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# Strategic Assessment of Banana Research Priorities

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# Abstract

In 2013/14 RTB conducted a strategic assessment of research priorities for its major target crops (cassava, banana, potato, sweet potato, and yam). All five studies followed a common framework jointly developed by a priority assessment taskforce. The six-step process for the assessment comprised of i) definition of agro-ecological zones and mapping of crop production to identify target areas; ii) analysis of key constraints; iii) selection of research options to be included in the assessment; iv) quantification of model parameters; v) estimation of research impacts; and vi) communication of findings.

This report gives an overview of the approach and then focuses on the methods and results for the assessment of banana research priorities (steps 3 through 5).

Based on the results of a large scale, carefully targeted online banana expert survey (523 respondents from more than 50 countries) and the outcomes of a global expert workshop held in early 2013, 12 high priority candidate banana research options were identified. Based on availability of time and resources, the following six banana research options were included in the quantitative assessment: 1) recovery of production affected by banana bunchy top virus (BBTV); 2) integrated management of banana Xanthomonas wilt (BXW) and other bacterial diseases: develop improved cultural practices & low-cost diagnostic kits; 3) integrated management of banana Xanthomonas wilt (BXW) and other bacterial diseases: resistant genetically modified (GM) East African Highland banana (EAHB) varieties; 4) sustainable intensification of banana-based cropping systems; 5) breeding EAHB varieties resistant to nematodes, weevils, and black leaf streak; 6) breeding plantain varieties resistant to black leaf streak, nematodes, weevils, and with improved quality traits.

For each of these research options, resource persons identified the expected research costs, likelihood of success, time period until research outputs are available for scaling out, expected farm-level effects, the target domain (region/country and production systems), likely adoption profile (including adoption start, pace and ceiling). In addition to these expert estimates, we used country level production and price information from the FAOStat database and FruiTrop as well as population, economic and poverty indicators taken from the World Development Indicators (World Bank).

An economic surplus model was used for the assessment, extended to include estimations of the potential number of beneficiaries and poverty reduction effects. Cost-benefit analysis estimated the economic returns to potential investments in each of the six banana research options. We found that all assessed research options yield sizeable positive internal rates of returns (IRR). Even under the (50%) lower adoption scenario, IRRs are positive and far above a standard 10% interest rate. There is, however, considerable variation in the return on investment among research options, with the highest IRR realized by “BXW management: cultural practices” yielding an estimated 72% and the lowest IRR for “Breeding of resistant EAHB (NEW)” with an estimated 23%. Estimated NPVs are positive throughout, confirming profitable investments.

The results also cover a regional breakdown of the benefits and potential adoption area for each technology assessed. While some research options, namely the breeding of resistant EAHB varieties and the management of BXW focus only on sub-Saharan Africa, all other research options will have positive impact in sub-Saharan Africa and Asia and/or Latin America and the Caribbean.

Sensitivity analysis showed that the assessment results are robust to variation in some of the key parameters. We modified the adoption ceiling, the start of adoption as well as the magnitude of the yield increase and/or the reduction in post-harvest losses. NPVs remained positive for most research options even under rather extreme scenarios. Not surprisingly, those research options with increases in production costs were most susceptible to a reduction of the yield effect and when a 50% reduction was assumed (in addition to a 50% reduced adoption ceiling), two research options returned negative NPVs.

The results of the poverty reduction model show a different "ranking" of the research options compared to the NPV and IRR results. 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. In addition, 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. Poverty effect results indicate that some 1.6 million persons could be lifted out of poverty through investing into developing and disseminating improved cultural BXW management practices even under the low adoption scenario.

The study produced the anticipated ex ante impact estimates which have already been used to support priority setting within RTB. The report closes with a summary of lessons learnt as well as outlining suggested next steps.

# Acknowledgements

The authors are grateful for the support received by numerous individuals, including (but not limited to) the participants of the expert workshop held in Kampala as well as contributors to the online forum. This study would not have been possible without the dedicated input from the resource persons who accepted the challenge to provide estimates for the key parameters of the research options. For this we especially would like to thank Guy Blomme, Lava Kumar, Leena Tripathi, Eldad Karamura, Piet van Asten, Thierry Lescot, Rony Swennen, Frédéric Bakry, Celestin Niyongere and Edson Perito Amorim. Over the course of the study we benefitted from many discussions with and suggestions from fellow taskforce members Guy Hareau, Ulrich Kleinwechter, Tahirou Abdoulaye, Joseph Rusike, Alene Arega, and Bernardo Creamer. Thank you. We would also like to thank Hildegard Garming for her role in initiating and launching this study as well as providing useful comments on an earlier version of this report. We are very thankful for valuable comments provided by Abdou Tenkouano and Richard Markham.

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All errors and omissions remain the authors’ responsibility.

# Acronyms and Abbreviations

| | |
|---|---|
| BBTV/BBTD | Banana bunchy top virus / Banana bunchy top disease |
| BLS | Black leaf streak |
| BXW | Banana Xanthomonas Wilt |
| CAR | Central African Republic |
| CIP | Centro Internacional de la Papa (International Potato Center) |
| CIRAD | Centre de coopération internationale en recherche agronomique pour le développement (French Agricultural Research Centre for International Development) |
| DRC | Democratic Republic of Congo |
| EA | Eastern Africa |
| EAHB | East African Highland Bananas |
| ECA | Eastern and Central Africa |
| FAO | Food and Agricultural Organization of the United Nations |
| FW | Fusarium Wilt |
| GM | Genetically modified |
| HH | Household(s) |
| IDO | Intermediate Development Outcome |
| IITA | International Institute of Tropical Agriculture |
| IRR | Internal Rate of Return |
| LAC | Latin America and the Caribbean |
| NARS | National Agricultural Research Systems |
| NPV | Net Present Value |
| P | Pacific |
| PNG | Papua New Guinea |
| R&D | Research & Development |
| RBM | Results-based Management |
| RTB | CGIAR Research Program on Roots, Tubers and Bananas |
| SA | Southern Africa |
| SAs | South Asia |
| SEA | Southeast Asia |
| SSA | sub-Saharan Africa |
| WCA | West and Central Africa |

# Strategic Assessment of Banana Research Priorities

## 1 Introduction

Following its official launch in 2012, the CGIAR Research Program on Roots, Tubers and Bananas (RTB)[1] embarked on a strategic assessment of research priorities for five of its major crops (banana, cassava, potato, sweet potato, and yams). The objective of this exercise was to determine the expected impact each research options would generate in terms of economic benefits, poverty reduction, food security, nutrition and health, gender equity, and environmental sustainability. The priority assessment was a collaborative study conducted by RTB members and partners using a common methodology across all five crops. This report documents the procedure and results of the priority assessment for key banana research options (steps 3–5 of the RTB priority assessment). Similar reports summarizing the process and results of the strategic assessment are available for the other four crops included in the RTB priority assessment.

More specifically, the following research questions were addressed:

- What is the expected impact of research options considering standard economic indicators?
- (How) does expected impact of assessed research options differ?
- Which research options are likely to reach the largest number of beneficiaries?
- What are the poverty reduction impacts of the selected research options?

The results of the priority assessment exercise are directly feeding into RTB strategic priority setting. Collated information and estimates obtained have been used to quantify intermediate development indicators (IDOs) supporting the RTB flagship cases and the results can guide budget allocation decision across RTB research areas, crops and regions.

The report in hand is structured as follows: the next section (2) gives an overview of the assessment methodology including the process of selecting research options to be included. The report continues with a detailed description of the research options assessed (3), the parameter elicitation process (4), and an overview of parameters and assumptions used in the assessment (5). Finally, the results of the banana priority assessment are presented in section 6 together with a brief sensitivity analysis. The document concludes with a discussion of results (7), lessons learnt, and a list of suggested follow-up activities to complete the exercise.

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[1] The CGIAR Research Program on Roots, Tubers and Bananas (RTB) is a broad alliance of research-for-development stakeholders and partners. Their shared purpose is to tap the underutilized potential of root, tuber, and banana crops for improving nutrition and food security, increasing incomes and fostering greater gender equity – especially amongst the world's poorest and most vulnerable populations (www.rtb.cgiar.org). CGIAR is a global agriculture research partnership for a food-secure future. Its science is carried out by the 15 research centers who are members of the CGIAR Consortium in collaboration with hundreds of partner organizations. www.cgiar.org

illustrates the methodological framework which is organized as a six step process[2].

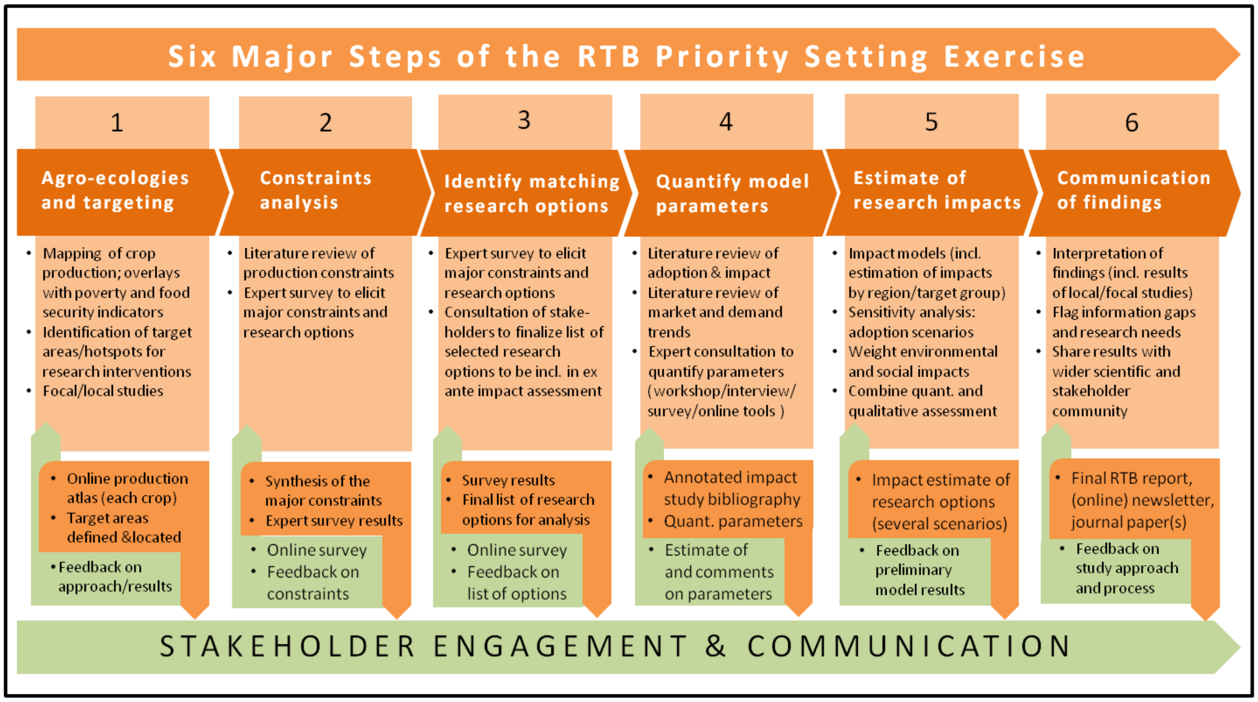
The first step involved defining agro-ecological zones and mapping of crop production for different geographic regions aimed at identifying target areas for RTB research interventions. Best suited for research interventions are “hot spots”, which are defined as geographic regions and/or production systems characterized by a large number of small-scale producers and/or high dependency of poor consumers on the respective RTB crop, the presence of major constraints or opportunities (suitable to be addressed by research) as well as high incidence of poverty and food insecurity. Overlays of different maps (e.g. crop production, biotic or abiotic constraints, and poverty and food security indicators) point to areas where targeted RTB research can lead to high impact[3].

The second step, a constraints analysis, aimed at identifying major production and marketing constraints of the RTB mandate crops and assessing the relative importance of these constraints to select high priority research interventions. As part of the constraint analysis and identification of priority research options (see step 2 and step 3 in Figure 1), expert surveys were carried out in mid-2012 to early 2013 for each of the five crops included in the RTB priority assessment.

[2] The steps are not necessarily carried out in chronological order, and the exact execution of the process may vary slightly across crops.

[3] The outcome of this mapping exercise is manifested in two online mapping resources called “RTB Maps” (http://www.rtb.cgiar.org/RTBMaps) and “Banana Mapper” (www.crop-mapper.org/banana). Building and populating the tools, however, took longer than initially anticipated and thus neither RTB Maps nor the Banana Mapper were used for targeting in the priority assessment exercise.

*FIGURE 1. GRAPHICAL PRESENTATION OF THE RTB STRATEGIC ASSESSMENT OF RESEARCH PRIORITIES*




One major purpose of the expert surveys was to engage the global scientific/stakeholder community in identifying research options to be included in a participatory way. The process and results of the global expert surveys are presented in separate reports, one for each crop[4].

The selection of the research options in step 3 was largely based on the expert survey results and complemented with focus group discussions with selected experts for each of the crops. The data and parameter estimates for the quantitative assessment (step 4) were derived from (inter)national statistics or elicited from experts knowledgeable on specific research fields, regions, and crop agro-ecologies.

Potential research impacts were assessed in step 5 using the economic surplus model, which has been used extensively to quantify expected economic impacts of technical change in agriculture (Alston et al. 1995). The model was extended to estimate the potential number of beneficiaries and poverty reduction effects. Cost-benefit analyses were undertaken to estimate the economic returns to potential investments on the development of each of the research options analyzed. The results also provide a regional breakdown of the benefits and potential adoption area. The effects of different assumptions regarding the pace and ceiling of adoption were tested through a sensitivity analysis using two different adoption scenarios.

A novel method was proposed to establish weights for technology options according to impact on gender equity. This was tested out in an expert workshop but proved problematic to operationalize as gender

[4] The reports are available under http://www.rtb.cgiar.org/category/resources/working-papers/

relevance is context specific. Gender specialists on the team subsequently opted to use a case study approach as a follow up to the main study to determine gender relevance and outcomes of technological choices.

The results of the analysis are being shared with the wider scientific and stakeholder community (step 6) and the feedback will be incorporated and, where necessary, parameter estimates and assumptions will be modified.

This report documents the procedure and results of the priority assessment for key banana research options (steps 3–5 of the RTB priority assessment). Similar reports summarizing the process and results of the strategic assessment are available for the other four crops included in the RTB priority assessment[5].

More specifically, the following research questions were addressed:

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The results of the priority assessment exercise are directly feeding into RTB strategic priority setting. Collated information and estimates obtained have been used to quantify intermediate development indicators (IDOs) supporting the RTB flagship cases and the results can guide budget allocation decision across RTB research areas, crops and regions.

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[5] The reports are available under http://www.rtb.cgiar.org/category/resources/working-papers/

# 2 Methodology and data

## 2.1 CONSTRAINTS ANALYSIS AND IDENTIFICATION OF RESEARCH OPTIONS

The main research activity for the constraints analysis and the identification of research options were expert surveys carried out for each of the included RTB crop[6]. For these surveys a broad range of crop specific expertise ranging from breeding, crop production and extension to policy and sector development is essential. The surveys served several purposes: firstly, the banana expert community was involved in the selection of research options assessed in the priority assessment exercise through survey participation. Secondly, consulting a broad range of experts with different fields of expertise increases the chance to capture key constraints irrespective of institutional priorities and capacity. Lastly, the surveys lead to empirically founded and ranked lists of constraints and associated research options, although different methods provided somewhat different priorities.

The selection of the banana research options started with the analysis of a global online expert survey in which a large sample of banana experts (N = 523) from more than 50 countries identified major constraints to banana production and marketing. The methodology and results of the expert survey are described in more detail in Pemsl et al. (2013a).

Bananas, as a crop, cover a wide diversity of cultivar types grown for different purposes by different types of farm households, affected by different pests and diseases and entering into different local, urban and export value chains. They are grown in mixed cropping as a secondary crop with perennial crops, in mixed food cropping and in diverse systems in which banana is the primary or only crop in the field. To reflect this diversity, respondents were given the option to choose from eight categories of cultivars and six different crop associations (Table 1). Moreover, respondents were given the option to complete the prioritization section of the survey for more than one production system (combination of cultivar group and crop association). The categorization of small-scale banana production into key production systems is an important step to disaggregate crop priorities. The categories used were developed based on consultations with banana specialists in Asia, Africa and Latin America from Bioversity, CIRAD and IITA.

The eight cultivar groups represent a combination of factors: banana taxonomy, use or type of market and disease susceptibility. Four groups are from AAA type of bananas: (1) Cavendish bananas are the major export banana covering over 40% of world banana production (FruiTrop 2012), (2) Gros Michel is the original export banana which lost favor due to the spread of Fusarium wilt (FW) Race 1, (3) other AAA dessert bananas are produced for local and national markets primarily in Asia, while (4) East Africa Highland AAA is grown as a major food staple throughout the highlands of East and Central Africa.

[6] The basic tool for the expert surveys was a structured questionnaire with questions about the major constraints for each crop. To facilitate the participation of especially national and local level experts, the questionnaires were provided in different languages (English, Spanish and French for all crops, in the case of potato also Chinese, and Russian and in the case of cassava also Portuguese). Besides conducting an online survey with personal invitations and individualized links, all surveys were also available online through the RTB and ProMusa webpage. A total of 1,681 respondents completed the survey across all five crops.

*TABLE 1. CATEGORIZATION OF BANANA PRODUCTION SYSTEMS BASED ON PREDOMINANT CULTIVAR GROUP AND CROP ASSOCIATION*

| **Predominant cultivar group or cultivar present:** | **Crop associations and duration** |
|---|---|
| - Cavendish AAA | - Musa associated with established perennial crops (e.g. coffee, coconut) |
| - Gros Michel AAA | - Annual food crops intercropped with Musa (2-5 years) |
| - other AAA dessert types | - Perennial Musa planting underplanted with annual crops |
| - East African Highland AAA | - Musa field (2-5 years) intercropped with short term annual crops during Musa establishment |
| - Plantain AAB | - Perennial Musa monocrop |
| - other AAB, incl. South Pacific plantains | - Frequently replanted Musa monocrop |
| - ABB cooking bananas | |
| - Diploid types | |

Note: Bananas in any geographic location can be categorized by one descriptor from each column

Two groups are AAB: the plantain group of importance as a food staple grown primarily in West and Central Africa and Latin America and other AAB which have diverse uses, but all show susceptibility to Fusarium wilt. The final two groups are separated based on differences in taxonomy.

Across the eight cultivar groups, one group, East African Highland banana (EAHB) AAA, is a major food staple only in Africa, another group, ABB plantain, is a major food staple in Africa and Latin America, one group, Cavendish AAA, is the major export banana found globally, although with greater concentration in Asia and Latin America, while the other five groups are found globally with specific countries often having quite varied cultivar preferences (FruiTrop 2012).

The six cropping systems represent a gradient of density of banana planting from 100-300 mats/hectare for banana associated with perennial crops to over 2,000 plants/hectare for frequently replanted Musa monocrop. Certain of these cropping systems are linked primarily to one or two cultivar groups such as perennial banana gardens underplanted with annual crops found throughout the East and Central Africa highlands and annual food crops mixed with Musa and Musa field (2-5 years) intercropped with short term annual crops found primarily in plantain production. While one cultivar group is usually predominant in a cropping system, smallholders often mix cultivars from up to 5-6 groups in a single field.

This production system categorization is also the basis for the banana mapping web site (see footnote 3 on page 1) designed not only to facilitate targeting within the priority assessment exercise described here, but also to serve for national and international planning and discussion for homologue zones, impacts of climate change and the role of Musa in poverty reduction and the conservation of natural resources.

In the survey, 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).

While there were regional and cultivar group specific differences in the results, we only report the global averages here for brevity and refer the interested reader to the separate expert survey report (Pemsl et al. 2013a) mentioned earlier for details.

The experts indicated production-related factors (43% of allocated points), postharvest, processing and marketing factors (26% of points), and information and knowledge factors (21% of points) as the key categories of income-determining factors.

In a subsequent scoring exercise, experts could then rate the importance of 71 different research options on a five point scale (ranging from 1 = not important to 5 = extremely important). 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, 34 banana scientists were convened in an expert workshop in Kampala, Uganda. Scientists originated from Bioversity and International Institute of Tropical Agriculture (IITA), the French Agricultural Research Centre for International Development CIRAD and national banana programs in Latin America, Africa, and Asia. During the four-day workshop, participants reviewed the priority assessment methodology and results of the expert survey, selected research options to be included in the assessment, and worked in groups on the parameters for the calculation of returns to research investment; 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 completion of the calculation of results for several quite important production problems is still pending.

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[7] are shown in Table 2. 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.

[7] An important emphasis of RTB in 2014 was 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 2: 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) | - Breeding for resistance to virus diseases (BBTV, BSV): global score: 3.82 and rank #19, WCA score: 4.10 and WCA rank #5<br>- Research on management of virus diseases excl. resistant varieties: global score: 3.71, global rank #32, WCA score 3.78 and rank #21 | Preemptive, emergency and ongoing response capacity to **viral diseases** affecting smallholder banana and plantain systems |
| 2. Integrated management of banana Xanthomonas wilt (BXW) and other bacterial diseases: develop improved cultural practices & 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 cultivar group score of 4.59 and 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; EAHB AAA score: 4.51 and EAHB AAA rank #2 | Game changing traits/solutions (**GMO**) |
| 4. Sustainable intensification of banana-based cropping systems, including integrated pest management of BLS, weevils and nematodes | - Strategies to improve soil fertility (micronutrients and fertilizer): global score 4.08, global rank #4; WCA rank #2;<br>- Strategies to manage microbes/microbial communities for soil, root & plant health; global score 3.88, global rank #13; P rank #1<br>- Strategies to improve water management in crop production: global score 3.81, global rank #20; EAHB rank #8, | **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:<br>- weevils: EAHB AAA score 4.06; EAHB AAA rank #12<br>nematodes: EAHB AAA score 4.00; EAHB AAA rank #17<br>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<br>- fungal leaf diseases: AAB Plantain: score 4.20 and rank #2<br>- nematodes: AAB Plantain score 4.10 and rank #9<br>- weevils: AAB Plantain score 3.97 and rank #15 | **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; lowest average score = rank #71).

| Research Option | Related scores and ranks[1] from Expert Survey | RTB Flagship Link |
|---|---|---|
| 7. Developing sweet acid banana varieties resistant to FW, 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 Caribbean: 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**;<br>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):<br>→ just in time supply; develop rural agri-business options for improved income and gender equity<br>→ 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.

## 2.2 ECONOMIC SURPLUS MODEL AND COST-BENEFIT ANALYSIS

Several impact studies of agricultural technologies have estimated aggregate economic benefits through extrapolation of farm-level yield or income gains using partial equilibrium simulation models such as the economic surplus model (Alston et al., 1995).

The economic surplus method is the most widely used procedure for economic evaluation of expected benefits and costs of a new technology. Agricultural research can lead to technological change mainly through increased yield, reduced yield losses, or reduced cost of production. If the new technology is yield increasing, adoption leads to lower per-unit costs of production as well as a higher quantity of goods sold on the markets. This will shift the supply function of the commodity and lead to an increase in the quantity sold and a fall in the price for that good assuming the demand function is downward-sloping and the market for the commodity is perfectly competitive. As a result, consumers benefit from a price reduction and producers benefit from selling larger quantities of the product.

A closed economy[8] economic surplus model was used to derive summary measures of the potential impacts of different banana research options for a period of 25 years (2014-2039). The benefits were measured based on a parallel downward shift in the (linear) supply curve. We estimated the change in economic surplus (defined as the combined benefit consumers and producers receive when a good or service is exchanged)[9] using formulas presented in the standard book written by Alston et al. (1995). Annex 1 lists the key formulas used in the RTB priority assessment.

For the cost-benefit analysis, the estimated annual flows of gross economic benefits from each banana technology for each target country were aggregated, and each year's aggregate benefits and estimated R&D costs were discounted to derive the present value (in 2014) of total net benefits from the research interventions. The key parameters that determine the magnitude of the economic benefits are the following: (1) the expected technology adoption in terms of area under improved technologies, (2) expected yield gains (or avoided losses) following adoption, and (3) pre-research levels of production and prices. To ensure comparability across the five crop studies, the same set of assumptions and data sources were used for all crop studies conducted under the RTB priority assessment (see Table 3 for an overview).

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[8]Despite the presence of global and regional integration arrangements that aim to facilitate trade on global markets, commodities such as those included in RTB are mostly produced and consumed domestically and not easily traded on the global markets especially in less developed countries due to low production, lack of processing technologies, high perishability of the roots and tubers, and trade rules and regulations that hinder free trade. We assumed that a closed economy model best represents the market for all those crops.

[9] 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).

TABLE 3: ASSUMPTIONS / DATA USED IN ALL FIVE PRIORITY ASSESSMENT STUDIES

| Parameter | Assumption |
|---|---|
| **Time period** | 25 years (starting in 2014 and running to 2039) |
| **Elasticities** | Supply elasticity: 1.0;<br>Demand elasticity: 0.5 |
| **Productivity effects** | Specific to the technology and based on expert estimation;<br>If possible supported by field or trial data or any previous studies available |
| **Input cost changes** | Specific to the technology and based on expert estimation;<br>If possible supported by farm-level survey results;<br>Cost changes for particular inputs 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); technology specific and can vary across countries for the same technology if necessary/info available. |
| **Depreciation rate** | Use 1 across all technologies/crops |
| **Price** | Three-year averages (2010-2012) of country specific producer price ($/t) from FAO Stat;<br>Assumptions/ inferences where data are missing or other information if available;<br>Same price in all years of the model |
| **Quantity** | Three-year averages (2010-2012) of country specific crop production (t) from FAO Stat;<br>Assumptions/ inferences where data are missing or other information if available; |
| **Adoption** | Logistic adoption curve; adoption ceiling based on expert estimates; time to reach adoption ceiling (years); set adoption in first year equal to 1% of adoption ceiling for all technologies and crops; year of first adoption ($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 only 50% of adoption ceiling indicated by experts |
| **R&D costs and dissemination costs** | Research costs: budgets available for each Center (investment by crop) and RTB budget (Table 8.2); budgets of research proposals; available information from past studies.<br>NARS costs: assume same amount as RTB investment;<br>Dissemination costs: fixed costs per ha of new adoption (i.e. only costs for the marginal adoption area); different dissemination costs by type of innovation: new variety: $50/ha, other (knowledge intensive) technologies (e.g., crop management); $80/ha |
| **Discount rate** | 10% discount rate |
| **Poverty data** | World Bank Development Indicators data for extreme poverty ($1.25/day); elasticities adjust based on geographic location for each country: 0.48 for Asia, 0.15 for LAC, and 0.72 for Africa; poverty reduction report is reached at highest adoption level; |
| **Population** | Most recent total population data from World Bank Development Indicators |
| **Number of beneficiaries** | Country-specific estimates prepared for RTB proposal: crop area per HH for specific crop and number of persons per HH; (justify and support any deviations in estimates) |

## 2.3 ESTIMATION OF POVERTY EFFECT

Extending the results of the conventional economic surplus and cost-benefit analysis, the impact of each of the banana research options on rural poverty reduction was estimated following the approach in Alene et al. (2009). It weighs the economic surplus results according to the poverty levels in each of the countries, the share of agriculture in total GDP, and the agricultural growth elasticity of poverty. The impact of each research option on rural poverty reduction was estimated by first estimating the marginal impact on poverty reduction of an increase in the value of agricultural production using poverty reduction elasticities of agricultural productivity growth. The reduction in the total number of poor was then calculated by considering the estimated economic benefits as the additional increase in agricultural production value. Thirtle et al. (2003) found that a 1% growth in agricultural productivity reduces the total number of rural poor by 0.72% in Africa, 0.48% in Asia, and 0.15% in Latin America and the Caribbean (LAC). Under the assumption of constant returns to scale, a 1% growth in total factor productivity leads to a 1% growth in agricultural production. For each country, the number of poor lifted above the \$1-a-day poverty line was thus derived as follows:

$$\Delta N_p = \underbrace{\underbrace{\underbrace{\left(\frac{\Delta \text{ES}}{\text{Agriculture value added}} \times 100\%\right)}_{\text{Gains from R\&E as \% of agricultural production}} \times \underbrace{\frac{\partial \ln\left(\frac{N_p}{N}\right)}{\partial \ln(Y)}}_{\text{Poverty elasticity}}}_{\text{Poverty reduction as \% of the poor}} \times N_p}_{\text{Number of poor escaping poverty}}$$

where $\Delta N_p$ is the number of poor lifted above the poverty line, $N_p$ is the total number of poor, $N$ is the total population, $Y$ is agricultural productivity, and $\Delta$ES is the change in economic surplus. The poverty elasticity is interpreted as the marginal impact of a 1% increase in agricultural productivity in terms of the number of poor reduced as a percentage of the total poor ($N_p$), and not of the total population.

## 2.4 ESTIMATION OF THE NUMBER OF POTENTIAL BENEFICIARIES

Data on average crop area per household and average household size were used to estimate the numbers of beneficiaries, following a procedure and dataset developed to estimate total number of RTB poor beneficiaries (CGIAR 2011). Data for individual countries were obtained mostly from FAO database, published sources of information, or expert opinion when needed. Estimated area under two adoption scenarios (high and low adoption) was divided by the average area per household to estimate the number of adopting households, and then multiplied by household size to estimate total number of beneficiaries.

# 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, Celestin Niyongere

**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 banana-free period to eliminate banana aphids on-site and a buffer area free of bananas to reduce aphid re-invasion into a newly-planted field
- 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
- Strategies for supplying clean planting materials
- Integrated approaches to the recovery of BBTD-affected areas involving the creation of a banana-free period and adequate buffer, 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 AAA-Cavendish and other AAAs in Asia (Philippines, Taiwan, Vietnam, Sri Lanka) and on diverse smallholder perennial systems of AAA EAHB and plantain (AAB) in 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 XANTHOMONAS 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, Pisang Awak 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 in Pisang Awak, 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, Eldad Karamura, 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). A 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, CAR, DRC, Gabon, 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, a consortium led by IITA started a project to develop EAHB AAA and AAA banana varieties resistant to BXW. The work 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 estimated 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, especially for off-season production

**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), including pest management practices such as clean and uniform planting material and BLS, improved plant nutrition, irrigation and soil health practices.

**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 adapted to different degrees of market access, natural resource quality and farm household resources
- 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, planting material)
- 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, Myanmar, Papua New Guinea (PNG), Philippines, Sri Lanka, Vietnam; Africa: Burundi, Cameroon, Cote d'Ivoire, DRC, Ghana, Guinea, Nigeria, Rwanda, Tanzania, Uganda; LAC: Cuba, Dominican Republic, Haiti, Honduras, Nicaragua, Peru.

## 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 FW (*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: Cameroon, Congo, Cote d'Ivoire, DRC, Gabon, Ghana, Liberia, Nigeria; LAC: Brazil, Colombia, Costa Rica, Ecuador, Honduras, Mexico, Nicaragua, Panama, and Venezuela;
- Monoculture and mixed systems of sweet acid banana in Asia: India, Indonesia; Africa: Burundi, Cameroon, Ghana, Rwanda, Tanzania, Uganda; LAC: Brazil, Colombia, Mexico, Peru, Venezuela (not assessed at this stage).

# 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 and 3) 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 4–9 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 was thus considered a more reliable source for banana production information, especially since in the FruiTrop tables production information is already disaggregated by major cultivar groups within each country. Some adjustment was needed, though, since 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 2). 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 2 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 (names listed in Section 3) and they adjusted the parameters to reflect country and/or cultivar group specific conditions. Table 4 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: (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 4: 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 banana production data; |
| Crop price (Farm-gate banana price) | FAOSTAT (2010–2012 average; if available: weighted average 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 |
| Research and Development (R&D) costs | Expert estimates |
| Demand and supply elasticities | Taskforce agreement (see Table 3) |
| Dissemination costs of technologies | Taskforce agreement (see Table 3) |
| 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 5. 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 5 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 2). 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 3.

The data on banana area per household (HH) and household 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 5: 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 |

*TABLE 5: 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) |
|---|---|---|---|---|---|---|
| Ethiopia | 171.70 | 22.89 | 0.2 | 5 | 181 | 30.65 |
| Gabon | 133.60 | 25.37 | 0.2 | 5 | 300 | 4.84 |
| 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 used for this analysis represents a closed economy model with no demand shift (see section 2.2 for details). 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 4–9.

## 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 research and development (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 Table 3). 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 Table 3) 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[10] (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 internal rates of returns (IRRs) with higher shares of disregarded costs. Also, technologies for which research has been going on for some time will likely perform more favorable in the

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[10] 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).

assessment for two other 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.

Table 6 shows an overview of the aggregated information (see Annexes 4–9 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.

*TABLE 6: 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.

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).

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 plantations 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 Table 3).

## 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 4) 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 4 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 4 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 Table 3).

### *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 6 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 6 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 Table 3).

### 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 5 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 5 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 Table 3). 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 “EAHB 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, higher quality planting material 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 7 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 (Table 3).

### 5.4.5 Breeding resistant EAHB varieties

Six African countries (Burundi, Cameroon, DRC, Rwanda, Tanzania, and Uganda) where EAHB are 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 EAHB genome, only production area currently grown with this cultivar group is considered as target domain (see Annex 8 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 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 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 and disregarded in the assessment. The existing improved material would be subjected to 4 years of multi-locational 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 Table 3). 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 8, RELEASE sub-option). 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 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 multi-locational 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 Table 3). 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 8, NEW sub-option). Since the material available from a new breeding effort would perform better than the currently available improved planting material (see previous research option), 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, Côte d'Ivoire, DRC, Gabon, Ghana, 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 9 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 multi-locational 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 Table 3). 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 9, 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 multi-locational 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 Table 3). 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 9, NEW sub-option). Since material available from a new breeding effort would perform better than the currently existing planting material (see "RELEASE" research option) 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 of banana research options

## 6.1 Results from cost-benefit analysis 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 4–9). For the computation of the NPV of cost and benefit streams a standard discount rate of 10% was used (taskforce agreement, Table 3). 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 Table 3). 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 7. 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 76% and the "Breeding of resistant EAHB (NEW)" an estimated 23%.

*Table 7: 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 | 1,340,032 | 63 | 2,740,802 | 79 |
| BXW management: GM-resistant varieties | 436 | 872 | 105,619 | 38 | 216,028 | 46 |
| BXW management: cultural practices | 643 | 1,287 | 1,980,437 | 76 | 4,083,161 | 95 |
| Cropping system intensification* | 627 | 1,253 | 547,506 | 43 | 1,127,387 | 54 |
| Resistant EAHB (NEW) | 592 | 1,185 | 98,516 | 23 | 214,366 | 28 |
| Resistant EAHB (RELEASE) | 397 | 795 | 300,974 | 51 | 612,477 | 61 |
| 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.

Estimated NPVs are positive throughout, confirming profitable investments. Since R&D costs (i.e., the level of investment) vary substantially across research options ($2.8 million–$35.4 million, Table 6), the two indicators IRR and NPV produce somewhat different rankings of the research options in terms of their profitability (see Table 7).

Table 7 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.

## 6.2 Number of beneficiaries, poverty reduction and regional distribution of impacts

To explore this aspect more, Table 8 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 8 show the results of the calculation of the estimated poverty reduction effects of the different research options. We followed the methodology applied by Arega et al. (2009), which is described in the methods section (2.3). 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.

*Table 8: Results of banana ex-ante assessment – beneficiaries and poverty reduction*

| | Number of Beneficiaries | | | | Poverty Reduction | |
|---|---|---|---|---|---|---|
| | Lower Adoption | | Higher Adoption | | Lower Adoption | Higher Adoption |
| Technology | HH ('000) | Persons ('000) | HH ('000) | Persons ('000) | Persons ('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: NPV calculated using a real interest rate of 10%.Lower adoption scenario: 50% lower adoption ceiling.

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 9 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.

*TABLE 9: 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.

## 6.3 Sensitivity analysis of priority assessment results

Ex ante impact assessments in general are often criticized on two fronts: i) assumptions are usually overly optimistic and thus in most cases subsequent ex post assessments find much lower actual returns on investments; and ii) that the considerable uncertainty in key parameters make the reliability of results questionable. One common way to address these two issues is to include a sensitivity analysis which considers variation in uncertain key variables thus testing the robustness of the results. Alston et al. (1995) caution, that parameters used in the assessment may be mutually dependent (e.g. adoption rate probably depends on the expected yield/cost effect) and thus building scenarios requires careful consideration. We have only skimmed the surface of conducting sensitivity analysis, but want to include some of the results to give the reader a sense of how variation in some of the key parameters will affect the results.

For the sensitivity analysis we have focused on those parameters which we have elicited from the resource persons (i.e. experts) rather than model inherent parameters (such as elasticities or discount rates) or those parameters populated based on (inter)national statistics (e.g. banana production area, yield or farm-gate prices). In order to keep this section (and the number of scenarios) manageable, we focused on the most crucial parameters which at the same time seem most prone to overly optimistic assumptions.

The key parameter driving the assessment is the area on which the new technology is adopted. In section 6.1, we have presented results for two different adoption ceilings (lower and higher adoption). To further test robustness of the results, we included a third scenario (Table 10), in which the adoption ceiling is only 25% of the original estimate provided by resource persons for each research option and country.

*Table 10: Results of banana ex-ante assessment—benefits under different adoption scenarios*

| | All Benefits | | | | | |
|---|---|---|---|---|---|---|
| | Higher Adoption (expert estimate) | | Lower Adoption I (50% of estimate) | | Lower Adoption II (25% of estimate) | |
| **Technology** | **NPV ($'000)** | **IRR (%)** | **NPV ($'000)** | **IRR (%)** | **NPV ($'000)** | **IRR (%)** |
| Recovery from BBTV | 2,740,802 | 79 | 1,340,032 | 63 | 784,064 | 50 |
| BXW management: GM-resistant varieties | 216,028 | 46 | 105,619 | 38 | 29,572 | 24 |
| BXW management: cultural practices | 4,083,161 | 95 | 1,980,437 | 76 | 1,355,413 | 62 |
| Cropping system intensification* | 1,127,387 | 54 | 547,506 | 43 | 171,119 | 29 |
| Resistant EAHB (NEW) | 214,366 | 28 | 98,516 | 23 | 55,526 | 20 |
| Resistant EAHB (RELEASE) | 612,477 | 61 | 300,974 | 51 | 152,671 | 39 |
| Resistant plantain (NEW) | 618,668 | 34 | 295,359 | 29 | 200,928 | 27 |
| Resistant plantain (RELEASE) | 2,264,126 | 75 | 1,110,961 | 64 | 703,716 | 57 |

**Note:** 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.

The estimated impact for all research options under the three different adoption ceiling scenarios are presented in Table 10 for easy comparison. Even under the extremely conservative scenario where adoption is reduced to only 25% of the expert estimate, all assessed research options reach positive NPVs and the IRRs are well above the 10% benchmark level. Since a reduced adoption ceiling affects all research options in the same way, the ranking of the research options is not changed compared to the results reported in section 6.1 and 6.2.

For the remaining sensitivity analysis scenarios, we selected the 50% lower adoption scenario as the starting point that seemed most likely to us and then modified two additional key parameters: i) the time when adoption starts and ii) the magnitude of the farm-level benefit realized when adopting the technology.

In our own experience, everything always takes more time than initially anticipated (including completing this report), thus we considered a delayed start of. Delays in starting adoption are common due to several factors: delays in start of the research that produces the outputs, in the total duration of the research project, and in subsequent out-scaling and dissemination efforts in making available the research output to farmers due to, for example, regulatory and administrative approvals in host countries. For scenario I we assumed that adoption would start 2 years later than originally planned, while keeping the adoption ceiling and pace at the same level. While this reduces NPVs and IRRs for all research options (and considerably so for some), all research options would still be ranked as economically viable investments (Table 11). The reason why some research option assessments are more affected than others under this delayed adoption scenario lies in the specific nature of associated cost and benefit streams. For the two new breeding options (EAHB and plantain), the number of beneficiaries is reduced under this scenario as the adoption ceiling is no longer reached within the 25-year time period considered for the assessment.

As next step in the sensitivity analysis we assume a lower yield increase and/or smaller reduction in post-harvest losses (which together account for the total output increase) for example because the average effect is smaller under actual farm conditions than anticipated based on experiment or trial outcomes. We re-ran the assessment with a 25% and 50% reduced effect (i.e. 25% or 50% lower total output increase) for scenario II and scenario III, respectively. While all research options are still performing well according to economic indicators under the 25% reduced effect scenario (see scenario II column in Table 11), we found negative NPVs for two research options under scenario III. The research options which perform poorly under this scenario are those in which technology adoption leads to increased production costs (e.g. due to higher seed costs or increased input levels of other production factors). In the case of GM resistant varieties for BXW management for example, the original expert estimates are a 50% yield increase and a 40% increase in production costs (see Annex 5). Similar increases in production costs have been assumed for the resistant EAHB and resistant plantain (Annex 8 and 9) as well as the cropping system intensification (Annex 7) research options If the yield effect is substantially lower than anticipated (as modeled under scenario III), the increased production costs outweigh the value of the yield benefit.

*TABLE 11: CHANGE OF BANANA EX-ANTE ASSESSMENT RESULTS UNDER DIFFERENT SCENARIOS*

| Technology | All Benefits (based on lower adoption I scenario) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Scenario I** adoption delay[1] | | **Scenario II** 25% reduced effect[2] | | **Scenario III** 50% reduced effect[2] | | **Scenario IV** adopt.delay[1] + 50% reduced effect[2] | |
| | **NPV ($'000)** | **IRR (%)** | **NPV ($'000)** | **IRR (%)** | **NPV ($'000)** | **IRR (%)** | **NPV ($'000)** | **IRR (%)** |
| Recovery from BBTV | 1,031,108 | 46 | 784,064 | 50 | 214,450 | 30 | 155,547 | 24 |
| BXW management: GM-resistant varieties | 75,016 | 31 | 29,572 | 24 | -46,487 | NA | -36,134 | NA |
| BXW management: cultural practices | 1,542,274 | 52 | 1,355,413 | 62 | 724,591 | 48 | 551,855 | 37 |
| Cropping system intensification* | 408,085 | 35 | 171,119 | 29 | -219,246 | NA | -174,711 | NA |
| Resistant EAHB (NEW) | 24,495 | 16 | 55,526 | 20 | 14,962 | 14 | -6,414 | 7 |
| Resistant EAHB (RELEASE) | 224,446 | 41 | 152,671 | 39 | 2,411 | 12 | -351 | 10 |
| Resistant plantain (NEW) | 91,281 | 22 | 200,928 | 27 | 105,474 | 23 | 25,256 | 16 |
| Resistant plantain (RELEASE) | 832,989 | 51 | 703,716 | 57 | 286,312 | 44 | 211,870 | 36 |

**Notes:** NPV calculated using a real interest rate of 10%. All scenarios based on 50% lower adoption estimate.
[1] Adoption delay modeled by pushing year of first adoption back by 2 years, adoption ceiling and pace remain unchanged.
[2] Reduced effect scenarios assume a 25% or 50% reduction in the yield (and postharvest) effect. Production costs remain as in the original assessment.
* 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.

Finally, scenario IV captures a delay in adoption (scenario I) combined with a reduced total output effect (scenario III). Even under this rather extreme scenario (which assumes a 50% reduction in adoption area, a two year delay in adoption start, and a 50% reduced effect all at the same time) four of the assessed research options still perform well judged on positive NPVs and IRRs above the 10% threshold.

The scenarios I – IV presented above show that the results of the assessment seem robust even under rather extreme conditions, and findings presented in Table 10 and 11 indicate that the assessed research options will even perform well under less favorable conditions. Still, there is definitely scope for more in-depth sensitivity analysis considering variability in other parameter estimates and preferably building scenarios on stakeholder feedback on the original assumptions and estimates (see section 7.2). Such areas where stakeholder feedback might be incorporated included the price of banana, especially for different cultivars, the cost of planting material and the cost of extension.

# 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 6 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 12: 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 |
| **Description of constraint** (yield loss, area affected by disease, rate of disease spread) | Expert estimates | No reliable global data available which quantifies the current and future spread and severity of the constraint. Likely highly variable based on other factors. | Banana mapper compiles existing data and knowledge. More systematic (scoring) method to predict likelihood/ pace of disease spread |
| **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 10). 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 only includes a brief sensitivity analysis, capturing the effects of a 50% reduced adoption ceiling estimate on the total adoption area, IRR, NPV, number of beneficiaries reached, and poverty effect. We also ran additional scenarios to further reduce the adoption ceiling (75% reduction), delay the start of adoption by 2 years and reduce the effect on yield increases and/or post-harvest losses. Ideally, an extended sensitivity analysis would be conducted for additional key parameters to demonstrate the effect of "variability" in the estimates and help channel funds and efforts into the direction that would most improve the quality of the results of subsequent assessments.

**Improving parameter estimates**

In the previous section, we highlighted challenges related to the data that have been used for the priority assessment. In Table 10 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, a new push to complete the calculations for four research options addressing FW has been organized. These include: 1) research linked to avoided losses – more effective quarantine, surveillance and containment, 2) integrated crop and disease management, 3) conventional breeding for FW resistance, and 4) GMO bananas for FW resistance. The FW assessment could serve as a preamble to 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 several 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[11].
- 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.

[11] Despite the success of the online survey, there is a concern whether relying on only electronic communication strategies is inclusive enough to ensure participation of a broad range of stakeholders. We will thus explore how stakeholder groups with no or limited access to computers and the internet can be encouraged to participate and be kept informed and consulted to ensure they are not excluded from participation and thus not heard. This is of particular interest if exclusion would lead to a systematic bias in the results. One possible approach is to additionally use printed media and face-to-face meetings.

- 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-assessment 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 the final results at the meetings of the four regional banana networks which have already reviewed and discussed methods and partial results 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. Definition of economic surplus, NPV and IRR

In a closed economy, economic surplus measures can be derived using the following formulas (Alston et al. 1995):

(1) change in economic surplus ($\Delta$ES) = $P_0Q_0K_t(1+0.5Z_t\eta)$;

(2) consumer surplus ($\Delta$CS) = $P_0Q_0Z_t(1+0.5Z_t\eta)$; and

(3) producer surplus ($\Delta$PS) = $(K_t{-}Z_t)P_0Q_0(1+0.5Z\eta)$,

where $K_t$ is the supply shift representing the product of cost reduction per ton of output as a proportion of product price (K) and technology adoption at time t ($A_t$); $P_0$ represents pre-adoption price; $Q_0$ is pre-adoption level of production; $\eta$ is the price elasticity of demand; and $Z_t$ is the relative reduction in price at time t, which is calculated as $Z_t = K_t\varepsilon/(\varepsilon+\eta)$, where $\varepsilon$ is the price elasticity of supply.

The research-induced supply shift parameter, K, is the single most important parameter influencing total economic surplus results from unit-cost reductions and is derived as

$$K_t=[((\Delta Y/Y)/\varepsilon-(\Delta C/C))/(1+(\Delta Y/Y))]\times A_t,$$

where $\Delta Y/Y$ is the average proportional yield increase per hectare; $\varepsilon$ is the elasticity of supply that is used to convert the gross production effect of research-induced yield changes to a gross unit production cost effect; $\Delta C/C$ is the average proportional change in the variable costs per hectare required to achieve the yield increase; and $A_t$ is the rate of adoption of the improved technology at time t—the proportion of total cropped area under the improved varieties and practices. In the RTB priority assessment, annual supply shifts were then projected based on projected adoption profile for improved technologies ($A_t$) for the period 2014–2039 (25 years). Adoption ($At$) is assumed to follow a logistic diffusion curve.

For each country i (i=1, …, N), the changes in economic surplus ($\Delta$ES) and the research and extension costs ($C_t$) are discounted at a real discount rate, $r$, of 10% per annum to derive the net present values (NPV) as follows:

$$\mathrm{NPV} = \sum_{t=1}^{25}\sum_{i=1}^{N}\left(\frac{\Delta \mathrm{ES}_{i,t}}{(1+r)^t}\right) - \sum_{t=1}^{25}\left(\frac{\mathrm{C}_t}{(1+r)^t}\right)$$

The aggregate internal rate of return (IRR) was also calculated as the discount rate that equates the aggregate NPV to zero as follows:

$$\sum_{t=1}^{25}\sum_{i=1}^{N}\left(\frac{\Delta \mathrm{ES}_{i,t}}{(1+\mathrm{IRR})^t}\right) - \sum_{t=1}^{25}\left(\frac{\mathrm{C}_t}{(1+\mathrm{IRR})^t}\right) = 0$$

## Annex 2. Banana production and yield by country and cultivar group

| | Cavendish AAA | | Other AAA, Gros Michel, AA | | EAHB AAA | | AAB Plantain | | Other AAB | | ABB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Country** | 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 | | EAHB 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 3. 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 4. 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 4. 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 5. 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 5. 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 6. 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 6. 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 7. 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 7. 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 8. 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.

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

**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 9. 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 9. 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 9. 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 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