



# RTB Working Paper

## Strategic Assessment of Banana Fusarium Wilt Research Priorities

Lars Scheerer<sup>1</sup>, Charles Staver<sup>1</sup>, Miguel Dita<sup>1, 2</sup>, Luis Perez Vicente<sup>3</sup>, Diemuth Pems<sup>1</sup>

<sup>1</sup>Bioversity International, Montpellier, France; <sup>2</sup>Embrapa Cassava and Fruits, Bahia, Brazil; <sup>3</sup>INISAV, Cuba

M A Y 2 0 1 8



## RTB Working Paper

**Correct citation:** Scheerer, L., Staver, C., Dita, M., Perez V., L., and Pems, D. 2018. Strategic Assessment of Banana Fusarium Wilt Research Priorities. A quantified approach to project losses caused by Fusarium Wilt Tropical Race 4 & Results of the ex-ante assessment of four Fusarium research options. Lima (Peru). CGIAR Research Program on Roots, Tubers and Bananas (RTB). RTB Working Paper 2018-2. Available online at: [www.rtb.cgiar.org](http://www.rtb.cgiar.org)

## Published by the CGIAR Research Program on Roots, Tubers and Bananas

The CGIAR Research Program on Roots, Tubers and Bananas (RTB) is a partnership collaboration led by the International Potato Center implemented jointly with Bioversity International, the International Center for Tropical Agriculture (CIAT), the International Institute of Tropical Agriculture (IITA), and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), that includes a growing number of research and development partners. RTB brings together research on its mandate crops: bananas and plantains, cassava, potato, sweetpotato, yams, and minor roots and tubers, to improve nutrition and food security and foster greater gender equity especially among some of the world's poorest and most vulnerable populations.

### Contact:

RTB Program Management Unit  
International Potato Center (CIP)  
Apartado 1558, Lima 12, Peru  
rtb@cgiar.org • [www.rtb.cgiar.org](http://www.rtb.cgiar.org)

ISSN 2309-6586

DOI: 10.4160/23096586RTBWP20182

© International Potato Center on behalf of RTB

### Creative Commons License



This working paper is licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc-sa/4.0/>.

### Disclaimer:

This RTB Working Paper is intended to disseminate research and practices about production and utilization of roots, tubers and bananas and to encourage debate and exchange of ideas. The views expressed in the papers are those of the author(s) and do not necessarily reflect the official position of RTB, CGIAR or the publishing institution.

# Contents

Executive Summary .....	i
Acknowledgements .....	iii
1. Introduction .....	1
2. Description of Fusarium research options .....	3
2.1 Fusarium research option (A): Improved quarantine and surveillance measures to avoid spread of Fusarium TR4.....	4
2.2 Fusarium research option (B): Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4 .....	5
2.3 Fusarium research option (C): Development of Fusarium resistant banana cultivars .....	6
2.4 Fusarium research option (D): Development of genetically modified (GM) Fusarium resistant banana cultivars .....	7
3. A quantified approach to project losses caused by Fusarium Wilt TR4 .....	9
3.1 Foc Scale: Methodology .....	9
3.2 Foc Scale: Results .....	10
4. Parameter estimates and assumptions of Fusarium research options.....	21
4.1 Fusarium research option (A): Improved quarantine and surveillance measures to avoid spread of Fusarium TR4.....	21
4.3 Fusarium research option (B): Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4.....	25
4.3 Fusarium research option (C): Development of Fusarium resistant banana cultivars .....	28
4.4 Fusarium research option (D): Development of GM Fusarium resistant banana cultivars .....	29
5. Results of the ex-ante assessment of Fusarium research options.....	32
Results from Cost-Benefit Analysis using Economic Surplus Model .....	32
5.2 Number of beneficiaries, poverty reduction and regional distribution of impacts .....	33
5.3 Sensitivity analysis of Fusarium research option results.....	35
6. Conclusions .....	37
7. Literature .....	40

## List of Tables

Table 1: Key factors for risk of Foc arrival and respective coding .....	10
Table 2: ‘Risk categories’ of Fusarium wilt TR4 arrival and corresponding countries .....	11
Table 3: Key factors for the internal spread and respective coding .....	12
Table 4: Internal spread categories of Foc and corresponding countries .....	12
Table 5: Estimated total loss of production area per cultivar group after Fusarium arrival (50% spread scenario) .....	14
Table 6: Estimated national production area lost due to Fusarium wilt TR4 in Africa, disaggregated by cultivar group .....	15
Table 7: Estimated national production area lost due to Fusarium wilt TR4 in Asia and Pacific, disaggregated by cultivar group .....	16

Table 8: Estimated national production area lost due to Fusarium wilt TR4 in Latin America & Caribbean, disaggregated by cultivar group .....	18
Table 9: Estimated total banana production area lost globally due to Foc TR4 .....	20
Table 10: Loss of total national banana production area (in %) with and without intervention and subsequent losses avoided in year 25 of the assessment period.....	23
Table 12: Summary of parameter estimates and assumptions regarding Fusarium Research Option B .....	28
Table 11: Summary of parameter estimates and assumptions regarding Fusarium Research Option A .....	25
Table 13: Summary of parameter estimates and assumptions regarding Fusarium Research Option C .....	30
Table 14: Summary of parameter estimates and assumptions regarding Fusarium Research Option D .....	31
Table 15: Results – Adoption area and benefits (Fusarium Research Option A) .....	33
Table 16: Results - Adoption area and benefits (Fusarium Research Options B, C, D) .....	33
Table 17: Results – Beneficiaries and poverty reduction (Fusarium Research Option A) .....	34
Table 18: Results – Beneficiaries and poverty reduction (Fusarium Research Option A, B, C) .....	34
Table 19: Results - Regional breakdown of adoption .....	35
Table 20: Sensitivity Analysis - Benefits under different adoption scenarios (1) .....	36
Table 21: Sensitivity Analysis - Benefits under different adoption scenarios (2) .....	36

## List of Figures

Figure 1: Internal rate of spread of Foc TR4 by cultivar group .....	13
Figure 2: Internal rate of spread of Foc TR4 by cultivar group .....	14
Figure 3: Estimated total production area lost due to Foc, all countries (in hectares and % of total production, years from now).....	20

# Executive Summary

Global banana production is seriously threatened by the emergence of a new, highly virulent strain of Fusarium Wilt (FW), caused by the soil-borne fungus *Fusarium oxysporum f. sp. cubense* (Foc). Foc (tropical race 4 - TR4) was first diagnosed in Cavendish banana in Taiwan in 1967, but has since reached Indonesia, Australia, Malaysia, China, Philippines, Vietnam, India, Pakistan and Myanmar, the Middle East (Jordan, Oman) and most recently Mozambique in Africa in 2013. Recent estimates suggest that the disease is already affecting over 100,000 hectares and threatens millions of smallholders worldwide because many banana cultivars are susceptible. Projections based on the current distribution of cultivars suggest that TR4 could affect 80% of the global banana production. As the pathogen persists in the soil for many decades and many cultivars are susceptible, there has been a call to address the threat of TR4 with a mobilization of resources and plant quarantine initiatives globally to limit spread and losses.

As part of a study to assess the economic returns to different banana research investments through the CGIAR Research Program focusing on Roots, Tubers and Bananas (RTB), a set of banana research options has been formulated based on priorities identified through a large-scale online stakeholder survey. In this survey, Fusarium wilt was rated as the fourth most important constraint globally and ranked first in Asia. Since it has not yet or to a lesser extent spread in other geographies, rankings were lower in other regions: seventh most important constraint in East and Southern Africa and sixth in Latin America. Fusarium was not in the top ten constraints for West and Central Africa.

Based on informal expert consultation, four distinct research portfolios addressing Fusarium in different ways were identified. The assessment of these four research interventions follows the same general methodology and assumptions that were used in the earlier RTB priority assessment. While the estimation of costs were relatively straightforward and followed the assumptions used in the previous assessments, the estimation of benefits largely depends on future disease spread and the loss avoided through the intervention i.e. the value of production that would be affected by Fusarium without the intervention but could either be “saved” (i.e. disease does not reach the area) or “recovered” (i.e. production can continue even in affected areas). The four Fusarium related research options assessed are: (A) Improved quarantine and surveillance measures to avoid spread of Fusarium TR4, (B) Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4, (C) Development of Fusarium resistant banana cultivars, and (D) Development of GM Fusarium resistant banana cultivars.

To quantify expected losses, we developed the ‘Foc Scale’, that allows to categorize countries according to the risk of Foc arrival and the rate of internal spread of the disease within the country. The results of the ‘Foc Scale’ risk assessment then serve as basis to calculate benefits (aggregated future production losses avoided) for each research option over the 25-year assessment period. The following key factors linked to the likelihood of TR4 to reach a country were identified from risk analyses conducted in Africa, Latin America and Asia: the importance of mono-cropped Cavendish, global banana traffic to and from a country, quality of border and internal plant quarantine measures and land and other links to countries where TR4 is currently present. Each factor was scored from 0 to 1 or from 0 to 2 depending on the relative importance of the factor. The aggregate score for each

country potentially ranging from 0-8 provided a quantified rating for the risk of Foc introduction and establishment in the country. The rate of internal spread was estimated based on three factors: quality of internal quarantine measures, importance of Cavendish, and importance of banana for national research investment and public policy. The higher the aggregated score for a country, potentially ranging from 0 to 4, the more rapid the internal spread and the higher the expected loss of banana production due to TR4. To account for varying risk and susceptibility, estimated losses linked to the Foc scale index were differentiated depending on cultivar types. In the 29 countries analyzed, production area affected was estimated as a total of 1.68 million hectares by 2040. In a more conservative scenario, cutting back the increase of spread rate from 50% to 25% decreased estimated global production area affected to a total of 1.24 million hectares.

An economic surplus model and cost-benefit analysis were applied to estimate the net benefits resulting from each research option. Thereby, two scenarios were considered: the original estimated maximum adoption area is referred to as “higher adoption” and the more conservative (50% of the estimated maximum adoption area) scenario as “lower adoption.” The results show that all assessed research options yield positive Internal Rates of Return (IRR) i.e., returns on the investment above a standard 10% interest rate. For the higher adoption scenario, Fusarium research options B, C, and D are calculated to have an IRR of 36, 25 and 34%, respectively. Under the lower adoption scenario research options B, C, and D show IRRs of 30%, 20% and 28%, respectively. Research option A (Quarantine) yields the lowest returns to investment, just slightly above the standard 10% interest rate threshold. This is because we included additional cost variables compared to the other research options. Apart from the R&D costs and the dissemination costs, we introduced the costs of establishing quarantine systems reflecting the initial capacity strengthening efforts and the costs of maintaining the quarantine and surveillance system. Thus, the costs during the first ten years are exceptionally high and results for Option A should not be directly compared with the other research options since arguably establishing quarantine systems would have benefits beyond the containment of Foc. The Net Present Values (NPV) of all Fusarium research options are positive. Since R&D costs of investment vary substantially across research options (\$8.51 million - \$47.73 million), the two indicators IRR and NPV produce slightly different rankings of the research options in terms of their profitability.

The calculation of number of beneficiaries show that Option A benefited 6.7 million people in the case of a scenario with very conservative assumptions and more than 9.1 million people in the case of the least conservative scenario. For Options B, C, and D the number of beneficiaries was estimated to be nearly 7.9 million, 14 million and 2.7 million, respectively, using the lower adoption scenario. Poverty reduction analysis for the four options (high adoption scenario) estimated substantial numbers of beneficiaries to be lifted out of poverty: 807,000 for Option A; 157,000 for Option B; 850,000 for option C; and 89, 000 persons for option D.

Sensitivity analysis was conducted to test robustness of the priority assessment results which seems prudent considering the uncertainty involved in estimating parameters and making assumptions on future events. The results showed that only one research option, the development of Fusarium resistant banana cultivars, failed to deliver positive results under the most extreme scenario. All other research options yielded positive NPVs and IRRs well above the 10% threshold even under rather extreme scenarios.

# Acknowledgments

This research was undertaken as part of, and funded by, the CGIAR Research Program on Roots, Tubers and Bananas (RTB) and supported by CGIAR Trust Fund contributors  
<https://www.cgiar.org/funders/>.



# Strategic Assessment of Banana Fusarium Wilt Research Priorities

---

A quantified approach to project losses  
caused by Fusarium Wilt Tropical Race 4

&

Results of the ex-ante assessment of four Fusarium research options

## 1. INTRODUCTION

Global banana production is seriously threatened by the emergence of a new strain of Fusarium Wilt (FW), caused by the soil-borne fungus *Fusarium oxysporum f. sp. cubense* (Foc). Starting in the 1920s and culminating in the 1950s, FW of banana caused one of the most devastating plant disease epidemics in history, wiping out large production areas of Gros Michel (AAA), the initial export banana from Latin America and the Caribbean. Foc is particularly devastating, because it not only causes wilting and rapid death of the mat, but also remains in the soil for decades (Stover, 1962). The race of Foc affecting Gros Michel became known as Race 1 (R1) and also affects other cultivars such as Pisang Awak (ABB), Apple (AAB), Prata (AAB), and Isla (AAB). Race 2 (R2) affects certain ABB Bluggoe-type cooking bananas. The migration of production to un-infested soils, used by the export industry initially to address Foc, is the only management practice available to smallholders. The export industry eventually circumvented R1 by a shift to R1-resistant Cavendish cultivars, which are currently the source of 99% of banana exports. R1 and R2 are found globally, limiting banana production of susceptible cultivars grown by smallholder farmers for home consumption or to be sold at local and national urban markets.

In 1967, a new highly virulent strain of Foc (tropical race 4 - TR4) was diagnosed in Taiwan in Cavendish (Ji Su, Hwang, & Ko, 1986) spreading slowly at first, but reaching 1,200 hectares within 12 years. Since that time, TR4 has spread further in Asia to Indonesia, Australia, Malaysia, China, Philippines, Vietnam, India, Pakistan and Myanmar, the Middle East (Jordan, Oman) and most recently Mozambique in Africa in 2013. Recent estimates suggest that where the disease is present over 100,000 hectares are already affected (Ordonez et al., 2015). TR4 also threatens millions of smallholders worldwide because, unlike R1 and R2, more banana cultivars are susceptible (Ploetz, 2005). Based on the current distribution of cultivars, Ploetz (2007) projected that TR4 could affect 80% of the global banana production. As the pathogen persists in the soil for many decades and many cultivars have shown some susceptibility, concern has grown that the threat of TR4 needs to be addressed with a mobilization of resources and plant quarantine initiatives globally (Kema & Weise, 2013).

As part of a study to assess the economic returns to different banana research investments through the CGIAR Research Program focusing on Roots, Tubers and Bananas (RTB), a set of banana research options has been formulated based on priorities identified through a large-scale online stakeholder survey. Among the key constraints identified were banana bunchy top virus (BBTV), *Xanthomonas wilt*

(BXW) and Fusarium. Research options addressing these constraints were formally assessed by comparing the discounted estimated costs of the intervention with the discounted expected benefits to determine if the investment would be worthwhile. The assessment of Fusarium related research options, however, was delayed in thus not included in the initial assessment and report (Pemsl & Staver, 2014). Since the results of the assessment support the resource allocation process and direct funds to areas with the largest potential for returns, there was a strong interest in completing the assessment for Fusarium related research.

The assessment of four research interventions addressing Fusarium in different ways is documented in this report and follows the same general methodology and assumptions that were used in the earlier RTB priority assessment. While the costs were relatively straightforward to estimate following the standard assumptions used in the other research lines assessed the estimation of benefits largely depends on the assumptions on disease spread i.e. the area that would have been affected by Fusarium without the intervention but could be either “saved” (i.e. not reached by the disease) or “recovered” (for example by using resistant varieties). Based on the data demands of the economic model applied, we needed a country by country estimate of losses caused by FW that would serve as a baseline to estimate each research options benefits or so-called ‘avoided losses’.

This report, therefore, has three objectives: (1) presenting in detail the four different Fusarium research options; (2) describing the method developed to project production losses that would be caused by FW under a status quo situation (i.e. without the research interventions), presenting the resulting expected loss by country, and discussing further steps in the refinement of the method applied; and (3) presenting the parameter estimates and assumptions of each Fusarium research option as well as the results of the economic assessment (cost-benefit analysis and economic surplus modelling).

The report has six sections, including this introduction. Section 2 describes the four Fusarium related research options, namely (A) Improved quarantine and surveillance measures to avoid spread of Fusarium TR4, (B) Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4, (C) Development of Fusarium resistant banana cultivars, and (D) Development of GM Fusarium resistant banana cultivars. Section 3 is concerned with the quantification of expected losses from FW for which we developed the ‘Foc Scale’, that allows to categorize countries according to the risk of Foc arrival and likely pace and extent of internal spread of the disease within the country. The results of the ‘Foc Scale’ serve as a basis to calculate the benefits of the Fusarium research options. Section 4 outlines the parameter estimates and assumptions used in the assessment of each of the four Fusarium research options. To make the assessment transparent, we have listed the following information for each of the research options: target countries included, cultivar groups considered, current and likely future spread of FW, benefits (such as increase in yield or reduction in postharvest losses or changes in production costs) resulting from the research intervention, the adoption profile, probability of success (up-take of technology), as well as the total costs of the research. In section 5, we present the results of the ex-ante assessment of Fusarium research options followed by a sensitivity analysis of the findings. Finally, in section 6 we conclude and illustrate limitations of the approach as well as lessons learnt.

## 2. DESCRIPTION OF FUSARIUM RESEARCH OPTIONS

When starting to think about possible research interventions addressing Fusarium wilt, it became clear that activities can be clustered around three general themes. First, the issue of preventing the spread of the disease (especially of Fusarium TR4) across continents and to currently unaffected countries, which could be achieved through research on (and implementation of) improved quarantine and surveillance measures aiming at containing the disease. Secondly, once present in a certain geography, the further internal spread as well as the recovery of banana yields in already affected areas can be addressed through research in the area of integrated crop and disease management (for all Fusarium strains). Lastly, in line with how the banana export industry managed to cope with previous Fusarium epidemics, research could result in banana cultivars resistant to Fusarium. Resistant cultivars could be obtained i) either through conventional breeding making use of the large genetic diversity of banana stored both in situ and in gene banks, either as parent lines for formal breeding or through somaclonal selection; or ii) through genetic modification of economically important but susceptible cultivars. These three themes are generally complementary since research activities focusing on improved quarantine and surveillance will likely only delay and not fully prevent the (further) spread of Fusarium thus requiring (additional) approaches to manage banana crops in affected areas and/or have resistant cultivars available to producers. Thus, there is some degree of overlap between research themes and returns to the latter two themes will be lower if prevention of spread is successful since benefits would only occur later (or in the most extreme case – if a spread of Fusarium was prevented all together – there would be no return to better management practices or resistant varieties in those areas “saved” from the disease). Since, however, the integrated crop and disease management research option addresses all Fusarium strains (including the earlier ones which have already spread widely), we think they still merit to be a separate research theme. Similarly, while the outcome of resistant banana cultivars could be achieved in different ways (conventional breeding vs genetically modified (GM) crops), these two hold very different prospects for smallholder farmers since very likely only few economically important cultivars will be addressed using GM techniques and the scope of planting such cultivars is currently limited to only few countries with regulatory frameworks and biosafety protocols already in place.

We thus decided to proceed with the assessment of four distinct Fusarium research options:

- Improved quarantine and surveillance measures to avoid spread of Fusarium TR4
- Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4
- Development of Fusarium resistant banana cultivars
- Development of GM Fusarium resistant banana cultivars

While we think this approach is justified, we want to caution the reader that results should not be simply added up since there is – as explained above - some interdependency and overlap of benefits among the themes.

The remainder of this section contains a detailed description of the four research options.

## 2.1 Fusarium research option (A): Improved quarantine and surveillance measures to avoid spread of Fusarium TR4

**Resource persons:** Charles Staver, Miguel Dita, Luis Perez Vicente

**Constraint:** As Foc TR4 persists in the soil for many decades, susceptible varieties cannot effectively be planted ever again without the use of as yet undeveloped cropping system strategies. Preventing the entrance and further spread of TR4 is the first strategy. Therefore, research actions aiming at pathogen exclusion and the strengthening of quarantine and surveillance measures are necessary. Also, included here are measures to eradicate the first infected plants detected and contain the spread of the disease from these initial sites.

### **RTB research addressing the constraint:**

- Strengthen science-based risk analysis protocol for Foc movement for local, national, regional and intercontinental use
- Validate efficient surveillance protocols to detect, delimitate and monitor Foc spreading
- Understand risk and pathways of Foc dissemination in soil, suckers, humans, other banana parts, diverse agricultural and non-agricultural practices within country, across borders and between continents
- Determine the effectiveness of different eradication and isolation procedures for first detected Foc affected banana plants in Foc-free areas
- Develop/improve protocol to produce Foc-free planting material from tissue culture (TC), suckers and macro propagation
- Develop models for Foc epidemiology and pathogenicity and more efficient tools for epidemiological studies
- Determine the population structure of the pathogen, cultivar-specific disease intensity and distribution of Foc populations currently present in major banana producing countries
- Develop and optimize diagnostic protocols for TR4 and other relevant Foc strains
- Evaluate susceptibility/resistance of major cultivars and parental lines used in breeding programs to Foc TR4 and other relevant Foc strains

**Status of research:** Research initiatives focusing on (improved) quarantine and surveillance are limited. There are advances in the production of Foc-free planting material through tissue cultures, but protocols need to be improved to increase the adoption levels. A diagnostic protocol is available for TR4, but not for other Foc strains. Recent concerns about specificity of the TR4 diagnostic for in planta detection have emerged, indicating the need of further improvements. Development of improved quarantine and surveillance measures would take 5 years with an estimated probability of research success of 80%.

**Adoptable innovations:** (Improved) exclusion, surveillance, containment and early eradication measures on farm, community, national and international level

### **Expected impact:**

- Yield loss avoided through containment
- Slower and/or reduced spread of disease
- Increase in (production) cost

**Target region/system:**

- Production areas of all six cultivar groups (Cavendish AAA; other AAA + Gros Michel + AA; East African Highland AAA; AAB Plantain; other AAB; ABB) in countries in Africa, LAC and Asia where Fusarium is either already present or will very likely spread in the near future
- Africa: Burundi, Cameroon, Congo, D.R., Côte d'Ivoire, Ghana, Kenya, Mozambique, Nigeria, Rwanda, Tanzania, Uganda; Asia/Pacific: China, India, Indonesia, Malaysia, Myanmar, Pakistan, Papua New Guinea, Philippines, Thailand, Vietnam; LAC: Brazil, Columbia, Costa Rica, Ecuador, Guatemala, Mexico, Nicaragua, Peru

## 2.2 Fusarium research option (B): Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4

**Resource persons:** Charles Staver, Miguel Dita, Luis Perez Vicente

**Constraint:** As the pathogen persists in the soil for many decades, susceptible varieties cannot effectively be planted ever again. While preventing the spread of TR4 should be the first strategy, disease management must be strengthened in parallel. There has been some success with cultural practices to manage Fusarium (in Asia and for R1 in LAC), but further and more in-depth research aiming to reduce pathogen inoculum, create suppressive and healthy soils and boost plant defenses are necessary. These practices formulated into integrated cropping systems are proposed to enable banana production in Foc-infested soils.

**RTB research addressing the constraint:** Recent research proves that FW can be managed in small plots within acceptable control levels through soil and crop management. However, a better understanding of both disease epidemiology and host-soil-pathogen relationships is necessary in order to generate science-based and scalable management strategies. RTB research would comprise the following interventions:

- Strengthen science-based risk analysis protocol for Foc movement for local, national, regional and intercontinental use
- Develop/improve protocol to produce Foc-free planting material from TC, suckers and macro propagation
- Develop model for Foc epidemiology & pathogenicity + more efficient tools for epidemiological studies
- Determine the population structure of the pathogen, cultivar-specific disease intensity and distribution of Foc populations currently present in major banana producing countries
- Develop and optimize diagnostic protocols for TR4 and other Foc races
- Evaluate susceptibility/resistance of major cultivars to Foc TR 4 and other races
- Identify and evaluate cover crops, intercrops and other agronomic and soil management practices that suppress or accelerate Foc in banana and clarify mechanisms involved
- Understanding functional diversity of suppressive vs. conducive soils in banana production contrasting biological, physical, chemical properties
- Screen and characterize root-associated microorganisms w/ Foc suppressive & growth promotion capacity

- Prototype integrated Foc management strategies based on biological inputs (including microorganisms), crop (including resistant genotypes and chemical fertilizers fine tuning) and cropping (including) systems

**Status of research:** Diverse research groups in Brazil, China, Indonesia and Australia have advanced pilot strategies to combine soil management, soil amendments and endophytes to permit several cycles of crop harvest prior to plantation uprooting. However, much work is still needed to develop more effective combinations for different cultivars in different agroclimatic regions. A complete crop and disease management package will be developed, tested, and ready for adoption in ten years (partial results will be used by farmers in 5 years), with an estimated probability of research success of 90%.

**Adoptable innovations:** Crop and disease management package

**Expected impact:**

- Reduced yield loss (avoided losses) when Fusarium is present
- Increase in labor/input cost

**Target region/system:**

- Production area of all six cultivar groups (Cavendish AAA; other AAA + Gros Michel + AA; East African Highland AAA; AAB Plantain; other AAB; ABB) in LAC and Asia (integrated management of Foc TR4)
- 'Cavendish AAA' production areas in Africa (integrated management of TR4)
- 'Other AAA' and 'other AAB' in LAC and Asia (integrated management of Race 1)
- We do not consider Race 2 in the assessment of this research option since it is not very likely that the research output would be used for planting ABB, which, while being susceptible to Race 2 has not been intensified in the vast majority of locations where it is grown.
- Africa: Cameroon, Côte d'Ivoire, Ghana; Asia/Pacific: China, India, Indonesia, Malaysia, Myanmar, Pakistan, Philippines, Thailand, Vietnam; LAC: Brazil, Columbia, Costa Rica, Ecuador, Guatemala, Mexico, Nicaragua, Peru

## 2.3 Fusarium research option (C): Development of Fusarium resistant banana cultivars

**Resource persons:** Charles Staver, Miguel Dita, Luis Perez Vicente

**Constraint:** Currently, no cultivars resistant to TR4 are available, but opportunities exist to breed for resistance on different fronts - exploration of germplasm banks; use of wild type species already identified with high levels of resistance in renewed efforts to breeding and somaclonal variation.

**RTB research addressing the constraint:**

- Prospection for new sources of resistance to Foc in germplasm collection, including breeding lines
- Identify and characterize resistance genes (and molecular markers) to support breeding processes including Marker Assisted Selection
- Generate diploid pre-breeding lines with Foc resistance (emphasis on TR4) for major cultivar groups
- Develop efficient protocols for phenotyping of breeding lines

- Employ conventionally breeding methods to develop bananas with Foc resistance
- Strengthen protocols and develop somaclonal & clonal selection for Foc resistance in susceptible cultivars
- Identify possible Foc resistant substitutes for the major susceptible market and food security cultivars and select for clones with superior traits
- Evaluate and select resistant genotypes on multi-site field experiments
- Evaluate and develop post-harvest and market oriented strategies

**Status of research:** Some clonal variants with quantitative resistance have been identified and are currently explored in Asia. However, remarkable genotype-environment interactions have been reported, too. Wild species with full resistance have been identified, but these genes need to be transferred to commercial cultivars. Resistant cultivars could be available in 15 years, with an estimated probability of research success of 60%.

**Adoptable innovations:** High yielding and market accepted Fusarium resistant varieties

**Expected impact:**

- High yield despite Fusarium presence (avoided losses)
- Increase in seed costs
- Lower price (since new varieties don't meet consumer preferences)

**Target region/system:**

- Production area of all six cultivar groups (Cavendish AAA; other AAA + Gros Michel + AA; East African Highland AAA; AAB Plantain; other AAB; ABB) in Africa, LAC and Asia
- Africa: Burundi, Cameroon, Congo, D.R., Côte d'Ivoire, Ghana, Kenya, Mozambique, Nigeria, Rwanda, Tanzania, Uganda; Asia/Pacific: China, India, Indonesia, Malaysia, Myanmar, Pakistan, Philippines, Thailand, Vietnam; LAC: Brazil, Columbia, Costa Rica, Ecuador, Guatemala, Mexico, Nicaragua, Peru

## 2.4 Fusarium research option (D): Development of genetically modified (GM) Fusarium resistant banana cultivars

**Resource persons:** Charles Staver, Miguel Dita, Luis Perez Vicente

**Constraint:** Currently no cultivars resistant to TR4 are available. While conventional breeding offers opportunities and needs to be explored, technologies that speed up the development of resistant commercial varieties, such as trans-/cisgenic and gene editing must be researched in parallel.

**RTB research addressing the constraint:**

- Identify pathogenicity factors and defense/resistance genes and develop cisgenic and/or transgenic constructs to generate Foc resistant bananas
- Develop GM bananas for Foc resistance
- Phenotype GM bananas lines for Foc resistance at greenhouse level
- Evaluate and select commercial GM lines resistant to Foc on multi-site field experiments
- Evaluate and develop post-harvest and market oriented strategies

**Status of research:** Technologies to introduce genes in commercial varieties are already available, but the number of candidate genes is still low. In addition, a better understanding of basic principles of

plant-pathogen interaction is needed to guarantee broad spectrum and durable resistance. GM Fusarium resistant cultivars will be ready for adoption in 10 years, with an estimated probability of research success of 40%.

**Adoptable innovations:** High yielding and market-accepted genetically modified Fusarium resistant varieties

**Expected impact:**

- High yield despite Fusarium presence (avoided losses)
- Increase in seed costs
- Lower price (since new varieties don't meet consumer preferences)

**Target region/system:**

- Production area of 'Cavendish AAA' in countries where local markets for this cultivar are important. We assume that countries with export-oriented production patterns wouldn't adopt GM varieties due to political and consumer concerns in importing countries whereas countries with strong local markets for 'AAA Cavendish' would be more likely to adopt GMO varieties.
- Africa: Burundi, Congo, D.R., Kenya, Mozambique, Nigeria, Rwanda, Tanzania, Uganda; Asia/Pacific: China, India, Indonesia, Malaysia, Myanmar, Pakistan, Thailand, Vietnam; LAC: Brazil, Mexico, Peru

### 3. A QUANTIFIED APPROACH TO PROJECT LOSSES CAUSED BY FUSARIUM WILT TR4

Fundamental to the case for allocating more resources and to directing those resources to areas with the largest potential for returns is an understanding of how Fusarium will spread and the factors related to where and how fast. Cook, Taylor, Meldrum, & Drenth (2015) estimated the financial impact of TR4 in Australia using a partial equilibrium model relating price and quantity of banana. To estimate FW losses, they used coefficients and equations drawn from models of the spread of other invasive organisms. They note that little research exists to build a spread model for FW using organism-specific probabilities. Yet, to date no systematic assessment or approach to estimate the risk of introduction, the rate of internal spread and the estimated production losses by country has been done. Thus, given the time and resource constraints, we developed a “Foc Scale” which allows for a rapid estimation of expected production losses for all countries targeted by the four Fusarium research options. Furthermore, the intention was to base the “Foc Scale” on quantifiable parameters that can be presented to stakeholders for feedback and that allow for conducting a sensitivity analysis by adjusting them based on the feedback. In this section, our objective is to describe the method developed to project production losses caused by FW and present the results which indicate that within 25 years over 1,684,410 hectares could be affected. Since the “Foc Scale” is new and at this stage not well tested, we discuss further steps and areas for refinement of the approach.

#### 3.1 Foc Scale: Methodology

Using the general principles of disease epidemiology, we proposed to use indices which differentiate the likelihood and rate of disease spread into three factors: 1) the likelihood that TR4 would reach a country and establish, 2) factors which affect the within-country spread of the disease, and 3) the differential rate of spread for different cultivars, even though susceptibility characterization is still incomplete and subject to methods debates.

The dataset of production statistics compiled as input to the assessment of the other research options provided specific starting points. The countries with major banana production in Asia, Africa and Latin America and the Caribbean were identified, resulting in a list of 29 countries. All of these countries had been included in the assessment of one or more other research options and as a result, banana area and production were already available disaggregated by six key cultivar groups (Cavendish AAA; East African Highland AAA; other AAA, Gros Michel, AA; Plantain AAB; other AAB; cooking bananas ABB). These data were based on both FAOSTAT (yield per ha, total production in tons and total production area in hectares) for banana and plantain as well as Fruitrop data (total production) subdivided into four groups (Pemsl & Staver, 2014). Splitting into six groups reflecting different uses and disease susceptibility and estimating yields was done based on expert knowledge among banana scientists.

The factors included in the indices were identified from a growing number of documents addressing the threat to TR4 movement. The most thorough is the contingency plan developed by OIRSA (Dita, Echegoyen, & Perez-Vicente, 2013), the regional plant health agency covering Central America and the Caribbean. Draft documents from workshops organized by regional banana networks in East and Southern Africa (Barnesa) and Asia and the Pacific (Bapnet) were also screened to identify factors linked to the risk of initial introduction and the rate of internal spread. The purported factors in the

most recent spread of Foc TR4 throughout Asia, Africa and the Middle East were also taken into account, although documentation is incomplete. The scoring system from low to high for each factor was proposed with scoring carried out by the authors based on the information from the above sources and personal expert knowledge. Scores were summed across factors and categories were established for the aggregate scores under the assumption that over the next 20 years TR4 would move globally.

Finally, differential rates of spread were proposed for the internal spread index by cultivar group. Initial rates of spread were proposed for the first five years with an increase of 50% in the rate for each successive five-year block. In addition, a second scenario with a 25% increase was computed to determine sensitivity to the rate of spread. Countries already having FW at the beginning of the calculation were assumed to have 5 years of spread, since few countries have a published estimate of area affected. The area available for banana production was kept constant. No new “clean” lands were incorporated into banana production, although in practice, lands are lost to production due to infested soils and production is extended to clean lands. Linked spreadsheets were then used to calculate the percentage losses, hectares and production lost by country for each successive five-year period.

### 3.2 Foc Scale: Results

The proposed procedure for projecting losses provides a logical sequence to identify key variables in disease spread. Each of the three steps refers to a different set of information which could be addressed by drawing on relevant documentation and experience from a user’s perspective. The steps are described below before final projected losses are presented.

For the risk of a first Foc TR4 outbreak, six key factors were identified that ultimately determine how long it will take for Foc TR4 to reach the country (Table 1). The diffusion dimension across immediate borders and the jump function across non-contiguous countries and continents as proposed by Cook et al. (2015) are captured in the six proposed factors.

**Table 1: Key factors for risk of Foc arrival and respective coding**

Key factors	Area addressed <sup>1</sup>				Coding
	Cav	ho	jp	dif	
How important are Cavendish monocrops?	X				0 (not important), 0.5 (some importance), 1 (large sector for export / domestic market)
How strict is the plant health border control?		X	X	X	0 (strict), 0.5 (somewhat strict), 1 (poor control)
How strong is internal plant quarantine?		X	X	X	0 (strict), 0.5 (somewhat strict), 1 (poor)
How abundant are informal border crossings?				X	0 (low), 0.5 (somewhat), 1 (abundant)
Does global banana traffic move to and from the country?	X				0 (very little), 0.5 (some), 1 (much), 2 (very much)
Does the country have links with a country with TR4 – either a common border or other links (importance of fresh fruits/vegetable/ ornamentals trade and cultural affinities)?		X	X	X	0 (another continent from TR4 with weak links), 0.5 (another continent from TR4 with moderate links), 1 (several countries away on same continent and weak to moderate links/another continent with strong links), 1.5 (only one country buffer or several countries with moderate link), 2 (bordering country or several countries with strong links)

<sup>1</sup> Cav=importance of Cavendish; ho=importance of horticulture, jp=jump function, dif=diffusion function

**Source:** Results of the ‘Foc Scale’ as part of the Strategic Assessment of Banana Research Priorities

The six risk factors address the level of contact with the export banana industry, the importance of Cavendish and its high susceptibility to TR4 and the potential for the pathogen to move associated with soil as a contaminant on shipping containers, shoes, tools and nursery substrates and linked to other horticultural crops. Two factors, judged of greater importance by the authors, were scored from 0-2 (thus having greater weight), while the other factors were scored 0-1. The aggregate score for each country potentially ranging from 0-8 provided a quantified rating for the risk of Foc introduction and establishment in the country which could be linked to the length of time from the present until Foc TR4 reaches each country within the 25-year time horizon. The risk categories, their respective score range and length of time for Foc arrival are as follows:

- Risk category 1 (score of 0 to 2): Foc TR4 reaches the country in 20 years
- Risk category 2 (score of 2.5 to 3): Foc TR4 reaches the country in 15 years
- Risk category 3 (score of 3.5 to 4): Foc TR4 reaches the country in 10 years
- Risk category 4 (score of 4.5 to 8): Foc TR4 reaches the country in 5 years

Based on their scores, each country could be assigned to the respective risk categories (Table 2). As a result, one country falls under risk category 1 (Nicaragua), four countries under risk category 2 (Brazil, Guatemala, Mexico, Peru), nine countries under risk category 3 (Colombia, Congo, D.R., Costa Rica, Ecuador, Ghana, India, Nigeria, Rwanda, Uganda), and eight countries under risk category 4 (Burundi, Cameroon, Côte d'Ivoire, Kenya, Myanmar, Papua New Guinea, Tanzania, Thailand). In seven countries (China, Indonesia, Malaysia, Mozambique, Pakistan, Philippines, Vietnam) Foc TR4 is already present and thus they are not placed in any of these categories. In this scale we assume that all countries considered will be affected by latest twenty years from now, an important point for later stakeholder feedback.

**Table 2: 'Risk categories' of Fusarium wilt TR4 arrival and corresponding countries**

Foc present Country	Risk category 1 (20 years)		Risk category 2 (15 years)		Risk category 3 (10 years)		Risk category 4 (5 years)	
	Country	Score	Country	Score	Country	Score	Country	Score
China	Nicaragua	1.5	Guatemala	3	Congo, D.R.	4	Cameroon	5.5
Indonesia			Mexico	3	Ghana	4	Tanzania	5.5
Malaysia			Peru	3	Uganda	4	Myanmar	5.5
Mozambique			Brazil	2.5	India	4	Côte d'Ivoire	5
Pakistan					Costa Rica	4	Burundi	4.5
Philippines					Ecuador	4	Kenya	4.5
Vietnam					Nigeria	3.5	PNG	4.5
					Rwanda	3.5	Thailand	4.5
					Colombia	3.5		

*Source: Results of the 'Foc scale' as part of the Strategic Assessment of Banana Research Priorities*

In order to further fine-tune the first outbreak risk, we adjusted the scale after each five-year run for the factor ('Does the country have links with a country with TR4?') (Table 1). Clearly as Foc TR4 spreads across the globe, the distance of a country without FW to a country with FW will also change. Thus, after every five-year run, we recoded this closeness factor for every country. Although this resulted in a changed score for a few countries, this did not affect the risk category for any of the countries.

To estimate the rate of internal spread once TR4 has reached a country, the second aggregate score was based on three independent factors (Table 3): How strong is internal plant quarantine?, How important/dominant is Cavendish?; and How important are banana crops in the public investment policy? Factors capturing the patterns of banana distribution, the type of cropping systems and the proximity between large rivers and banana areas may have also been relevant, but information is not yet available across the 29 countries. The internal plant quarantine capacity appears in both scores, since it is linked to early detection included in the first score and here as an important element in the spread once established. The scoring for internal quarantine ranged from 0-2 in this case, while for the other two factors scoring was 0-1. The aggregate scores range from 0 to 4 and were divided into four rates of spread: “low” (score of 0 to 1.5), “moderate” (score of 2), “high” (score of 2.5), and “very high” (score of 3 to 4).

**Table 3: Key factors for the internal spread and respective coding**

Key factors	Coding
How strong is internal plant quarantine?	0 (strict), 0.5 (quite strict), 1 (average), 1.5 (weak), 2 (very weak)
How important/dominant is Cavendish?	0 (not important), 0.5 (somewhat important), 1 (very important)
How important are banana crops in the public investment policy?	0 (high importance), 0.5 (some importance), 1 (low importance)

*Source: Results of the ‘Foc Scale’ as part of the Strategic Assessment of Banana Research Priorities*

Based on each country’s score, they were assigned to a category (Table 4). Ten countries fall under the spread category “very high” (China, Congo, D.R., Ghana, Mozambique, Myanmar, Pakistan, Philippines, Tanzania, Thailand, Vietnam), five countries under spread category “high” (Burundi, Cameroon, Côte d'Ivoire, Indonesia, Papua New Guinea), five countries under the “moderate” (Guatemala, India, Kenya, Malaysia, Rwanda), and nine countries under the “low” (Brazil, Colombia, Costa Rica, Ecuador, Mexico, Nicaragua, Nigeria, Peru, Uganda).

**Table 4: Internal spread categories of Foc and corresponding countries**

Very high <sup>1</sup>		High <sup>2</sup>		Moderate <sup>3</sup>		Low <sup>4</sup>	
Country	Score	Country	Score	Country	Score	Country	Score
Pakistan	4	Burundi	2.5	Kenya	2	Nigeria	1.5
Ghana	3.5	Cameroon	2.5	Rwanda	2	Ecuador	1.5
Myanmar	3.5	Côte d'Ivoire	2.5	India	2	Mexico	1.5
Philippines	3.5	Indonesia	2.5	Malaysia	2	Nicaragua	1.5
Congo, D.R.	3	PNG	2.5	Guatemala	2	Peru	1.5
Mozambique	3					Uganda	1
Tanzania	3					Brazil	1
China	3					Colombia	1
Thailand	3					Costa Rica	1
Vietnam	3						

*Remarks:* <sup>1</sup>Score of 3 to 4; <sup>2</sup>Score of 2.5; <sup>3</sup>Score of 2; <sup>4</sup>Score of 0 to 1.5

*Source: Results of the ‘Foc Scale’ as part of the Strategic Assessment of Banana Research Priorities*

The final step in the calculation was to differentiate the rate of spread by cultivar group. To establish a first estimate of total losses, 8%, 4%, 2% and 1% of the Cavendish production area were assumed to be affected after the first five years of Foc arrival in countries differentiated by the country score for internal spread - “very high”, “high”, “moderate”, and “low” internal spread, respectively. Other AAA, ABB and other AAB were also projected to be affected at this same rate, since most of these cultivars show similar susceptibility to Cavendish, while both East African Highland AAA and AAB plantains feature a smaller affected area after the first five years of arrival in comparison to Cavendish - 3%, 2%, 1%, and 0.5% after the first five years of FW arrival by projected rate of internal spread. Thus, both the cultivar group and the spread category determine the initial area affected (= loss of production) after the first five years of Foc arrival. The rate of loss of production area is then assumed to increase by 50% every five years after the first round of losses until the time horizon of the economic analysis (25 years) is reached. This means that with each five-year period new losses accumulate. For example, as illustrated in Figure 1, during the first five years after Foc arrival, 8% of the Cavendish area of a country with a “very high” spread will be affected. During the second five years of Foc arrival, 12% of the remaining, non-affected production area will be affected. During the third five years, 18% of the remaining, non-affected area will be affected, et cetera. Apart from the increase of the rate of loss of production area by 50% every five years after the first round of losses, we established a second, more conservative spread scenario with an increase of 25% every five years. The respective results for the internal rate of spread are presented in the following Figure 2.

**Figure 1: Internal rate of spread of Foc TR4 by cultivar group (50% increase in affected area)**

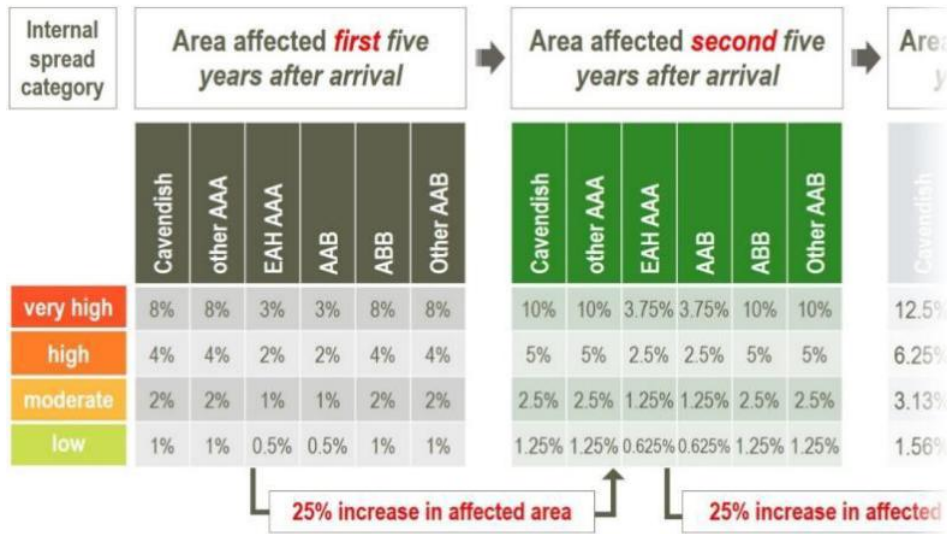
Internal spread category	Area affected <i>first five</i> years after arrival						Area affected <i>second five</i> years after arrival						Area affected <i>third five</i> years after arrival
	Cavendish	other AAA	EAH AAA	AAB	ABB	Other AAB	Cavendish	other AAA	EAH AAA	AAB	ABB	Other AAB	
very high	8%	8%	3%	3%	8%	8%	12%	12%	4.5%	4.5%	12%	12%	18%
high	4%	4%	2%	2%	4%	4%	6%	6%	3%	3%	6%	6%	9%
moderate	2%	2%	1%	1%	2%	2%	3%	3%	1.5%	1.5%	3%	3%	4.5%
low	1%	1%	0.5%	0.5%	1%	1%	1.5%	1.5%	0.75%	0.75%	1.5%	1.5%	2.25%

50% increase in affected area
50% increase in affected area

**Remarks:** Area affected = % of unaffected national banana production area that is affected by Foc TR4 in each five-year block

**Source:** Results of the ‘Foc Scale’ as part of the Strategic Assessment of Banana Research Priorities

**Figure 2: Internal rate of spread of Foc TR4 by cultivar group (25% increase in affected area)**



**Remarks:** Area affected = % of unaffected national banana production area that is affected by Foc TR4 in each five-year block  
**Source:** Results of the 'Foc Scale' as part of the Strategic Assessment of Banana Research Priorities

These numbers translate into a 6-71% loss of total banana production area 25 years after Foc TR4 arrival depending on the spread category and cultivar group, assuming an increase of the rate of loss of production area by 50% every five years after the first round of losses (Table 5). The estimated total loss of production area per cultivar group after Fusarium arrival decreases to 451% in the case of the 25% spread scenario.

**Table 5: Estimated total loss of production area per cultivar group after Fusarium arrival (50% spread scenario)**

Spread category	Cultivar group					
	Cavendish AAA	Other AAA	EAH AAA	AAB plantain	ABB	Other AAB
<i>Total area lost due to Fusarium 5 years after arrival (% of production area of each cultivar)</i>						
Very high	8	8	3	3	8	8
high	4	4	2	2	4	4
Moderate	2	2	1	1	2	2
Low	1	1	0.5	0.5	1	1
<i>Total area lost due to Fusarium 10 years after arrival (% of production area of each cultivar)</i>						
Very high	19	19	7	7	19	19
high	10	6	5	5	6	6
Moderate	5	5	2	2	5	5
Low	2	2	1	1	2	2
<i>Total area lost due to Fusarium 15 years after arrival (% of production area of each cultivar)</i>						
Very high	34	34	14	14	34	34
high	18	18	9	9	18	18
Moderate	9	9	5	5	9	9
Low	5	5	2	2	5	5
<i>Total area lost due to Fusarium 20 years after arrival (% of production area of each cultivar)</i>						
Very high	52	52	22	22	52	52
high	29	29	15	15	29	29
Moderate	15	15	8	8	15	15
Low	8	8	4	4	8	8
<i>Total area lost due to Fusarium 25 years after arrival (% of production area of each cultivar)</i>						
Very high	71	71	34	34	71	71
high	43	43	24	24	43	43
Moderate	24	24	13	13	24	24
Low	13	13	6	6	13	13

**Source:** Results of the 'Foc Scale' as part of the Strategic Assessment of Banana Research Priorities

Based on the proposed scoring and rates of spread for the 29 countries considered for this analysis, we can now calculate how much of the national banana production area of each cultivar would be lost after 25 years from now. The following Table 6, Table 7, and Table 8 illustrate the estimated national production losses in Africa, Asia/Pacific and Latin America & Caribbean, respectively, depending on the time when Foc TR4 arrives, the internal spread category, as well as cultivars grown in the country, disaggregated by cultivar groups. Thus, the tables show how each cultivar group in the countries considered is affected by Foc over the course of the 25 years assessment time horizon.

**Table 6: Estimated national production area lost due to Fusarium wilt TR4 in Africa, disaggregated by cultivar group**

Country	Production area ('000 ha)	Increase of loss rate: 50%					Increase of loss rate: 25%				
		Losses after ... years from now (% of production area)					Losses ... years from now (% of production area)				
		5	10	15	20	25	5	10	15	20	25
<b>Burundi</b>	<b>371.05</b>	<b>0.00</b>	<b>2.72</b>	<b>6.67</b>	<b>12.33</b>	<b>20.24</b>	<b>0.00</b>	<b>2.72</b>	<b>6.01</b>	<b>9.97</b>	<b>14.69</b>
<i>AAA Cavendish</i>	27.31		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<i>Other AAA</i>	46.00		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<i>EAH AAA</i>	203.74		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
<i>AAB Plantain</i>	34.00		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
<i>Other AAB</i>	20.00		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<i>ABB</i>	40.00		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<b>Cameroon</b>	<b>184.41</b>	<b>0.00</b>	<b>2.74</b>	<b>6.73</b>	<b>12.43</b>	<b>20.39</b>	<b>0.00</b>	<b>2.74</b>	<b>6.06</b>	<b>10.05</b>	<b>14.80</b>
<i>AAA Cavendish</i>	29.41		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<i>Other AAA</i>	24.44		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<i>EAH AAA</i>	7.78		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
<i>AAB Plantain</i>	108.33		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
<i>Other AAB</i>	0.00		NA	NA	NA	NA		NA	NA	NA	NA
<i>ABB</i>	14.44		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<b>Congo, D.R.</b>	<b>391.62</b>	<b>0.00</b>	<b>0.00</b>	<b>4.35</b>	<b>10.51</b>	<b>19.00</b>	<b>0.00</b>	<b>0.00</b>	<b>4.35</b>	<b>9.48</b>	<b>15.46</b>
<i>AAA Cavendish</i>	73.12			8.00	19.04	33.61			8.00	17.20	27.55
<i>Other AAA</i>	6.00			8.00	19.04	33.61			8.00	17.20	27.55
<i>EAH AAA</i>	25.00			3.00	7.37	13.62			3.00	6.64	11.01
<i>AAB Plantain</i>	261.25			3.00	7.37	13.62			3.00	6.64	11.01
<i>Other AAB</i>	0.00			NA	NA	NA			NA	NA	NA
<i>ABB</i>	26.25			8.00	19.04	33.61			8.00	17.20	27.55
<b>Côte d'Ivoire</b>	<b>411.19</b>	<b>0.00</b>	<b>2.18</b>	<b>5.36</b>	<b>9.98</b>	<b>16.54</b>	<b>0.00</b>	<b>2.18</b>	<b>4.83</b>	<b>8.06</b>	<b>11.94</b>
<i>AAA Cavendish</i>	9.76		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<i>Other AAA</i>	0.75		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<i>EAH AAA</i>	0.00		NA	NA	NA	NA		NA	NA	NA	NA
<i>AAB Plantain</i>	375.00		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
<i>Other AAB</i>			NA	NA	NA	NA		NA	NA	NA	NA
<i>ABB</i>	25.68		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<b>Ghana</b>	<b>191.75</b>	<b>0.00</b>	<b>0.00</b>	<b>3.54</b>	<b>8.62</b>	<b>15.77</b>	<b>0.00</b>	<b>0.00</b>	<b>3.54</b>	<b>7.77</b>	<b>12.79</b>
<i>AAA Cavendish</i>	16.25			8.00	19.04	33.61			8.00	17.20	27.55
<i>Other AAA</i>	1.25			8.00	19.04	33.61			8.00	17.20	27.55
<i>EAH AAA</i>	3.13			3.00	7.37	13.62			3.00	6.64	11.01
<i>AAB Plantain</i>	168.00			3.00	7.37	13.62			3.00	6.64	11.01
<i>Other AAB</i>	0.00			NA	NA	NA			NA	NA	NA
<i>ABB</i>	3.13			8.00	19.04	33.61			8.00	17.20	27.55
<b>Kenya</b>	<b>80.49</b>	<b>0.00</b>	<b>1.40</b>	<b>3.47</b>	<b>6.50</b>	<b>10.89</b>	<b>0.00</b>	<b>1.40</b>	<b>3.13</b>	<b>5.24</b>	<b>7.82</b>
<i>AAA Cavendish</i>	11.36		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
<i>Other AAA</i>	10.00		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
<i>EAH AAA</i>	10.00		1.00	2.49	4.68	7.90		1.00	2.24	3.77	5.64
<i>AAB Plantain</i>	38.13		1.00	2.49	4.68	7.90		1.00	2.24	3.77	5.64

Other AAB	1.00		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
ABB	10.00		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
<b>Mozambique</b>	<b>27.86</b>	<b>5.82</b>	<b>13.95</b>	<b>24.90</b>	<b>38.82</b>	<b>55.03</b>	<b>5.82</b>	<b>12.60</b>	<b>20.34</b>	<b>29.00</b>	<b>38.41</b>
AAA Cavendish	14.53	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
Other AAA	0.43	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
EAH AAA	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AAB Plantain	12.14	3.00	7.37	13.62	22.36	34.16	3.00	6.64	11.01	16.23	22.36
Other AAB	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ABB	0.76	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
<b>Nigeria</b>	<b>455.55</b>	<b>0.00</b>	<b>0.00</b>	<b>0.59</b>	<b>1.46</b>	<b>2.76</b>	<b>0.00</b>	<b>0.00</b>	<b>0.59</b>	<b>1.32</b>	<b>2.22</b>
AAA Cavendish	43.88			1.00	2.49	4.68		1.00	2.24	3.77	
Other AAA	14.17			1.00	2.49	4.68		1.00	2.24	3.77	
EAH AAA	0.00			NA	NA	NA		NA	NA	NA	
AAB Plantain	376.33			0.50	1.25	2.36		0.50	1.12	1.89	
Other AAB	0.00			NA	NA	NA		NA	NA	NA	
ABB	21.17			1.00	2.49	4.68		1.00	2.24	3.77	
<b>Rwanda</b>	<b>343.64</b>	<b>0.00</b>	<b>0.00</b>	<b>1.23</b>	<b>3.05</b>	<b>5.72</b>	<b>0.00</b>	<b>0.00</b>	<b>1.23</b>	<b>2.74</b>	<b>4.61</b>
AAA Cavendish	15.00			2.00	4.94	9.22		2.00	4.45	7.44	
Other AAA	12.50			2.00	4.94	9.22		2.00	4.45	7.44	
EAH AAA	231.25			1.00	2.49	4.68		1.00	2.24	3.77	
AAB Plantain	33.75			1.00	2.49	4.68		1.00	2.24	3.77	
Other AAB	18.75			2.00	4.94	9.22		2.00	4.45	7.44	
ABB	32.39			2.00	4.94	9.22		2.00	4.45	7.44	
<b>Tanzania</b>	<b>537.68</b>	<b>0.00</b>	<b>4.16</b>	<b>10.08</b>	<b>18.27</b>	<b>29.15</b>	<b>0.00</b>	<b>4.16</b>	<b>9.09</b>	<b>14.86</b>	<b>21.49</b>
AAA Cavendish	16.67		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
Other AAA	8.33		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
EAH AAA	337.33		3.00	7.37	13.62	22.36		3.00	6.64	11.01	16.23
AAB Plantain	75.35		3.00	7.37	13.62	22.36		3.00	6.64	11.01	16.23
Other AAB	50.00		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
ABB	50.00		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
<b>Uganda</b>	<b>1,866.25</b>	<b>0.00</b>	<b>0.00</b>	<b>0.63</b>	<b>1.56</b>	<b>2.95</b>	<b>0.00</b>	<b>0.00</b>	<b>0.63</b>	<b>1.41</b>	<b>2.37</b>
AAA Cavendish	60.25			1.00	2.49	4.68		1.00	2.24	3.77	
Other AAA	41.00			1.00	2.49	4.68		1.00	2.24	3.77	
EAH AAA	1,353.64			0.50	1.25	2.36		0.50	1.12	1.89	
AAB Plantain	36.36			0.50	1.25	2.36		0.50	1.12	1.89	
Other AAB	125.00			1.00	2.49	4.68		1.00	2.24	3.77	
ABB	250.00			1.00	2.49	4.68		1.00	2.24	3.77	

Source: Results of the 'Foc Scale' as part of the Strategic Assessment of Banana Research Priorities

**Table 7: Estimated national production area lost due to Fusarium wilt TR4 in Asia and Pacific, disaggregated by cultivar group**

Country	Production area ('000 ha)	Increase of loss rate: 50%					Increase of loss rate: 25%				
		Losses after ... years from now (% of production area)					Losses ... years from now (% of production area)				
		5	10	15	20	25	5	10	15	20	25
<b>China</b>	<b>398.19</b>	<b>8.00</b>	<b>19.04</b>	<b>33.61</b>	<b>51.54</b>	<b>71.16</b>	<b>8.00</b>	<b>17.20</b>	<b>27.55</b>	<b>38.87</b>	<b>50.81</b>
AAA Cavendish	347.79	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
Other AAA	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
EAH AAA	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AAB Plantain	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other AAB	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ABB	50.40	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
<b>India</b>	<b>1,858.28</b>	<b>0.00</b>	<b>0.00</b>	<b>1.91</b>	<b>4.71</b>	<b>8.79</b>	<b>0.00</b>	<b>0.00</b>	<b>1.91</b>	<b>4.24</b>	<b>7.09</b>
AAA Cavendish	191.61			2.00	4.94	9.22			2.00	4.45	7.44
Other AAA	714.67			2.00	4.94	9.22			2.00	4.45	7.44
EAH AAA	0.00			NA	NA	NA			NA	NA	NA
AAB Plantain	173.33			1.00	2.49	4.68			1.00	2.24	3.77

Other AAB	178.67			2.00	4.94	9.22			2.00	4.45	7.44
ABB	600.00			2.00	4.94	9.22			2.00	4.45	7.44
<b>Indonesia</b>	<b>320.03</b>	<b>3.96</b>	<b>9.67</b>	<b>17.72</b>	<b>28.72</b>	<b>43.00</b>	<b>3.96</b>	<b>8.72</b>	<b>14.37</b>	<b>21.00</b>	<b>28.63</b>
AAA Cavendish	40.42	4.00	9.76	17.88	28.97	43.35	4.00	8.80	14.50	21.18	28.88
Other AAA	78.67	4.00	9.76	17.88	28.97	43.35	4.00	8.80	14.50	21.18	28.88
EAH AAA	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AAB Plantain	5.83	2.00	4.94	9.22	15.35	23.92	2.00	4.45	7.44	11.05	15.39
Other AAB	3.45	4.00	9.76	17.88	28.97	43.35	4.00	8.80	14.50	21.18	28.88
ABB	191.67	4.00	9.76	17.88	28.97	43.35	4.00	8.80	14.50	21.18	28.88
<b>Malaysia</b>	<b>56.82</b>	<b>1.94</b>	<b>4.78</b>	<b>8.93</b>	<b>14.87</b>	<b>23.19</b>	<b>1.94</b>	<b>4.31</b>	<b>7.20</b>	<b>10.71</b>	<b>14.92</b>
AAA Cavendish	23.18	2.00	4.94	9.22	15.35	23.92	2.00	4.45	7.44	11.05	15.39
Other AAA	10.91	2.00	4.94	9.22	15.35	23.92	2.00	4.45	7.44	11.05	15.39
EAH AAA	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AAB Plantain	3.64	1.00	2.49	4.68	7.90	12.56	1.00	2.24	3.77	5.64	7.95
Other AAB	10.91	2.00	4.94	9.22	15.35	23.92	2.00	4.45	7.44	11.05	15.39
ABB	8.18	2.00	4.94	9.22	15.35	23.92	2.00	4.45	7.44	11.05	15.39
<b>Myanmar</b>	<b>65.43</b>	<b>0.00</b>	<b>7.75</b>	<b>18.45</b>	<b>32.59</b>	<b>50.05</b>	<b>0.00</b>	<b>7.75</b>	<b>16.66</b>	<b>26.71</b>	<b>37.72</b>
AAA Cavendish	10.83		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
Other AAA	5.00		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
EAH AAA	0.00		NA	NA	NA	NA		NA	NA	NA	NA
AAB Plantain	3.33		3.00	7.37	13.62	22.36		3.00	6.64	11.01	16.23
Other AAB	20.83		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
ABB	25.43		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
<b>Pakistan</b>	<b>31.98</b>	<b>7.94</b>	<b>18.89</b>	<b>33.36</b>	<b>51.17</b>	<b>70.70</b>	<b>7.94</b>	<b>17.07</b>	<b>27.34</b>	<b>38.59</b>	<b>50.45</b>
AAA Cavendish	22.78	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
Other AAA	3.00	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
EAH AAA	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AAB Plantain	0.40	3.00	7.37	13.62	22.36	34.16	3.00	6.64	11.01	16.23	22.36
Other AAB	3.00	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
ABB	2.80	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
<b>Papua New Guinea</b>	<b>45.18</b>	<b>0.00</b>	<b>4.00</b>	<b>9.76</b>	<b>17.87</b>	<b>28.96</b>	<b>0.00</b>	<b>4.00</b>	<b>8.80</b>	<b>14.49</b>	<b>21.17</b>
AAA Cavendish	6.43		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
Other AAA	3.00		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
EAH AAA	0.00		NA	NA	NA	NA		NA	NA	NA	NA
AAB Plantain	0.04		2.00	4.94	9.22	15.35		2.00	4.45	7.44	11.05
Other AAB	0.00		NA	NA	NA	NA		NA	NA	NA	NA
ABB	35.71		4.00	9.76	17.88	28.97		4.00	8.80	14.50	21.18
<b>Philippines</b>	<b>391.88</b>	<b>8.00</b>	<b>19.04</b>	<b>33.61</b>	<b>51.53</b>	<b>71.16</b>	<b>8.00</b>	<b>17.20</b>	<b>27.55</b>	<b>38.87</b>	<b>50.80</b>
AAA Cavendish	96.15	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
Other AAA	81.27	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
EAH AAA	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AAB Plantain	0.08	3.00	7.37	13.62	22.36	34.16	3.00	6.64	11.01	16.23	22.36
Other AAB	4.38	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
ABB	210.00	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
<b>Thailand</b>	<b>132.08</b>	<b>0.00</b>	<b>7.81</b>	<b>18.60</b>	<b>32.86</b>	<b>50.43</b>	<b>0.00</b>	<b>7.81</b>	<b>16.80</b>	<b>26.92</b>	<b>38.01</b>
AAA Cavendish	54.24		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
Other AAA	18.67		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
EAH AAA	0.00		NA	NA	NA	NA		NA	NA	NA	NA
AAB Plantain	5.00		3.00	7.37	13.62	22.36		3.00	6.64	11.01	16.23
Other AAB	16.67		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
ABB	37.50		8.00	19.04	33.61	51.54		8.00	17.20	27.55	38.87
<b>Vietnam</b>	<b>102.17</b>	<b>7.99</b>	<b>19.02</b>	<b>33.59</b>	<b>51.50</b>	<b>71.11</b>	<b>7.99</b>	<b>17.19</b>	<b>27.53</b>	<b>38.84</b>	<b>50.77</b>
AAA Cavendish	46.99	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
Other AAA	13.96	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81
EAH AAA	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AAB Plantain	0.14	3.00	7.37	13.62	22.36	34.16	3.00	6.64	11.01	16.23	22.36
Other AAB	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ABB	41.08	8.00	19.04	33.61	51.54	71.16	8.00	17.20	27.55	38.87	50.81

Source: Results of the 'Foc Scale' as part of the Strategic Assessment of Banana Research Priorities

**Table 8: Estimated national production area lost due to Fusarium wilt TR4 in Latin America & Caribbean, disaggregated by cultivar group**

Country	Production area ('000 ha)	Increase of loss rate: 50%					Increase of loss rate: 25%				
		Losses after ... years from now (% of production area)					Losses ... years from now (% of production area)				
		5	10	15	20	25	5	10	15	20	25
<b>Brazil</b>	<b>498.45</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.97</b>	<b>2.40</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.97</b>	<b>2.17</b>
AAA Cavendish	256.78				1.00	2.49				1.00	2.24
Other AAA	14.29				1.00	2.49				1.00	2.24
EAH AAA	0.00				NA	NA				NA	NA
AAB Plantain	32.38				0.50	1.25				0.50	1.12
Other AAB	192.86				1.00	2.49				1.00	2.24
ABB	2.14				1.00	2.49				1.00	2.24
<b>Colombia</b>	<b>461.43</b>	<b>0.00</b>	<b>0.00</b>	<b>0.64</b>	<b>1.58</b>	<b>2.99</b>	<b>0.00</b>	<b>0.00</b>	<b>0.64</b>	<b>1.42</b>	<b>2.40</b>
AAA Cavendish	75.35			1.00	2.49	4.68			1.00	2.24	3.77
Other AAA	39.08			1.00	2.49	4.68			1.00	2.24	3.77
EAH AAA	5.00			0.50	1.25	2.36			0.50	1.12	1.89
AAB Plantain	331.25			0.50	1.25	2.36			0.50	1.12	1.89
Other AAB	2.00			1.00	2.49	4.68			1.00	2.24	3.77
ABB	8.75			1.00	2.49	4.68			1.00	2.24	3.77
<b>Costa Rica</b>	<b>61.22</b>	<b>0.00</b>	<b>0.00</b>	<b>0.93</b>	<b>2.30</b>	<b>4.34</b>	<b>0.00</b>	<b>0.00</b>	<b>0.93</b>	<b>2.07</b>	<b>3.49</b>
AAA Cavendish	51.22			1.00	2.49	4.68			1.00	2.24	3.77
Other AAA	0.83			1.00	2.49	4.68			1.00	2.24	3.77
EAH AAA	0.00			NA	NA	NA			NA	NA	NA
AAB Plantain	9.00			0.50	1.25	2.36			0.50	1.12	1.89
Other AAB	0.00			NA	NA	NA			NA	NA	NA
ABB	0.17			1.00	2.49	4.68			1.00	2.24	3.77
<b>Ecuador</b>	<b>266.88</b>	<b>0.00</b>	<b>0.00</b>	<b>0.81</b>	<b>2.02</b>	<b>3.81</b>	<b>0.00</b>	<b>0.00</b>	<b>0.81</b>	<b>1.82</b>	<b>3.06</b>
AAA Cavendish	152.94			1.00	2.49	4.68			1.00	2.24	3.77
Other AAA	10.00			1.00	2.49	4.68			1.00	2.24	3.77
EAH AAA	0.00			NA	NA	NA			NA	NA	NA
AAB Plantain	100.00			0.50	1.25	2.36			0.50	1.12	1.89
Other AAB	0.00			NA	NA	NA			NA	NA	NA
ABB	3.94			1.00	2.49	4.68			1.00	2.24	3.77
<b>Guatemala</b>	<b>50.55</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>1.76</b>	<b>8.15</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>1.76</b>	<b>3.93</b>
AAA Cavendish	35.71				2.00	9.22				2.00	4.45
Other AAA	0.83				2.00	9.22				2.00	4.45
EAH AAA	0.00				NA	NA				NA	NA
AAB Plantain	11.92				1.00	4.68				1.00	2.24
Other AAB	0.00				NA	NA				NA	NA
ABB	2.08				2.00	9.22				2.00	4.45
<b>Mexico</b>	<b>86.31</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.90</b>	<b>2.26</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.90</b>	<b>2.02</b>
AAA Cavendish	66.73				1.00	2.49				1.00	2.24
Other AAA	2.50				1.00	2.49				1.00	2.24
EAH AAA	0.00				NA	NA				NA	NA
AAB Plantain	16.00				0.50	1.25				0.50	1.12
Other AAB	0.25				1.00	2.49				1.00	2.24
ABB	0.83				1.00	2.49				1.00	2.24
<b>Nicaragua</b>	<b>14.46</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.70</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.70</b>
AAA Cavendish	1.52					1.00					1.00
Other AAA	0.63					1.00					1.00
EAH AAA	0.00					NA					NA
AAB Plantain	8.57					0.50					0.50
Other AAB	0.00					NA					NA
ABB	3.75					1.00					1.00
<b>Peru</b>	<b>120.83</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.69</b>	<b>1.72</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.69</b>	<b>2.07</b>
AAA Cavendish	22.50				1.00	2.49				1.00	2.24

<i>Other AAA</i>	10.00		1.00	2.49		1.00	2.24
<i>EAH AAA</i>	0.00		NA	NA		NA	NA
<i>AAB Plantain</i>	75.00		0.50	1.25		0.50	1.12
<i>Other AAB</i>	13.33		1.00	2.49		1.00	2.24
<i>ABB</i>	0.00		NA	NA		NA	NA

*Source: Results of the 'Foc Scale' as part of the Strategic Assessment of Banana Research Priorities*

For instance, Ghana scored 4 points on the 'Foc Scale' with respect to the arrival time of Foc, translating into an arrival time of 10 years from now. Furthermore, the internal spread rate of Foc TR4 once it reaches the country was categorized as "very high" based on a score of 3.5. Applying the 'Foc Scale' as illustrated in Table X, Ghana would lose 33.61% of its Cavendish production area and 13.62% of its AAB plantain production area after 25 years. The total loss of production area summed across all cultivar would amount to 15.77% of the national banana production area (see Table 6).

Colombia falls into the same scale segment as Ghana with respect to the Foc arrival time: Foc TR4 is estimated to arrive after 10 years from now, based on a score of 3.5. Yet, the internal spread rate of Foc TR4 once it reaches the country was categorized as "low" based on a score of 1 in comparison to the "very high" spread rate category calculated for Ghana. Thus, Colombia would lose only 2.99% of its national banana production area after 25 years from now (see Table 8) due to Foc TR4 since all cultivar groups experience a very slow infection with Foc TR4.

Assuming an increase of the rate of loss of production area by 50% every five years after the first round of losses, the loss of national banana production area summed across losses for each cultivar group ranges from 0.7% in the case of Nicaragua, where Foc TR4 would arrive only in twenty years, internal inspection stations can be mobilized and plantains are an important component of total banana production to 71.2% in the case of China, where TR4 is already present, internal quarantine procedures are limited and only cultivar groups with high spread rates are grown (see Table 7). In the case of the more conservative spread scenario with an increase of 25% every five years, China would show a loss of 50.8% of current national production area (see last column of Table 7).

Adding up the numbers of the 29 countries that were considered for the assessment of the Fusarium research options, the production area lost globally converts to 1,684,410 hectares at the 50% increasing spread rate, representing 17.1% of current land in banana production. Under the 25% scenario, the area affected drops to 1,242,430 hectares, 12.6% of total area (Table 9 and Figure 3).

**Table 9: Estimated total banana production area lost globally due to Foc TR4**

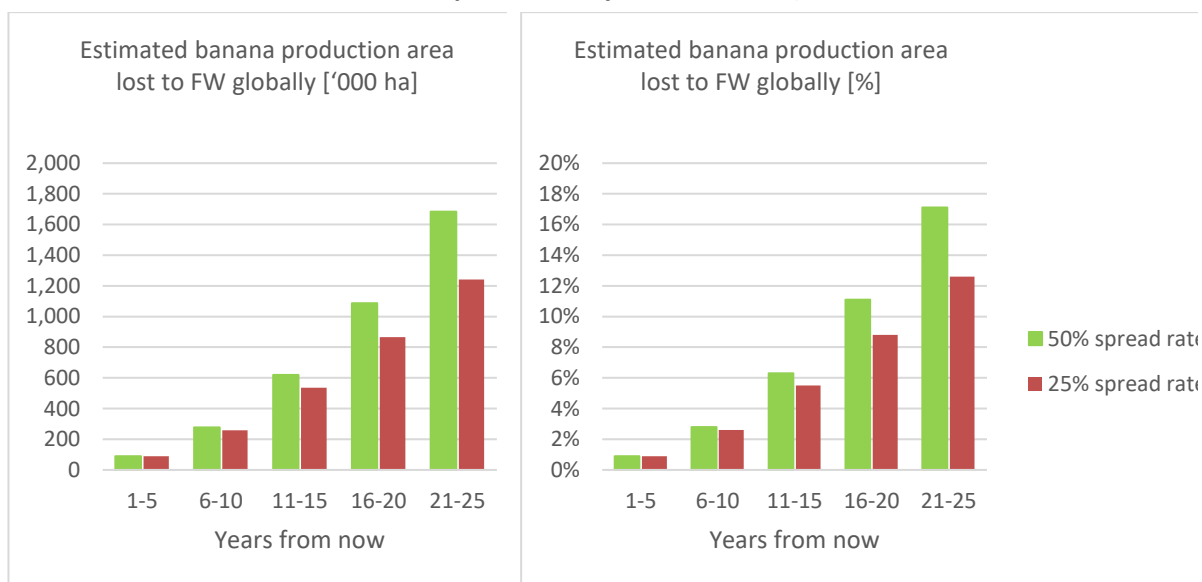
**(‘000 ha and % of total production area)**

Spread scenario	Global losses (years from now)									
	1-5 years		6-10 years		11-15 years		16-20 years		21-25 years	
	‘000 ha	%	‘000 ha	%	‘000 ha	%	‘000 ha	%	‘000 ha	%
<b>50% spread rate</b>	89	0.9	278	2.8	620	6.3	1,086	11.1	1,684	17.1
<b>25% spread rate</b>	89	0.9	258	2.6	536	5.5	865	8.8	1,242	12.6

*Remarks: Results represent estimations for 29 countries*

*Source: Results of the ‘Foc Scale’ as part of the Strategic Assessment of Banana Research Priorities*

**Figure 3: Estimated total production area lost due to Foc, all countries (in hectares and % of total production, years from now)**



*Remarks: Results represent estimations for 29 countries*

*Source: Results of Strategic Assessment of Banana Research Priorities*

As stated previously, the ‘Foc Scale’ serves as a basis to calculate the benefits of the four Fusarium research options of the priority assessment exercise. After having given insights into the methodology and the results of the ‘Foc Scale’, we can now continue to illustrate the parameter estimates and assumptions of the research options and then go on to present the results of the ex-ante assessment.

## 4. PARAMETER ESTIMATES AND ASSUMPTIONS OF FUSARIUM RESEARCH OPTIONS

This section presents the parameter estimates and assumptions made for each one of the four Fusarium research options considered (based on expert estimates and the 'Foc Scale'), namely (1) Improved quarantine and surveillance measures to avoid spread of Fusarium TR4, (2) Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4, (3) Development of Fusarium resistant banana cultivars, and (4) Development of GMO Fusarium resistant banana cultivars.

### 4.1 Fusarium research option (A): Improved quarantine and surveillance measures to avoid spread of Fusarium TR4

Twenty-nine countries from Asia/Pacific, Africa and Latin America and the Caribbean where Fusarium is either already present or will very likely spread in the near future have been considered for the ex-ante impact assessment. For the assessment of this research option, all six cultivar groups were considered threatened/susceptible and research would target 100 % of the area of all six cultivar groups. Although Fusarium TR4 is already present in some countries, we assume that the production area currently affected is zero percent in all countries since there are no reliable figures about the actual spread. Three different quarantine and surveillance scenarios were developed in order to account for uncertainty and different levels of effectiveness of the quarantine and surveillance measures. The likely future spread of Fusarium TR4 without intervention was estimated separately for each cultivar group and country based on the 'Foc Scale' previously mentioned. We thereby chose the 25% spread rate of the 'Foc Scale' (increase of 25% in the initial rate of spread for each successive five year block) to represent the counterfactual "without intervention" situation. The 'Foc Scale' was then adjusted for each quarantine and surveillance measure scenario to comply with the respective assumptions, for example, an earlier or later arrival of Foc TR4. The difference between the affected area without intervention and the affected area with quarantine and surveillance measures ultimately represents the area where losses could be avoided. Hence benefits of this research option occur as losses avoided - i.e. increases in yield (100%) - through a delayed Fusarium arrival and/or slower internal spread and thus smaller affected area.

**Scenario 1** assumes that the arrival time of Foc TR4 doubles in countries where Foc TR4 is estimated to arrive not earlier than year 10 of the assessment period. This is because experts estimated that the first year of adoption of the technology by farmers would be year 8 of the assessment period. Thus, in countries where Foc TR4 is estimated to arrive in year 1 or year 5 of the assessment period, the quarantine and surveillance measures would not be in place yet that would permit to protect banana production and thus double arrival time. Furthermore, in Scenario 1, the increase of loss rate is reduced by 50% once Foc TR4 reaches the country as compared to a scenario without intervention (hence the increase in the initial rate of loss for each successive five year block is 12.5%).

**Scenario 2** is somewhat more conservative and expects the arrival time of Foc TR4 to be as in Scenario 1 minus 5 years. The increase of loss rate in scenario 2 is reduced by 50% once Foc TR4 reaches the country (hence, the increase in the initial rate of loss for each successive five year block is 12.5%) as compared to a scenario without intervention.

**Scenario 3** assumes the arrival time of Foc TR4 to be as in Scenario 1 minus 5 years and suggests a reduction in increase of loss rate by 25% once the fungus reaches the country (hence, the increase in the initial rate of loss for each successive five-year block is 18.75%) as compared to a scenario without intervention

Given the 5-year block nature of the 'Foc Scale', there were two points to consider: First, the reduced rate of loss is only applied from year 10 onwards since we assume that the first year of adoption of the technology by farmers is year 8 of the assessment period. Second, losses avoided occur stepwise in our model and not exponential due to these 5-year blocks. For instance, if the losses avoided were estimated to be 0%, 0%, 0.33%, 1.07%, and 2.30% of the total national banana production area after 5, 10, 15, 20, and 25 years, respectively (as it is the case for Burundi under scenario 1), we applied them as follows in the model: 0% from year 5 to year 9, 0% from year 10 to year 14, 0.33% from year 15 to year 19, 1.07% from year 20 to year 24, and 2.30% in year 25. Year 1 to year 4 in this model are always assumed to comprise avoided losses of 0%. The assumptions made for both points are rather of conservative nature which means that the avoided losses under quarantine and surveillance measures would most likely be underestimated instead of overestimated.

Using the 'Foc Scale' to run the three scenarios developed yields the losses avoided in year 25 of the assessment period (Table 10).

With quarantine and surveillance research, the loss of total national production area including all six cultivar groups due to Fusarium in year 25 of the assessment period ranges from 0% (e.g., Brazil that wouldn't be reached by Fusarium within the 25-year time horizon of the priority assessment) to 44.95% (e.g. China; Fusarium is already present and spreading, though with a lower spread rate compared to a situation without research, and only cultivar groups with high spread rates are grown in the country). The 29 countries that were considered for the assessment of this Fusarium research option would jointly lose 839,480 ha (Scenario 1), 999,810 ha (Scenario 2) or 1,062,380 ha (Scenario 3) of production area until the end of the assessment period, representing 8.54%, 10.17% and 10.81% of their total banana and plantain production area, respectively. The losses avoided through investments in quarantine and surveillance measures (difference between with and without investment) range between 0.70% and 13.29% (Scenario 1), 0.70% and 10.91% (Scenario 2), and 0.70 and 10.78% (Scenario 3) of the total national banana production area. Avoided losses among all 29 countries considered ultimately amount to 4.11% (Scenario 1), 2.47% (Scenario 2) and 1.83% (Scenario 3) of the total banana production area.

The new technology package when adopted is assumed to have no effect on postharvest losses however it is assumed to lead to an increase in production costs of 1%. In comparison to the other research options assessed, we did not only consider dissemination costs of \$50/ha (on time payment for all new hectares under technology adoption in each 5 year block), but also the costs of establishing as well as maintaining the quarantine system. The costs of establishing quarantine system reflect the initial capacity strengthening efforts and are estimated to be a one-time payment of \$50/ha in year 5 for countries with high importance to banana and in year 10 for countries with low importance to banana. The costs of maintaining the quarantine and surveillance system are \$5/ha/year prior to Foc arrival, and \$10/ha/year after Foc arrival.

**Table 10: Loss of total national banana production area (in %) with and without intervention and subsequent losses avoided in year 25 of the assessment period**

Country	Production area [%] affected without intervention (Scenario 1)	Scenario 1		Production area [%] affected without intervention (Scenario 2 & 3)	Scenario 2		Scenario 3	
		Production area [%] affected with intervention	Avoided losses*		Production area [%] affected with intervention	Avoided losses*	Production area [%] affected with intervention	Avoided losses*
Brazil	2.17	0.00	2.17	2.17	0.00	2.217	0.00	2.17
Burundi	14.69	12.39	2.30	20.24	17.53	2.71	18.84	1.40
Cameroon	14.80	12.48	2.32	20.39	17.66	2.73	18.98	1.41
China	50.81	44.95	5.86	50.81	44.95	5.86	47.82	2.99
Colombia	2.40	0.32	2.08	2.40	1.06	2.71	1.09	2.67
Congo, D.R.	15.46	2.17	13.29	15.46	4.55	10.91	4.68	10.78
Costa Rica	3.49	0.46	3.03	3.49	0.98	2.51	1.01	2.48
Côte d'Ivoire	11.94	10.05	1.89	16.58	14.32	2.26	15.41	1.17
Ecuador	3.06	0.41	2.66	3.06	0.86	2.20	0.89	2.18
Ghana	12.79	1.77	11.02	12.79	3.72	9.08	3.83	8.97
Guatemala	3.93	0.00	3.93	3.93	0.00	3.93	0.00	3.93
India	7.09	0.95	6.14	7.09	2.02	5.08	2.07	5.02
Indonesia	28.63	24.90	3.73	28.63	24.90	3.73	26.71	1.92
Kenya	7.82	6.56	1.26	10.94	9.42	1.52	10.15	0.79
Malaysia	14.92	12.86	2.05	14.92	12.86	2.05	13.86	1.06
Mexico	2.02	0.00	2.02	2.02	0.00	2.02	0.00	2.02
Mozambique	38.41	33.80	4.61	38.41	33.80	4.61	36.05	2.36
Myanmar	37.72	32.33	5.39	49.36	43.65	5.71	46.44	2.92
Nicaragua	0.70	0.00	0.70	0.70	0.00	0.70	0.00	0.70
Nigeria	2.22	0.29	1.93	2.22	0.62	1.60	0.64	1.58
Pakistan	50.45	44.63	5.82	50.45	44.63	5.82	47.48	2.97
PNG	21.17	17.91	3.26	28.87	25.11	3.76	26.93	1.94
Peru	1.55	0.00	1.55	1.55	0.00	1.55	0.00	1.55
Philippines	50.80	44.95	5.85	50.80	44.95	5.85	47.81	2.99
Rwanda	4.61	0.61	3.99	4.61	1.30	3.30	1.34	3.27
Tanzania	21.49	18.25	3.24	28.98	25.32	3.66	27.09	1.88
Thailand	38.01	32.58	5.43	49.73	43.99	5.75	46.80	2.94
Uganda	2.37	0.31	3.27	2.37	0.67	1.71	0.69	1.69
Vietnam	50.77	44.92	5.85	50.77	44.92	5.85	47.78	2.99

Remarks: \*% of production area

Source: Results of Strategic Assessment of Banana Research Priorities

Given that quarantine and surveillance measures are executed at the national level, we assumed that all farmers “adopt” or benefit from the technology once the country implements the quarantine scheme. This translates into an adoption ceiling of 100% of the (future) area affected by Fusarium across all countries. Thus, adoption ceilings were calculated to be 1-50.81% of the total national production area which translates into adoption ceilings of 1-71% of total national production area. Uncertainties about the uptake of the technology on a national level are represented by the probability of success (likelihood that the technology will actually be up-taken and available in the country) of 80% among all countries. The probability that the planned research outputs will be achieved is also estimated to be 80% and the technology will be available after 5 years of research. Technology release (number of years from last year of research to year of first adoption) will start after 3 years in all included countries. The time from first adoption until the estimated adoption ceiling will be reached is 10 years for all countries.

The total R&D costs of this research option are estimated to be \$16,238,000 and are roughly evenly spread over the 5-year research period. Staff comprises 4 global team leaders (plant pathologist, social scientist, GIS specialist, molecular scientist; all senior scientists) and one regional team each in Asia, Latin America, and Africa. In Asia, China was chosen as a study site since Fusarium is spreading towards South-East Asia. In Latin America and the Caribbean, Brazil and its regional plant health organization (OIRSA) would be the base for a national research team. Brazil has good research capacities especially in the fields of breeding and tissue culture. Furthermore, Brazil features strong ties and a lot of movement with Mozambique, a country where Fusarium TR4 is already present. In Africa, Tanzania was chosen to be the study place to run the program. Even though we choose three countries where research is carried out, cultivars existent in all countries included in the analysis are considered in the research. All national research teams consist of 3 NARS scientists, 4 research assistants, 4 PhD students and 6 Master students. Additional costs include field work/greenhouse (cultivar testing, eradication, etc.), laboratory, equipment (such as cars, PCR machines, etc.), workshops, travels (\$25,000 per person per year for global team leaders, \$4,000 per person per year for regional staff), others and institute support. In the assessment the R&D costs are matched 1:1 with additional country-level costs as per the general assumptions made for the priority assessment exercise.

Table 11 provides a brief summary of the parameter estimates and assumptions regarding Fusarium Research Option A:

**Table 11: Summary of parameter estimates and assumptions regarding Fusarium Research Option A**

<b>(6a) Fusarium Research Option A: Improved quarantine and surveillance measures to avoid spread of Fusarium TR4</b>	
Countries	<b>29</b> (11 African countries, 10 Asian countries, 8 LAC countries) where Fusarium is either already present or will very likely spread in the near future if no major intervention occurs.
Cultivar groups considered	<b>6</b> <b>AAA Cavendish, other AAA, EAH AAA, AAB Plantain, other AAB, and ABB</b> in all African, Asian and LAC countries included
Current and likely future spread	Although Fusarium TR4 is already present in some countries, we assume that the production area currently affected is zero percent in all countries since there are no reliable figures about the actual spread. The estimation of the likely future spread of the disease was made <b>separately for each cultivar group and country</b> by applying a 'Foc Scale' that we developed. We assumed that 100% of the banana production area in the included countries is susceptible to Foc.
Benefits: - Increase in yield - Reduction in postharvest losses	<b>100%</b> (Yield loss avoided through containment and reduced spread) <b>No effect</b>
Production and other costs	<b>Production costs: Increase of 1%</b> <b>Costs of establishing quarantine system: \$50/ha</b> in year 5 for countries with high importance to banana and in year 10 for countries with low importance to banana <b>Costs of maintaining quarantine system: \$5/ha/year</b> prior to Foc arrival, <b>\$10/ha/year</b> after Foc arrival
Adoption ceiling	Given that quarantine and surveillance measures are executed at the national level, we assumed that all farmers "adopt" or benefit from the technology once the country implements the quarantine scheme. This translates into an adoption ceiling of <b>100% of the (future) area affected by Fusarium</b> across all countries. This translates into <b>1-51% of the total national production area</b> .
Research period	<b>5 years</b>
Technology release	The technology will be available in <b>8 years</b> in all included countries (5 years of research and 3 more years until technology is released to farmers)
Time from first adoption until estimated adoption ceiling will be reached	<b>10 years</b>
Probability of success (up-take of technology)	<b>80%</b>
R&D costs	<b>\$16.24 million</b>
Additional country-level costs	<b>\$16.24 million</b> (matched 1:1 with R&D costs)
Resource persons	Charles Staver, Miguel Dita, Luis Perez Vicente

*Source: Results of the Strategic Assessment of Banana Research Priorities based on expert estimates*

### 4.3 Fusarium research option (B): Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4

Twenty countries from Africa, Asia/Pacific, and from LAC where Fusarium is either already present or will very likely spread in the near future have been considered for the ex-ante impact assessment of the integrated management research option. For the assessment of this research option, all six cultivar groups were considered threatened/susceptible to TR4 whereas only 'other AAA' and 'other AAB'

were considered threatened/susceptible to Race 1. We do not consider Race 2 in the assessment of this research option since it is not very likely that the research output would be used for planting ABB. The reason therefore is that ABB is a cultivar susceptible to Race 2 which has not been intensified almost anywhere it has been grown. In the case of integrated management of TR4, the target domain comprises the production area of all cultivar groups in LAC and Asia whereas in Africa only the 'AAA Cavendish' production areas in Cameroon, Ghana and Ivory Coast are targeted. With respect to integrated management of Race 1, only 'other AAA' and 'other AAB' in Asia and LAC are assumed to be targeted. Although Fusarium TR4 and Race 1 are already present in some countries, we assume that the production area currently affected is zero percent in all countries since there are no reliable figures about the actual spread. The likely future spread of Fusarium TR4 and Race 1 were estimated separately for each cultivar group and country based on the 'Foc Scale' previously mentioned. The likely spread of Fusarium TR4 and Race 1 in 25 years without research investment ranges from 1% to 51% of the entire national production area, respectively.

In the assessment, benefits of adopting the integrated management technology occur as losses avoided, i.e. increases in yield (80%). The new technology when adopted is assumed to have no effect on postharvest losses but results in a 20% increase in production costs. The adoption ceiling is assumed to vary as follows: in each country of Asia and LAC, the adoption ceiling will be 50% of the 'AAA Cavendish' area and 30% of all other cultivar group production areas affected with Fusarium TR4 in 25 years. Yet, Brazil represents a special case where the adoption ceiling with respect to 'other AAB' will be higher (50%) due to the importance of Prata. In Africa (only considering Cameroon, Ghana and Ivory Coast) the adoption ceiling is assumed to be 50% of 'AAA Cavendish' production area affected with Fusarium in 25 years. These figures translate into adoption ceilings of 0.2-24.6% of the total national production area. In the case of Fusarium Race 1, the adoption ceiling will be 30% of future Fusarium race 1 affected 'other AAA' and 'other AAB' area in all LAC and Asian countries. Again, Brazil represents a special case where the adoption ceiling with respect to Prata ('other AAB') will be higher (50%). It is estimated that it will take 10 years of research to develop a successful output. The technology will then immediately be adopted by farmers.

In theory we assumed that farmers in those countries where TR4 is already present would use the technology already in 5 years from now with partial results from the ongoing research. In all other target countries, farmers would start using the partial results and preliminary research output whenever Fusarium TR4 reaches the country. In practice, however, due to the characteristics of our model and for simplicity, we assumed that in all countries, technology adoption starts in year 10 of the assessment period, right when the technology is released. In this case it could happen that the adoption area might be slightly bigger than the estimated affected area in some years which is practically impossible. We then down-adjusted the adoption area to the size of the affected area to avoid overestimation.

The time from first adoption until the estimated adoption ceiling will be reached was set at 15 years for all countries. The probability of research success is 90% whereas the likelihood that the technology will actually be up-taken and available in the country was set at 25%, 50% or 75% according to the importance of banana in national public policy and research investment ('Foc Scale' code 1, 0.5, and 0, respectively, of variable "Importance of banana in national public policy and research investment"). The more a country prioritizes banana and invests in research, the higher the likelihood that the technology will be up-taken by the country.

The total costs of this research option are estimated to be \$30.475.750 and are roughly evenly spread over the 10-year research period. Staff comprises 4 global team leaders (plant pathologist, soil ecologist, cropping system agronomist, molecular microbiologist; all senior scientists) and one regional team each in Asia, Latin America, and Africa. In Asia, China or the Philippines would serve as a study site. This is because the chances of research success are higher in these countries than in others as there are already some initiatives in place that are related to the research component. In Latin America and the Caribbean, Brazil would be the base for a national research team since research on soil management is already going on in collaboration with Bioversity International. All national research teams consist of 3 NARS scientists, 2 research assistants, 4 PhD students and 5 Master students. Additional costs include field work/greenhouse, laboratory, equipment, workshops, travels (\$25.000 per person per year for global team leaders, \$4.000 per person per year for regional staff), others and institute support. This “integrated management” research option excels in more field trials and more agronomy than the “quarantine” research option. In the assessment the R&D costs are matched 1:1 with additional country-level costs as per the general assumptions made for the priority assessment exercise.

The following Table 12 provides a brief summary of the parameter estimates and assumptions regarding Fusarium Research Option B:

**Table 12: Summary of parameter estimates and assumptions regarding Fusarium Research Option B**

<b>(6b) Fusarium Research Option B: Integrated crop and disease management to reduce the impact of Fusarium R1, R2, STR4, TR4</b>	
Countries	<b>20</b> (3 African countries, 9 Asian countries, 8 LAC countries) where Fusarium is either already present or will very likely spread in the near future if no major intervention occurs.
Cultivar groups considered	For the assessment of this research option, all <b>6</b> cultivar groups ( <b>AAA Cavendish, other AAA, AAB Plantain, other AAB, ABB</b> ) were considered threatened/susceptible to TR4 whereas <b>only 'other AAA' and 'other AAB'</b> were considered threatened/susceptible to Race 1. We do not consider Race 2 in the assessment of this research option since it is not very likely that the research output would be used for planting ABB. In the case of integrated management of TR4, the target domain comprises the production area of all cultivar groups in LAC and Asia whereas in Africa only the 'AAA Cavendish' production areas in Cameroon, Ghana and Ivory Coast are targeted. With respect to integrated management of Race 1, only 'other AAA' and 'other AAB' in Asia and LAC are assumed to be targeted.
Current and likely future spread	Although Fusarium TR4 and Race 1 are already present in some countries, we assume that the production area currently affected is zero percent in all countries since there are no reliable figures about the actual spread. The estimation of the likely future spread of the disease was made <b>separately for each cultivar group and country</b> by applying a 'Foc Scale' that we developed. We assumed that 100% of the banana production area in the included countries is susceptible to Foc.
Benefits:	
- Increase in yield	<b>80%</b> (Yield recovered)
- Reduction in postharvest losses	<b>No effect</b>
Production costs	<b>Increase of 20%</b>
Adoption ceiling	<b>30-50% of future Foc affected and targeted area</b> , depending on country and cultivar group. This translates into <b>0.3-24.6% of the total national production area</b> .
Research period	<b>10 years</b>
Technology release	The technology will be available in <b>10 years</b> in all included countries (immediately after successful development of research output)
Time from first adoption until estimated adoption ceiling will be reached	<b>15 years</b>
Probability of success (up-take of technology)	<b>25%, 50%, 75%</b> depending on the importance of banana in national public policy and research investment
R&D costs	<b>\$30.46 million</b>
Additional country-level costs	<b>\$30.46 million</b> (matched 1:1 with R&D costs)
Resource persons	Charles Staver, Miguel Dita, Luis Perez Vicente

*Source: Results of the Strategic Assessment of Banana Research Priorities based on expert estimates*

### 4.3 Fusarium research option (C): Development of Fusarium resistant banana cultivars

Twenty-eight countries from Asia/Pacific, Africa and Latin America and the Caribbean where Fusarium is either already present or will very likely spread in the near future have been considered for the ex-ante impact assessment of this research option. All six cultivar groups are assumed to be susceptible to Fusarium and this research option targets all production areas currently grown with these cultivars. This is because the research carried out will provide resistant varieties to all Fusarium races. Our

calculations based on the 'Foc Scale' show that without major intervention, the likely spread of Fusarium will range from 1% to 51% of national production area in 25 years. Developing Fusarium resistant banana cultivars would require a 15-year research phase. The likelihood that the planned research output will be achieved is lower compared to the previous Fusarium research options and is estimated to be 60%. It would then take two further years until farmers would adopt those cultivars for the first time. The adoption ceiling was estimated at 80% of the affected targeted area across all countries (no country specific differentiations were made), translating into adoption ceilings of 0.8-40.7% of the total national production area. The time from first adoption until the estimated adoption ceiling will be reached is estimated to be 15 years. In case the adoption area is slightly bigger than the estimated affected area in a certain year, we down-adjusted the adoption area to the size of the affected area to avoid overestimation.

Benefits occur as losses avoided due to adopting the technology, i.e. increase in yield of 100% assuming that the new varieties perform as well as the old varieties. We expect that using the new resistant varieties doesn't lead to a change in production costs or postharvest losses. The probability of actual successful uptake of the technology in the countries was set at 90% across all target countries, a high value since we assume that changing to a resistant cultivar with otherwise similar characteristics is rather uncomplicated.

The total costs of this research option are estimated to be \$47.730.750 and are roughly evenly spread over the 15-year research period. Staff comprises 3 global team leaders (plant pathologist, breeder, molecular biologist; all senior scientists) and one regional team each in Asia, Latin America, and Africa. In Asia, China or Taiwan would serve as a study site due to the recent start of a breeding program and huge historical involvement, respectively. In Latin America and the Caribbean, Brazil would be the base for a national research team and in Africa, Tanzania would be the base for the national research team. All national research teams consist of 3 NARS scientists, 4 research assistants, 5 PhD students and 6 Master students. Additional costs include field work/greenhouse, laboratory, equipment, workshops, travels (\$25.000 per person per year for global team leaders, \$2000 per person per year for regional staff in first phase and \$4.000 in the second and third phase), others and institute support.

Table 13 provides a brief summary of the parameter estimates and assumptions regarding Fusarium Research Option C.

#### **4.4 Fusarium research option (D): Development of GM Fusarium resistant banana cultivars**

Nineteen countries from Asia/Pacific, Africa and Latin America and the Caribbean where Fusarium is either already present or will very likely spread in the near future have been considered for the ex-ante impact assessment of this research option. We only included countries where local markets for 'AAA Cavendish' are important. This is because it is assumed that countries with export-oriented production patterns wouldn't adopt GMO varieties due to political and consumer concerns in importing countries whereas countries with strong local markets for 'AAA Cavendish' would be more likely to adopt GMO varieties. All six cultivar groups are assumed to be susceptible to Fusarium, but only production areas grown with 'AAA Cavendish' are targeted with the research since efforts to develop GM varieties to Fusarium TR4 will focus only on 'AAA Cavendish'. The estimated future spread is 1-51% of national 'AAA Cavendish' production area. Presumably, it will take 10 years from

now until a GMO resistant variety will be available. It will take further two years until farmers start adopting the new technology. It was assumed that the adoption ceiling will be 40% of the (future) area affected by Fusarium in the target domain. This translates into adoption ceilings of 0.1-17.8% of the total national production area. The time from first adoption until the estimated adoption ceiling will be reached is 15 years for all countries. In case the adoption area is slightly bigger than the estimated affected area in a certain year, we down-adjusted the adoption area to the size of the affected area to avoid overestimation.

**Table 13: Summary of parameter estimates and assumptions regarding Fusarium Research Option C**

<b>(6c) Fusarium Research Option C: Development of Fusarium resistant banana cultivars</b>	
Countries	<b>28</b> (11 African countries, 9 Asian countries, 8 LAC countries) where Fusarium is either already present or will very likely spread in the near future if no major intervention occurs.
Cultivar groups considered	<b>6</b> <b>AAA Cavendish, Other AAA, EAH AAA, AAB Plantain, Other AAB, ABB</b> in all countries considered. The research carried out will provide resistant varieties to all Fusarium races.
Current and likely future spread	Although Fusarium is already present in some countries, we assume that the production area currently affected is zero percent in all countries since there are no reliable figures about the actual spread. The estimation of the likely future spread of the disease was made <b>separately for each cultivar group and country</b> by applying a 'Foc Scale' that we developed. We assumed that 100% of the banana production area in the included countries is susceptible to Foc.
Benefits:	
- Increase in yield	<b>100%</b> (losses avoided)
- Reduction in postharvest losses	<b>No effect</b>
Production costs	<b>No effect</b>
Adoption ceiling	<b>80% of the affected targeted area</b> across all countries. This translates into adoption ceilings of <b>0.8-40.7% of the total national production area</b> .
Research period	<b>15 years</b>
Technology release	The technology will be available in <b>17 years</b> in all included countries (15 years of research plus 2 years until farmers start adopting the innovation)
Time from first adoption until estimated adoption ceiling will be reached	<b>15 years</b>
Probability of success (up-take of technology)	<b>90%</b>
R&D costs	<b>\$47.73 million</b>
Additional country-level costs	<b>\$47.73 million</b> (matched 1:1 with R&D costs)
Resource persons	Charles Staver, Miguel Dita, Luis Perez Vicente

*Source: Results of the Strategic Assessment of Banana Research Priorities based on expert estimates*

Benefits occur as losses avoided due to adopting the technology, i.e. increase in yield of 100% assuming that the new variety performs as well as the old one. We expect that switching to GM-resistant varieties won't increase production costs or postharvest losses. The probability of research success is estimated to be rather low (40%) whereas the likelihood that the technology will actually be up-taken by the target countries is assumed to be 70%.

The total costs of this research option are estimated to be \$8.510.000 and are roughly evenly spread over the 10-year research period. In comparison to the other Fusarium research options, the research for this component will be seen as a global effort carried out in only one site. Staff comprises 2 team leaders/senior scientists (plant pathologist, molecular scientist), 2 NARS scientists, 2 research assistants, 3 PhD students and 2 Master students. Additional costs include field work/greenhouse, laboratory, equipment, workshops, travels (\$1.000 per person per year in first phase, \$2.000 per person per year in second phase), others and institute support.

The following Table 14 provides a brief summary of the parameter estimates and assumptions regarding Fusarium Research Option D:

**Table 14: Summary of parameter estimates and assumptions regarding Fusarium Research Option D**

<b>(6d) Fusarium Research Option D: Development of GM Fusarium resistant banana cultivars</b>	
Countries	<b>19</b> (8 African countries, 8 Asian countries, 3 LAC countries) where Fusarium is either already present or will very likely spread in the near future if no major intervention occurs. We only included countries where local markets for 'AAA Cavendish' are important. This is because it is assumed that countries with export-oriented production patterns wouldn't adopt GMO varieties due to political and consumer concerns in importing countries whereas countries with strong local markets for 'AAA Cavendish' would be more likely to adopt GMO varieties
Cultivar groups considered	All six cultivar groups are assumed to be susceptible to Fusarium, but only production areas grown with ' <b>AAA Cavendish</b> ' are targeted with the research since efforts to develop GM varieties to Fusarium TR4 will focus only on 'AAA Cavendish'
Current and likely future spread	For simplicity reasons we assumed the current spread of Foc to be zero percent of the production area even though the disease is present in some countries. The estimation of the likely future spread of the disease was made <b>separately for each country</b> by applying a 'Foc Scale' that we developed. We assumed that 100% of the banana production area in the included countries is susceptible to Foc.
Benefits: - Increase in yield - Reduction in postharvest losses	<b>100%</b> (losses avoided) <b>No effect</b>
Production costs	<b>No effect</b>
Adoption ceiling	<b>40% of the affected targeted area</b> across all countries. This translates into adoption ceilings of <b>0.1-17.8% of the total national production area</b> .
Research period	<b>10 years</b>
Technology release	The technology will be available in <b>12 years</b> in all included countries (10 years of research plus 2 years until farmers start adopting the innovation)
Time from first adoption until estimated adoption ceiling will be reached	<b>15 years</b>
Probability of success (up-take of technology)	<b>70%</b>
R&D costs	<b>\$8.51 million</b>
Additional country-level costs	<b>\$8.51 million</b> (matched 1:1 with R&D costs)
Resource persons	Charles Staver, Miguel Dita, Luis Perez Vicente

*Source: Results of the Strategic Assessment of Banana Research Priorities based on expert estimates*

## 5. RESULTS OF THE EX-ANTE ASSESSMENT OF FUSARIUM RESEARCH OPTIONS

This part of the report presents and discusses the findings which emerged from the assessment of the Fusarium research options. The section is divided into three main sub-sections. The first sub-section presents the results from Cost-Benefit Analysis using Economic Surplus Model. It then goes on to illustrate the number of beneficiaries, poverty reduction and regional distribution of impacts. The section closes with the presentation and discussion of the results of the conducted sensitivity analysis.

The methods applied to assess the research options are the same that were used for the other research options evaluated in the context of the Strategic Assessment of Banana Research Priorities by (Pemsl & Staver, 2014). Thus, we do not outline the methodology here at this point and kindly like to refer to the aforementioned report.

### Results from Cost-Benefit Analysis using Economic Surplus Model

For the estimation of benefits and costs of the four Fusarium research options we used the same methodological framework as (Pemsl & Staver, 2014) in the previous assessments of other banana research options. For instance, we used a 25-year assessment horizon, a standard discount rate of 10% to calculate the NPV, and in case of Fusarium research options B, C and D, we ran the model for a second adoption scenario for which the adoption ceiling was reduced by 50% of the original expert estimate. The scenario with the original adoption ceiling estimates is referred to as “higher adoption” and the more conservative (50% adoption) scenario as “lower adoption.” Fusarium research option A didn’t allow for reducing the adoption ceiling given that quarantine and surveillance measures are executed at the national level (as noted in section 4.1). Instead, we developed the three different scenarios that represent different degrees of conservativeness.

The results of the economic surplus modeling and cost-benefit analysis are displayed in Table 15 and 16. All assessed research options yield positive IRRs (i.e., returns on the investment above a standard 10% interest rate). Even under the (50%) lower adoption scenario (in the case of Fusarium research options B, C, and D in Table 16) the IRRs are positive and well above 10%. Yet, there is considerable variation in the return on investment between research options, with “Foc A (Quarantine) – Scenario 3” yielding an estimated 11% and the “Foc B (Management) – Lower adoption” an estimated 30%. All three “Foc A (Quarantine)” scenarios yield the lowest returns to investment, just slightly above the 10% threshold. This is because we included more cost variables compared to the other research options. Apart from the R&D costs and the dissemination costs (task force agreement), we introduced the costs of establishing quarantine system reflecting the initial capacity strengthening efforts and the costs of maintaining the quarantine and surveillance system. Thus, the costs during the first ten years are exceptionally high thereby lowering the IRR. The Net Present Values of all Fusarium research options are positive, confirming profitable investments. Since R&D costs, or the level of investment, vary substantially across research options (\$8.51 million - \$47.73 million), the two indicators IRR and NPV produce slightly different rankings of the research options in terms of their profitability.

**Table 15: Results – Adoption area and benefits (Fusarium Research Option A)**

Technology	Adoption area after 25 years		All Benefits	
	['000 ha]		NPV [US\$'000]	IRR
Foc A (Quarantine) - Scenario 1*	404		260,842	14%
Foc A (Quarantine) - Scenario 2**	363		156,691	13%
Foc A (Quarantine) - Scenario 3***	300		35,095	11%

**Note:** The adoption area of Fusarium Research option A represents the area after 25 years where losses could be avoided due to the execution of the quarantine and surveillance measures at a national level \*Doubling of arrival time and 50 percent reduced increase of loss rate (12.50%) once Foc reaches the country as compared to a scenario without intervention; \*\*Arrival time as in Scenario 1 minus 5 years; 50 percent reduced increase of loss rate (12.50%) once Foc reaches the country; \*\*\*Arrival time as in Scenario 1 minus 5 years; 25 percent reduced increase of loss rate (18.75%) once Foc reaches the country

**Source:** Results of the Strategic Assessment of Banana Research Priorities

**Table 16: Results - Adoption area and benefits (Fusarium Research Options B, C, D)**

Technology	Adoption area after 25 years		All Benefits			
	Higher adoption	Lower adoption	Higher adoption		Lower adoption	
	['000 ha]	['000 ha]	NPV [US\$'000]	IRR	NPV [US\$'000]	IRR
Foc B (Management)	344	170	1,040,288	36%	501,083	30%
Foc C (Resistant cultivars)	593	297	418,539	25%	183,361	20%
Foc D (GMO resistant cultivars)	127	63	286,030	34%	137,024	28%

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

**Source:** Results of the Strategic Assessment of Banana Research Priorities

Table 15 and 16 also display the estimated area on which the new technologies will be adopted. In the case of Fusarium Research Option A, this adoption area represents the area after 25 years where losses could be avoided due to the execution of the quarantine and surveillance measures at a national level. In comparison, the adoption area regarding Fusarium Research Options B, C, and D is the area where farmers actually apply the new technologies themselves and thus can avoid losses. The estimated adoption area is another indicator that should be considered when making funding decisions because it translates into the number of people that benefit from the new technologies (Pemsl & Staver, 2014).

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

Table 17 and 18 show the number of households and persons that are estimated to benefit from each Fusarium Research Option. These figures are determined by the adoption area at the end of the assessment horizon in each of the countries, the number of countries considered, and the production area within those countries. Similar to the NPV and IRR results, these numbers should be interpreted regarding the different magnitude of the investments required/assumed across research options (Pemsl & Staver, 2014).

**Table 17: Results – Beneficiaries and poverty reduction (Fusarium Research Option A)**

Technology	Number of beneficiaries		Poverty reduction
	Households ['000]	Persons ['000]	Persons ['000]
Foc A (Quarantine) - Scenario 1*	1,876	9,107	807
Foc A (Quarantine) - Scenario 2**	1,693	8,237	714
Foc A (Quarantine) - Scenario 3***	1,375	6,654	615

**Note:** \*Doubling of arrival time and 50 percent reduced increase of loss rate (12.50%) once Foc reaches the country as compared to a scenario without intervention; \*\*Arrival time as in Scenario 1 minus 5 years; 50 percent reduced increase of loss rate (12.50%) once Foc reaches the country; \*\*\*Arrival time as in Scenario 1 minus 5 years; 25 percent reduced increase of loss rate (18.75%) once Foc reaches the country

**Source:** Results of the Strategic Assessment of Banana Research Priorities

**Table 18: Results – Beneficiaries and poverty reduction (Fusarium Research Option A, B, C)**

Technology	Number of beneficiaries				Poverty reduction	
	Higher adoption		Lower adoption		Higher adoption	Lower adoption
	Households ['000]	Persons ['000]	Households ['000]	Persons ['000]	Persons ['000]	Persons ['000]
Foc B (Management)	1,634	7,875	814	3,926	157	79
Foc C (Resistant cultivars)	2,873	14,040	1,437	7,020	850	422
Foc D (GMO resistant cultivars)	612	2,743	306	1,371	89	44

**Note:** Lower adoption scenario: analysis with 50% lower adoption ceiling

**Source:** Results of the Strategic Assessment of Banana Research Priorities

Tables 17 and 18 also show the poverty reduction effects of the different research option by indicating the estimated number of persons that can be lifted out of poverty. The detailed methodology about how to calculate the poverty effects is described in (Pemsl & Staver, 2014). The ranking of research options is different when looking at the results of the poverty reduction model and constitutes another important factor for decision making.

We also estimated the regional distribution of the adoption area which is illustrated in the following Table 19. It can be seen that most adoption occurs in either Africa or Asia/Pacific. However, these numbers are largely driven by the choice of countries to be included into each Fusarium Research Option. It also has to be mentioned that the regional distribution of benefits is not only determined by the adoption area, but also by other parameters used in the model, such as cost effects, crop prices, and likely success rate (Pemsl & Staver, 2014)

**Table 19: Results - Regional breakdown of adoption**

Technology	Adoption area after 25 years (higher adoption scenario)						
	Africa		LAC		Asia/Pacific		ALL
	['000 ha]	Share [%]	['000 ha]	Share [%]	['000 ha]	Share [%]	['000 ha]
Foc A (Quarantine) - Scenario 1*	174	43	35	9	194	48	404
Foc A (Quarantine) - Scenario 2**	157	43	30	8	175	48	363
Foc A (Quarantine) - Scenario 3***	133	44	32	11	135	45	300
Foc B (Management)	6	2	21	6	317	92	344
Foc C (Resistant cultivars)	201	34	18	3	373	63	593
Foc D (GMO resistant cultivars)	18	14	3	2	106	83	127

**Note:** The adoption area of Fusarium Research option A represents the area after 25 years where losses could be avoided due to the execution of the quarantine and surveillance measures at a national level \*Doubling of arrival time and 50 percent reduced increase of loss rate (12.50%) once Foc reaches the country as compared to a scenario without intervention; \*\*Arrival time as in Scenario 1 minus 5 years; 50 percent reduced increase of loss rate (12.50%) once Foc reaches the country; \*\*\*Arrival time as in Scenario 1 minus 5 years; 25 percent reduced increase of loss rate (18.75%) once Foc reaches the country

**Source:** Results of the Strategic Assessment of Banana Research Priorities

### 5.3 Sensitivity analysis of Fusarium research option results

All ex ante assessments are trying to predict future outcomes of (hypothetical) investments and the results are based on (expert) estimates of the costs and effects. It is thus very reasonable to ask how robust the results of the priority assessment are considering the large uncertainty involved in estimating parameters and making assumptions on future events. In most cases, the experts are too optimistic with regard to the future adoption and the effect of a new technology. To address this problem, it is good practice to conduct a sensitivity analysis which helps explore how sensitive the results of the assessment are to changes in the estimates of key variables.

The sensitivity analysis of the Fusarium Research Option results is based on the steps and methodologies outlined in (Pemsl & Staver, 2014) and 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 adoption area of the new technology. In the results section you have seen that we have already included a much more conservative “lower adoption” scenario which assumes a 50% lower adoption ceiling. For the purpose of testing the robustness of our results, we have gone even further and tested if investments would still be profitable if adoption was only 25% of what experts predicted. Even under this extremely conservative scenario, all assessed Fusarium research options reach positive Net Present Values and the Internal Rates of Return are well above the 10% benchmark level (Table 20). Since a reduced adoption ceiling affects all research options in the same way, the ranking of the research options is not changed. However, the adjustment of the adoption ceiling does not apply to the Quarantine and Surveillance research option since it is executed at the national level to prevent Fusarium to enter the country or to contain it.

**Table 20: Sensitivity Analysis - Benefits under different adoption scenarios (1)**

Technology	All benefits					
	Higher adoption (expert estimate)		Lower adoption I (50% of estimate)		Lower adoption II (25% of estimate)	
	NPV [US\$'000]	IRR	NPV [US\$'000]	IRR	NPV [US\$'000]	IRR
Foc A (Quarantine)						
Foc B (Management)	1,040,288	36%	501,083	30%	230,709	24%
Foc C (Resistant cultivars)	418,539	25%	183,361	20%	66,937	15%
Foc D (GMO resistant cultivars)	286,030	34%	137,024	28%	63,055	23%

*Note:* NPV calculated using a real interest rate of 10%

*Source:* Results of the Strategic Assessment of Banana Research Priorities

Based on the 50% lower adoption scenario, two additional key parameters were modified: 1) the time when adoption starts and ii) the magnitude of the farm-level benefit realized when adopting the technology. For more detailed information about the characteristics of the scenarios developed please refer to (Pemsl & Staver, 2014).

Scenario I comprises a 2 year delay in adoption, while keeping the adoption ceiling and pace at the same level. This is because delays in starting adoption are common. This is, for example, because the start of the research that produces the outputs or dissemination efforts might be delayed due to regulatory and administrative approvals in host countries (Pemsl & Staver, 2014). This scenario reduces NPVs and IRRs for all three Fusarium research options considered in this sensitivity analysis, but they would still be ranked as economically viable investments (Table 21). 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 instance, for the Fusarium resistant cultivars research option (Foc C), 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: the adoption ceiling would be reached in year 27 instead of year 25.

**Table 21: Sensitivity Analysis - Benefits under different adoption scenarios (2)**

Technology	All Benefits (based on lower adoption I scenario)							
	Scenario I 2 yr adoption delay		Scenario II a 25% reduced effect		Scenario II b 50% reduced effect		Scenario III delay + 50% red. effect	
	NPV [US\$'000]	IRR	NPV [US\$'000]	IRR	NPV [US\$'000]	IRR	NPV [US\$'000]	IRR
Foc A (Quarantine)								
Foc B (Management)	329,066	26%	332,224	27%	160,871	22%	97,208	18%
Foc C (Resistant cultivars)	19,155	12%	124,657	18%	66,148	15%	-15,103	8%
Foc D (GM resistant cultivars)	80,352	24%	99,872	26%	62,812	23%	34,606	19%

*Note:* NPV calculated using a real interest rate of 10%

*Source:* Results of the Strategic Assessment of Banana Research Priorities

The next two scenarios, Scenario II a and Scenario II b, assume 25% and 50% lower yield increases and/or smaller post-harvest losses (which together account for the total output increase), respectively, for example because the average effect is smaller under actual farm conditions than anticipated based on experiment or trial outcomes (Pemsl & Staver, 2014). Even under the more

extreme 50% reduced effect scenario, all research options can still be considered economically viable investments although the NPVs and IRRs are reduced significantly.

The last scenario, Scenario III, captures a delay in adoption (Scenario 1) in combination with a 50% reduced total output effect (Scenario II b). 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), two out of three *Fusarium* research options still perform well, namely the Management option and the GM resistant varieties option. Their NPVs are still positive and the IRRs well above the threshold of 10%. Only the Resistant cultivars research options failed to pass the test.

The scenarios I – III presented above show that the results of the assessment seem robust even under rather extreme conditions which is why it is very likely that the research options will even perform well under less favorable conditions. We did not include *Fusarium* research option (A) – Quarantine and surveillance measures – into this sensitivity analysis since the scenarios do not apply to the nature of that option. Instead, the three quarantine and surveillance scenarios developed and presented in section 2.1 and 4 and in the results section constitute a sensitivity analysis in itself and results reveal positive outcomes even under the least favorable scenario.

## 6. CONCLUSIONS

*Fusarium oxysporum f. sp. cubense* (Foc), tropical race 4 (TR4) has been characterized as primarily a threat to export Cavendish bananas, although others highlight the potential risk to smallholder banana livelihoods globally. As part of a study to assess the economic returns to different banana research investments through the CGIAR Research Program, Roots, Tubers and Bananas, we developed a method to project losses from FW as it spreads between and within countries. The developed 'Foc Scale' indicates the risk and magnitude of the problem taking into account cultivar differences thus providing estimates of expected losses that were used to evaluate the returns to four different research investments. A research investment in improved exclusion and containment measures acts on different values of the indices for the time to first outbreak and rate of internal spread. The investments in resistant cultivars and practices to produce susceptible cultivars on FW-infested lands address the recovery of production once losses have occurred. The method to project losses is transparent and open for review in that factors, scores and rates are identified and can be modified at different points in the process. The overall scoring system at each step and the scores for individual countries can be adjusted.

*Fusarium* was identified as one of the key constraints in the global online banana expert survey conducted in 2013 and based on the spread estimates derived from the 'Foc Scale', we calculated the benefits of the following four potential *Fusarium* related research investments: (1) Improved quarantine and surveillance measures to avoid spread of *Fusarium* TR4, (2) Integrated crop and disease management to reduce the impact of *Fusarium* R1, R2, STR4, TR4, (3) Development of *Fusarium* resistant banana cultivars, and (4) Development of GM *Fusarium* resistant banana cultivars. The ex-ante assessment of these four research options thereby followed the same general methodology and assumptions used in the earlier RTB priority assessment.

The results of all research options show positive returns to investment and yield sizeable Net Present Values. For instance, the Net Present Value of Research Option Foc A ("Quarantine – Scenario 1") is

estimated to be ~US\$ 261 million, for Foc B (“Management – higher adoption”) ~US\$ 1 billion, Foc C (“Resistant cultivars – higher adoption”) US\$ 425 million, and Foc D (“GM resistant cultivars – higher adoption”) US\$ 286 million. The Internal Rates of Return range from 14% in the case of “Quarantine – Scenario 1” and 36% in the case of “Integrated crop and disease management – higher adoption”. To test the robustness of the results, we conducted a sensitivity analysis and explored how the results would be altered if changes in the estimates of key variables occur. The analysis illustrates that all research options yield positive returns even under extreme scenarios. All research options have positive Net Present Values and Internal Rates of Return above the threshold of 10%, with the only exception of the development of Fusarium resistant banana cultivars, which failed to deliver positive results under the most extreme out of four sensitivity analysis scenarios. In general, the Quarantine and Surveillance research option (Scenario 1, 2 and 3) yielded the lowest returns on investments (note that IRRs are still slightly above the standard 10% interest rate threshold). This is because we included additional cost variables compared to the other research options. Apart from the R&D costs and the dissemination costs (task force agreement), we introduced the costs of establishing quarantine system reflecting the initial capacity strengthening efforts and the costs of maintaining the quarantine and surveillance system. Thus, the costs during the first ten years are exceptionally high – and arguable not entirely attributable to FOC quarantine - thereby lowering the IRR.

The calculation of number of beneficiaries showed that the quarantine research option might benefit 6.7 million people in the case of a scenario with very conservative assumptions to nearly 9.1 million people in the case of the least conservative scenario. For Options B, C, and D the number of beneficiaries was estimated to be nearly 8 million, 14 million and 2.7 million, respectively, using the lower adoption scenario. Poverty reduction analysis for the four options estimated substantial numbers of beneficiaries to be lifted out of poverty: 807,000 for Option A (Scenario 1); 157,000 for Option B (high adoption scenario); 865,000 for option C (high adoption scenario); and 89,000 persons for option D (high adoption scenario). The regional distribution of benefits, shows that most avoided loss occurs in either Africa or Asia/Pacific and substantially less in Latin America and the Caribbean. These geographical differences are the result of both the current distribution of Fusarium and the application of different options among different types of growers.

Two issues need to be raised with respect to the Fusarium research option results: First, the estimates are more likely underestimations than overestimations due to conservative adjustments of the model to account for the static nature of the ‘Foc Scale’. Second, the relatively weak performance of the quarantine and surveillance research option (yet with positive returns) in comparison to the other options is due to a more detailed elaboration of its costs in comparison to the other research options included in the banana research priority assessment. We included additional cost factors that are characteristic for quarantine and surveillance and an exclusion of these factors did not come into question since this would have drawn a heavily biased picture of the research option and consequently would have led to a drastic overestimation of its impact. Possibly, a solution in which a certain share of these costs is allocated to Foc as compared to other pathogens would solve this issue and make the numbers more comparable across all four research options.

Furthermore, several important themes were identified to improve the projection of losses. This would ultimately increase the quality of the estimation of research benefits since the projection of losses serves as a baseline to assess the returns on investments in Fusarium research:

- Standards to guide scoring for the risk of outbreak which in the current version were based on the experience of the authors and on regional banana network working documents. Information sources are needed which allow rating of the status of the 29 countries for such elements as strictness of border quarantine controls, effectiveness of internal quarantine measures and global banana movement to and from the country. Standards may represent a challenge beyond available information sources, in which case a broader multi-round consultation process might be designed to refine scores.
- Analysis of documentation and personal perspectives on how FW has moved from first outbreak in Taiwan across Asia and into the Middle East and Africa followed up by a documentation of internal spread in each country including containment measures. Such an analysis would illuminate key factors to validate and improve the rating scales.
- Review of data sets on the rate of spread at sub-country scale to provide empirical evidence of both important factors and rates and the shape of the curve, especially as the disease spreads farther and farther. If clean banana lands are unlimited and containment measures are not taken, then spread may be exponential without major effects on total production, but many other scenarios are possible depending on cultivars grown, cropping systems and landscape and infrastructure features.
- Field studies to monitor the role of diverse channels in both diffusion and jump spread of diseases – planting material, contaminated soil on shoes, containers, water and other vectors and the disease cycle of Foc and the dispersal role of the different reproductive phases.

This exercise to develop a quantified approach to estimate losses due to disease spread, points to the priority of building more complete models, both bio-economic and spatial, to project disease spread and accompanying economic losses. Such models are central to decisions on resource allocation and the design of more effective exclusion and containment strategies. Yet, this preliminary exercise also highlights the many gaps in the available information required to populate such models. The current calculations provide a rapid estimate of quantified losses using a transparent index approach used as a baseline to assess the benefits of the four selected Fusarium research options that were pending to complete the strategic assessment of banana research priorities.

## 7. LITERATURE

- Cook, D., Taylor, A., Meldrum, R. A., & Drenth, A. (2015). Potential economic impact of Panama disease (tropical race 4) on the Australian banana industry. *Journal of Plant Diseases and Protection*, *122*(5/6), 229–237.
- Dita, M., Echegoyen, P., & Perez-Vicente, L. (2013). *Plan de contingencia ante un brote de la raza 4 tropical de Fusarium oxysporum f. sp. cubense en un país de la región del OIRSA*. San Salvador, El Salvador.
- Ji Su, H., Hwang, S. C., & Ko, W. H. (1986). Fusarial Wilt of Cavendish Bananas in Taiwan. *Plant Disease*, *70*(9), 814. <http://doi.org/10.1094/PD-70-814>
- Kema, G. H. J., & Weise, S. (2013). Pathogens: Appeal for funds to fight banana blight. *Nature*, *504*(7479), 218–218. <http://doi.org/10.1038/504218b>
- Ordóñez, N., Seidl, M. F., Waalwijk, C., Drenth, A., Kilian, A., Thomma, B. P. H. J., ... Kema, G. H. J. (2015). Worse Comes to Worst: Bananas and Panama Disease—When Plant and Pathogen Clones Meet. *PLOS Pathogens*, *11*(11), e1005197. <http://doi.org/10.1371/journal.ppat.1005197>
- Pemsl, D., & Staver, C. (2014). *Strategic Assessment of Banana Research Priorities* (RTB Working Paper No. 2014-2). Montpellier. Retrieved from [www.rtb.cgiar.org](http://www.rtb.cgiar.org)
- Ploetz, R. C. (2005). Panama Disease: An Old Nemesis Rears its Ugly Head Part 2: The Cavendish Era and Beyond. *APSnet Feature Articles*. <http://doi.org/10.1094/APSnetFeature-2005-1005>
- Ploetz, R. C. (2007). Assessing threats that are posed by destructive banana pathogens. In *ISHS ProMusa Symposium: Recent advances in Banana Crop Protection for Sustainable Production and Improved Livelihoods*. (p. 88). White River, South Africa.
- Stover, R. H. (1962). *Fusarial wilt (Panama disease) of bananas and other Musa species*. Kew Surrey, UK: CMI.



RESEARCH  
PROGRAM ON  
Roots, Tubers  
and Bananas

The CGIAR Research Program on Roots, Tubers and Bananas (RTB) is a partnership collaboration led by the International Potato Center implemented jointly with Bioversity International, the International Center for Tropical Agriculture (CIAT), the International Institute of Tropical Agriculture (IITA), and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), that includes a growing number of research and development partners. RTB brings together research on its mandate crops: bananas and plantains, cassava, potato, sweetpotato, yams, and minor roots and tubers, to improve nutrition and food security and foster greater gender equity especially among some of the world's poorest and most vulnerable populations.

[www.rtb.cgiar.org](http://www.rtb.cgiar.org)

