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Strategic Assessment of Banana Research Priorities

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Strategic Assessment of Banana Research Priorities

1. Introduction

The strategic assessment of research priorities for banana is part of a multi-crop priority assessment exercise coordinated by the CGIAR Research Program on Roots, Tubers and Bananas (RTB). The aim of the overall study is to generate information that can inform the strategy development and priority-setting process for RTB research. The study follows a six-step framework: (1) identification of target domains, (2) a constraints analysis, (3) identification of research options matching key constraints, (4) quantification of model parameters, (5) estimation of research impact, and (6) the communication of findings. The five crops included in the study are bananas, cassava, potatoes, sweetpotatoes, and yams. The assessment emphasizes the needs of poor farmers and other vulnerable groups. The methodology for this assessment has drawn on previous priority-setting studies, especially those conducted at the International Potato Center (CIP) as described in Fuglie and Thiele (2009).

This report documents the procedure and results of assessing key banana research options (steps 3–5 of the RTB priority assessment) using an economic surplus model1 and subsequent cost-benefit analysis. The next section explains the process of selecting research options to be included in the assessment, followed by a detailed description of the research options, the parameter elicitation process, an overview of parameters used in the assessment and an account of the information sources, and finally the results of the banana priority assessment. The document closes with a list of follow-up activities suggested to complete the exercise.

2. List of candidate research options for ex-ante impact assessment

The selection of the research options started with the analysis of a global online expert survey in which a large sample of banana experts (N = 523) identified major constraints to banana production and marketing. Experts were first asked to indicate the major factors that limit yield and determine income for a specific banana production system (combination of cultivar group and crop association) in a particular geographic region by allocating a fixed number of points among different factors from a list. As major categories of yield-limiting factors, the experts identified diseases (32% of allocated points); pests (19% of allocated points), and climatic constraints and soil condition constraints (each with 18% of points). The experts indicated production-related factors (43% of allocated points), postharvest,

[1] **Economic surplus** refers to the combined benefit consumers and producers receive when a good or service is exchanged. The **consumer surplus** is the difference between the maximum price consumers are willing to pay and the actual price they do pay. If a consumer would be willing to pay more than the current asking price, then she is getting more benefit from the purchased product than she spent to buy it. The **producer surplus** is the benefit a producer receives from providing a good/service at a market price higher than what he would have been willing to sell for. Through economic modeling of **supply and demand equations**, the related quantities of consumer and producer surplus are determined. The consumer surplus (individual or aggregated) is the area under the (individual or aggregated) demand curve and above a horizontal line at the actual price (in the aggregated case: the equilibrium price). The producer surplus (individual or aggregated) is the area above the (individual or aggregated) supply curve and below a horizontal line at the actual price (in the aggregated case: the equilibrium price).

processing and marketing factors (26% of points), and information and knowledge factors (21% of points) as the key categories of income-determining factors. The methodology and results of the expert survey are described in detail in Pemsl et al. (2013a).

In a scoring exercise, experts could then rate the importance of 71 different research options. The five highest ranked research areas in the survey were: (1) research on disease and pest management (excl. resistant varieties); (2) breeding for higher yield; (3) breeding for biotic stress resistance; (4) crop management and production systems research; and (5) genetic resources management research.

In April 2013, an expert workshop was organized in Kampala, Uganda, convening 34 banana scientists from Bioversity and International Institute of Tropical Agriculture (IITA), CIRAD and national banana programs in Latin America, Africa, and Asia to share the priority assessment methodology and results of the expert survey, select research options to be included in the assessment, and start the elicitation of parameters; see Pemsl et al. (2013b) for details.

In the workshop, working groups were formed to start the elicitation of parameters required for the assessment. The following nine priority banana research options were identified:

- Recovery of smallholder banana production affected by banana bunchy top virus (BBTV)
- Integrated management of Xanthomonas wilt (BXW) and other bacterial diseases in smallholder systems
- Sustainable intensification of banana-based cropping systems
- Breeding for host-plant resistance to pathogens and pests in banana
- Sustainable Fusarium wilt (FW) management system
- Risk assessment, diagnostic tools, predictive models, and strategy for disease surveillance
- Use/availability of existing genetic diversity for (a)biotic stress and consumer acceptability
- Rapid and enhanced genetic gains by diploid breeding
- Reducing losses and expanding utilization of banana products and waste.

Subsequent to the workshop, small teams of resource persons (names are listed in the next section under the respective research options) worked on the further refinement of parameters. During this process, some of the research options were divided into sub-options that were assessed separately (e.g., due to differences in timeframe, success probabilities, and/or because they were substitutes rather than complements). At the same time, not all of the nine identified research options were assessed under this study, mainly due to time constraints and unavailability of resource persons.

The final list of research options, the average scores and ranks of related technology options from the global expert survey, as well as links to related RTB flagships[2] are shown in Table 1. We included the global results from the survey as well as results for a specific region or cultivar group if they are particularly relevant or indicate higher importance of the respective research for the subset than implied by the global average.

[2] An important emphasis of RTB in 2014 will be the piloting of **Results-Based Management** (RBM) to optimize research-for-development outcomes and enhance value for money through evidence-based impacts. RBM is guided by the achievement of quantified indicators of progress in research and of Intermediate Development Outcomes (IDOs). The RBM framework links strategic objectives to a set of *flagship products*, which are the centerpiece of a work package that also consists of linked, or enabling, products and is embedded in a *flagship* that includes a theory of change with quantified indicators (see RTB 2013 for more details).

TABLE 1: RESEARCH OPTIONS WITH RELATED EXPERT SURVEY SCORES AND LINKS TO RTB FLAGSHIPS.

Research Option	Related Scores and Ranks[1] from Expert Survey	RTB Flagship Link
1. Recovery of production affected by banana bunchy top virus (BBTV)	- Global score: 3.82 (Breeding for resistance to virus diseases (BBTV, BSV), global rank #19, score for West & Central Africa (WCA) 4.10; - Global score: 3.71 (Research on management of virus diseases (excl. resistant varieties), global rank #32, score for WCA 4.10)	Preemptive, emergency and ongoing response capacity to **viral diseases** affecting smallholder banana and plantain systems
2. Integrated management of banana Xantomonas wilt (BXW) and other bacterial diseases: develop improved cultural practices and a low-cost diagnostic kit	- Management of bacterial diseases (excluding resistant varieties): global score 3.79, global rank #25; for East African Highland banana (EAHB) AAA: score of 4.59; rank #1	Preemptive, emergency and ongoing response capacity to **bacterial diseases** affecting smallholder banana/plantain systems
3. Integrated management of BXW and other bacterial diseases: develop resistant GM (EAHB) AAA varieties	- Breeding for resistance to bacterial diseases: global score 3.80; global rank #23;	Game changing traits/solutions (**GMO**)
4. Sustainable intensification of banana-based cropping systems	- Strategies to improve soil fertility (micronutrients and fertilizer): global score 4.08, global rank #4; - Strategies to manage microbes/microbial communities for soil, root & plant health; global score 3.88, global rank #13; - Strategies to improve water management in crop production: global score 3.81, global rank #20;	**Production models & planting material alternatives** suited to different market, production and livelihood systems, resulting from yield gap, market, and gender analyses
5. Developing EAHB (AAA) varieties resistant to nematodes (N), weevils, black leaf streak (BLS)	- Breeding for resistance to nematodes: EAHB AAA score 4.00; - Breeding for resistance to weevils: EAHB AAA score 4.06; - Breeding for resistance to fungal leaf diseases: EAHB AAA score 3.98	**Improved banana varieties**; Preemptive, emergency and ongoing response capacity to **fungal diseases** affecting smallholder banana and plantain systems
6. Developing AAB plantain varieties resistant to BLS, N, and weevils, and with improved quality traits	- Breeding for resistance to fungal leaf diseases: Plantain AAB score 4.20; - Breeding for resistance to nematodes: Plantain score 4.10; - Breeding for resistance to weevils: Plantain score 3.97;	**Improved banana varieties;** Preemptive, emergency and ongoing response capacity to **fungal diseases** affecting smallholder banana and plantain systems

[1] Scale for scoring research options: 1 = not important, 2 = low importance, 3 = important, 4 = very important, 5 = most important; all 71 included research options were ranked according to average scores given by the experts (i.e., highest average score = rank #1).

Research Option	Related scores and ranks[1] from Expert Survey	RTB Flagship Link
7. Developing sweet acid banana varieties resistant to FOC, BLS, and N, and with improved quality traits	- Breeding for resistance to fungal leaf diseases: global score: 4.11 (global rank #3), for Latin America and the Carribbean: score 4.45, rank #1; - Research on fungal leaf disease management: score 4.11, global rank #2;	**Improved banana varieties**; Preemptive, emergency and ongoing response capacity to **fungal diseases** affecting smallholder banana and plantain systems
8. Sustainable Fusarium wilt management	- Breeding for resistance to fungal leaf diseases: global score: 4.11, global rank #3, for LAC: score 4.45; rank #1; - Research on management of fungal leaf diseases (excl. resistant varieties): global score: 4.11, global rank #2; - Research on Fusarium management (excl. resistant. var.): score 3.69, global rank #3	Preemptive, emergency and ongoing response capacity to **fungal diseases** affecting smallholder banana and plantain systems
9. Risk assessment, diagnostic tools, predictive models, and strategy for disease surveillance	NA	**Predictive models, diagnostic tools and IPM solutions** for climate change induced pest and disease risks and outbreaks
10. Better use/availability of existing genetic diversity for (a)biotic stress and consumer acceptability	- Phenotyping of land races in search of high-value traits/new source of tolerance/resistance to stress: global score 3.75, global rank #27	Global-to-local **seeds system for Musa genetic diversity**; Framework for analyzing and intervening in RTB **seed systems**
11. Rapid and enhanced genetic gains by diploid breeding	- Germplasm enhancement and pre-breeding: global score 3.41; global rank #48; - Breeding for higher yield: global score 4.21, global rank #1;	RTB **transformational breeding** platform utilizing genomics, metabolomics, phenomics
12. Reducing losses, expanding utilization of banana products and waste (through post-harvest systems): → just in time supply; develop rural agri-business options for improved income and gender equity → processing and value addition	- Improving small scale processing of bananas for human consumption: global score 3.67; global rank #37; - Alternative on-farm utilization/ processing for value addition: score 3.66, global rank #39; - Improve management of residues: score 3.48; global rank #45;	Demand oriented solutions for **value adding through improved postharvest and risk management**

[1] Scale for scoring research options: 1 = not important, 2 = low importance, 3 = important, 4 = very important, 5 = most important; all 71 included research options were ranked according to average scores given by the experts (i.e. highest average score = rank #1).

Research options with light grey highlight have ongoing assessment and those with darker gray highlight have not been assessed under the current study.

3. Description of the research options

3.1 Recovery of smallholder banana production affected by BBTV

Resource person(s): Charles Staver, Guy Blomme, Lava Kumar

Constraint: Banana bunchy top disease (BBTD) is one of the most devastating diseases of banana and plantain particularly for smallholders (Dale 1987). BBTD, caused by the banana bunchy top virus (BBTV), produces erect, narrow, short brittle leaves with yellow borders and typical dark green streaks on leaves and pseudostems and stunted suckers. It results in very small or no bunches (i.e., complete yield loss). Infected mats eventually die, but often remain as a source of inoculum. The disease spreads through infected suckers and via the banana aphid (vector). BBTD is widespread in Asia. The first cases of BBTD in sub-Saharan Africa (SSA) were reported in 1958, with an increase in the rate of spread in the last decades. The disease is now found from southern Malawi and Burundi/Rwanda/eastern Democratic Republic of the Congo (DRC) all the way to Nigeria, Central African Republic (CAR), and Benin (Kumar et al. 2011). While laboratory techniques for virus detection and development of BBTV-free planting materials are well established, neither of these services nor commercial sources of BBTV-free planting material are available in rural areas of Asia and Africa.

(Potential) RTB research: generation of alternative practices, models, decision tools, and technologies for use in different land-use systems:

- Clean seed supply through tissue culture and/or macro-propagation
- Community strategies for a fallow period free of bananas
- Approaches for eliminating or reducing re-infection of virus-free banana gardens.

Status of research: The research will build on extensive knowledge and field experience generated in Asia and the incipient experience in SSA. The focus of new research will be to build a more robust understanding of BBTV, its vector, and the interaction both with host diversity and with farmer practice and the surrounding agricultural system. Pilot sites will also be set up to generate tools for building community capacity to recover from BBTD destruction and to mobilize containment when BBTD is first identified. This represents a major research initiative, since most BBTD recovery to date has focused on commercial monocrop plantations. The estimated completion time for the research is nine years with a research success rate of 90%.

Adoptable innovations:

- Diagnostic tools
- Tolerant/less susceptible varieties
- Strategies for supplying clean planting materials
- Integrated approaches to the recovery of BBTD-affected areas involving the creation of a banana-free fallow, replanting strategies, and the management of reinfection

Expected impact:

- Increase/recovery of crop yield
- Increase in production costs (seed, labor for harvest)

Target region/system: Focus is on diverse smallholder perennial systems of AAA EAHB, plantain (AAB), and AAA-Cavendish in Asia (Philippines, Taiwan, Vietnam, Sri Lanka); West and Central Africa (DRC, Republic of Congo-Brazzaville, Equatorial Guinea, Cameroon, CAR, Gabon, Benin, Nigeria); East Africa (Burundi, Rwanda); and Southern Africa (Malawi, Angola), although other minor cultivar groups in the same areas would also be affected.

3.2 Integrated management of banana Xantomonas wilt in smallholder systems

Constraint: The rapid spread of banana Xanthomonas wilt (BXW), caused by *Xanthomonas campestris pv. musacearum*, endangers the livelihoods of millions of farmers in East and Central Africa who rely on banana as a source of food and cash (Tushemereirwe et al. 2004; Tripathi et al. 2009). It is mainly transmitted via contaminated farming tools, insects acting as vectors, and infected planting material. Unchecked, the disease can destroy entire banana plantations. The pathogen infects all cultivated banana varieties in Eastern and Central Africa (ECA), including East African Highland bananas (AAA-EAHB), plantains, and exotic types. Overall economic losses in ECA have been estimated at over US $2 billion over the past decade in ECA, due to price increases, significantly reduced production, and revenue losses (Abele and Pillay 2007). In Central Uganda alone, yields declined by 80–100% between 2003 and 2008 due to infections of BXW, with corresponding income loss and higher prices of banana beer. In affected areas, banana production has declined by more than 50%. Effects on AAA-EAHB highland production in the Kivu provinces of eastern DRC have been catastrophic due to lack of institutional infrastructure and knowledge dissemination networks. The disease has reportedly spread farther toward the southern parts of South Kivu (Uvira and Fizi) and the Oriental province in DRC. BXW has spread across 15 of the 17 provinces in Burundi over a two-year period. Many farmers are still unfamiliar with disease symptoms and control options. In addition, the current control options are highly labor intensive, expensive, and time consuming, limiting adoption.

RTB research addressing the constraint: Evaluation and dissemination of genotypes escaping insect vector transmission; better understanding of host-pathogen interaction for more easily adoptable control packages; develop stakeholders' platforms for delivery of clean planting materials; raising public awareness to enhance adoption.

The research option was divided into two sub-options and the involved resource persons, the status of research, adoptable innovations, and expected impact are listed for each sub-option separately.

3.2.1 Management of BXW: Cultural practices and low-cost diagnostic kit

Resource person(s): Guy Blomme, Charles Staver

Status of research: Research on improved cultural practices for management of BXW is ongoing, and the current effort started in the year 2003. Past experiences have shown that is it very important to develop cultural practices in a participatory manner to ensure the technology package is attractive for adoption (Blomme et al. 2014) and does not conflict with resource (time, tools, knowledge, capital) limitations common for smallholder farmers (see, e.g., Jogo et al. 2011, 2013). The technology package will be developed, tested, and ready for adoption in seven years, with an estimated research success of 90%.

Adoptable innovations:

- Low-cost diagnostic kit
- Improved cultural practices: eradication, timely bud removal, tool disinfection, short banana-free fallow, diseased stem removal.

Expected impact:

- Increase/recovery of crop yield
- Increase in production costs
- Avoidance/lower pace of BXW spread (local and regional).

Target region/system:

- All cultivar groups; smallholder banana production systems in ECA in countries where the disease is currently present: Burundi, DRC, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda
- All cultivar groups; smallholder banana production systems in ECA in countries under direct BXW threat: Angola, Cameroon, DRC, Gabon, CAR, Malawi, Mozambique, South Sudan, and Zambia.

3.2.2 Management of BXW: GM-resistant varieties

Resource person(s): Leena Tripathi, Guy Blomme

Status of research: Development of GM resistant banana is ongoing at several institutions. In 2005 IITA started a project to develop AAA banana varieties resistant to BXW. The project is now in its second phase, and resistant varieties will be ready for adoption in eight years (plan to release the resistant variety in 2020), with research success of 90%.

Adoptable innovations:

- GM-resistant varieties of dessert cultivars and East African Highland bananas

Expected impact:

- Increase/recovery of crop yield
- Increase in production costs
- Avoidance/lower pace of BXW spread (local and regional).

Target region/system:

- Dessert cultivars and East African Highland bananas in ECA in countries where the disease is currently present: Burundi, DRC, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda
- Dessert cultivars and East African Highland bananas in ECA in countries that are under direct threat of the disease: Angola, Cameroon, CAR, Malawi, Mozambique, South Sudan, and Zambia.

3.3 Sustainable intensification of banana-based cropping systems

Resource person(s): Charles Staver, Piet van Asten, Thierry Lescot

Opportunity: Smallholder farmers access (urban) markets with good prices and (growing) demand

Constraint: Banana yields realized by smallholder farmers are generally low and do not bring high revenues due to suboptimal timing of harvest for two main reasons: (1) farmers are not sufficiently aware and/or responsive to market prices, they have limited market access opportunities, and prices fluctuate largely (seasonality); and (2) farmers are not technically equipped (production system knowledge) or have insufficient resources to produce high yields (at the right time).

RTB research addressing the constraint: Develop an integrated crop intensification package adapted to the local biophysical and socioeconomic environment, including quality planting material, timing of production: sucker/planting (timing for high prices), select suitable varieties (fit for local market and agro-ecology), integrated soil fertility management (ISFM), integrated pest management (IPM), plant densities, irrigation/water management, improved intercrop systems, and postharvest management.

Status of research: Ongoing, but new research started in year 2013; technology ready for adoption in five years (2018), with research success of 90%.

Adoptable innovations:

- Diagnostic survey tools and models to identify key constraints/entry points to improve yields
- Recommendations for improved productivity technologies
- Communication/training tools—for example, technical sheets, short videos to reach end-users through training of trainers, (innovative and effective) farmer organizations.

Expected impact:

- Increased crop yield
- Increase in production costs (irrigation, fertilizer)
- Reduced yield variability (*at this stage not included in the assessment*)
- Positive effect on natural resources (e.g., soil) (*at this stage not included in the assessment*).

Target region/system: Smallholder systems of EAHB in Eastern Africa; AAB plantain in WCA and LAC; Cavendish and other AAA dessert bananas in Asia (excluding major export areas with intensive production); Asia: Bangladesh, Indonesia, Vietnam, Philippines, Papua New Guinea (PNG), Sri Lanka, Myanmar; Africa: Uganda, Tanzania, Burundi, Rwanda, DRC, Ghana, Cote d'Ivoire, Cameroon, Guinea, Nigeria; LAC: Peru, Haiti, Nicaragua, Cuba, Dominican Republic, Honduras.

3.4 Conventional breeding for improved disease resistance of banana

Resource person(s): Rony Swennen (EAHB, plantain); Frédéric Bakry (plantain, sweet acid), Edson Perito Amorim (sweet acid)

Constraint: Infestation with nematodes, weevils, black leaf streak (BLS, Sigatoka), and Fusarium result in substantial yield and postharvest losses in banana production in LAC, Africa, and Asia.

RTB research addressing the constraint: Mitigating losses from the mentioned pests/diseases (namely BLS, nematodes, weevils, and Fusarium) through breeding for (improved) disease resistance and high-quality fruit; research on pathogen population structures.

Status of research: Banana breeding has been ongoing at IITA and CARBAP (African Centre for Research on Banana and Plantains), first- and second-generation hybrids with improved disease resistance are available (see, e.g., Lemchi et al. 2005), but room for improvement (distinguish release of existing improved material and new breeding efforts in the assessment). Release of existing material would take some 7 years (some issues with built-in virus), new breeding would result in improved varieties in 17 years, with research success of 100%.

Adoptable innovations:

- East African Highland banana varieties (AAA) resistant to nematodes, weevils, and BLS
- Plantain-like varieties (AAB) resistant to BLS, nematodes, and weevils, and with improved quality traits
- Sweet acid banana varieties (other AAB and ABB) resistant to Foc (*Fusarium oxysporum* f. sp. *Cubense*), BLS, and nematodes, and with improved quality traits. Assessment still ongoing (has not been completed).

Expected impact:

- Yield recovery where disease has already reduced yields (yield increase)
- Reduction of postharvest losses due to reduced stress of the plant
- Increase in production costs due to higher seed costs.

Target region/system:

- Mixed AAA EAHB cropping systems of smallholders in East Africa: Burundi, DRC, Rwanda, Tanzania, and Uganda
- Mixed AAB plantain cropping systems of smallholders in Asia: India; Africa: Liberia, Cote d'Ivoire, Ghana, Nigeria, Cameroon, Gabon, Congo, DRC; LAC: Brazil, Honduras, Nicaragua, Costa Rica, Mexico, Panama, Colombia, Ecuador, and Venezuela
- Monoculture and mixed systems of sweet acid banana in Asia: India, Indonesia; Africa: Burundi, Rwanda, Tanzania, Uganda, Cameroon, Ghana; LAC: Brazil, Colombia, Peru, Venezuela, and Mexico.

4. Parameter elicitation process and information sources

This section provides a brief account of the parameter elicitation process and the information sources used. The first step after having identified the research options (see section 2) was to identify target countries for each research intervention. The original plan for the targeting was the application of the online banana mapper (http://www.crop-mapper.org/banana) to identify areas/countries that meet the following criteria: (1) high and severe incidence of the constraint, (2) substantial importance of banana as food or source of income for poor producers and/or high dependence on banana as staple of (poor) consumers; and (3) high incidence of poverty and food insecurity and thus the prospect to achieve a large positive impact through banana research. Unfortunately, the development of the banana mapper and especially populating the tool with (sub-) national data were delayed. The population of the tool with sub-country information has been continued since, but the mapper could not be used for a formal targeting exercise.

Instead, the lists of countries to be targeted by each of the research interventions were put together by the resource person(s) working on the parameterization of the respective research option (see names in the description of research options). The criteria for the inclusion of countries were that (1) the constraint was currently present or would be present over the next 25 years (the assessment period); (2) a large area in absolute terms is affected by the constraint (i.e., larger banana production area and/or large-scale spread of the constraint); and (3) RTB will likely be working in (collaboration with) the respective country to make adoptable innovations addressing the constraint available to farmers. Thus the list of countries included in the assessment varies for the different research options, though there naturally is some overlap (see Annexes 3–8 for country lists for each research option).

For each selected country we used the production data provided by FruiTrop (2010), which uses the FAO crop production statistics but includes other additional references, surveys, and professional sources and is thus considered a more reliable source for banana production information. Moreover, production information is already disaggregated by major cultivar groups within each country in the FruiTrop tables, though the cultivar groups used by FruiTroP and those decided on for the RTB banana priority assessment do not match perfectly. While two of the cultivar group categories are identical (plantains AAB and Cavendish AAA), expert assessment was used to allocate the production from the other two cultivar categories used by FruiTrop (cooking bananas other than plantain AAB; and dessert bananas other than Cavendish AAA) to the remaining four cultivar groups of the priority assessment (see Annex 1). As a next step, these production data and the average banana yield (FAOSTAT, banana yield, average of the last three years available by country, separately for banana and plantain where available) were used to calculate banana production area. Since FAO data do not separate production from large scale, commercial plantations from (semi-) subsistence production under smallholder conditions, yield figures especially for countries with sizable banana export industry seemed too high for the RTB target group of poor (small-scale) producers. Thus, expert judgment was used to cap some of the yield figures to adequately reflect smallholder conditions by adjusting within the ranges provided by FAO data for the different types. Annex 1 shows the production and yield information by cultivar group for all countries included in the assessment.

Yield gap reviews were also conducted for plantain, Cavendish, and other minor cultivars, including an online expert survey. Experts in the Kampala workshop also provided input on yield levels. This offered background to estimate yield levels, but a proposed strategy for more complete review by production system did not prove workable. The most knowledgeable and best suited national experts could not free their time for such work.

With the country lists and production and yield information available by cultivar group, a template was designed for each research option to be assessed in which the technology and adoption parameter estimates derived from the group work during the Kampala workshop were entered as a starting point. The template was sent to the respective resource persons (see names listed in Section 3) and they adjusted the parameters to reflect country and/or cultivar group specific conditions.

Table 2 gives an overview of the different sources of information used for parameter estimation.

There are still two missing steps of the parameter elicitations process that would ideally be addressed in a follow-up activity during the first half of 2014: (1) cross-checking the expert estimates with information available in the literature (compiled in an annotated bibliography as well as overview tables for extracted indicators, see Jacobsen 2013); and (2) inviting and incorporating feedback from a larger group of banana experts on the parameters across research options. (Only a relatively small number of resource persons have been involved in the exercise so far, and most of them have only worked on one or few of the research options.)

TABLE 2: INFORMATION SOURCES USED IN THE BANANA PRIORITY ASSESSMENT

Parameter (type)	Information source
Banana production	FruiTrop 2010; disaggregated by cultivar group
Banana yield	FAOSTAT, average crop yield of last three years available (caps on non-Cavendish cultivar groups)
Area harvested	Computed by authors using the FAOSTAT yield information and FruiTrop production figures;
Crop price (Farm-gate banana price)	FAOSTAT (averages from 2010–2012; if available: weighted average price for banana/plantain; $300/MT default if no data
Target domain for technology and/or current and future spread of the constraint	Expert estimates
Changes in yields, production costs, and postharvest losses after technology adoption	Expert estimates
Adoption ceiling, adoption start and pace	Expert estimates
R&D costs	Expert estimates
Demand and supply elasticities	Taskforce agreement (see Annex 9)
Dissemination costs of technologies	Taskforce agreement (see Annex 9)
Population, poverty rate, %GDP from agriculture	World Development Indicators (World Bank)
Household (HH) size and crop area/HH	RTB estimate of beneficiaries (CGIAR 2011)

5. Parameter estimates

5.1 Socioeconomic parameters

The socioeconomic parameters for the individual countries used in the analysis are presented in Table 3. Following the general methodology agreed by the taskforce for the RTB priority assessment, for crop prices, three-year averages of the period 2010–2012 were taken from FAO (2013). Where indicated, adjustments were made in cases where FAO data were either not available (we used a default price of $300/MT) or significantly departed from information available from other sources. While Table 3 displays aggregated production figures for banana/plantain at the country level, the data were disaggregated by major cultivar group as explained in the previous chapter for the definition of the target domain and to derive at adoption estimates (see tables in Annex 1). Indicators used for the assessment for the poverty-reducing effect of the technologies was taken from the World Development Indicators database (World Bank 2013) and listed in Annex 2.

The data on banana area/HH and HH size that were used for the estimation of the numbers of beneficiaries were taken from a dataset put together for the preliminary estimation of the potential number of beneficiaries of the RTB program (CGIAR 2011). Data for individual countries in this dataset were based on specific sources of published information or expert opinion.

Table 3: Socioeconomic parameters used for banana ex-ante impact assessment

Country	Banana Production ('000 MT/year)	Banana Area ('000 ha)	Banana Area per Farm (ha/HH)	Average HH Size (persons)	Farm Gate Banana Price ($/MT)	Poverty (% poor)
Angola	432.70	36.76	0.2	6	300	43.4
Bangladesh	818.25	47.39	0.1	6	243	43.25
Benin	72.10	14.42	0.2	5	300	47.3
Brazil	6,978.31	498.45	0.5	4	70	6.14
Burundi	1,855.24	371.05	0.2	5	382	81.3
Cameroon	2,220.00	184.41	0.2	5	286*	9.56
CAR	214.00	49.17	0.2	5	300	62.8
Colombia	5,338.39	461.43	0.8	4	386*	8.16
Congo	114.10	20.93	0.2	5	300	54.1
Costa Rica	2,202.00	61.22	0.5	4	376*	3.12
Cote d'Ivoire	2,111.45	411.19	0.2	5	363*	23.8
DRC	1,566.47	391.62	0.2	5	300	87.7
Cuba	695.40	80.88	0.5	4	300	0
Dominican Republic	1,085.71	65.89	0.5	4	233*	2.24
Ecuador	5,867.29	266.88	0.5	4	150*	4.61
Equatorial Guinea	51.00	9.49	0.2	5	300	50
Ethiopia	171.70	22.89	0.2	5	181	30.65
Gabon	133.60	25.37	0.2	5	300	4.84

TABLE 4: SOCIOECONOMIC PARAMETERS USED FOR BANANA EX-ANTE IMPACT ASSESSMENT (CONTINUED)

Country	Banana Production ('000 MT/year)	Banana Area ('000 ha)	Banana Area per Farm (ha/HH)	Average HH Size (persons)	Farm Gate Banana Price ($/MT)	Poverty (% poor)
Ghana	1,870.00	191.75	0.2	4	404*	28.6
Guinea	663.40	132.68	0.2	6	57	43.34
Haiti	428.50	64.07	0.5	4	300	61.71
Honduras	642.23	30.56	0.5	4	233	17.9
India	31,897.90	1,858.28	0.2	5	300	32.7
Indonesia	5,814.58	320.03	0.2	6	472	16.2
Kenya	791.57	80.49	0.2	4	501	43.4
Liberia	100.50	27.75	0.2	6	300	83.8
Malawi	324.90	26.99	0.2	4	241	61.6
Mexico	2,103.36	86.06	0.5	4	174	0.72
Mozambique	195.00	27.86	0.2	5	434	59.6
Myanmar	785.10	44.59	0.2	6	300	25.6
Nicaragua	207.00	14.46	0.5	4	300	11.9
Nigeria	2,733.30	455.55	0.2	4	300	54.37
Panama	317.80	15.35	0.5	4	99	6.56
PNG	632.50	45.18	0.1	5	300	20
Peru	1,450.00	107.50	0.45	4	138	4.9
Philippines	9,101.43	391.88	0.2	5	187	18.4
Rwanda	2,749.15	343.64	0.2	4	194	63.17
South Sudan	42.65	7.11	0.2	5	754	19.8
Sri Lanka	572.42	52.04	0.2	6	299	4.11
Tanzania	2,924.70	537.68	0.2	5	300	67.9
Uganda	9,550.00	1,763.98	0.2	5	**150**	38
Venezuela	909.90	79.79	0.5	4	295	6.63
Vietnam	1,481.40	102.17	0.2	4	262	16.9
Zambia	0.82	0.23	0.2	5	300	74.5
Zimbabwe	91.50	18.30	0.2	4	300	50

Notes: Production data from FruiTRoP (2010); production area computed with FAOSTAT yield information (with caps on non-Cavendish cultivar groups); HH size and farm-level crop area from dataset used for estimation of beneficiaries of the RTB program (CGIAR 2011); farm gate banana price from FAOSTAT; parameters highlighted in grey are authors' estimates; prices marked with asterisks are weighted averages (based on area shares) of banana and plantain crop prices from FAOSTAT; poverty figures from World Development Indicators database (World Bank 2013).

5.2 Research option (technology) parameters

The economic surplus model (see p.4) used for this analysis represents a closed[3] economy model with no demand shift. Accordingly, the technology effects that are directly captured by the model and for which explicit parameter values have been estimated are changes in yields (and/or postharvest losses) and costs of production resulting from the adoption of the innovation.

These effects were estimated by the resource person(s) for target countries and, if applicable, also by cultivar group for each technology to be assessed. The parameter values used in the assessment are listed by research option and country in Annexes 3–8.

5.3 Parameters related to research and dissemination process

In addition to the technological parameters described above, the economic surplus model uses a number of parameters that relate to the research and dissemination process. These parameters comprise the duration of the research phase until an adoptable innovation will be available to farmers (i.e., the research lag), the costs required to conduct the research (annual R&D costs), the number of countries and regions that will be targeted and where adoption is expected over the 25-year assessment period, and the dissemination costs for each technology (either $80 or $50 for every new ha of adoption depending on the type of technology; see Annex 9). In further fine-tuning the model or conducting sensitivity analysis, higher dissemination costs could be used for countries with less well-developed infrastructure. We suspect that there may be an inverse relationship between poverty levels and costs for adoption posing an additional challenge when trying to overcome acute poverty through the proposed research options.

The R&D costs were derived from detailed budgets (see Annex 10 for the example of BBTV) extracted from either existing proposal or specifically compiled for this exercise (not actual past research expenditures as in the other crop assessments). The agreement to match those costs 1:1 with similar costs expected at the level of national agricultural research systems (NARS) in the process of developing and adapting the technologies (see taskforce agreements in Annex 9) leads to conservative results since costs will very likely be overestimated. The proposed research budgets developed already contained (some) NARS expenditures (e.g., for staff time and operational costs).

We also included the year when the respective research has started as an indicator of how much of the research has been completed. In this assessment we treat all past research costs as sunk costs (i.e., disregard them for the computation of research costs). Thus the information of how much of the research has already been completed puts the result of the assessment in perspective, as one would expect higher net present values (NPVs) and rates of returns (IRRs) the higher the share of disregarded research. Also, technologies for which research has been going on for some time will likely perform more favorable in the assessment for two more reasons: (1) the research lag will be shorter as adoptable innovations will be available soon compared to similar research options just starting; and (2) chances are that the probability of research success will be higher—effectively a factor with which benefits are multiplied—as some of the research has already been completed and thus the outcome is better known/success closer within reach.

[3] An economy that does not interact with the economy of any other country. A closed economy is self-sufficient, meaning that no imports are brought in and no exports are sent out (www.investopedia.com).

Table 4 shows an overview of the aggregated information (see Annexes 3–8 for country information).

For our assessment we have used a broader success probability. It not only accounts for the likelihood that the planned research outputs will be achieved, but also captures (some of) the uncertainty related to the acceptance and up-take of research products at the national level and thus the likelihood that the innovation will actually be available and can be adopted by farmers in a specific country. This compound probability of success was estimated by informally assessing the capacity of the respective NARS sector, past experiences of collaboration, and the overall conditions/situation in each target countries. A good example is the development of genetically modified (GM) banana varieties resistant to, for example, bacterial wilt for which (official/legal) release and adoption depends on the enactment of biosafety laws and regulations. The probability of success is thus defined as probability that a certain technology will be successfully developed **and** released (i.e., is available). It is conceptually different from the rate of adoption (assumed to be a technology choice at the producer level).

TABLE 5: SUMMARY OF RESEARCH AND DISSEMINATION RELATED PARAMETERS OF RESEARCH OPTIONS

Research Option	Duration of Research Phase (years)	Year when Research Started	No. of Countries Targeted	Regions Targeted	Total R&D Costs ($ millions)[1]	Dissemination Costs ($/ha)	Probability of Research Success (%)
Recovery from BBTV	9	new	22	Africa, Asia	34.40	80	90
BXW management: cultural practices	7	2003	14	Africa	35.40	80	80
BXW management: GM-resistant varieties	7	2005	14	Africa	2.8 [2]	50	90
Cropping system intensification	10	2013	23	Africa, LAC, Asia	22.72	80	90
Resistant EAHB (new)	16	new	6	East Africa	13.65	50	90
Resistant EAHB (release)	7	2003	6	East Africa	5.00	50	100
Resistant plantain (new)	16	new	18	Africa, LAC, Asia	19.65	50	90
Resistant plantain (release)	7	2003	18	Africa, LAC, Asia	11.00	50	100

[1] For the analysis, these costs are matched with additional costs of the same magnitude (1:1) at the NARS level.

[2] Costs do not include costs for deregulation and establishing biosafety laws at the national level.

To improve the accuracy of our adoption ceiling estimates, we included three additional steps:

1. Resource person(s) estimated the share of production area in each country (and cultivar group if applicable) that is susceptible to the target constraint/suitable for the respective innovation (= target domain for the respective research option). This, for example, excluded large-scale commercial plantains or area planted with cultivar groups that are not susceptible to the constraint or production area outside the agro-ecological zones affected (e.g., higher altitudes where disease vectors are absent). For the breeding research options, the target domain is only the share of total production area currently planted with the respective cultivar group.
2. For research options addressing a particular constraint, resource person(s) estimated the share of the target domain that is currently affected by the constraint and will likely be affected by the constraint in 25 years without major intervention (segment of the target domain relevant for our assessment; refined target domain).
3. We then asked the resource person(s) to estimate the likely maximum adoption of the new innovation in the refined target domain (% of area) over the next 25 years.

Finally, to derive the adoption ceiling parameter that is used in the economic surplus model, we computed the percentage share of the total national banana production area that corresponds with the likely adoption in the refined target domain as described above. The three other parameters defining the shape of the adoption curve are the first year of adoption (expert estimate), the time until maximum adoption is reached (in years from first year of adoption, expert estimate), and the pace of adoption determined by the adoption reached in the first year after adoption starts (taskforce agreement to use 1% of estimated adoption ceiling, see Annex 9).

5.4 Research option specific parameters and considerations

5.4.1 Recovery of production affected by BBTV

Twenty-two countries (4 from Asia, 18 from Africa) where BBTV is either already present or will very likely spread in the near future if no major intervention occurs have been considered for the ex-ante impact assessment. For the assessment all six cultivar groups were considered threatened/susceptible, though for most countries a slower spread and thus lower future affected area was assumed for the ABB cultivar group. For countries with commercial plantations (Cameroon, Ghana, Mozambique, Philippines) some share of the AAA Cavendish production area (see Annex 3) was excluded from the target domain since clean seed and good management practices are used and thus infection with BBTV is less likely. The estimation of the current and likely future spread of the disease was made separately for each cultivar group and country. Annex 3 shows the average current and future spread as share of the entire national production area (explaining the uneven national numbers that result from calculating weighted averages of the cultivar group estimates). In the assessment, benefits occur as increases in yield (increase of 80%). Production area lost due to the disease (area where production had to be discontinued due to high disease pressure and large yield losses; e.g., in the Philippines, Malawi, DRC) has been disregarded. The new technology package when adopted is assumed to have no effect on postharvest losses but result in a 40% increase in production costs (mainly due to higher costs associated with purchase of clean seed). Given the high yield losses caused by the disease, it was assumed that the adoption ceiling will be around 50% of the (future) area affected by BBTV, which translates into adoption ceilings of 8–45% of the total national production area (see Annex 3 for details). The technology release will be staggered, and first adoption is expected in 3, 5, or 7 years depending on the country. Owing to lack of information, the time from first adoption until the estimated adoption ceiling will be reached was set at 8 years for all countries. Given that the recovery from BBTV will focus on making clean seed available and improving production practices to avoid the spread of the disease, the probability of success is rather high (80% for countries with stronger NARS and extension systems and 50% for countries where challenges to make the innovation available to farmers will likely be larger). The R&D costs are estimated at $34.4 million and roughly evenly spread over the 9-year research period. In the assessment these costs are matched 1:1 with additional country-level costs as per the general assumptions made for the priority assessment exercise (see Annex 9).

5.4.2 BXW management: cultural practices

Fourteen African countries where BXW is either already present or will very likely spread in the near future if no major intervention occurs have been considered for the ex-ante impact assessment. For the assessment, all six cultivar groups were considered threatened/susceptible. But a faster spread and thus higher percentage values for future affected area was assumed for the ABB cultivar group. The estimation of the current and likely future spread of the disease was made separately for each cultivar group and country. Annex 3 shows the average current and future spread as share of the entire national production area (explaining the uneven national numbers that result from calculating weighted averages of the cultivar group estimates). In the assessment, benefits occur as increases in yield (increase of 90%). The new technology package when adopted is assumed to have no effect on postharvest losses but result in a 20% increase in production costs (mainly due to higher costs associated with purchase of clean seed but simultaneous lower costs for labor). Given the high yield losses caused by the disease, it was assumed that the adoption ceiling will be 30–70% of the (future) area affected by BXW. This translates into adoption ceilings of 7–60% of the total national production area (see Annex 3 for details). The technology release will start in 3 years in all included countries. The time from first adoption until the estimated adoption ceiling will be reached is 7 years for all countries but Burundi and DRC, where adoption will be a bit slower (8 years from first to maximum adoption). Given the high level of damage resulting from the disease and the low level of complexity of the new technology, the probability of success is high (80% for all countries, with the exception of CAR and South Sudan, where additional challenges at the national level are expected). The R&D costs are estimated at $35.4 million and roughly evenly spread over the 7-year research period. In the assessment these costs are matched 1:1 with additional country-level costs as per the general assumptions made for the priority assessment exercise (see Annex 9).

5.4.3 BXW management: GM-resistant varieties

Fourteen African countries where BXW is either already present or will very likely spread in the near future if no major intervention occurs have been considered for the ex-ante impact assessment. Since the efforts to develop GM varieties resistant to BXW currently focus on the AAA genome, only the three cultivar groups “AAA Cavendish,” “other AAA,” and “EAH AAA” were considered as target domain for this research option (see Annex 4 for the share of AAA genome cultivar groups). The estimated current and future affected areas match the ones used in the assessment of “BXW management: cultural practices.” Given the high yield losses caused by the disease, it was assumed that the adoption ceiling will be 30–75% of the (future) area affected by BXW in the target domain. This translates into adoption ceilings of 3–40% of the total national production area (see Annex 4 for details). It is assumed that the GM varieties will be available to farmers in all included countries in 8 years (year of first adoption). The time from first adoption until the estimated adoption ceiling will be reached is 10 years for all countries. In the assessment, benefits occur as increases in yield (increase of 50%). We assumed that switching to GM-resistant varieties will increase the production costs by 40% (more expensive seed) while having no effect on postharvest losses. Given the high level of damage resulting from the disease and the low level of complexity of the new technology, the probability of success should be high. However, since at this point the legal status of GM crops is unclear in most countries included in the assessment, we assumed lower success probabilities compared to, for example, the "BXW management with cultural practices." For Kenya, Uganda, Tanzania, and Ethiopia, where changes in the national law are in place or are underway, and thus release of GM varieties seems much more likely, probability of success estimates range 60–80%. For all other included countries, we assumed a probability of success of 40% to account for uncertainty in the legal framework. However, regulatory issues or delays may not necessarily stop farmers from adopting the technology, and farm-level benefits can occur without having a legal framework in place. The effort to develop GM BXW-resistant banana varieties has been ongoing for the past 8 years. As per the general agreement, all past expenses are considered sunk costs and disregarded in the assessment. The R&D costs for the remaining 7 years of research are estimated at $2.8 million and roughly evenly spread over the 7-year research period. In the assessment these costs are matched 1:1 with additional country-level costs as per the general assumptions made for the priority assessment exercise (see Annex 9). Costs incurred at the country level for developing and enacting biosafety regulations or additional costs for licensing in excess of what is covered by the 1:1 matching funds of $2.8 million for all countries are not included in this assessment. We also assumed that consumer preferences are the same for the new GM varieties and there will be no price differentials.

5.4.4 Cropping system intensification

Twenty-three countries (7 from Asia, 6 from LAC, and 10 from Africa) have been considered for the ex-ante impact assessment of the cropping system intensification research option. Countries were selected when the major cultivar group grown by small-scale farmers was substantial. For the East African countries (Burundi, Rwanda, Tanzania, and Uganda), the target domain is all area planted with "EAH AAA"; for all other African countries (Cameroon, Cote d'Ivoire, DRC, Ghana, Guinea, and Nigeria), the target domain is "AAB Plantain" area. For most countries in Asia (Bangladesh, Myanmar, PNG, Sri Lanka, and Vietnam) the technology focuses on "AAA Cavendish" and "other AAA" production area. For Asian countries with considerable share of commercial Cavendish production (Indonesia and Philippines), only "other AAA" area was considered as target domain. Finally, in the LAC countries (Cuba, Dominican Republic, Haiti, Honduras, Nicaragua, and Peru), the target domain is area planted with "AAB Plantain." Since the technology will be a package of specific agronomic practices, it seemed more realistic to focus on only one cultivar group (production system) first, though much of the generated knowledge will be applicable to other cultivar groups as well. Since this research option is not targeting a specific constraint, 100% of the target domain was considered for the assessment and no "affected area" estimates were necessary. In the assessment, benefits occur as increases in yield (increase of 60%). The new technology package when adopted is assumed to have no effect on postharvest losses but result in a 50% increase in production costs (mainly due to higher costs associated with increased use of fertilizer and irrigation). For this assessment, we did not quantify and include the benefits from cropping system intensification realized through reduced yield variability and an improvement of the status of (on-farm) natural resources (e.g., increased soil fertility). Including these effects can be done, but would require models other than the economic surplus model and was thus not done in this first round of assessment. We note that this omission results in an underestimation of the benefits from this research option. It was assumed that the adoption ceiling will be 30% of the target domain in each of the countries, which translates into adoption ceilings of 6–27% of the total national production area (see Annex 6 for details). The technology release will be staggered, and first adoption is expected in 3 or 7 years depending on the country. Owing to lack of information, the time from first adoption until the estimated adoption ceiling will be reached was set at 15 years for all countries. This is longer than for most other research options. The rationale is that the technology is more knowledge intensive and thus likely to spread slower than, for example, an improved variety. The probability of success is rather high (80% for countries with stronger NARS and extension systems and 50% for countries where challenges to make the innovation available to farmers will likely be larger). The R&D costs are estimated at $22.72 million and roughly evenly spread over the 10-year research period. In the assessment, these costs are matched 1:1 with additional country-level costs as per the general assumptions made for the priority assessment exercise (see Annex 9).

5.4.5 Breeding resistant EAHB varieties

Six African countries (Burundi, Cameroon, DRC, Rwanda, Tanzania, and Uganda) where EAHB are widely grown are included in the ex-ante impact assessment of this research option. Since efforts to develop high-yielding varieties resistant to major pests and diseases (specifically nematodes, weevils, and BLS) focus on the AAA EAH genome, only production area currently grown with this cultivar group is considered as target domain (see Annex 7 for EAHB share in each of the countries). The biotic constraints addressed through the resistant varieties are very widespread in the target domain, so it was assumed that 100% of the EAHB area in the included countries is currently affected by these constraints and will continue to be affected over the next 25 years without major intervention. For this research option we considered two different scenarios: (1) the release of available first- or second-generation hybrids with improved disease resistance and (2) a new breeding program starting at year 1 of the assessment period. Some of the subsequent impact and adoption parameter estimates are different for the two scenarios, thus they are discussed separately in the next two paragraphs. The scenarios are substitutes because yield increases from adopting improved verities are estimated as difference to the yield of varieties currently used by farmers. If the available hybrids were to be released, the yield effect of a new breeding program would very likely be lower.

Release of available improved first- or second-generation EAHB hybrids. The first sub-option assesses the expected benefits of releasing existing second-generation improved EAHB varieties. All costs incurred for past breeding work until now are treated as sunk costs[4] and disregarded in the assessment. The existing improved material would be subjected to 4 years of multilocational testing and 3 subsequent years of on-farm testing. Adoptable varieties will be available to farmers in 7 years. The R&D costs are estimated at $5 million. In the assessment, these costs are matched 1:1 with additional country-level costs as per the general assumptions made for the priority assessment exercise (see Annex 9). The adoption ceiling was estimated at 40% of the target domain in all countries translating into adoption ceilings of 2–31% of the total national production area (see Annex 7, RELEASE sub-option). The

[4] A cost that has already been incurred and thus cannot be recovered. A sunk cost differs from other, future costs that a business may face, such as inventory costs or R&D expenses, because it has already happened. Sunk costs are independent of any event that may occur in the future (www.investopedia.com).

time from first adoption until the estimated adoption ceiling will be reached varies between 8 and 12 years depending on the country. In the assessment, benefits occur as increases in yield (increase of 40%) as well as a reduction in the postharvest losses (25%). It is assumed that adopting the improved EAHB varieties will increase the production costs by 40% (more expensive seed). The probability of success is high (50–80%) since the improved material is already available and is mainly driven by the extension capacity and infrastructure in the respective country.

New breeding program to develop improved EAHB varieties. This second sub-option assesses the expected benefits of a new breeding effort to develop resistant and high-yielding EAHB varieties. This would require a 9-year research phase to develop improved material that would then be subjected to 4 years of multilocational testing and 3 subsequent years of on-farm testing. Adoptable varieties would be available to farmers in 17 years. The R&D costs are estimated at $13.65 million. In the assessment these costs are matched 1:1 with additional country-level costs as per the general assumptions made for the priority assessment exercise (see Annex 9). The adoption ceiling was estimated at 60% of the target domain in all included countries, translating into adoption ceilings of 3–46% of the total national production area (see Annex 7, NEW sub-option). Since the material available from a new breeding effort would perform better than the release of existing material, it was considered reasonable to assume a higher adoption ceiling. The time from first adoption until the estimated adoption ceiling will be reached varies between 8 and 12 years depending on the country. In the assessment, benefits occur as increases in yield (increase of 60%) as well as a reduction in the postharvest losses (25%). We assumed that adopting the improved EAHB varieties will increase production costs by 30% (more expensive seed, but scale effects due to increased availability and thus lower costs per unit seed, assuming that more labs will be operating at the time the improved material will be available for introduction). The probability of success is high (50–80%) and is mainly driven by the extension capacity and infrastructure in the respective country.

5.4.6 Breeding resistant plantain varieties

Eighteen countries (8 African countries: Cameroon, Congo, DRC, Gabon, Ghana, Côte d'Ivoire, Liberia, and Nigeria; 1 Asian country: India; and 9 LAC countries: Brazil, Colombia, Costa Rica, Ecuador, Honduras, Mexico, Nicaragua, Panama, and Venezuela) where plantains are widely grown have been included in the assessment of this research option. Since the efforts to develop high-yielding varieties resistant to major pests and diseases (specifically nematodes, weevils, and BLS) focus on the AAB plantain genome, only production area currently grown with this cultivar group was considered as target domain (see Annex 8 for the share of AAB plantain in each of the countries). The biotic constraints addressed through the resistant varieties are very widespread in the target domain, so it was assumed that 100% of the plantain area in the included countries is currently affected by the constraints and will continue to be affected over the next 25 years without major intervention. For this research option we considered two different scenarios: (1) the release of available first- or second-generation hybrids with improved disease resistant and (2) a new breeding program starting at year 1 of the assessment period. Some of the subsequent impact and adoption parameter estimates are different for the two scenarios, thus they are discussed separately in the next two paragraphs. The scenarios are substitutes because yield increases from adopting improved varieties are estimated as difference to the yield of varieties currently used by farmers. If the available hybrids were to be released, the yield effect of a new breeding program would very likely be lower.

Release of available improved first- or second-generation AAB plantain hybrids. This sub-option assesses the expected benefits of releasing existing second-generation improved plantain varieties. All costs incurred for past breeding work are sunk costs and disregarded in the assessment. Existing improved material will be subjected to 4 years of multilocational testing and 3 subsequent years of on-farm testing. Adoptable varieties would be available to farmers in 7 years. The R&D costs are estimated at $11 million. In the assessment these costs are matched 1:1 with additional country-level costs as per the general assumptions made (see Annex 9). The adoption ceiling was estimated at 10–70% of the target domain in the included countries, translating into adoption ceilings of 2–46% of the total national production area (see Annex 8, RELEASE sub-option). The time from first adoption until the adoption ceiling will be reached varies between 8 and 15 years depending on the country. In the assessment, benefits occur as increases in yield (increase of 70% compared to varieties currently used by farmers) as well as a reduction in the postharvest losses (25%). We assumed that adopting improved plantain varieties will increase the production costs by 40% (more expensive seed). The probability of success is moderate (30–80%) since the available plantain hybrids have integrated banana streak virus (BSV) which will limit the adoption in some countries. Differences in the probability of success are further driven by the extension capacity and infrastructure in the respective country.

New breeding program to develop improved AAB plantain varieties. This second sub-option assesses the expected benefits of a new breeding effort to develop resistant and high-yielding AAB plantain varieties. This would require a 9-year research phase to develop improved material which would then be subjected to 4 years of multilocational testing and three subsequent years of on-farm testing. Adoptable varieties would be available to farmers in 17 years time. The R&D costs are estimated at US$19.65 million. In the assessment these costs are matched 1:1 with additional country level costs as per the general assumptions made for the priority assessment exercise (see Annex 9). The adoption ceiling was estimated at 20% to 80% of the target domain in all included countries translating into adoption ceilings of 3% to 55% of the total national production area (see Annex 8, NEW sub-option). Since material available from a new breeding effort would perform better than the release of existing material and would not contain the banana streak virus (BSV), it was considered reasonable to assume a higher adoption ceiling. The time from first adoption until the estimated adoption ceiling will be reached varies between 8 and 15 years depending on the country. In the assessment, benefits occur as increases in yield (increase of 90%) as well as a reduction in the postharvest losses (25%). We assumed that adopting improved plantain varieties will increase production costs by 20–30% (e.g., more expensive seed, but scale effects due to increased availability and thus lower costs per unit seed assuming that more labs will be operating at the time the improved material will be available; in-vitro propagated seedlings currently much cheaper in LAC and Asia at $0.2–0.4 per piece compared to $1–2 per piece in Africa). The probability of success is moderate to high (40–80%) and mainly driven by the research and extension capacity and infrastructure in the respective country.

6. Results of the ex-ante assessment using economic surplus model

For the estimation of benefits resulting from technology adoption we used a 25-year horizon. We did not model any technology disadoption given that the assessed technologies have a research phase of some 7–16 years from now and estimated time to reaching maximum adoption ranged from 7 to 15 years (see Annexes 3–8). For the computation of the NPV of cost and benefit streams a standard discount rate of 10% was used (taskforce agreement, Annex 9). To correct for potential overestimation of benefits, we ran the model for a second, more conservative adoption scenario for which the adoption ceiling estimated by the resource persons was reduced by 50% while all other parameters were held constant. This procedure was agreed by the taskforce and will be followed by all crop teams (see Annex 9). The scenario with the original adoption ceiling estimates is referred to as "higher adoption" and the more conservative (50% adoption) scenario as "lower adoption."

The results of the economic surplus modeling and cost-benefit analysis are displayed in Table 6. In a nutshell, all assessed research options yield sizeable positive IRRs (i.e., returns on the investment well above a standard 10% interest rate). IRRs are positive and way above 10%, even under the (50%) lower adoption scenario. There is, however, considerable variation in the return on investment between research options, with "BXW management: cultural practices" yielding an estimated 72% and the "Breeding of resistant EAHB (NEW)" an estimated 23%. Estimated NPVs are positive throughout, confirming profitable investments. Since R&D costs (i.e., investments) vary substantially across research options ($2.8 million–$35.4 million, Table4), the NPVs shown in Table 5 should not be used to rank the research options in terms of their estimated profitability.

TABLE 6: RESULTS OF BANANA EX-ANTE ASSESSMENT—ADOPTION CEILING AND BENEFITS

	Adoption Ceiling		All Benefits			
	Lower Adoption	Higher Adoption	Lower Adoption		Higher Adoption	
Technology	('000 ha)	('000 ha)	NPV ($'000)	IRR (%)	NPV ($'000)	IRR (%)
Recovery from BBTV	404	807	1,337,092	61	2,734,922	75
BXW management: GM-resistant varieties	436	872	103,608	36	212,006	42
BXW management: cultural practices	643	1,287	1,981,603	72	4,085,493	87
Cropping system intensification*	627	1,253	547,506	43	1,127,387	54
Resistant EAHB (NEW)	592	1,185	95,406	23	208,147	27
Resistant EAHB (RELEASE)	397	795	298,804	49	608,135	57
Resistant plantain (NEW)	524	1,049	295,359	29	618,668	34
Resistant plantain (RELEASE)	449	898	1,110,961	64%	2,264,126	75

Note: Lower adoption scenario: analysis with 50% lower adoption ceiling. NPV calculated using a real interest rate of 10%.
* Benefits from reduced yield variability and improved status of (on-farm) natural resources (e.g., soil fertility) have not been included in this assessment, which thus likely shows an underestimation or lower boundary of the effect.

Table 5 also displays the estimated area on which the new technology will be adopted under both the lower and higher adoption scenarios. As per definition of the scenarios, the adoption ceiling reached under the lower adoption scenario is half of the higher adoption scenario area. The estimated adoption area is an additional indicator to be considered when making funding decisions as it translates into the likely number of beneficiaries of the new technology.

To explore this aspect more, Table 6 shows the estimated number of households and persons who will benefit from each of the research options. These figures are determined by the adoption ceiling in each of the countries, the number of countries included, and the production area within those countries. Similar to the NPV results, this information should be interpreted with respect to the different magnitude of the investments required/assumed across research options.

The last two columns in Table 6 show the results of the calculation of the estimated poverty reduction effects of the different research options. We follow the methodology described in Arega et al. (2009), which predicts poverty reduction based on estimated growth in the agricultural sector of a given country. To this end, the NPV of the benefits generated by the surplus model is interpreted as agricultural growth. The poverty model uses the country-specific poverty level, the relative size of the agricultural sector (% GDP from agriculture), and the total national population as inputs. Country-level data were obtained from the World Bank's World Development Indicators database (see Annex 2).

TABLE 7: RESULTS OF BANANA EX-ANTE ASSESSMENT – BENEFICIARIES AND POVERTY REDUCTION

Technology	Number of Beneficiaries				Poverty Reduction	
	Lower Adoption		Higher Adoption		Lower Adoption	Higher Adoption
	HH ('000)	Persons ('000)	HH ('000)	Persons ('000)	HH ('000)	Persons ('000)
Recovery from BBTV	2,018	9,674	4,036	19,348	638	1,285
BXW management: GM-resistant varieties	2,173	10,745	4,346	21,489	155	311
BXW management: cultural practices	3,217	15,665	6,434	31,329	1,611	3,287
Cropping system intensification	1,397	6,428	2,794	12,856	342	686
Resistant EAHB (NEW)	934	4,326	1,869	8,652	953	1,935
Resistant EAHB (RELEASE)	634	2,937	1,267	5,874	389	782
Resistant plantain (NEW)	1,979	8,820	3,957	17,641	390	800
Resistant plantain (RELEASE)	1,696	7,566	3,393	15,133	247	502

Note: Lower adoption scenario: analysis with 50% lower adoption ceiling. NPV calculated using a real interest rate of 10%.

TABLE 8: RESULTS OF BANANA EX-ANTE ASSESSMENT—REGIONAL BREAKDOWN OF ADOPTION

	Adoption Ceiling (higher adoption scenario)						
	Africa		LAC		Asia/Pacific*		ALL
Technology	('000 ha)	Share (%)	('000 ha)	Share (%)	('000 ha)	Share (%)	('000 ha)
Recovery from BBTV	706	87	-	-	101	13	807
BXW management: GM-resistant varieties	872	100	-	-	-	-	872
BXW management: cultural practices	1,287	100	-	-	-	-	1,287
Cropping system intensification	1,051	84	69	5	134	11	1,253
Resistant EAHB (NEW)	1,185	100	-	-	-	-	1,185
Resistant EAHB (RELEASE)	795	100	-	-	-	-	795
Resistant plantain (NEW)	646	62	371	35	31	3	1,049
Resistant plantain (RELEASE)	548	61	315	35	35	4	898

*Not including China.

One additional parameter required for the assessment of the poverty reduction effect is the location-specific elasticity of poverty reduction with respect to agricultural growth (i.e., the percentage change in the incidence of poverty brought about by a 1% growth in the agricultural sector). This effect is strongest in SSA (0.72), followed by Asia (0.48), and lowest in LAC (0.15).

The results of the poverty reduction model show a different “ranking” of research options. The expected number of poor persons lifted out of poverty is partly determined by the magnitude of the NPV, which is an input used for the calculation. But the model adjusts for the specific region where benefits will occur by including national poverty indicators and region-specific elasticities. As a consequence, research options that have a high share of adoption predicted within SSA (e.g., breeding for resistant EAHB) rank higher using this performance indicator and those with larger share of adoption in LAC (e.g., breeding for resistant plantain varieties) rank lower.

Table 7 displays information about the regional distribution of the adoption area for the different research options. We note that these numbers are determined by the choice of countries to be included and, although resource persons have compiled the lists of countries to be included based on the severity/presence of the constraint or the suitability of the new technology, there may be scope to broaden the target region(s) and/or adapt the innovations in question to other areas. Also, the regional distribution of benefits is not only driven by the adoption area, but also by other parameters used in the model, such as productivity and cost effects, crop prices, and likely success rate.

7. Discussion

Conducting this priority assessment not only produced estimated benefits and other performance indicators useful to help guide research investment decisions, it was a great learning opportunity. Developing and implementing the methodology for this priority assessment as a team for the five major

RTB crops resulted in a very rich set of information and a community of practice of economists and crop scientists familiar with the approach in participating CGIAR Centers and among national partner institutions.

Based on this experience and the results of this exercise, there are a number of lessons learned that will be useful for subsequent similar priority assessment studies. In the second part of this section, we suggest and discuss a number of follow-up activities for the current study that would help to close the loop described at the outset in the six-step methodology.

7.1 Summary of lessons learned

The priority assessment exercise at hand went through large efforts to elicit stakeholder feedback on the most pressing constraints and most promising opportunities to be addressed by future RTB research. An impressive number of 523 banana experts with different disciplinary backgrounds, occupations (extension officers, researchers, private sector, and government employees), and with fairly even shares from SSA, Asia/Pacific, and LAC contributed through an online survey conducted in three languages. Survey responses were analyzed for each (sub-) region and cultivar group and yielded the most important constraints in producing and marketing bananas as well as a ranking of different research areas.

The next step of reformulating constraints and research areas ranked in the survey into the research options to be assessed ex ante in the priority assessment was not in all cases straightforward. The process of identifying research options with a group of experts in a workshop setting was productive in terms of selecting key research areas. However, the process was lengthy and not always easy; including a larger group of stakeholders through e-Forum proved challenging. Moreover, the nature of the priority assessment evolved from the initial task of producing numbers to guide investment decisions (i.e., comparing alternative research endeavors) more toward supporting the RTB research portfolio as manifested in the RTB flagships. In retrospect, this made a good match of research options with existing RTB flagships more desirable.

For the assessment, we include research options with a wide range of R&D costs (with magnitude of investment ranging from $2.8 million to $35.4 million) limiting the use of the NPV, adoption area, and number of beneficiaries, as well as poverty effect as success indicators. Alternatively, the research question could have been phrased as “in which area of research would a given investment of US$ x million yield the largest benefits?” That is, use the same level of R&D costs for all research options.

Another challenge faced in the priority assessment is the inclusion of research options at very different points in the “research life cycle” (i.e., some are almost completed research endeavors—release of existing hybrids for example) that only need some fine-tuning and/or local adaptation. Some are ongoing activities with part of the research agenda completed (e.g., development of GM varieties resistant to BXW), still others are completely new or future research programs (e.g., breeding of new varieties).

This poses several methodological challenges:

- All past research costs have been treated as sunk costs (i.e., are disregarded in the assessment).
- New/future research options by definition have longer research lags, so it will take longer until adoption starts. This penalizes those options as benefits are discounted based on the year when they materialize and are thus smaller the further in the future they occur.

- There will inevitably be differences in the level of certainty of parameters such as yield or cost effects as well as the probability of research success between research options that are further advanced (e.g., in trials already) compared to future research with totally unknown outcome. This will further limit the scope to compare assessment results of different options.

It is important to consider the status of the respective research options (see Table 5 and description of research options) when comparing and discussing results of the ex-ante assessment. Direct comparisons of the performance indicators of research options at different stages will lead to misleading conclusions with regard to the profitability of research options.

TABLE 9: SOURCES OF INFORMATION USED IN ASSESSMENT, MAJOR CHALLENGE AND ALTERNATIVES

Information	Source	Major challenge	Alternative
Production	FruiTRoP (2010)	Cultivar groups did not match	Banana mapper built on modified crowd sourcing
Yield	FAOSTAT (average of last 3 available years)	Aggregated for banana and/or plantain; incl. large-scale commercial production	Literature, field studies/ surveys, experts
Crop price	FAOSTAT(average of last 3 available years)	Missing data, aggregated for all banana/plantain	National statistics, literature, experts
Impacts (change in yield, production costs, PH losses)	Expert estimates	Likely overestimates benefits; not location specific	Literature, trials, based on crop loss figures by constraint?
Adoption	Expert estimate	Likely overly optimistic	Literature, national extension staff
R&D costs	Experts, existing proposals	Underestimating costs?	Actual Bioversity/ IITA/RTB budget?

When revisiting the data sources used in the priority assessment, there are a number of challenges and concerns regarding the quality and suitability of the information used (see Table 9). For some of the parameters, data quality could be improved by investing more time and/or resources (e.g., information on production area, crop yields, production costs, and prices). For others there is inherent uncertainty that will remain (e.g., adoption ceiling and pace, future spread of constraints) but could potentially be reduced by modifying the parameter elicitation process (e.g., consulting more and/or local stakeholders). A key problem inherent to the ex-ante assessment of technologies is that the most knowledgeable experts are those who are personally involved in the development of the technologies. Past studies have shown that researchers tend to be overoptimistic with regard to the likely research success, but especially when estimating future adoption rates and pace as well as the impact of their own work. This issue could be addressed by conducting a more systematic sensitivity analysis as part of the assessment. At this stage we have included a modified (much more conservative) adoption ceiling assumption through the "lower adoption" scenario in the assessment.

Another methodological simplification chosen for the current assessment is the assumption that one single market exists for all "bananas," disregarding differences in price and elasticities for different types of banana (e.g., dessert vs. cooking) and assuming that all production will be traded fresh within the country and not processed or exported. Ideally, the model would of course be more disaggregated to better match reality in each of the countries included. Along the same lines, there is definitely scope to refine the results by including the spatial dimensions of production area (ideally distinguishing different cultivar groups, agro-ecological zones, and production systems), current and future spread and severity of constraints, yields, production costs, and crop prices. When the six-step methodology for this ex-ante assessment was developed, the plan was to use digital maps created with GIS tools for targeting (as one example). It turned out that the development and population of both RTB maps and the banana mapper took much longer than originally planned and this spatial component never materialized.

Finally, while stressed in the original methodology description, the inclusion of stakeholder feedback loops proved more challenging than anticipated. The (online) expert surveys were very successful in reaching a large number of stakeholders from different countries, disciplinary backgrounds, ages, and gender. However, there is still some concern that the sample includes mainly researchers and much fewer (if any) producers, extension staff, and private sector players. Also, though the banana team made a large effort to include stakeholders in the selection and parameterization of research options through a webpage, diverse communication channels, and the e-Forum, the actual participation and degree of feedback received and included in the assessment were minimal. We suggest stakeholder consultation as one important follow-up activity to close the loop of this first assessment circle.

7.2 Suggested follow-up activities

Given the complexity and scope of the exercise, there are a number of follow-up activities that could not be completed within the timeframe and resources available but would complete or enrich the current exercise and/or help refine its results.

Sensitivity analysis

The assessment at this stage does not include a formal sensitivity analysis. Instead, it only captures the effects of a 50% reduced adoption ceiling estimate (see lower vs. higher adoption results) on the total adoption area, IRR, NPV, number of beneficiaries reached, and poverty effect. Ideally, a formal sensitivity analysis would be conducted for all key parameters to demonstrate the effect of "variability" in the estimates and help direct funds and efforts into the direction that would most improve the quality of the results. This seems like a logical next step before moving on to any of the subsequent activities.

Improving parameter estimates

In the previous section, we highlighted challenges related to the data that have been used for the priority assessment. In Table 9 we list some alternative sources for the information required in the ex-ante analysis. For some of the parameters, such as the production area, average yields, and production costs, as well as the spread of and damage from different major constraints (preferably all disaggregated by cultivar group and production system), this would require ***improved routine data collection and management*** and thus constitutes a longer term effort to, say, compile and maintain data in a geo-referenced database such as the banana mapper. The information to be included could come from a combination of data sources, such as data routinely collected by national statistic services; information provided by regional- or local-level actors, projects, or research stations; and independent data collection efforts aimed at establishing a baseline for future impact assessment and targeting. For other parameters such as the estimated adoption ceiling, yield and cost effects of new technologies, and some of the model assumptions such as elasticities, a ***shorter term concentrated effort*** would make parameter estimates used in the assessment more accurate. The current set of parameter values is based on the expert opinion of a small number of knowledgeable resource persons. Widening the pool of experts and have them review all parameters (or at least all for a specific country or region) across all research options (e.g., in a workshop setting) would likely improve the quality and consistency of the estimates. In addition, a more thorough literature review and cross-checking of reported indicators (e.g., adoption levels realized for similar technologies in the same region in the past, yield efforts in farmers' fields, farm-gate prices, yield loss from a certain pest or disease) could support the expert estimates used.

Assessment of more/remaining research options

At this stage only 6 of the selected 12 research options have been assessed. Given the high importance and devastating effect of ***Fusarium*** as a constraint to banana production, it would definitely be desirable to assess this research option (likely split into two sub-options to capture the different nature of preemptive vs. emergency and ongoing response and management of the disease). The preemptive aspect of Fusarium management could either focus solely on this aspect—mainly avoidance of Fusarium tropical race 4 (Foc TR4) introduction. Or it could be part of a wider "***surveillance and quarantine of banana pests and diseases***" research option that assesses the impact of research to prevent the introduction of major pests and diseases to continents or regions where they are currently not present. The other two very appealing candidates to be included are research on ***"(improved) postharvest management and processing"*** as well as ***"use of existing diversity."*** Assessing these additional research options would require some more time and resources, as well as the availability of knowledgeable experts to help with the parameterization at the country level.

Model refinement and disaggregation

When embarking on this priority assessment for banana research options, it was clear that treating "banana" as one homogeneous crop would not yield very useful results. Thus efforts were made from the beginning to elicit major constraints and production area as well as average yields and yield losses for each of the identified six main cultivar groups. This information was used to determine the target area for each research option. However, when running the economic surplus modeling, all banana production was used as the basis for the assumptions due to lack of more detailed information of separate products and markets. Also, expert estimates were used to exclude large-scale commercial plantations from the target area when applicable. But export-oriented production was not excluded from the model runs. In refining the assessment it would be preferable to exclude all (large-scale) export orientated production, both in terms of area and production, from the assessment. Further, if it was possible to disaggregate production by cultivar group, agro-ecological zone, and production system, the definition of the target domain of specific technologies would be much more accurate. By including spatial considerations such as the area affected by a constraint, the adoption and yield effect estimates could likely be refined substantially and the results could be used to target interventions. Finally, disaggregating markets for different types of bananas (e.g., those used for cooking, beer, and dessert) among which there is little or no substitution effect, and using respective prices and elasticity estimates, would be an additional step toward a more realistic quantification of research option impacts.

Capacity building and strengthening of regional banana networks and ProMusa

The six-step methodology framework developed for the priority assessment placed a strong focus on the participation of and feedback from stakeholders. We feel that, despite our best efforts, this has only been partially achieved and thus see the need for some follow-up in this area. There are three distinct areas for capacity building and strengthening of banana networks:

- Given the success of the large-scale online survey and the availability of a global database of banana experts obtained through the regional network country representatives, there is scope to develop and test online tools to include feedback from a broader group of stakeholders to estimate and/or refine parameter estimates.
- The generated pool of banana researchers and practitioners could be used for other studies as well as for testing new models of communication and participation.
- Also, a wide group of stakeholders has been exposed to and to a large share has contributed to the priority assessment exercise (at a minimum by filling the survey). They could be contacted for the elicitation of feedback on the process and, in particular, how they have been involved in the assessment. Many of the stakeholders have never been involved in a full exercise as this, although many have participated in priority setting based on expert opinion. This is an opportunity to incorporate not only the results, but also a user-friendly explanation of the results, the limitations, and the actions in order to improve the quality and applicability of the results. Combined with a rating of how interesting they found this study and whether and what they have learned as well as their suggestions on how to improve the process for subsequent exercises, such feedback would be a valuable addition to the results of the priority assessment and useful to improve subsequent similar studies.
- It might also be interesting to make the developed tools together with an “instructions manual” and a write-up of lessons learned available to national or regional RTB partners and/or help them to conduct similar priority assessments for their own research strategy. This would help to strengthen expertise in assessing and setting priorities that could be built upon in subsequent rounds of assessment for the RTB. It may also contribute to an increased awareness of where data are missing and needs and possibly even national efforts to collect additional information and/or contribute to global databases such as the banana mapper.
- Finally, some of the more advanced research options (e.g., “BXW management through improved cultural practices”) or other past banana research efforts will be jointly selected by IITA, CIRAD, and Bioversity as candidates for ex-post impact assessment studies to close the loop.

Sharing of methodology, lessons learned, and results of the assessment

Though listed as the final follow-up activity, the sharing of the developed methodology, lessons learned, and the results of this priority assessment exercise are a “must-have” next step in determining the success of the entire endeavor. Since there are different types of information and a variety of different groups of recipients, this will require a diverse set of communication channels and materials. The most immediate next step will be the publication of the individual crop reports and a synthesis final report of the priority assessment study on the RTB webpage and among RTB members and partners. These will be announced through newsletters, blogs, twitter, and other e-communication. A short summary with the results and next steps could be placed on RTB and individual Center (incl. ProMusa) webpages. The priority-setting taskforce has started to develop a publication plan to share methodology and results with the scientific community and to advance the tools and methods available for future similar priority assessments. Finally—and this links back to the previous point—a concentrated effort will be made to share the process and findings with the global banana community (e.g., by presenting at the meetings of the four regional banana networks and posting a summary and links to the full reports on the regional network webpages). To reach a broad group of stakeholders, it will be essential to translate key communications and documents to French and Spanish.

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ANNEXES

Annex 1. Banana production and yield by country and cultivar group

Country	Cavendish AAA		Other AAA, Gros Michel, AA		EAH AAA		AAB Plantain		Other AAB		ABB	
	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)
Angola	287.00	18.00	15.70	7.00	0.00		120.00	7.00	0.00		10.00	7.00
Bangladesh	468.73	16.00	216.52	16.00	0.00		13.00	16.00	60.00	16.00	60.00	16.00
Benin	18.00	5.00	9.00	5.00	0.00		45.00	5.00	0.00		0.10	5.00
Brazil	3,594.96	14.00	200.00	14.00	0.00		453.35	14.00	2,700.00	14.00	30.00	14.00
Burundi	136.56	5.00	230.00	5.00	1,018.68	5.00	170.00	5.00	100.00	5.00	200.00	5.00
Cameroon	500.00	17.00	220.00	9.00	70.00	9.00	1,300.00	12.00	0.00		130.00	9.00
CAR	96.00	6.00	30.00	6.00	0.00		81.00	3.00	0.00		7.00	3.00
Colombia	2,034.34	27.00	469.00	12.00	60.00	12.00	2,650.00	8.00	20.00	10.00	105.05	12.00
Congo	27.00	7.00	3.00	7.00	0.00		81.10	5.00	0.00		3.00	5.00
Costa Rica	2,100.00	41.00	10.00	12.00	0.00		90.00	10.00	0.00		2.00	12.00
DRC	292.47	4.00	24.00	4.00	100.00	4.00	1,045.00	4.00	0.00		105.00	4.00
Côte d'Ivoire	400.00	41.00	6.00	8.00	0.00		1,500.00	4.00	0.00		205.45	8.00
Cuba	88.00	9.00	182.40	9.00	0.00		180.00	6.00	120.00	6.00	125.00	6.00
Dom. Republic	590.00	28.00	4.20	6.00	0.00		400.00	11.00	45.00	6.00	46.51	6.00
Ecuador	5,200.00	34.00	120.00	12.00	0.00		500.00	5.00	0.00		47.29	12.00
Equ. Guinea	8.00	5.00	1.00	5.00	0.00		39.00	5.50	0.00		3.00	5.00
Ethiopia	169.64	7.50	0.96	7.50	0.50	7.50	0.10	7.50	0.00		0.50	7.50
Gabon	12.60	7.00	1.00	7.00	0.00		110.00	5.00	0.00		10.00	7.00
Ghana	130.00	8.00	10.00	8.00	25.00	8.00	1,680.00	10.00	0.00		25.00	8.00
Guinea	181.70	5.00	20.00	5.00	0.00		445.70	5.00	8.00	5.00	8.00	5.00
Haiti	100.00	5.00	18.00	5.00	0.00		238.50	7.00	40.00	5.00	32.00	5.00
Honduras	520.00	30.00	20.00	8.00	0.00		82.23	10.00	0.00		20.00	8.00
India	6,897.90	36.00	10,720.00	15.00	0.00		2,600.00	15.00	2,680.00	15.00	9,000.00	15.00
Indonesia	2,223.23	55.00	1,180.00	15.00	0.00		70.00	12.00	41.35	12.00	2,300.00	12.00
Kenya	238.57	21.00	80.00	8.00	80.00	8.00	305.00	8.00	8.00	8.00	80.00	8.00

Country	Cavendish AAA		Other AAA, Gros Michel, AA		EAH AAA		AAB Plantain		Other AAB		ABB	
	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)	Production ('000 MT)	Yield (MT/ha)
Liberia	40.00	11.00	10.00	11.00	0.00		45.50	2.00	0.00		5.00	11.00
Malawi	140.00	20.00	10.00	10.00	0.00		134.90	9.00	0.00		40.00	10.00
Mexico	1,868.36	28.00	30.00	12.00	0.00		192.00	12.00	3.00	12.00	10.00	12.00
Mozambique	101.70	7.00	3.00	7.00	0.00		85.00	7.00	0.00		5.30	7.00
Myanmar	130.00	12.00	60.00	12.00	0.00		40.00	12.00	250.00	12.00	305.10	12.00
Nicaragua	82.00	54.00	5.00	8.00	0.00		90.00	10.50	0.00		30.00	8.00
Nigeria	263.30	6.00	85.00	6.00	0.00		2,258.00	6.00	0.00		127.00	6.00
Panama	210.00	44.00	9.00	8.00	0.00		85.00	11.00	0.00		13.80	8.00
PNG	90.00	14.00	42.00	14.00	0.00		0.50	14.00	0.00		500.00	14.00
Peru	270.00	12.00	120.00	12.00	0.00		900.00	12.00	160.00	12.00	0.00	
Philippines	5,000.00	52.00	1,300.34	16.00	0.00		1.00	13.00	70.00	16.00	2,730.00	13.00
Rwanda	120.00	8.00	100.00	8.00	1,850.00	8.00	270.00	8.00	150.00	8.00	259.15	8.00
Sri Lanka	162.00	11.00	55.00	11.00	0.00		62.00	11.00	0.00		293.42	11.00
Tanzania	100.00	6.00	50.00	6.00	2,024.00	6.00	150.70	2.00	300.00	6.00	300.00	6.00
Uganda	241.00	4.00	164.00	4.00	7,445.00	5.50	200.00	5.50	500.00	4.00	1,000.00	4.00
Venezuela	300.00	13.50	100.00	13.50	0.00		477.90	10.00	12.00	13.50	20.00	13.50
Vietnam	681.40	14.50	202.40	14.50	0.00		2.00	14.50	0.00		595.60	14.50
Zambia	0.72	3.50	0.05	3.50	0.00		0.00	3.50	0.00		0.05	3.50
Zimbabwe	90.25	5.00	0.60	5.00	0.00		0.15	5.00	0.00		0.50	5.23

Note: Production data from FruiTrop (2010) with expert adjustment to meet cultivar groups and realign where necessary; yield info from FAOSTAT (average of most recent 3 years) with cap on yields highlighted in orange.

Annex 2. Economic and poverty information used in ES models

Country	Poor Population (persons with < $1.25/day)	Value Added by Agriculture ($/year)	Value Added by Agriculture (% of GDP)	National GDP ($/year)	GDP per Capita ($/year)	Population (no. of persons)	Poverty rate (% population below $1.25 poverty line)
Angola	9,036,108	11,445,550,951	10.0	114,197,143,594	5,485	20,820,525	43.4
Bangladesh	66,905,747	20,261,464,643	17.5	115,609,650,525	747	154,695,368	43.3
Benin	4,753,982	2,451,669,280	32.4	7,557,286,829	752	10,050,702	47.3
Brazil	12,197,480	126,681,038,700	5.6	2,252,664,120,777	11,340	198,656,019	6.1
Burundi	8,007,700	857,793,993	34.7	2,471,954,069	251	9,849,569	81.3
Cameroon	2,074,485	4,924,890,569	19.7	24,983,980,484	1,151	21,699,631	9. 6
CAR	2,841,831	1,215,434,881	56.8	2,138,965,636	473	4,525,209	62.8
Colombia	3,892,681	24,111,593,674	6.5	369,812,739,540	7,752	47,704,427	8.2
Congo	2,346,345	462,740,415	3.4	13,677,928,884	3,154	4,337,051	54.1
Costa Rica	149,925	2,862,195,887	6.3	45,127,292,711	9,391	4,805,295	3.1
Cote d'Ivoire	4,721,861	6,164,781,856	25.0	24,680,372,724	1,244	19,839,750	23.8
DRC	57,623,367	8,276,609,688	46.3	17,869,718,210	272	65,705,093	87.7
Cuba	0	3,035,382,379	5.0	60,806,200,000	5,395	11,270,957	0.0
Dom. Republic	230,196	3,587,520,297	6.1	58,951,239,186	5,736	10,276,621	2.2
Ecuador	714,193	8,103,685,630	9.6	84,532,444,000	5,456	15,492,264	4.6
Equ. Guinea	368,148	461,971,563	2.6	17,697,394,251	24,036	736,296	50.0
Ethiopia	28,114,892	20,007,916,109	46.4	43,133,073,100	470	91,728,849	30.7
Gabon	79,016	904,344,700	4.9	18,661,104,043	11,430	1,632,572	4.8
Ghana	7,254,808	9,226,459,079	22.7	40,710,447,429	1,605	25,366,462	28.6
Guinea	4,962,982	1,542,518,192	22.8	6,767,919,333	591	11,451,273	43.3
Haiti	6,278,237	3,593,499,488	20.0	17,967,497,441	1,766	10,173,775	61.7
Honduras	1,420,516	2,747,725,922	15.3	17,967,497,441	2,264	7,935,846	17.9
India	404,396,561	320,189,746,222	17.4	1,841,717,371,770	1,489	1,236,686,732	32.7

Country	Poor Population (persons with < $1.25/day)	Value Added by Agriculture ($/year)	Value Added by Agriculture (% of GDP)	National GDP ($/year)	GDP per Capita ($/year)	Population (no. of persons)	Poverty rate (% population below $1.25 poverty line)
Indonesia	39,991,999	112,601,134,811	12.8	878,043,028,442	3,557	246,864,191	16.2
Kenya	18,739,313	10,099,202,390	27.1	37,229,405,067	862	43,178,141	43.4
Liberia	3,511,585	938,329,804	53.1	1,767,121,781	422	4,190,435	83.8
Malawi	9,798,394	1,286,247,748	30.2	4,263,794,984	268	15,906,483	61.6
Mexico	870,102	42,175,661,832	3.6	1,177,271,329,644	9,742	120,847,477	0.7
Mozambique	15,021,223	4,547,337,116	31.2	14,587,709,350	579	25,203,395	59.6
Myanmar	13,516,114	25,528,520,429	48.4	52,797,319,000	1,000	52,797,319	25.6
Nicaragua	713,016	1,957,196,405	18.6	10,507,356,838	1,754	5,991,733	11.9
Nigeria	91,794,924	85,909,314,341	32.7	262,605,908,770	1,555	168,833,776	54.4
Panama	249,430	920,640,793	2.5	36,252,500,000	9,534	3,802,281	6.6
PNG	1,433,402	6,277,222,468	40.1	15,653,921,367	2,184	7,167,010	20.0
Peru	1,469,402	12,605,507,116	6.4	196,961,048,689	6,568	29,987,800	4.9
Philippines	17,794,045	31,564,712,311	12.6	250,265,341,493	2,588	96,706,764	18.4
Rwanda	7,237,893	2,340,519,324	33.0	7,103,000,861	620	11,457,801	63.2
South Sudan	2,145,830	2,334,328,170	25.0	9,337,312,682	862	10,837,527	19.8
Sri Lanka	835,481	7,183,907,960	12.1	59,421,426,075	2,923	20,328,000	4.1
Tanzania	32,444,730	7,788,509,136	27.6	28,248,844,763	591	47,783,107	67.9
Uganda	13,811,427	4,649,733,433	23.4	19,881,412,441	547	36,345,860	38.0
Venezuela	1,986,002	22,147,461,784	5.8	382,424,454,340	12,767	29,954,782	6.6
Vietnam	15,003,060	30,173,309,967	21.3	141,669,099,289	1,596	88,775,500	16.9
Zambia	10,485,949	4,033,315,474	19.5	20,678,025,802	1,469	14,075,099	74.5
Zimbabwe	6,862,159	1,457,697,056	13.5	10,813,914,265	788	13,724,317	50.0

Source: World Development Indicators; World Bank (used most recent year available for each indicator). Red font indicates author's assumptions where data was not available. Columns highlighted in orange are used in the poverty assessment.

Annex 3. Parameter estimates: Recovery from BBTV

Country	Production Area ('000 ha)	Area Threatened by/ Susceptible to BBTV (% of total)	Current Spread of BBTV (% of potentially threatened area)	Spread of BBTV in 25 years without Major Intervention (% of threatened area)	Adoption Ceiling (% of area affected in 25 years)
Angola	36.76	100.00	14.61	53.83	63
Benin	14.42	100.00	1.00	39.98	50
Burundi	371.05	100.00	5.00	37.84	50
Cameroon	184.41	86.44	13.19	44.85	50
CAR	49.17	100.00	14.76	59.17	50
Congo	20.93	100.00	14.80	59.28	50
DRC	391.62	100.00	20.00	43.66	60
Equ. Guinea	9.49	100.00	5.00	67.47	50
Gabon	25.37	100.00	29.44	68.87	50
Ghana	191.75	92.80	0.00	34.82	50
Kenya	80.49	100.00	0.00	18.14	50
Malawi	26.99	100.00	41.11	74.82	60
Mozambique	27.86	55.67	0.00	19.27	50
Nigeria	455.55	100.00	1.00	48.84	50
Rwanda	343.64	100.00	1.00	33.59	50
Tanzania	537.68	100.00	0.00	19.07	50
Uganda	1,763.98	100.00	0.00	20.78	50
Zimbabwe	18.30	100.00	0.00	19.92	50
Indonesia	320.03	100.00	11.02	30.06	50
Philippines	391.88	79.14	9.15	20.82	50
Sri Lanka	52.04	100.00	5.00	29.50	50
Vietnam	102.17	100.00	3.39	25.90	50

Source: Production information from FruiTrop (2010); threatened and affected area and adoption ceiling are estimates from resource persons; current and estimated future spread of constraint displayed in table above is weighted average of estimates by cultivar group.

Annex 3. Parameter estimates: Recovery from BBTV (continued)

Country	Adoption Ceiling (% of total area) (At_{max})	Years to First Adoption (t_0)	Years to At_{max}	Yield Increase (%)	Reduction in Postharvest Losses (%)	Change in Input Costs (%)	Probability of Success (%)
Angola	34	7	8	80	0	40	50
Benin	20	5	8	80	0	40	50
Burundi	19	3	8	80	0	40	80
Cameroon	19	5	8	80	0	40	80
CAR	30	5	8	80	0	40	50
Congo	30	3	8	80	0	40	80
DRC	24	3	8	80	0	40	50
Equ. Guinea	34	5	8	80	0	40	50
Gabon	34	3	8	80	0	40	80
Ghana	16	7	8	80	0	40	80
Kenya	9	7	8	80	0	40	80
Malawi	45	3	8	80	0	40	80
Mozambique	5	7	8	80	0	40	50
Nigeria	24	5	8	80	0	40	80
Rwanda	17	5	8	80	0	40	80
Tanzania	10	5	8	80	0	40	80
Uganda	10	7	8	80	0	40	80
Zimbabwe	10	7	8	80	0	40	50
Indonesia	15	3	8	80	0	40	80
Philippines	8	3	8	80	0	40	80
Sri Lanka	15	3	8	80	0	40	80
Vietnam	13	3	8	80	0	40	80

Source: Expert estimates.

Annex 4. Parameter estimates: BXW management—GM resistant varieties

Country	Production Area ('000 ha)	Share of AAA Cultivar Group = Target Domain (% of total area)	Current Estimated Spread of BXW in Target Domain (%)	Spread of BXW in Target Domain in 25 Years without Major Intervention (%)	Adoption Ceiling (% of area affected in 25 years)
Angola	36.76	49.48	0.00	20.00	30
Burundi	371.05	74.67	30.00	50.00	30
Cameroon	184.41	29.20	0.00	20.00	30
CAR	49.17	42.71	0.00	100.00	30
DRC	391.62	28.71	20.00	100.00	30
Ethiopia	22.89	99.65	10.00	20.00	30
Kenya	80.49	38.96	5.00	10.00	75
Malawi	26.99	29.64	0.00	100.00	30
Mozambique	27.86	53.69	0.00	50.00	30
Rwanda	343.64	75.30	60.00	60.00	30
South Sudan	7.11	100.00	0.00	100.00	30
Tanzania	537.68	67.39	10.00	20.00	30
Uganda	1,763.98	82.48	60.00	65.00	75
Zambia	0.23	93.90	0.00	100.00	30

Source: Production information from FruiTrop (2010); threatened and affected area and adoption ceiling are estimates from resource persons; current and estimated future spread of constraint displayed in table above is weighted average of estimates by cultivar group.

Annex 4. Parameter estimates: BXW management—GM resistant varieties (continued)

Country	Adoption Ceiling (% of total area) (At_{max})	Years to First Adoption (t_0)	Years to At_{max}	Yield Increase (%)	Reduction in Postharvest Losses (%)	Change in Input Costs (%)	Probability of Success (%)
Angola	3	8	10	50	0	40	40
Burundi	11	8	10	50	0	40	40
Cameroon	2	8	10	50	0	40	40
CAR	13	8	10	50	0	40	40
DRC	8	8	10	50	0	40	40
Ethiopia	6	8	10	50	0	40	60
Kenya	3	8	10	50	0	40	80
Malawi	9	8	10	50	0	40	40
Mozambique	8	8	10	50	0	40	40
Rwanda	14	8	10	50	0	40	40
South Sudan	30	8	10	50	0	40	40
Tanzania	4	8	10	50	0	40	60
Uganda	40	8	10	50	0	40	70
Zambia	28	8	10	50	0	40	40

Source: Expert estimates.

Annex 5. Parameter estimates: BXW management—cultural practices

Country	Production Area ('000 ha)	Area Threatened by/ Susceptible to BXW (% of total)	Current Spread of BXW (% of potentially threatened area)	Spread of BXW in 25 years without Major Intervention (% of threatened area)	Adoption Ceiling (% of area affected in 25 years)
Angola	36.76	100.00	0.00	20.78	40
Burundi	371.05	100.00	32.16	52.16	55
Cameroon	184.41	100.00	0.00	22.41	40
CAR	49.17	100.00	0.00	100.00	30
DRC	391.62	100.00	21.45	100.00	50
Ethiopia	22.89	100.00	10.06	20.06	60
Kenya	80.49	100.00	7.48	12.48	60
Malawi	26.99	100.00	0.00	100.00	60
Mozambique	27.86	100.00	0.00	50.54	40
Rwanda	343.64	100.00	61.89	61.89	70
South Sudan	7.11	100.00	0.00	100.00	30
Tanzania	537.68	100.00	11.86	21.86	50
Uganda	1,763.98	100.00	62.06	67.06	60
Zambia	0.23	100.00	0.00	100.00	50

Source: Production information from FruiTrop (2010); threatened and affected area and adoption ceiling are estimates from resource persons; current and estimated future spread of constraint displayed in table above is weighted average of estimates by cultivar group.

Annex 5. Parameter estimates: BXW management—cultural practices (continued)

Country	Adoption Ceiling (% of total area) (At_{max})	Years to First Adoption (t_0)	Years to At_{max}	Yield Increase (%)	Reduction in Postharvest Losses (%)	Change in Input Costs (%)	Probability of Success (%)
Angola	8	3	7	90	0	20	80
Burundi	29	3	8	90	0	20	80
Cameroon	9	3	7	90	0	20	80
CAR	30	3	7	90	0	20	50
DRC	50	3	8	90	0	20	80
Ethiopia	12	3	7	90	0	20	80
Kenya	7	3	7	90	0	20	80
Malawi	60	3	7	90	0	20	80
Mozambique	20	3	7	90	0	20	80
Rwanda	43	3	7	90	0	20	80
South Sudan	30	3	7	90	0	20	50
Tanzania	11	3	7	90	0	20	80
Uganda	40	3	7	90	0	20	80
Zambia	50	3	7	90	0	20	80

Source: Expert estimates.

Annex 6. Parameter estimates: Cropping system intensification

Country	Production	Area Targeted with Research	Current	Spread of Constraint in 25 Years	Adoption Ceiling
Burundi	371.05	54.91	100.00	100.00	30
Cameroon	184.41	58.75	100.00	100.00	30
Cote d'Ivoire	411.19	91.20	100.00	100.00	30
DRC	391.62	64.05	100.00	100.00	30
Ghana	191.75	87.61	100.00	100.00	30
Guinea	132.68	67.18	100.00	100.00	30
Nigeria	455.55	82.61	100.00	100.00	30
Rwanda	343.64	67.29	100.00	100.00	30
Tanzania	537.68	62.74	100.00	100.00	30
Uganda	1,763.98	76.74	100.00	100.00	30
Bangladesh	47.39	90.37	100.00	100.00	30
Indonesia	316.59	24.85	100.00	100.00	30
Myanmar	44.59	35.51	100.00	100.00	30
PNG	45.18	20.87	100.00	100.00	30
Philippines	391.88	20.74	100.00	100.00	30
Sri Lanka	52.04	37.91	100.00	100.00	30
Vietnam	102.17	59.66	100.00	100.00	30
Cuba	80.88	37.09	100.00	100.00	30
Dom. Republic	65.89	55.19	100.00	100.00	30
Haiti	64.07	53.18	100.00	100.00	30
Honduras	30.56	26.91	100.00	100.00	30
Nicaragua	14.46	59.26	100.00	100.00	30
Peru	107.50	69.77	100.00	100.00	30

Source: Production from FruiTrop (2010); threatened and affected area and adoption ceiling estimates from resource persons.

Annex 6. Parameter estimates: Cropping system intensification (continued)

Country	Adoption Ceiling (% of total area) (At_{max})	Years to First Adoption (t_0)	Years to At_{max}	Yield Increase (%)	Reduction in Postharvest Losses (%)	Change in Input Costs (%)	Probability of Success (%)
Burundi	16	3	15	60	0	50	50
Cameroon	18	3	15	60	0	50	50
Cote d'Ivoire	27	3	15	60	0	50	80
DRC	20	7	15	60	0	50	80
Ghana	26	3	15	60	0	50	50
Guinea	20	7	15	60	0	50	80
Nigeria	25	7	15	60	0	50	50
Rwanda	20	7	15	60	0	50	50
Tanzania	19	3	15	60	0	50	80
Uganda	23	3	15	60	0	50	80
Bangladesh	27	7	15	60	0	50	80
Indonesia	11	3	15	60	0	50	80
Myanmar	11	7	15	60	0	50	50
PNG	6	3	15	60	0	50	80
Philippines	14	3	15	60	0	50	80
Sri Lanka	11	7	15	60	0	50	80
Vietnam	18	3	15	60	0	50	80
Cuba	11	7	15	60	0	50	80
Dom. Republic	17	7	15	60	0	50	80
Haiti	16	3	15	60	0	50	80
Honduras	8	7	15	60	0	50	80
Nicaragua	18	3	15	60	0	50	80
Peru	21	3	15	60	0	50	80

Source: Expert estimates.

Annex 7. Parameter estimates: Breeding resistant EAHB varieties

New EAHB breeding program (NEW) and Release of existing 2nd generation EAHB hybrids (RELEASE)

Country	Production Area ('000 ha)	Share of EAHB = Target Domain (% of total area)	Current Spread of Constraint (% of target domain)	Spread of Constraint in 25 Years without Major Intervention (% of target domain)	Adoption Ceiling NEW (% of target domain)	Adoption Ceiling RELEASE (% of target domain)
Burundi	371.05	54.91	100.00	100.00	60	40
Cameroon	184.41	4.22	100.00	100.00	60	40
DRC	391.62	6.89	100.00	100.00	60	40
Rwanda	343.64	67.29	100.00	100.00	60	40
Tanzania	537.68	62.74	100.00	100.00	60	40
Uganda	1,763.98	76.74	100.00	100.00	60	40

Source: Production from FruiTrop (2010); threatened and affected area and adoption ceiling estimates from resource persons.

New EAHB breeding program (NEW)

Country	Adoption Ceiling (% of Total Area) (At_{max})	Years to First Adoption (t_0)	Years to At_{max}	Yield Increase (%)	Reduction in Postharvest Losses (%)	Change in Input Costs (%)	Probability of Success (%)
Burundi	33	17	10	60	25	30	60
Cameroon	3	17	8	60	25	30	70
DRC	3	17	12	60	25	30	50
Rwanda	40	17	8	60	25	30	80
Tanzania	19	17	10	60	25	30	70
Uganda	46	17	8	60	25	30	80

Source: Expert estimates.

Release of existing 2nd generation EAHB hybrids (RELEASE)

Country	Adoption Ceiling (% of total area) (At_{max})	Years to First Adoption (t_0)	Years to At_{max}	Yield Increase (%)	Reduction in Postharvest Losses (%)	Change in Input Costs (%)	Probability of Success (%)
Burundi	22	7	10	40	25	40	60
Cameroon	2	7	8	40	25	40	70
DRC	2	7	12	40	25	40	50
Rwanda	27	7	8	40	25	40	80
Tanzania	13	7	10	40	25	40	70
Uganda	31	7	8	40	25	40	80

Source: Expert estimates.

Annex 8. Parameter estimates: Breeding resistant plantain varieties

New plantain breeding program (NEW) and Release of existing 2nd generation plantain hybrids (RELEASE)

Country	Production Area ('000 ha)	Share of Plantain = Target Domain (% of total area)	Current Spread of Constraint (% of target domain)	Spread of Constraint in 25 Years without Major Intervention (% of target domain)	Adoption Ceiling NEW (% of target domain)	Adoption Ceiling RELEASE (% of target domain)
Cameroon	184.41	58.75	100.00	100.00	60	50
Congo	20.93	77.48	100.00	100.00	20	10
DRC	391.62	64.54	100.00	100.00	20	10
Gabon	25.37	86.71	100.00	100.00	40	30
Ghana	191.75	87.61	100.00	100.00	60	50
Cote d'Ivoire	411.19	91.20	100.00	100.00	60	50
Liberia	27.75	81.98	100.00	100.00	20	10
Nigeria	455.55	82.61	100.00	100.00	60	50
India	1,858.28	9.33	100.00	100.00	30	20
Brazil	498.45	6.50	100.00	100.00	80	70
Colombia	461.43	71.79	100.00	100.00	70	60
Costa Rica	61.22	14.70	100.00	100.00	80	70
Ecuador	266.88	37.47	100.00	100.00	60	50
Honduras	30.56	26.91	100.00	100.00	50	40
Mexico	86.06	18.59	100.00	100.00	70	60
Nicaragua	14.46	59.26	100.00	100.00	40	30
Panama	15.35	50.34	100.00	100.00	50	40
Venezuela	79.79	59.89	100.00	100.00	50	40

Source: Production from FruiTrop (2010); threatened and affected area and adoption ceiling estimates from resource persons.

Annex 8. Parameter estimates: Breeding resistant plantain varieties (continued)

New plantain breeding program (NEW)

Country	Adoption Ceiling (% of total area) (At_{max})	Years to First Adoption (t_0)	Years to At_{max}	Yield Increase (%)	Reduction in Postharvest Losses (%)	Change in Input Costs (%)	Probability of Success (%)
Cameroon	35	17	10	90	25	30	70
Congo	15	17	15	90	25	30	60
DRC	12	17	15	90	25	30	60
Gabon	35	17	10	90	25	30	60
Ghana	53	17	10	90	25	30	80
Cote d'Ivoire	55	17	10	90	25	30	80
Liberia	16	17	10	90	25	30	60
Nigeria	5	17	10	90	25	30	80
India	3	17	15	90	25	20	60
Brazil	5	17	8	90	25	20	60
Colombia	50	17	8	90	25	20	50
Costa Rica	12	17	8	90	25	20	60
Ecuador	22	17	8	90	25	20	50
Honduras	13	17	8	90	25	20	40
Mexico	13	17	8	90	25	20	40
Nicaragua	24	17	8	90	25	20	40
Panama	25	17	8	90	25	20	40
Venezuela	30	17	8	90	25	20	40

Source: Expert estimates.

Annex 8. Parameter estimates: Breeding resistant plantain varieties (continued)

Release of existing 2nd generation plantain hybrids (RELEASE)

Country	Adoption Ceiling (% of total area) (At_{max})	Years to First Adoption (t_0)	Years to At_{max}	Yield Increase (%)	Reduction in Postharvest Losses (%)	Change in Input Costs (%)	Probability of Success (%)
Cameroon	29	7	10	70	25	40	50
Congo	8	7	15	70	25	40	50
DRC	6	7	15	70	25	40	50
Gabon	26	7	10	70	25	40	50
Ghana	44	7	10	70	25	40	70
Cote d'Ivoire	46	7	10	70	25	40	80
Liberia	8	7	10	70	25	40	50
Nigeria	41	7	10	70	25	40	80
India	2	7	15	70	25	40	40
Brazil	5	7	8	70	25	40	40
Colombia	43	7	8	70	25	40	30
Costa Rica	10	7	8	70	25	40	40
Ecuador	19	7	8	70	25	40	30
Honduras	11	7	8	70	25	40	30
Mexico	11	7	8	70	25	40	30
Nicaragua	18	7	8	70	25	40	30
Panama	20	7	8	70	25	40	30
Venezuela	24	7	8	70	25	40	30

Source: Expert estimates.

Annex 9. Assumptions for economic surplus model parameters

Parameter	Assumption
Time period	Starting in 2014, 25 years; ~ 10 years for research investment (max. time period for RTB)
Elasticities	Supply elasticity: 1.0; Demand elasticity: 0.5
Productivity effects	According to the technology and experts estimation; can be supported by field or trial data
Input cost changes	Based on technology and experts estimation; can be supported by farm-level surveys; cost changes for particular inputs has to be figured in as relative share of overall production costs;
Probability of research success	Probability of RESEARCH being successful and delivering an adoptable technology at the country level; max value of 0.8 for quick wins and lower values if uncertainty of research success is higher (or implementation uncertain; e.g., GM crops); different across technologies, allow for differences across countries for the same technology if necessary/info available.
Depreciation rate	Use 1 across all technologies/crops
Price	Use FAO data (average price over past three years) for each country; make assumptions/ inferences where data are missing and use other information if available; use same price in all years of the model
Quantity	FAO data (three year average); allow for corrections if other sources available
Adoption	Logistic adoption curve; adoption ceiling based on expert estimates; time to reach adoption ceiling (years); set adoption in first year equal to 1% of adoption ceiling for all technologies and crops; year of first adoption (t_0); dis-adoption: based on expert assessment; two adoption scenarios: (1) adoption scenario based on expert assessment of adoption ceiling; (2) conservative scenario: assuming 50% of adoption ceiling indicated by experts
R&D costs and dissemination costs	Research costs: use figures available for each Center (investment by crop) and RTB budget (Table 8.2); budgets of research proposals; available information from past studies. NARS costs: same amount as RTB investment; dissemination costs: fixed figure per ha of adoption (annual during adoption time); dissemination cost only once (i.e., only the marginal adoption area); different dissemination costs for new variety ($50) versus other technologies (e.g., crop management interventions, $80)
Discount rate	10%
Poverty data	Use WB figures for extreme poverty ($1.25/day); adjust elasticities used in poverty measure in spreadsheet: 0.48 for Asia, 0.15 for LAC, and 0.72 for Africa; use poverty reduction reached at highest adoption level;
Population	Use WB figures provided
Number of beneficiaries	Use RTB proposal procedure, country-specific estimates (can correct assumptions)

Annex 10. R&D costs: Example of "Recovery from BBTV" research option

Item	#	Rate [US$/day]	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9
Senior scientist	1	800	160,000	160,000	160,000	160,000	160,000	160,000	160,000	160,000	160,000
Scientist	4	600	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
Research assistant	7	110	154,000	154,000	154,000	154,000	154,000	154,000	154,000	154,000	154,000
NARS scientist	7	250	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000
PHD students	4	100	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	
MSc students	14	80	224,000	224,000	224,000	224,000	224,000	224,000			
Field work			1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Laboratory			210,000	210,000	210,000	210,000	210,000	210,000	210,000	210,000	210,000
Equipment			350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000
Others			50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Travel			350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000
Institute support/ overheads (15% of costs)			511,200	511,200	511,200	511,200	511,200	511,200	477,600	477,600	465,600
TOTAL			3,919,200	3,919,200	3,919,200	3,919,200	3,919,200	3,919,200	3,661,600	3,661,600	3,569,600

Source: Budget compiled for the RTB Priority Assessment to show funds required for research and development activities described in Section 3 of this report under "Recovery of smallholder banana production from BBTV in Africa and Asia" www.rtb.cgiar.org