of RTB in combined farming systems, considering gender-specific roles in production, processing, marketing, and consumption. We will share and validate findings in stakeholder consultations. This will guide a pro-active approach to develop relevant agricultural technology that responds to the specific needs of poor farmers and other vulnerable groups (e.g., women and young children, minority groups) and performs well in the ecologies in which they farm and under the management they can apply within an evolving development environment.

Priority setting within the partnership learning cycle builds continuously on evidence provided by ex-post impact assessment. Special attention will also be given to anticipating gender-related effects and including other metrics such as Disability Adjusted Life Years for nutrition interventions (see Box 4.7.5).

Box 4.7.5: Ex-ante impact assessment of interventions to improve nutrition

Reducing nutrient deficiencies is an essential part of the overall effort to fight hunger and malnutrition. Currently, most efforts focus on supplements and food fortification. However, these approaches are limited by lack of infrastructure, logistical support, and regular financial disbursements by Ministries of Health. As a result, most nutritionists now consider diversifying the diet and increasing the micronutrient content of staple crops grown in developing countries (biofortification) to be a low-cost, sustainable way to reach people with poor access to health-care systems and/or formal markets. Ex-ante impact assessment studies can quantify the impact of crop and cultivar diversification and biofortification of RTB as an accessible vehicle for micronutrients. The effect on the health status of poor populations can be assessed by disability-adjusted life years analysis (Stein et al. 2005).

PL 2: Building effective partnerships

Underpinning the partnership learning cycle is a theory and strategy of partnership. Partnerships involve program and project partners as well as next-users and end-users. Next-users are expected to directly take up project outputs, including direct implementers of this CRP; end-users are those whose livelihoods are expected to benefit by the realization of the goals of the CRP-RTB. Next-user partners with gender skills will be important both for enhancing gender analysis skills within program activities as well as to ensure gender equity in collaborative links with end-users.

The partnership strategy involves a process of self-reflection about the aims and expectations of the partnership and of individual partners, roles, and responsibilities, and the expected dynamics of partnering, in terms of information sharing, leadership styles, accountability processes, and trust-building mechanisms. It also involves an analysis of the institutional arrangements of the partnership within partner organizations and specific commitments from those organizations to the partnership, including clarifications on potentially conflicting governance issues. Horizontal evaluation is a communication methodology that can be applied to foster knowledge exchange, social learning, and mutuality among RTB stakeholders and users. It combines self-assessment and external review by peers to stimulate a dynamic dialogue, mutual learning, and program improvement. Horizontal evaluation has been applied to evaluate multistakeholder platforms designed to access value market chains or to articulate the demands of small-scale producers for processing and postharvest technologies (Thiele et al. 2007).

The collaboration of our partners throughout the product lines is key to realizing Theme 7's impact pathways (see Table 4.7.1).

Table 4.7.1 Roles and Responsibility of Partners in Impact Pathways

Product Lines	Representative Key Partners	Roles and Responsibilities
PL 1. Targeting and setting priorities	▪ NARS social scientists ▪ Farmer organizations ▪ Ministries of Agriculture ▪ Extension organizations ▪ Gender specialists ▪ ARIs ▪ OECD ▪ FAO ▪ IFAD ▪ World Bank	A broad range of partners will be involved in characterizing production systems, and identifying and ranking constraints. Gender specialist will help identify production problems from gendered perspective. NARS scientists, including social and gender specialists, in close interaction with farmers and farmers organizations, will estimate adoption potential of new technologies, understanding gender and distributional consequences of adoption, and validate results of targeting. Integrate in regional targeting and priority-setting exercises.
PL 2. Building effective partnerships	▪ NARS (social scientists and gender specialists) ▪ Regional STB networks and societies ▪ ARIs ▪ Private sector actors	NARS and regional networks will conduct partner diagnosis and map actor networks. They will conduct joint analysis and learning about best partnership practice.
PL 3. Communication and knowledge sharing	▪ Social media specialists ▪ Communication specialists ▪ Private sector actors ▪ National, regional, and global STB networks ▪ RTB info/knowledge networks	Communication specialists will work closely with target user groups and RTB networks to define user needs, and compile feedback on content, and research advances. Together with social media specialists, they will jointly develop adapted communication tools.
PL 4. Capacity strengthening	▪ Universities ▪ ARIs ▪ NARIS ▪ High schools ▪ FBOs & CBOs	Partners will assess needs for capacity strengthening. NARS, ARIs, universities, high schools, and FBOs & CBOs will work together to develop capacity-strengthening tools, and participate in community of practice for capacity strengthening in RTB.
PL 5. Outcome and impact assessment	▪ NARS ▪ ARIs ▪ National and regional partners ▪ Private sector actors ▪ Investors ▪ Project implementers	National and regional partners will participate in developing shared database and baseline of crop yields, area, and production. They will jointly organize adoption and impact studies, and provide a gendered perspective on impacts. Private sector actors and investors will contribute to rate of return and studies of impact of technology on poverty.

Respondents in the August 2010 stakeholder regional survey ranked the importance of several methods (adapted from Woolley et al. 2009) for building effective partnerships among people and institutions (Table 4.7.2). These findings, elaborated in Annex 1, will be instrumental in guiding the development of a CRP-RTB partnership strategy.

Table 4.7.2 Ranked Methods for Building Partnerships

More Important	Ranking
Involve the right people and organizations	4.68
Transparent decision making and communication	4.64
Agree clear, shared, flexible objectives that reflect stakeholders' diverse interests and needs	4.54
Share recognition and responsibility for outcomes	4.37
Agree supervision responsibilities across institutional boundaries	4.31
Agree guidelines about how responsibilities are assigned	4.29
Make impact pathways explicit	4.20
Slightly less important	
Agree team standards for response time, sharing credit and time investment in discussion	4.03
Agree conflict resolution processes	3.98
Allow time for development of trust and a common language	3.97
Give leadership responsibilities to non-CGIAR partners	3.84
Clarify expectations about time investment in decision making	3.88

Note: (n = 164–175)

Partnership self-diagnosis tools will provide robust groundwork for formation of learning alliances and development of strategies for improving regional and thematic RTB partnership effectiveness and sustainability. Learning alliances support a process undertaken jointly by R4D agencies through which research outputs are shared, adapted, used, and innovated upon. This is done to facilitate learning, strengthen local capacities, improve the research outputs, generate and document R&D outcomes, and identify future research needs and potential areas of collaboration. The learning alliances process begins with the identification of research outputs or development outcomes susceptible to scaling-out by partners. It is followed by one or many adaptation and learning cycles, and is completed with the detection of new research demands, which feed back into the research process and help generate improved livelihood or policy outcomes. We will strengthen and consolidate the many RTB-linked learning alliances or multistakeholder platforms for innovation that already exist.

PL 3: Communication and knowledge sharing

The key to effective partnerships is communication. This CRP will connect partners through interactive platforms for project implementation, social networking, and knowledge sharing. The CRP-RTB will help connect existing RTB-related communication platforms or resources such as ProMusa, CLAYUCA, or RedLatinPapa (see Boxes 4.7.6, 4.6.3, and 4.7.3, respectively). Partners can benefit from the wider exchange of information, skills, or expertise offered by the extensive and global network of RTB partnerships. As one stakeholder respondent noted, “in sub-Saharan Africa there are multiple regional/sub-regional structures and initiatives like the Comprehensive Africa Agriculture Development Programme, Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel, Economic Community Of West African States, Southern African Development Community, East African Community, and East, Central, and Southern African and it is key to link into this architecture.” The ability to identify and map out the RTB-related resources, for example, would be a very valuable communication support activity, not only for this CRP, but also across the full system of other CRPs and the CGIAR. These platforms will also provide a framework for

interaction with end-users, allowing their feedback on R4D outputs and new technologies to be communicated to the RTB and partner scientists.

Feedback received from stakeholders in August has made it clear that effective RTB communication and knowledge sharing need a well-balanced mix of different tools and strategies, including face-to-face interactions, online tools, print, and other media. The choices made will need to be based on a clear understanding of our target audiences and their needs and expectations.

Box 4.7.6: ProMusa: Sharing information and knowledge on banana

The network strives to be a platform for exchanging information, synthesizing research results into knowledge products, and delivering outputs to various user groups. Its main tools are a biennial international research symposium (+ proceedings), an electronic newsletter, an electronic forum for *Musa* community engagement and a *Musa* knowledge resource centre, being developed for and by the community (<http://www.promusa.org/musapedia>). The development of the *Musa* knowledge resource centre is based on a user-centered approach. Key groups of target users were interviewed to get a deeper understanding of the users' goals, needs and attitudes, to guide the design of content and features in the website. The network has established an alliance with the International Society for Horticultural Sciences, which provides the opportunity to draw in expertise from other crops and disciplines, and to increase impact through the dissemination of results in widely read and well respected society publications. The network has linked in with the World Banana Forum, facilitated by FAO, as such ensuring an open dialogue with stakeholders of the global banana supply-chain on challenges facing the banana industry.

RTB Web Portal

An RTB Web portal and its different “modules” will tailor information and delivery to diverse users (e.g., the RTB scientific community, stakeholders and partners, donors, project beneficiaries, media, and the general public). As noted by respondents in the stakeholder workshops, publicity and linkages to the website are key to its effectiveness and use by farmer organizations and the private sector.

First, the site will profile the CRP-RTB, the R4D portfolio, and the program partners. It will publicize relevant developments to stakeholders and partners, highlight progress and results, and raise public awareness. We will customize RTB news for donors to illustrate the impact of their funds, feature PPP activities, and provide ways to facilitate broader and novel types of partnerships. This content can also show quantifiable impacts on gender and livelihoods—how the activities of the CRP-RTB are making achieving their objectives.

Second, with advances in social media, the site will provide a “workspace” to connect project partners, to share information (e.g., reports), and to offer a forum for discussion. We will post working papers for downloading through a password-protected “account” that can be set up to ensure confidentiality of proprietary data.

Third, to respond to the high value that stakeholders place on having access to research findings and knowledge, the site also will serve as an entry portal to knowledge resources on RTB crops to link users to the latest RTB science and R4D information. As such, it can support capacity building and delivery of new learning tools. By offering information in a concise and user-friendly form, it will help address “information overload.”

Communication is key to effective partnerships. The reverse is equally true: partnerships and networks are critical for extending the reach of the CRP-RTB to users to promote knowledge sharing and the uptake of research advances for impacts. Reaching multiple audiences in appropriate formats requires a multichannel approach, using multiple communication fora, including those that liaise or piggy-back onto the communication channels and activities of partners.

Partners offer skills, resources, and comparative advantages to complement the content expertise and knowledge of the CRP-RTB for creating effective and affordable communication tools or strategies. Special attention will be given to collaborative approaches where partners are actively sharing best practices and global public goods instead of simply being passive recipients of information. Examples of communication products/strategies that could benefit from the comparative advantages brought by partners could include:

- Outreach through local radio and e-alerts through mobile phones
- Web-based seminars or learning modules (benefiting from technology resources and expanded outreach through local universities, cable television, health centers, other partners)
- Development of tools adapted to specific languages, literacy levels, or age/gender groups
- Use of gender e-platform to provide access to gender analysis tools and learning opportunities
- Development of communication strategies building on cultural tradition (e.g., theater, oral history, music)
- Dynamic feedback mechanisms to inform research or improve communication modalities/products.

Another important communication aspect of the RTB partnerships is the “strength in numbers” they can represent, particularly to donors, policymakers, or value market-chain participants. The input and buy-in from partners will be solicited and reflected in the development of communication tools, priority setting, or strategies to offer stronger and more compelling messages and recommendations.

Finally, strategic investments will be made to increase overall public data availability on the production areas, yields, and prices of RTB. As locally traded crops grown by smallholders in often remote areas, RTB data are scarce and often represent rough estimates at best. The CRP will collaborate with country-level agricultural production surveillance and statistical institutes and the FAO to establish models for regular monitoring and updates of production data from national statistics and databases.

PL 4: Capacity strengthening

CS activities require effective internal CGIAR as well as external partnerships to achieve and sustain R&D outcomes by addressing three principal objectives:

1. Strengthening Capacities for Research

This will support activities and programs to identify and better respond to stakeholders’ needs, through an RTB Capacities and Needs Assessment Platform. This is a set of operational tools, resources, and activities with dedicated personnel to conduct regional, institutional, thematic, or crop-specific capacities and needs assessments to guide training strategies, CS investments, and local/regional CS strategies with our partners. In response to identified demands, the platform will implement new CS programs such as facilitated courses (face-to-face, online, or a blend of both) on priority themes, and incorporating new knowledge into curricula and learning resources.

2. Enhancing Effectiveness

A new CS research program for RTB will provide qualitative and quantitative analysis from the social sciences to generate new knowledge and empirical evidence on identified needs and capacities developed or utilized, while compiling lessons learned about best practices. CS research will complement the development of a shared CS evaluation system with agreed indicators across participating Centers to gather and interpret relevant reporting data for all CS-related activities, assess RTB capacity needs and investments, and design/implement appropriate tools and indicators

for measuring outcomes and impacts. The CS research program and evaluation system together will provide quality control of RTB investments as well as solid evidence to better influence and guide policy or program funding decisions.

3. Strengthening Capacities for Development Impacts

To achieve measurable impact, appropriate learning, training, and innovation systems with partners need to be adopted or strengthened. New participatory research strategies, platforms, and analytical/assessment tools and activities are needed. Achieving impact requires working with traditional partners (NARS) in new forms of collaboration. It also implies expanding and strengthening capacities to engage in new partnerships, consultations, and multistakeholder processes to broaden the reach and uptake of research among potential end-users on different parts of the impact pathway.

An inter-Center community-of-practice for RTB will collaborate to design and support key CS cross-cutting mechanisms or processes for reaching the greatest number of end-users for maximum development impact. Key cross-cutting products for RTB capacity strengthening are the development of quality learning resources (e.g., field guides and training manuals), reusable learning objects, protocols and analyses of RTB best practices, online training courses, and others. Many of these will be integrated into the RTB knowledge resource Web modules (PL 3). An excellent example is the ICT/KM Program (Box 4.7.7).

Box 4.7.7: CGIAR ICT/KM online learning resources project

The CGIAR's ICT/KM program promotes and supports use of ICT/KM to improve the effectiveness of the system's work on behalf of the poor in developing countries. From 2004 to 2008, CIP, the World Agroforestry Center, and the United Nations University coordinated an ICT/KM–World Bank sponsored project for Online Learning Resources (OLR), with other CGIAR Centers and partners. One aim was to improve the online content and delivery system for learning resources, tools, and courses across the CGIAR. The OLR project laid useful foundations for innovative CGIAR distance learning and research CS. New CRP 3 activities are planned with a focus on collaborative learning and training with RTB partners. The proposed RTB digital learning resources knowledge bank, RTB quality learning resources, and RTB online training courses will facilitate the development, archiving, easier use, and more cost-effective delivery of high-quality RTB learning resources, training, distance education, and evaluation tools. An RTB evaluation system will help assess new online learning work and development outcomes/impacts.

An RTB capacity-strengthening partnerships research and learning network will use social media, social network analysis, virtual dialogue platforms on special topics, consultations with partners, biannual conferences, special theme or regional events, and proceedings publications, all to gather lessons learned, improve outputs, outcomes, end-user delivery systems, and development impacts of all RTB CS investments.

PL 5: Outcome and impact assessment

PL 5 deals with assessing outcomes and impacts of RTB product lines as presented in Themes 1–6. Because of the time lag between achieving a research product and the realization of outcomes and impacts, it will systematically assess the results of previous RTB investment. Outcome and impact assessment is important for accountability purposes to stakeholders, and to guide future investment, but also to learn lessons about what works and to provide feedback to the R&D process. This PL will primarily assess development outcomes (monitoring research outcomes is an M&E function considered in section 6). A central part of the product line is to provide a comprehensive assessment of the socioeconomic and institutional determinants and impacts of RTB technology development and seed delivery efforts; outcomes of value chain and policy-related work will also be included.

Within the partnership learning cycle, outcome and impact assessment is a critical input for priority setting and learning among CRP Centers and partners. It comprises outcome documentation, process-related research, and ex-post impact assessment for a systematic review and synthesis of lessons learned from the assessment of similar crop-specific and cross-crop product lines within the different research themes. As well as demonstrating successes, impact assessment will include the documentation, analysis, and synthesis of lessons learned from previous experience—be it failure or success—and understand the underlying reasons and determinants for positive (and possibly negative) impacts on livelihoods of target populations.

PL 5 will be based on collaboration across RTB crops and related research centers to generate a shared framework and facilitate the synthesis of experiences based on similar characteristics of RTB. For example, gender impacts and changes in nutritional status can be viewed as an outcome of postharvest research on strategies for increased consumption of RTB and improved nutritional qualities through biofortification and processing. PL 5 comprises seven components.

First, we will establish a strong knowledge base through baseline studies and situation analyses in the identified hotspot target areas of this CRP to understand the context prior to interventions. This will be linked with targeting described in PL 1.

Second, to measure the impact of research on RTB on the livelihoods of the poor, we will identify a set of outcome and impact indicators by using the PIPA to create a plausible theory of change with stakeholders. This is linked with first-order, gender-disaggregated impact indicators that include (1) technology adoption; (2) crop yields, area, and production; (3) changes in practices and level of inputs; (4) changes in production costs and profitability; and (5) changes in attitudes and risks faced by farmers. Second-order longer term impacts include changes in welfare of producers and consumers due to income, asset accumulation, and price effects; changes in consumption, food, and nutritional security; distributional impacts as well as changes in resource management and environmental conditions; and other spillover and indirect economy-wide effects. Tracking RTB technology adoption pathways and assessing their long-term impacts on poverty and food security will require panel (or longitudinal) data across countries and regions. The resulting unique data sets provide the platform to test novel analytical models and to improve understanding of socioeconomic processes, development pathways, and the role of technological and institutional innovations. These databases will serve as a unique opportunity to attract partnership with ARIs and NARS.

Third, we will conduct studies to assess the extent, pathways, and determinants of technology adoption at the farm level. Research hypotheses will be formulated to test and explain gender differentials in adoption and impacts of improved RTB technologies with a view to enhance the intra-household distribution of the benefits. Attention will also be paid to generational issues and particularly technology adoption of the young, considering impacts on rural urban migration.

Fourth, the use of PIPA and evaluation methods such as horizontal evaluation will increase the relevance of impact assessment, foster learning alliances, and enhance the uptake and use of evaluation results for the targeting and planning of further research activities.

Fifth, environmental impact assessment of CGIAR technologies will become increasingly important. Choice experiments can be applied to assess traits and attributes most valued by households and end consumers in both rural and urban areas. Results from the choice experiments can orient policy by estimating the willingness-to-pay of different agents for specific traits and attributes, and establish appropriate dissemination strategies of promising technologies or compensation and

mitigation measures of potential negative impacts. These results can also be incorporated into extended cost-benefit analysis to improve traditional economic impact analysis.

Sixth, we propose to use randomized control trials, which could also be applied to RTB systems in a more integrated way for comparative analysis of alternative delivery and seed systems.

Finally, ex-post impact assessment will use innovative research design methodologies and statistical methods developed in the recent literature on program evaluation to assess the impact of new technology after introduction and adoption by farmers (Imbens and Wooldridge 2009; de Janvry, Dunstan, and Sadoulet 2010). These will focus on both stage 1 and stage 2 types of ex-post impact assessments (Walker et al. 2008). Stage 1 studies will include analyses of technology impact on intermediate impacts (area, yield, production cost, profitability, incomes) at geographically aggregate scale (district, region, country) after dissemination and adoption have occurred. Stage 2 analyses will focus down the impact pathway on poverty reduction, food security, gender equality, and environmental sustainability when adoption is sufficiently scaled up. Policy-oriented research studies will use econometric modeling to estimate supply responses and the elasticity of supply and demand to changes in factors such as prices, wage rates, credit, and marketing policy; as well as to evaluate the impact of alternative policy innovations.

4.7.4 Critical Assessment of Methods

PL 1: Targeting and setting priorities—Priority-setting methods

Relative scarcity of available resources justifies priority-setting exercises in agricultural research. Since the broad arrange of themes and projects available for a given research program is normally larger than the resources allocated to them, priority setting becomes a necessity to maximize the social benefits of research. Priority setting practice can be traced back to the earlier work of Griliches (1958) and his use of economic surplus methods to assess the ROIs into hybrid corn. Since then, the pioneer work of Ruttan (1982) linking priority setting, evaluation of agricultural technology, and agricultural policy making constituted a new milestone in the development of priority-setting approaches and methods and the relevance of such studies for research resource allocation. Alston, Norton, and Pardey (1995) developed an extensive and comprehensive review of the theory and methods available for use in priority-setting exercises and their work still remains a key reference for practitioners. The review presents an array of different econometric, partial, and general equilibrium methods for research evaluation and priority setting. Optimization techniques are suggested when research is to achieve different goals. Scoring models also offer an alternative when resources and time constraints or lack of proper data make more sophisticated quantitative approaches unfeasible.

The many years of experience of CGIAR Centers in applying these traditional economic methods and developing new ones (sometimes integrating a broader set of disciplines) have been compiled by Raitzer and Norton (2009). They show that CG Centers have been able to conduct priority-setting exercises adapting available methods to their specific objectives and conditions. In the past few years, a strengthened focus on poverty has also spurred the development of new approaches to refine targeting and measure ex ante the expected impacts on specific groups. Some of these methods still rely on economic theory and models (Moyo et al. 2007, Alene et al. 2007), while others make use of the increased precision of new tools (such as GIS) to produce information on potential agro-ecological zones of interest that helps agricultural research decision makers to define research programs and allocate resources accordingly (Wood and Anderson 2009, Byerlee 2000).

The partner Centers of the CRP-RTB have recently applied or developed adapted versions of priority-setting methods with different levels of rigor and under varying circumstances. IITA combines both qualitative and quantitative assessment to define research priorities. A priority ranking exercise is produced based on scoring models (Manyong et al. 2010, Manyong et al. 2009). The formal priority assessment exercise includes a number of quantitative priority-setting methods based on economic surplus models and poverty reduction assessments (Alene et al. 2007). At CIP, an extensive priority-setting exercise combined several measures of market price effects, poverty reduction estimates, and health improvements to define regional priorities by crop and research project. Information on ex-post impacts from previously released technologies was used to refine estimates of the ex-ante exercise (Fuglie 2007). As a tool to align the research program with the Millennium Development Goals, CIP also developed a targeting exercise by overlapping crop density maps with a combination of livelihood indicators, including poverty measures (Theisen and Thiele 2008). Bioversity has taken a regional approach to priority setting based on consultations with partners and stakeholders. Banana research organizations on a regional level of LAC, SSA, and Asia/Pacific region are collaborating in R4D networks supported and coordinated by Bioversity and come together regularly to identify and align research priorities within each region (see e.g., Molina et al. 2008).

CIAT, IITA, many NARS, and the private sector took part in a global priority-setting exercise led by the FAO as part of the Global Cassava Development Strategy in 2000, which contributed directly to the Implementation Plan ([rhttp://www.fao.org/ag/AGP/agpc/gcds/index_en.html#](http://www.fao.org/ag/AGP/agpc/gcds/index_en.html#)). The members of the regional networks for bananas are closely linked to the Global Musa R4D program ProMusa, which has carried out consultative identification of research priorities during bi-annual meetings of Steering committees of Musa research network (<http://www.promusa.org/musapedia>).

PL 3: Communication and knowledge sharing—Communication tools

International agricultural R4D is becoming increasingly complex, specialized, and global. We are starting to produce and organize our information less on our desktop and coming to rely more on the Internet. The emergence of Web 2.0 tools allows staff to practice horizontal and decentralized communication with colleagues and partners (Staiger-Rivas et al. 2009). This participatory and effective Web-based interaction blurs the boundaries between external and internal communications, and has consequences on the tools and platforms that the CRP will use to allow effective research collaboration among partners that provides quick best bets for research communication.

The CRP-RTB approach corresponds to those trends, and will work closely with the ICT-KM Program, drawing on its [TripleA](#) approach to assess the level of *availability*, *accessibility*, and *applicability* of research outputs, and identify pathways to turn these outputs into International Public Goods. The emergence of social media provides new horizons to research communications, transforming formerly unidirectional efforts composed almost exclusively of written material into more interactive and multimedia, bottom-up communications efforts (CIARD 2009). Examples are the now broad use of blogs and other social media, like Twitter, Facebook, or Wikis, combined with an effort to cultivate relationships and connect virtually through those media (“social media listening”). These approaches acknowledge the complexity of science while including beneficiaries and ensuring that their knowledge is taken into account. Creating this shared context (Snowden 2002) in turn requires skills such as facilitation, active listening, capacity strengthening, analytical skills, technical stewardship, and a good knowledge of the different cultures of our partners and stakeholders. Advances in ICTs that make technologies truly participatory can contribute to the way we communicate, share knowledge, and solve problems together, and thus facilitate the creation of learning alliances (Lundy, Gottret, and Ashby 2005). Participatory Learning and Action Research can be combined with technology-mediated learning methodologies through the use of

video, radio, and ICTs (Van Mele and Zakaria 2005, Africa Rice Center 2010) and participatory video documentation, knowledge-sharing tools, and methods (Staiger et al. 2009).

PL 4: Capacity strengthening—Evaluating capacity strengthening

Assessing capacity development is an integral part of enhancing the effectiveness of the CRP-RTB. If there is clarity about what is to be achieved through improved capacity in CRP 3.4 and the purpose of M&E, it is not difficult to come up with a blend of tools, methodologies, and approaches that can meet the needs of quite different stakeholders in this CRP.

Capacity development takes place at many distinct levels within innovation systems, including the levels of individuals, organizations, partnerships, and the system as a whole. There is a long tradition of evaluating capacity development at the level of **individuals**. Kirkpatrick's learning and training evaluation model assesses the results of training at four levels: (1) reaction of the trainee, (2) learning, (3) behavioral change, and (4) effects on the organization or environment. There has been extensive methodological development at the first two levels, but much less at the third, and especially fourth level.

There is extensive literature on **organizational** assessment that provides frameworks and methods for assessing an organization's capacity at one point in time and/or in relation to organizational motivation, the external operating environment and organizational performance. Harrison (2005), Lusthaus et al. (2002), Adrien (2003), Universal Management Group, and IDRC's evaluation unit have used the Lusthaus framework extensively. Horton et al. (2000, 2003) report on several cases where the framework was used to structure evaluations of capacity development in the fields of agricultural research, education, and rural development. Campilan et al. (2009) shows how evaluation can be used for capacity development in **community-based** natural resource management.

The Marguerite Casey Foundation has developed a useful online organizational capacity assessment tool for NGOs to assess organizational capacity and their capacity development efforts. It employs 59 indicators of capacity grouped under four capacity dimensions: leadership, adaptive, management, and operational). Simister and Smith (2010) provide a useful review of key concepts in capacity building and M&E for NGOs, and describes a variety of tools and approaches to plan, monitor, and evaluate capacity-building work.

Recent work on capacity development and its evaluation has stressed the importance of systems concepts and capacities. LaFond and Brown (2003) have done this in the health sector. Issues of system dynamics and capacity development are dealt with much more systematically by Baser and Morgan (2008), who present a general framework for analyzing and developing capacity that includes five broad capabilities resulting from a major study of capacity development undertaken by the European Centre for Development Policy Management and further elaborated by Engel, Keijzer, and Land (2007). The World Bank recently issued a comprehensive and detailed "Capacity Development Results Framework" (Otoo, Agapitova, and Behrens 2009), an approach to design, implement, monitor, and evaluate development programs with capacity development components. It includes a set of tools and a step-by-step guide for building results-focused capacity for development at a national or sub-national level.

Although there has been little work on the analysis of capacity and the evaluation of capacity development programs in agricultural research, Pound and Adolph (2005) present a useful literature review, websites, and indicators for monitoring success related to the development of the capacity of research systems in developing countries, in the natural resources, health, and governance sectors.

4.7.5 Partnerships

This theme has two distinct approaches to partnership. On the one hand, partnership is the subject of research attention and is a support function for this theme, helping other themes to successfully develop and implement their own partnership strategy, as discussed under PL 2 and in the theme-level partnership sections. On the other hand, Theme 7 will also work to develop strategic alliances for the different product lines. These will include collaboration with Michigan State University and Virginia Tech University (both in the United States) on priority setting and impact assessment issues, and with Wageningen University and Research Centre for research on communication and capacity strengthening. On the issue of partnership and partnering, this theme will foster collaboration with the Institutional Learning and Change Initiative of the CGIAR, hosted by Bioversity. We will also seek other strategic alliances with other centers of expertise in this field, such as the Partnering Initiative, based in London, and the Advanced Institute of Management Research at the University of Strathclyde, UK.

4.7.6 Linkages with other themes and other CRPs

This theme ensures relevance, contributes to CS, supports knowledge sharing, and documents outcomes and impacts. It has linkages with Themes 1–6, which deal with particular technologies and ensures as far as possible an optimal fit between them. It establishes a set of overlapping learning alliances for scientists involved with the CRP-RTB to support these themes for innovation science, social and economic analysis, and CS and knowledge management professionals.

It will have particularly close links with the product lines that are linked to capacity strengthening and reaching end-users in Themes 1–6 and to the theme-specific delivery platforms that will be set up with partners. The challenge will be to ensure knowledge sharing and feedback across all of these themes to optimize the use of CRP resources and cross-theme synergies.

There will be linkages with CRP 2 for priority setting and impact assessment, where tools and models developed can be applied and improved in the CRP-RTB. Similarly, knowledge and knowhow will be shared with CRPs 1, 4, and 7 related to priority setting and impact assessment linked to specific agro-ecosystem livelihoods, nutritional needs, and climate change factors, respectively.

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5.0 PROGRAM GOVERNANCE AND MANAGEMENT

The CRP-RTB governance, oversight, and management structures and relationships are shown in Figure 5.1. The proposed structure has been designed to comply with the following principles:

1. **Efficiency:** To ensure that transaction costs of governance are reasonable compared to the benefits of broader collaboration.
2. **Effectiveness:** To establish clear roles for the different entities in order to streamline management processes and ensure compliance with the performance contracts and achievement of scientific objectives.
3. **Transparency:** To promote financial and reporting accountability and engender trust across Centers.
4. **Effective investment:** To support partnerships for innovation.

The CRP does not change the independence of each Center to organize its respective crop programs as it sees best, to align with the goals and the structure of the CRP.

Roles, responsibilities, and accountabilities of each entity have been aligned with their level of authority to produce a coherent structure.

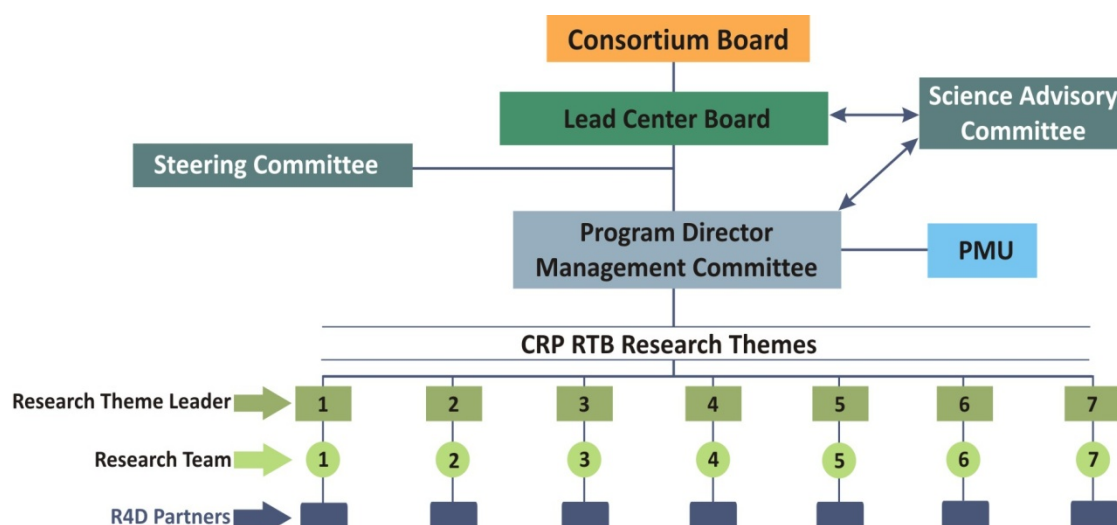


Figure 5.1 CRP-RTB organization.

The Lead Center Board (LCB) and Director General (DG) will exercise oversight of the CRP-RTB management to ensure full execution of the performance contract. They will support the Program Director (PD) and ensure that the proper systems and policies are in place in order to successfully manage and implement the performance contract.

The Steering Committee (SC) will provide strategic oversight of the overall performance of the CRP-RTB and will approve the strategic and annual plans and budget allocations. It will also oversee annual performance of the PD and arbitrate disputes as the last instance before these are brought to the Consortium Board.

The Management Committee (MC) will provide management of the CRP. The PD will chair the MC and will report to the SC and LCB on the implementation of the performance contract. The PD will be supported by a Program Management Unit (PMU).

Individual Centers will be responsible for managing their own scientists and ensuring that they are contributing to the CRP in line with the performance agreement. The Centers will be responsible for obtaining and maintaining bilateral grants to complement the CGIAR funds made available through the Consortium/Lead Center. The Center representatives on the MC will report on research activities associated with bilateral funding that are related to the CRP-RTB in their respective Centers to ensure thematic and institutional complementarity.

5.1 Lead Center

The LCB and DG will have fiduciary and legal responsibility/accountability for executing the CRP-RTB performance contract and subcontracts with the partner Centers, and will ensure that the CRP is governed by and managed through the principles of responsibility, authority, and accountability.

They will exercise oversight of management to ensure that appropriate systems and policies are in place to control the flow and management of funds, avoid conflicts of interest, and ensure transparency in financial and research reporting.

The LCB and DG will hire and support the CRP-RTB Director or PD, and supervise the management team and the production of results in line with the performance contract.

5.2 Role of Center Boards

All CGIAR Centers will maintain their own legal status and boards as well as authority over all Center management policies. CRP-RTB activities will be reported by the respective Centers in their audited financial statements. Research Theme Leaders (RTLs) will continue to interact with their Center Boards and management teams.

Center Boards will oversee implementation and compliance of each Center's commitments contained in the performance contracts and subcontracts.

5.3 Steering Committee

The SC will comprise four DGs of the CGIAR founding partners of the CRP-RTB, and the PD as an ex-officio member. The SC will be chaired by the DG of the Lead Center and will exercise an oversight and a conflict resolution role. The participation of the LCB is necessary because of their fiduciary role in the implementation of the CRP.

Additional strategic partners may join the CRP-RTB SC. These strategic partners would present a proposal to the MC addressing the global nature of their research engagement, their significant expertise in the RTB scientific areas, their work on one or ideally more of the RTB crops, their previous engagement with one or more of the CRP-RTB CGIAR partners, and the complementarity of their work with that of the CG Centers. If the strategic partner is willing to integrate their RTB research program(s) into the CRP, along with human and financial resources, and upon the recommendation of the MC, the SC would review and approve applications for membership in the SC.

The SC will:

- Oversee the strategic alignment of the CRP-RTB with the SRF, and make recommendations with respect to the overall direction of the program, including the identification of new investment and funding opportunities.
- Approve strategic and annual plans prepared by the MC.
- Approve annual budget prepared by the MC.
- Evaluate the PD.

- Ensure that M&E process for the CRP-RTB complies with CB and ISPC guidelines.
- Exercise dispute arbitration regarding funds allocation and others not settled at the MC level.
- Establish “rules” for membership.

The SC will meet once a year either in a virtual or a face-to-face annual meeting. Extraordinary meetings may be convened by the Chair to address priority topics as well as to propose and review commissioned external reviews on specific areas of research.

5.4 Management Committee

The MC will be the key strategic and executive entity and will be responsible for the establishment, execution, and monitoring of the full CRP-RTB research portfolio, including the development of strategy, work plans, business plans, and annual budgets.

The MC will be chaired by the PD and comprise the seven RTLs.

The MC will:

- Review progress in science and its relevance with respect to the performance contract.
- Review the progress of the agreed targets/deliverables in relation to the agreed criteria in the performance contract and provide recommendations to relevant Center and theme coordinators to improve performance.
- Determine annual budget. Decisions about assigning budget in the CRP will be based upon evidence-based criteria linked to targeting and priority setting in Theme 7. The procedure will be established by the MC and approved by the SC.
- Oversee financial impacts on planned research activities.
- Advise on the management and organization of the CRP-RTB and enable management mechanisms so that views of principal and other partners are heard.
- Plan scientific delivery of outputs through the development of rolling annual work plans and strategic progress reviews.
- Recommend the content of performance contracts and associated budgets to be signed between the Consortium Board/Lead Center and the Lead Center/sister Centers or partners.
- Determine the allocation of resources coming from the CGIAR Fund based on evidence derived from regular strategic priority assessments and agreed work plans submitted by the participating Centers and their strategic partners.
- Integrate across and within the CRPs and contribute to the synergy between different CRPs and CRP components.
- Ensure regional integration through mechanisms to be agreed by the MC and the SC.
- Guarantee that innovative partnerships are present across the CRP-RTB implementation, and that a coherent gender strategy is articulated and successfully implemented.
- Report against work plans, milestones, and outcomes.
- Exercise initial dispute arbitration.
- Support the establishment and functioning of innovative partnerships across the CRP-RTB. Ensure that a coherent gender strategy is articulated, fully supported and successfully implemented throughout the RTB program.

The MC will meet at least four times a year, in one face-to-face meeting and three virtual meetings. The MC will maintain frequent communication through other means. The directors of research of the institutions in the SC will be invited to the annual face-to-face meeting.

Decisions of the MC regarding funding will be made in a consultative and subsidiary manner among MC members. In the event that the MC is not able to come to agreement on allocation of Fund Council resources, the SC will take over the dispute arbitration process.

The MC will develop mechanisms for tracking progress against milestones and budget use and reporting regimes. It will organize periodic research reviews to be held in conjunction with existing periodic scientific conferences organized by the CRP-RTB Centers. The MC will internally commission ad hoc external reviews as it deems appropriate and implement changes in the program as indicated by these reviews.

Members of the MC will be responsible for ensuring that their Center's obligations are met as specified in the performance contract and subcontracts.

Individual Centers will be responsible for obtaining and maintaining bilateral grants. The Directors of Research will report back to the MC on research activities that are related to the CRP-RTB in their respective Centers.

5.5 Program Director

The PD will have decision-making authority with respect to day-to-day operations of the CRP-RTB. The PD will report to the Chair of the SC on a routine basis and will report on performance contract implementation to the entire SC and LCB on an annual basis.

The PD will be recruited by a selection committee that will include the Lead Center DG, the Director of Finance and Administration of the Lead Center, and representatives from each of the other three CRP Centers, as designated by the Center's DG. The PD will be contracted by the Lead Center.

The PD will be assisted by a small PMU, composed of a group of staff fully dedicated to support the CRP-RTB management.

The PD acts on behalf of all participating Centers and partners and will:

- Provide intellectual leadership and coordinate strategic foresight.
- Manage contracts between the Lead Center and the CRP-RTB partners.
- Collate and submit the midterm plan and annual work plans and budgets.
- Coordinate with Consortium and Fund on contracts, and technical and financial reporting.
- Sign off on all deliverables.
- Represent CRP-RTB at major research, development events, and meetings.
- Facilitate the fundraising efforts together with the Centers and other partners.
- Monitor and evaluate progress against agreed milestones.
- Manage the PMU.
- Prepare and support annual meetings of the SC and MC and other RTB-relevant workshops with the R&D community worldwide.
- Take special responsibility for implementing the gender strategy.

5.6 Program Management Unit

In its inception phase, the CRP-RTB will be implemented to a great extent through the support of existing research management and administrative support structures and systems of each Center and creation of a PMU.

The PMU will consist of one finance officer in charge of project management activities (contract and subcontract management and financial reporting); one planning, monitoring and evaluation officer; one communications officer; and a grants and contracts officer. All of these positions will be fully dedicated to CRP-RTB management and will report to the PD. They will be housed by the correspondent functional areas of the Lead Center.

The PD and the PMU will play a leadership role in developing the program partnership strategy, in building a broad-based constituency of support for the CRP-RTB amongst donors, decision makers, and other stakeholders and in bringing on board new strategic partners. They will also play a key role in promoting RTB crops and a shared vision of the CRP as well as preparing communication briefs to keep stakeholders updated about progress and new opportunities. This will contribute and build on the knowledge management and communication functions linked to research that cross-cut all themes and given particular consideration in Theme 7.

The PMU and any required administrative support structure resources will be allocated to the CRP-RTB on a full cost basis.

The PD and Lead Center will carefully evaluate the additional workload the CRP generates on existing structures and plan for a progressive scale-up of its capacity in response to its requirements. As the CRP-RTB grows, any need for additional resources within the Lead Center supporting structures (finance, grants and contracts, human resources, procurement, ITU, etc.) will be based upon recommendations by the MC and approval of the SC.

5.7 Research Theme Leaders

Management of research in the CRP-RTB will rely on the individual research Centers. Communication and advice of the RTLs will promote synergies and innovation in terms of R4D, with cross-cutting ideas and activities across Centers and crops, and integration of gender issues, communication and knowledge sharing, capacity strengthening, and partnerships within and across the themes.

Leadership of the seven themes will be distributed among the four Centers. RTLs will report to the PD and be elected according to a set of criteria agreed by the MC and approved by the SC. Criteria may include:

- Experience in the theme over several years in different places, continents, and/or institutions
- Coordination abilities
- Good interpersonal skills
- Professional qualifications
- Evidence of interdisciplinary understanding
- Commitment to gender mainstreaming.

In addition to management responsibilities, the RTLs will have the following tasks:

- Identify and promote cross-cutting synergistic research activities for their theme.

- Ensure integration across themes.
- Facilitate preparation of annual or medium-term research plans and budgets for their theme in coordination with the focal points for the theme in the other Centers.
- Facilitate preparation of annual reports for their theme in coordination with the focal points for the theme in the other Centers.
- Contribute to midterm and final evaluations at three and six years.
- Respond to other requests for support related to the appropriate functioning of the CRP from the PD.

5.8 Science Advisory Committee

The Science Advisory Committee (SAC) will provide independent advice to the LCB and the MC on the quality and relevance of the research, priority setting, strategic allocation of resources and need for external reviews. The SAC will comprise 5–6 independent science and development experts appointed by the SC.

The SAC will meet once a year either in a face-to-face annual meeting, with virtual meetings as the committee deems necessary. The SAC will meet independently, without CRP observers. Written reports will be submitted to the LCB, SC and MC, and a videoconference meeting of the SAC Chair with the full LCB will constitute part of the annual CRP report to the LCB.

5.9 Intellectual Property

The partners of the Roots, Tubers and Bananas for Food Security and Income CGIAR Research Program will adhere to the general principles of making available the results and outputs of their research and development activities as international public goods for the benefit of the poor, especially producers in developing countries.

The wide range of intellectual assets and users of those assets developed by the CRP imposes the management of intellectual property rights (IPR) in accordance with an IPR policy that orients CRP partners in making decisions about IPR without compromising our general principle. The Consortium IPR policy that is under development builds on commonly agreed principles from the CGIAR partners:

- The access, conservation, and distribution of genetic resources from the ex-situ “in-trust” collections of the CGIAR partners and the sharing of benefits associated with their use will follow the principles and procedures of the International Treaty on Plant Genetic Resources. Access and distribution of non-plant taxa as well as traditional knowledge will be in accordance with the Convention on Biological Diversity and other applicable international and national laws.
- The CRP partners will accept or impose restrictions on intellectual assets they acquire or produce only when such conditions are necessary for the accomplishment of CRP activities or for improvement and/or access of CRP intellectual assets to minimize impact on target beneficiaries. It will be, however, the intention of the CRP partners to accept or impose limited restrictions either in time and scope or any combination thereof.
- Benefits, in the form of financial returns, deriving from providing exclusive access to CRP intellectual assets will be vested in support of the completion of the objectives of the CRP and wide distribution of its results and outputs to the target beneficiaries.
- In all cases, CRP intellectual rights will remain freely available to target beneficiaries for their own use when it impacts on food security and/or poverty alleviations in their countries.

6.0 MONITORING AND EVALUATION

The program builds on four pillars of M&E:

- Program monitoring: overall supervision of program activities, especially cross-cutting elements such as gender mainstreaming, conducted by the program management.
- Performance monitoring: against the products and milestones listed in Annex 2, conducted by implementing partners against performance contracts.
- Outcome and impact measurement: referring to the foreseen outcomes and related impacts, which will be managed through Theme 7.
- Financial and due diligence monitoring: against program budget, conducted by the Lead Center.

The main purpose of M&E in the CRP-RTB is to assess progress in the completion and delivery of products and research outcomes for continuous improvements and adjustments in the research process and for reporting against performance contracts. The CRP-RTB will set up an M&E system to track completion of the milestones that are indicated in the product line description tables (Annex 2). Gender, which at present is not fully incorporated into the PL description tables, will be included in this fuller M&E system and gender-mainstreaming indicators will be developed for this purpose.

In addition, as the performance contracts come into operation and CRPs are held accountable for research outcomes, these will be integrated into the M&E system. This monitoring is different from the assessment of outcomes (and impacts) as a research activity in Theme 7. This will focus on development outcomes, and provides particular attention to the mechanisms of change and a deeper understanding of the long-range impacts on the beneficiaries. Each performance contract will include a clear M&E reporting framework that will feed into the overall program M&E set-up. Partners will be included in the M&E system to establish and assess completion of outcomes; particular care will be given to capturing the gender dimension of variables for monitoring. Training will be required as needed. The M&E system will be a crucial tool for the PD, the MC, and stakeholders to track progress and take corrective action, and for reporting.

The monitoring of milestones and, subsequently, outcomes will be linked to evaluations of the efficacy, efficiency, and relevance of the CRP-RTB. A midterm evaluation is proposed after three years linked to a final evaluation at the end of the six-year planning cycle. These evaluations will also draw on impact assessments conducted in Theme 7.

7. RISK ANALYSIS

7.1 Working Together

The type of work proposed by the CRP-RTB that relies on commonalities between RTB and the development of cross-cutting activities requires new ways of working across Centers and partners, which have not been common to this degree in the past. This new level of collaboration and engagement can initially result in some difficulties and the learning process linked to joint analysis, planning, and complementarity in implementation can take some time to becoming the normal *modus operandi*.

A clear definition of the role of various institutions, and the timelines elaborated for deliverables—both presented in this proposal—should mitigate this risk (see Annex 2). As discussed in section 5, the management structure provides further support by ensuring clear strategic guidance and oversight that will facilitate the inter-center and partner relationships. The implementation of the CGIAR's One Corporate System, by providing strong project management facilities and workflow capabilities linked to finance, human resources, and administration modules, will also be part of the solution.

7.2 Ensuring Funding of Activities

The R4D objectives of the CRP-RTB are ambitious, so the current funding base may be insufficient and too fragmented to successfully achieve the goals. To address this risk, we have developed a double financial scenario that largely relies on present levels of funding (with some inflationary adjustments) and an upside scenario that would allow growth to take place in 2012 and 2013 to the tune of 20% per annum. The MC, based on strategic priorities being identified through Theme 7 and building on existing efforts, will adjust the activity portfolio accordingly. In addition, the CRP-RTB will explore additional sources of funding (both public and private, both Consortium and non-Consortium) for developing its R4D activities. This fundraising activity will be supported by the communications group of the CRP and partner Centers.

7.3 Developing High-Quality Research

The CRP-RTB will require a significant amount of basic research capacity (both human and physical) to make progress in delivering on specific product lines—for example, bioinformatics in Theme 1. It also aims to develop integrated research and look at interfaces between disciplines (e.g., crop modeling in Theme 5). Not all this capacity may be available within the Centers.

A key risk mitigation strategy is therefore to develop strategic partnerships with universities and institutions that specialize in this type of research and have a track-history of excellence (e.g., CIRAD, KUL in Belgium).

7.4 Exploring New Ways of Collaborating with Partners

The CRP is looking at ways to partner more effectively, including encouraging greater accountability and ownership by partners. However, engaging and coordinating with key national and local actors can carry high transaction costs, particularly when these partners lack human, financial, and infrastructural resources. Governments may not act as quickly as expected to provide the additional investments needed for scaling up and out research results and lessons learned. This is particularly crucial in the case of RTB because of decades of limited investment in these crops. Efficiency of partnerships can also be affected by insufficient consideration of gender issues and poor communication. All these factors may seriously hamper progress and thus threaten impact.

This risk will be mitigated by working with a diversity of partners and developing common research agendas within the new CGIAR structure. Innovation capacity building and knowledge sharing are integral to this CRP and implemented throughout all the themes—particularly Theme 7. Development agencies and extension services will be involved in research planning and implementation and PPP will be actively developed. Capacity-strengthening activities of the CRP-RTB will be built into research efforts. Capacity-building needs have been clearly specified along the impact pathways (including support to capacity development organizations in target countries). Political and social risks will be mitigated by targeting multiple regions and institutions, taking a long-term perspective and building long-term partnerships.

7.5 Ensuring Delivery and Impact

Improvement of quality of life of the poor and vulnerable implies effective and rapid delivery of products and wide-scale adaptation and adoption. For example, impact of use of improved planting material by farmers may be threatened due to red tape in the approval process and registration of new cultivars developed with our national partners, poorly implemented quarantine regulations leading to restrictions in movement of improved material across regions, and lack of an effective seed system for planting material production and distribution.

The CRP-RTB has identified delivery as a high priority on the agenda when discussing with stakeholders. It will focus on the development of effective product-oriented breeding pipelines, based on a detailed understanding of target environments, markets, and delivery pathways, and will implement product management mechanisms guaranteeing strong safety and control standards and a delivery strategy based on steady and reliable communications. In addition, a clear impact pathway, combined with stakeholder platforms, will provide a mechanism to engage across specific areas of interest and responsibilities. The CRP-RTB will actively work with target country governments to encourage appropriate regulations thus providing a more enabling environment to achieve outcomes and impacts.

To make impact on poor producers, the challenge now is making available several already-developed improved varieties to them through a more aggressive technology delivery and extension system as well as market outlet and risk mitigation schemes.

(Leader of West African NARS)

Collection of germplasm depends on the readiness of countries to share genetic resources. Secure conservation of genetic resources depends on the readiness of donors and host organizations to commit resources to a long-term undertaking. Exchanges of germplasm and other biological materials depend on a reliable statutory framework of quarantine and other regulations. To address these risks, the RTB Centers will undertake advocacy activities to explain the value of germplasm exchange and long-term investment in conservation to policy-makers and donors (linked to CRP 2 and other CRP 3s). The RTB genebanks should have a biosafety framework to prevent the contamination of GM material. The genetic resources information exchanged and disseminated under Theme 1 is mainly collected in the first instance by national partners and therefore its success depends on their capacity to collect and their readiness to share such information across national boundaries (and, in some cases, among private sector entities). RTB Centers seek to build capacity through specific training and to create an environment conducive to data and knowledge sharing through the development of policy tools, and through advocacy and information dissemination.

8.0 BUDGET

The CRP-RTB has developed two budget scenarios: (1) the base case scenario, which considers the 2011 budget as year 2009 plus 10% and then annual increments of 5% per year, and (2) the upside growth scenario, which represents an increase of 20% per year with respect to the base case in 2012 and 2013. Section 8 presents the base case; the tables of the upside scenario are in Annex 5. While the first-year budget is final, 2012–2013 is indicative. As soon as the CRP is operative, partner Centers will consider future budget reallocations, in relation to the strategy proposed in the CRP-RTB proposal.

Budget Summary

The CRP base case budget scenario from 2011 to 2013 is US \$183 million (Table 8.1). Seven research themes represent an investment of \$145.9 million (79.7%), institutional overhead amounts to \$28.4 million (15.5%), and program management and coordination costs add up to \$8.7 million (4.8%). The budget in the upside scenario is \$207.3 million (Annex 5.1).

8.1 Themes

Theme 2, Accelerating the development and selection of varieties with higher, more stable yield and added value, is the largest component and represents 26% of the total budget, followed by Theme 3, managing priority pests and diseases, and Theme 1, conserving and accessing genetic resources. The distribution of investment has also been calculated within each theme at the product line level for both base and upside scenarios (Annexes 5.7–5.14).

Theme 1 includes genetic resources related to research, such as characterization, bioinformatics, and development of rationalization protocols, among others. Maintenance of existing collections has not been included as a theme activity.

Table 8.1 RTB Investment by Theme—Base Scenario (US\$ millions)

Research Theme	BASE SCENARIO				
	2011	2012	2013	Total	%
T1 Conserving and accessing genetic resources	6.4	6.5	6.7	19.6	10.7
T2 Accelerating the development and selection of varieties with higher, more stable yield and added value	14.8	15.7	16.7	47.3	25.8
T3 Managing priority pests and diseases	6.3	6.7	7.0	20.0	10.9
T4 Making available low-cost, high-quality planting material for farmers	5.5	5.7	5.9	17.1	9.4
T5 Developing tools for more productive, ecologically robust cropping systems	3.6	3.8	4.0	11.5	6.3
T6 Promoting postharvest technologies, value chains, and market opportunities	4.7	4.8	5.0	14.5	7.9
T7 Enhancing impact through partnerships	5.1	5.3	5.5	15.9	8.7
Sub Total	46.4	48.5	50.9	145.9	79.7
Institutional Overhead of Participating Centers	9.1	9.5	9.9	28.4	15.5
Total Budget before CRP Management Cost	55.5	58.0	60.8	174.3	95.2
CRP Management Cost	2.8	2.9	3.0	8.7	4.8
Total Budget	58.3	60.9	63.9	183.0	100

8.2 Crops

Cassava will receive the largest investment of the program, \$53.6 million (Table 8.2), representing 29% of total investments, followed by bananas, sweetpotato, and potato. In the upside growth scenario, investment in potato and bananas shows the highest rates of growth (Annex 5.2).

Table 8.2 RTB Investment by Crop—Base Scenario (US\$ millions)

Research Themes by Crops	BASE SCENARIO						
	2011 -2013						
	Potato	SWP	Banana	Cassava	Yams	Others RTB	Total
T1 Conserving and accessing genetic resources	0.3	0.2	7.1	8.0	2.6	1.5	19.6
T2 Accelerating the development and selection of varieties with higher, more stable yield and added value	12.0	14.0	4.6	11.4	3.6	1.6	47.3
T3 Managing priority pests and diseases	3.2	1.9	6.6	6.0	2.1	0.1	20.0
T4 Making available low-cost, high-quality planting material for farmers	3.5	2.4	3.8	5.4	1.9	0.1	17.1
T5 Developing tools for more productive, ecologically robust cropping systems	1.3	1.2	4.3	3.8	0.8	0.1	11.5
T6 Promoting postharvest technologies, value chains, and market opportunities	1.8	0.5	4.4	5.1	1.8	1.0	14.5
T7 Enhancing impact through partnerships	1.2	3.9	6.5	3.3	1.0	0.1	15.9
Sub Total	23.2	24.2	37.2	43.0	13.8	4.5	145.9
Institutional Overhead of Participating Centers	4.6	4.8	7.3	8.0	2.7	0.9	28.4
Total Budget before CRP Overhead	27.8	29.0	44.5	51.0	16.5	5.4	174.3
CRP Management Cost	1.4	1.4	2.2	2.6	0.8	0.3	8.7
Total Budget	29.2	30.4	46.7	53.6	17.3	5.7	183.0

8.3 Theme by Center

Table 8.3 summarizes the investments that Centers will make in each theme. Theme 2, *Accelerating the development and selection of varieties with higher, more stable yield and added value*, has the highest share in CIAT, CIP, and IITA; whereas Theme 7, *Enhancing impact through partnerships*, has the highest priority for Bioversity. Thematic priorities remain relatively stable in the upside growth scenario (Annex 5.3).

Table 8.3 RTB Theme Investment by Center—Base Scenario (US\$ millions)

Research Theme	BASE SCENARIO				
	2011 -2013				
	Bioversity	CIAT	CIP	IITA	Total
T1 Conserving and accessing genetic resources	4.8	3.1	1.8	9.9	19.6
T2 Accelerating the development and selection of varieties with higher, more stable yield and added value	1.4	4.6	27.5	13.8	47.3
T3 Managing priority pests and diseases	4.7	2.2	5.1	8.0	20.0
T4 Making available low-cost, high-quality planting material for farmers	2.0	1.8	5.9	7.4	17.1
T5 Developing tools for more productive, ecologically robust cropping systems	3.5	2.5	2.5	3.0	11.5
T6 Promoting postharvest technologies, value chains, and market opportunities	2.7	1.8	3.2	6.8	14.5
T7 Enhancing impact through partnerships	5.5	1.3	5.0	4.0	15.9
Sub Total	24.7	17.3	51.1	52.8	145.9
Institutional Overhead of Participating Centers	4.7	3.0	10.2	10.5	28.4
Total Budget before CRP Management Cost	29.4	20.3	61.3	63.3	174.3
CRP Management Cost			8.7		8.7
Total Budget	29.4	20.3	70.0	63.3	183.0

8.4 Geographic Priorities for Research Investment

The importance of RTB crops in contributing to food security and poverty reduction is most significant in SSA with a large number of beneficiaries and a higher relative dependence on this group of crops (see Table 1.3, p. 5). This is reflected in the pattern of investment that is focused in the SSA region (60%), followed by global investments (24%), which by nature cannot be attributed to a single region because of their global impact (Table 8.4). Although some adjustments may be made once the priority setting exercise is completed, we anticipate the general pattern of investment into the future will broadly be similar, i.e. with a concentration in SSA where RTBs are of widespread importance, and more targeted research in Asia and LAC, where RTB overlay with food security and poverty.

Heavy concentration in SSA is reflected in the fact that one Center is completely focused on that region, while two Centers currently have a high share of their investment portfolios in SSA. The upside scenario shows a similar distribution but adjustments will be made based on the priority setting outcomes (Annex 5.4).

Table 8.4 RTB Investment by Region by Center—Base Scenario (US\$ millions)

Regional Distribution by Center	BASE SCENARIO				
	2011 - 2013				
	SSA	ASIA	LAC	GLOBAL	TOTAL
BIOVERSITY	9.5	1.9	2.8	10.4	24.7
CIAT	2.4	2.4	5.4	7.2	17.3
CIP	22.2	7.1	4.9	16.9	51.1
IITA	52.8	-	-	-	52.8
Sub Total	86.9	11.5	13.2	34.4	145.9
Institutional Overhead of Participating Centers	17.2	2.2	2.4	6.6	28.4
Total Budget before CRP Management Cost	104.1	13.6	15.6	41.0	174.3
CRP Management Cost	5.2	0.7	0.8	2.1	8.7
Total Budget	109.3	14.3	16.4	43.1	183.0
%	60%	8%	9%	24%	100%

8.5 Cost Categories

Expenditures by cost categories are shown in Table 8.5. Assignments are based upon the Centers' historical experience in managing research projects. The most significant item is personnel, reflecting the fact that research to produce international public goods is intensive in human resources. Personnel costs (31.5%) represent the largest expenditure category, followed by operating expenses (22.0%) and by transfers to partners and collaborators (15.9%). Partners and collaborators include a wide array of non-CGIAR entities such as NARS and NGOs who will receive an aggregate amount of \$29.1 million. As budget increases in the upside scenario, the role of partners in the science program remains stable (Annex 5.5).

Capital investments add up to \$7.4 million over three years to support planned scientific work. Capital investments include the acquisition of new research equipment and the replacement of research and lab equipment and computers among others. In the upside growth scenario, the shares of the different cost categories remain relatively stable (Annex 5.5).

The budget developed for the CRP-RTB does not consider the generation or maintenance of reserves for the Centers nor for a substantial upgrade of the Centers' infrastructure.

Table 8.5 RTB Expenditures by Cost Categories—Base Scenario (in US\$ millions)

Cost Category	BASE SCENARIO				
	2011	2012	2013	Total	%
Personnel Cost	18.4	19.2	20.1	57.6	31.5
Travel	2.9	3.0	3.1	9.0	4.9
Operating expenses (Supplies & Services)	12.4	13.5	14.4	40.2	22.0
Traning / Workshop	0.8	0.9	0.9	2.5	1.4
Partners / Collaborator Contracts	9.4	9.7	10.1	29.1	15.9
Capital and other equipment for project	2.6	2.4	2.4	7.4	4.0
Sub Total	46.4	48.6	50.9	145.9	79.7
Institutional Overhead of Participating Centers	9.1	9.4	9.9	28.4	15.5
Total Budget before CRP Management Cost	55.5	58.0	60.8	174.3	95.2
CRP Management Cost	2.8	2.9	3.0	8.7	4.8
Total Budget	58.3	60.9	63.9	183.0	100

8.6 Program Management and Coordination

The PD and MC will be responsible for program management and coordination. They will be supported by a small group of professionals in the PMU under the oversight of the SC, the SAC, and the Lead Center's Board (see section 5).

The budget that will be allocated to this management structure is \$2.8M in the first year and represents 4.8% of the total CRP budget. This budget covers the work of the governance and management units, CRP external communications work, project management support (finance and contracts), and cross-theme and cross-regional integration workshops.

The total management costs for the three years will be \$8.7M and the share of these with respect to the total CRP budget will remain stable at 4.8%. This cost structure includes both the direct management costs, the charge on pass-through funds, and the CGIAR system costs (Table 8.6).

Table 8.6 RTB Program Management and Coordination Costs by Cost Category—Base Scenario (in US\$ millions)

Cost Category	BASE SCENARIO			
	2011	2012	2013	Total
Personnel Cost	0.71	0.66	0.67	2.04
Travel	0.22	0.22	0.22	0.65
Operating expenses (Supplies & Services)	0.17	0.18	0.18	0.53
Training / Workshop	0.03	0.03	0.03	0.09
Partners / Collaborator Contracts/ Consultancy Contracts	0.33	0.28	0.25	0.86
Capital and other equipment	0.03	-	-	0.03
Contingency	0.07	0.06	0.06	0.19
Sub Total (Direct Management Costs)	1.6	1.4	1.4	4.4
2% on passthrough funds (W1 & W2 to other centers)	0.45	0.54	0.61	1.6
Total Management Budget of Lead Center	2.0	2.0	2.0	6.0
CGIAR System Costs	0.77	0.92	1.03	2.7
Total Management Budget	2.8	2.9	3.0	8.7

Notes on cost categories:

1. **Personnel.** CIP will employ a PD, a planning, monitoring and evaluation officer, a finance officer, a communications officer, a grants and contracts officer, and administrative assistants. These officers will operate with the support of the existing management structure at CIP.
2. **Travel.** Travel expenses of the PD and MC, the SAC, and the SC.
3. **Operating Expenses.** Includes supplies and services. Services consider legal, publications and printing, facilities and IT, amongst others.
4. **Training.** Workshops, seminars, and conferences for the PD and MC.
5. **Partners/Collaborators/Consultancy Contracts.** Includes SAC honoraria and research consultancy contracts.
6. **Capital.** Furniture and computers for new staff recruited.
7. **Pass-through funds.** 2% charge on pass-through funds to partner Centers.

8.7 Funding Needs

Table 8.7 presents the funding required to implement the RTB program over the three-year cycle and the identified funding gap. The projection assumes the existing restricted funding commitments, and a moderate increase of other income. The funding gap (Research) amounts to \$67.1 million, or 36.6% of the total. The upside scenario is presented in Annex 5.6.

Table 8.7 RTB Funding—Base Scenario (in US\$ millions)

Funding	BASE SCENARIO				
	2011	2012	2013	Total	%
W1 - CGIAR Fund -(Research)	19.0	19.9	20.9	59.8	32.7
W1 - CGIAR Fund -Funding Gap (Lead Center)	2.8	2.9	3.0	8.7	4.8
W2 - CGIAR Fund -Funding Gap (Research)	16.6	23.0	27.5	67.1	36.6
Bilateral Funding (Secured)	19.1	14.4	11.9	45.5	24.8
Other Income	0.9	0.6	0.5	2.0	1.1
Total	58.3	60.9	63.9	183.0	100

The projected funding gap is expected to be filled by funds flowing through Windows 1-3 from the CGIAR Fund and from bilateral grants to the RTB participating Centers under full cost recovery policies. RTB participating Centers will continue to fund raise to fill the projected funding gaps.

The CRP-RTB will be creating global partnerships with many non-CGIAR partners from the developing and developed countries and playing an important catalytic role to increasingly mobilize resources from different contributing sources to RTB and directly to partners. Contributions may be in-kind—of scientist time, use of facilities, and the provision of other direct research costs.