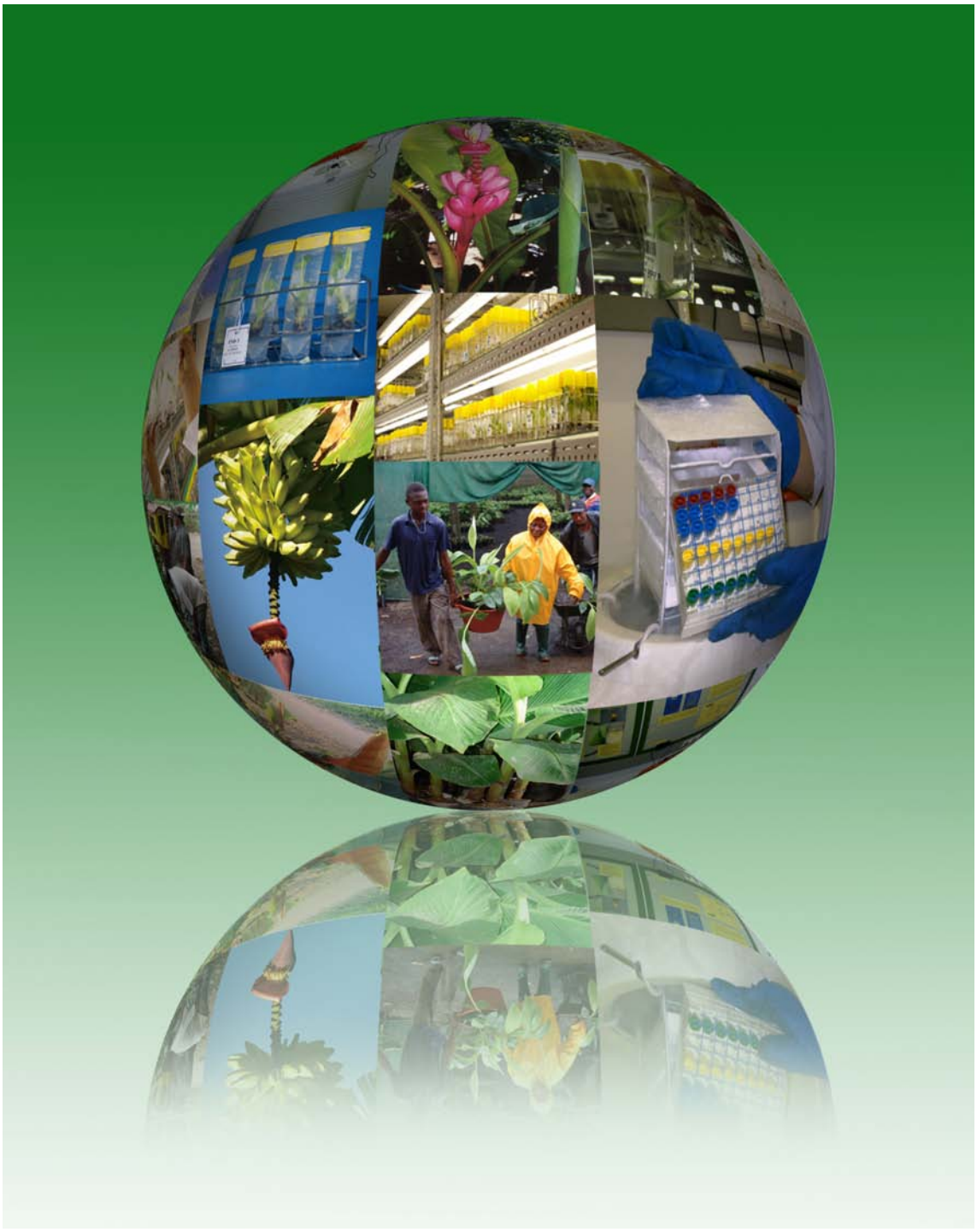
The impact of the *Musa* International Transit Centre

Review of its services and cost-effectiveness, and recommendations for rationalization of its operations

Hildegard Garming, Nicolas Roux and Ines Van den houwe



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List of abbreviations

ARC-PPRI	Agricultural Research Council-Plant Protection Research Institute (South Africa)
BanMMV	Banana mild mosaic virus
BAPNET	Banana Asia and Pacific Network
BARNESA	Banana Research Network East and Southern Africa
BBrMV	Banana bract mosaic virus
BBTV	Banana bunchy top virus
BLSD	Black leaf streak disease
BRIS	Banana Research Information System
BSV	Banana streak virus
BXW	Banana Xanthomonas wilt
CARBAP	Centre Africain de Recherches sur Bananiers et Plantains (Cameroon)
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Costa Rica)
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (Colombia)
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement (France)
CMV	Cucumber mosaic virus
CRI	Crops Research Institute (Ghana)
CTA	Technical Centre for Agricultural and Rural Cooperation ACP-EU
DArT	Diversity arrays technology
DGDC	Directorate General for Development Cooperation (Belgium)
DPI	Department of Primary Industries (Australia)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brazil)
FAO	Food and Agricultural Organization
FHIA	Fundación Hondureña de Investigación Agrícola (Honduras)
FW	Fusarium wilt
GCDT	Global Crop Diversity Trust
IAEA	International Atomic Energy Agency (Austria)
IDRC	International Development Research Centre (Canada)
IEB	Institute of Experimental Botany (Czech Republic)
IITA	International Institute for Tropical Agriculture (Nigeria)
IMTP	International *Musa* Testing Programme
INIBAP	International Network for the Improvement of Banana and Plantain
INIVIT	Instituto Nacional de Investigación de Viandas Tropicales (Cuba)

IPGRI	International Plant Genetic Resources Institute (Italy)
IRAZ	Institut de Recherches Agronomique y Zootechnique (Burundi)
IRD	Institut de Recherche pour le Développement (France)
ITC	Bioversity International Transit Centre / INIBAP Transit Centre
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
KCDP	Kagera Community Development Programme (Tanzania)
KULeuven	Katholieke Universiteit Leuven (Belgium)
LTS	Long-term storage
MGBMS	*Musa* Genebank Management System
MGC	*Musa* Genotyping Centre
MGIS	*Musa* Germplasm Information System
MTS	Medium-term storage
MUSACO	Réseau *Musa* pour l'Afrique Centrale et Occidentale
MUSALAC	Plantain and Banana Research and Development Network for Latin America and the Caribbean
NARO	National Agricultural Research Organization (Uganda)
NGO	Non-Governmental Organization
NRCB	National Research Centre for Banana (India)
PPRI	Plant Protection Research Institute (South Africa)
QDPI	Queensland Department of Primary Industries and Fisheries (Australia)
SINGER	System Wide Information Network of Genetic Resources
SMTA	Standard material transfer agreement
SPC	Secretariat of the Pacific Community (Fiji)
SSR	Single sequence repeat
TAG	Taxonomy Advisory Group
TGSMG	Technical guidelines for safe movement of germplasm
Trust	Global Crop Diversity Trust
TBRC	Taiwan Banana Research Centre (Taiwan)
VIC	Virus Indexing Centre

Executive summary

The Bioversity International Transit Centre (ITC), based at the Katholieke Universiteit Leuven (KULeuven), Belgium is the world's largest collection of *Musa* germplasm with 1212 accessions held in vitro. It is committed to the long-term conservation of *Musa* genetic resources under the auspices of the FAO in the context of a global conservation strategy supported by the Global Crop Diversity Trust. The distribution of germplasm from ITC is regulated within the framework of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA).

This study documents and assesses the performance of the ITC in terms of the conservation and distribution of *Musa* germplasm. It provides an overview of the impacts created through the distribution of germplasm and presents an evaluation of the service based on a survey among its users. An analysis of the costs of the ITC operations is presented, including a scenario analysis for possible future developments. Finally, recommendations are given with respect to rationalization and areas for further investments.

The ITC is an in vitro genebank, according to the particularity of bananas as a seedless crop. To secure the quality of the germplasm conservation, tissue cultures are regularly renewed (sub-cultured), regenerated and the genetic integrity is verified in the field. The germplasm health management includes regular checks of the accessions and initial health screening including full virus indexing. Basic molecular characterization is carried out. For these operations, ITC collaborates with partners and contracts external services providers. With respect to long-term conservation, ITC pursues the cryopreservation of the complete in vitro collection as safety back-up.

ITC distributes germplasm free of charge. Since its foundation it has distributed more than 8000 accessions to users in 103 countries. Distribution has increased with increasing diversity held at ITC and the utilization ratio of the available germplasm is about 33% per year. Main user groups are scientists in national agricultural research centres and advanced research institutes including universities. The results from the survey among users and interviews with key informants show that both the conservation and the distribution of *Musa* germplasm at ITC are highly appreciated throughout the community of banana researchers. They demonstrate the central role of ITC on a global level to ensure the long-term conservation of the largest possible diversity of *Musa* germplasm. The distribution of guaranteed healthy germplasm has enabled and facilitated a large body of research and played an important role in the implementation of banana-related development projects. The most important areas where impacts have been created are: a) the dissemination of superior germplasm to small-scale farmers with expected positive effects on their productivity. Several respondents

mentioned that positive effects have been created along the value chain of production and processing of bananas. b) research on resistance/tolerance to economically important banana pests and diseases, c) the supply of a broad genetic diversity to the breeding of superior banana germplasm, d) fundamental research carried out with materials from ITC. Here, impacts include the use of ITC codes for the identification of the germplasm, the generation of technologies for virus testing and therapy, improved understanding of banana physiology, plant pathogen relationships and breeding techniques.

While satisfaction with the service provided by ITC was generally high among survey respondents, suggestions were made to upgrade the documentation with photos, complement the information about the accessions with more evaluation data and more actively disseminate information to the user community.

The cost study confirmed that the *in vitro* conservation of *Musa* germplasm is costly, largely due to high labour requirements. The annual average cost of conservation is 136 € per accession, of distribution 217 € per accession. Cryopreservation is no substitute for *in vitro* conservation with initial costs of 1300 € per accession and no possibility of distribution of cryopreserved material. However it provides an important safety back-up, allowing to rationalize the *in vitro* collection in two possible ways. 1) A reduction in samples maintained *in vitro* per accession allows cost reduction of about 25 € per accession and year. 2) The elimination of a set of accessions from the *in vitro* collection which then would not be available for distribution on the medium term. The scenario analysis shows that the planned expansion of the collection to 2000 accessions over the next 10 years would cost about 1.4 million € and total annual operating costs would increase from currently 750 000 € to 970 000 € when the collection will have reached a stable size of 2000 accessions.

It is recommended that ITC invests in such expansion in response to its commitment to the global conservation strategy and to the demand of its users.

It is further recommended to invest in upgrading the documentation of the collection with respect to characterization and evaluation. This would allow further rationalization through the elimination of duplicates and definition of sets of accessions that could be transferred from the *in vitro* collection to cryopreservation. Also increased information provision about the germplasm would enhance utilization of the *Musa* genetic diversity to the benefit of banana researchers, producers and consumers worldwide.

Chapter 1. Introduction, objectives and research questions

1.1 Motivation

Crop genetic resources are the basis for agricultural production and food supply. The diversity of crop genetic resources is threatened in many different ways leading to a narrowing of the crop genetic exploitable base. Intensified cultivation of a reduced number of commercially important varieties is resulting in increasing rates of loss of old varieties (Iriondo et al. 2008). The globalization of pests and diseases contributes to the threat to traditional cultivars and eventually also to wild species. Habitats of crop wild relatives are disappearing under increasing human population pressure and the intensification of land use, and with them an important share of the genepool of the cultivated species is also at risk (Iriondo et al. 2008).

A steady increase in food demand leads to increasing demand for genetic improvement of food crops to achieve higher production levels and to reduce the losses due to pests and diseases through resistant cultivars. Also, many agronomic aspects and contexts are changing, such as soil fertility and climate, which require adaptation of crop characteristics.

Such challenges make the conservation of diversity of crop genetic resources a high priority task. This includes *in situ* conservation in terms of natural reserves for crop wild relatives and of on-farm conservation for traditional varieties and landraces. Also, there is a demand for *ex situ* conservation of crop genetic resources in genebanks, either as collections of plants in the field, as seed collections or as *in vitro* collections for vegetatively propagated crops. The collection of germplasm of crops in genebanks has two major objectives:

1) to ensure safe and long-term conservation of a broad range of genetic diversity of the crop and

2) to facilitate the use of the germplasm through the documentation and the distribution of viable and healthy seeds or *in vitro* materials to potential users.

As a response to the increasing need for sustainable conservation of crop genetic resources on one side, and insecure and mainly short-term funding of most of the 1400 genebanks worldwide on the other, in 2004, the Global Crop Diversity Trust[1] was established as independent international organization to ensure the conservation and availability of crop diversity for food security worldwide. At the centre of the Trust is the creation of an endowment fund to provide long-term funding for the conservation of crop genetic resources. Also, it promotes an effective, economically efficient global system of conservation and

[1] In the remainder of the text, the Global Crop Diversity Trust will be referred to as the 'Trust'

supports the implementation of best management practices for genebanks. The Future Harvest Centres of the Consultative Group on International Agricultural Research (CGIAR) maintain 11 genebanks with a total of more than 660,000 accessions of crops with high priority for agriculture in both developing and developed countries (Koo et al. 2004). These genebanks are central in the global conservation strategy implemented by the Trust, having a specific mandate to ensure conservation and sharing of germplasm as established in the International Treaty on Plant Genetic Resources for Agriculture (ITPGRFA), Article 15.1 (FAO 2001).

The Bioversity International Transit Centre for *Musa* germplasm (ITC) in Leuven, Belgium, belongs to this group of genebanks at the centres of the CGIAR, hosting the world's largest collection of germplasm of bananas and plantains. At present 1200 accessions are conserved *in vitro*, and 600 accessions are also cryopreserved in liquid nitrogen.

Bananas are not only the world's most popular fruit with a steadily increasing global production volume to more than 81 million tons in 2007 (FAOSTAT 2008), but also the fourth main global staple for millions of people in Asia, the Pacific, Africa, Latin America and an important food security crop especially for resource-poor subsistence farmers. Globalization impacts on the diversity of *Musa* cultivars through strong dominance of very few cultivars (e.g. 'Cavendish') in commercial production for international trade. Increasing risks of the spread of biotic stress factors such as pests and diseases and abiotic stress like flooding, drought and poor cultivation practices lead to severe losses in productivity and possibly even to the extinction of susceptible traditional cultivars. Hence there is a high demand for the conservation of the diversity of *Musa* in genebanks and for exchange of germplasm facilitating crop genetic improvement to meet our future needs.

This background and the mandate of the ITC to conserve *Musa* germplasm as global public good under the ITPGRFA, as well as the long-term funding opportunities for the ITC through the Trust, were the motivation to undertake the presented study.

1.2 Objectives and research questions

The objectives of the study are to document the use of the ITC and assess the impacts created for all types of stakeholders in banana research, production and processing. Recommendations for the improvement of the distribution service will be provided.

Another objective is to evaluate the efficiency of the ITC conservation and utilization strategy. The latter includes the identification, quantification and analysis of the costs of the genebank operation, as well as the evaluation of the performance in terms of service provided to the users and standards maintained

in the genebank operations. The purpose is to provide baseline information for developing a strategy for rationalization of the ITC operations

The specific research questions addressed in this study are:

1. Who are the beneficiaries of the ITC distribution service?
2. How often and for what categories are requests for materials made and how effectively are they used?
3. For what purposes are the materials from ITC used and what types of impacts have been created by the use?
4. Are there alternative sources for *Musa* germplasm? What is the comparative advantage of the ITC?
5. How do the users perceive the ITC service and how can it be improved?
6. What are the costs of the current conservation and distribution activities of the ITC genebank? How can the ITC operate in a more cost-effective manner?
7. How can ITC better respond to users' present and future needs? What are the constraints in terms of germplasm and information provision?

1.3 Overview of the study

The second chapter of the study provides the historical background of the ITC. It explains the rationale behind the foundation of the collection and its links with the hosting institute, the Katholieke Universiteit Leuven (KULeuven) in Belgium. The chapter describes the development of the collection over time in terms of diversity, the introduction of new technologies and challenges in the genebank management. Finally it illustrates the role of ITC in the networks on research on banana and plantain and within Bioversity International and previously INIBAP, and outlines the implications for the working modus of the genebank.

Chapter 3 introduces the theoretical background of the economic evaluation of impacts and costs and presents the conceptual framework for the study. It then describes the methods of data collection and analysis which were used in this study to answer the research questions.

The results are presented in chapters 4 to 7: Chapter 4 provides details on the distribution of germplasm by ITC, a categorization of the users and the types of germplasm requested. Chapter 5 describes the utilization of the germplasm as reported by the users and reviews the different types of impacts that were created, based on a survey among ITC germplasm users. Chapter 6 addresses the question of the quality of the service provided by ITC as perceived by its clients, and compares this with alternative sources of *Musa* germplasm, referring to the research questions 4 and 5. Chapter 7 addresses research question 6. It presents the analysis of costs of germplasm conservation and distribution, considering the

quality standards and output indicators of the genebank operation. The implications of the close links to KULeuven and the specific modus operandi for the cost structure are discussed.

Finally, Chapter 8 draws conclusions from the presented results and presents recommendations for the improvement of genebank service and its cost-effectiveness. It offers early indications about impacts created by ITC and proposals for follow-up studies on the quantification of impacts.

Chapter 2. Overview of ITC: Historical background - ITC as part of INIBAP and now Bioversity International

As a response to the increasing threats to banana production in numerous countries through the spread of black leaf streak disease (BLSD), in 1984 the International Network for the Improvement of Banana and Plantain (INIBAP) was founded by a group of donor countries and organizations. INIBAP operated first as an independent institution with major support of the International Development Research Centre (IDRC). Later it became a programme associated with the International Institute of Plant Genetic Resources (IPGRI) under the auspices of the CGIAR. As a network organization, INIBAP set its objectives to "*initiate, encourage, support, conduct and coordinate research aimed at improving the production of bananas and plantains, to encourage the collection and exchange of documentation and information relating to bananas and plantains and to support training for researchers and technicians from developing countries*" (INIBAP 1987). The conservation of *Musa* diversity and the facilitation of the safe exchange of *Musa* germplasm at a global level has been the core business of INIBAP since its first days. Therefore, as essential part of INIBAP, the INIBAP transit centre for *Musa* germplasm (ITC)[2] was established in 1985 at the KULeuven, Belgium. Why conserve banana germplasm in a country where bananas don't grow? And why in this particular place? There are a number of important reasons for this decision. Particularly the fact that Belgium is a non-banana-producing country was an important feature for establishing a germplasm transit centre, because germplasm from all places of the world can be received without the risk of introducing pests threatening domestic agriculture. Also, the risk of contamination of the germplasm from surrounding agriculture is low, so that the export of germplasm from Belgium to other places of the world is associated with very low risks of spreading diseases, given the effective health management of the collection.

Supported by the research interests of Prof. Edmond de Langhe in bananas and plantains, the laboratories at KULeuven already had a solid basis of scientific knowledge and experience in maintaining *Musa* germplasm *in vitro*, thus representing the ideal place for the establishment of the collection. In Belgium, banana research has a tradition since the 1950ies.

The *Musa* germplasm at ITC has always been kept as tissue culture material *in vitro*, due to the vegetative nature of the crop. In the first years, the collection expanded quickly from the initial stock of 14 accessions to about 1000 in 1993. The introduction of accessions received from *Musa* breeding programmes

[2] The ITC was established under the name of INIBAP Transit Centre. In 2006, when INIBAP became the Commodities for Livelihoods Programme of Bioversity International, the name of the ITC changed to Bioversity International Transit Centre.

worldwide and from major field collections in Guadeloupe, Honduras, Nigeria, Burundi, Australia and Costa Rica was complemented by targeted collecting in Papua New Guinea, Vietnam, Congo and Tanzania.

Concerns about potential spread of pests and diseases through the distribution of *Musa* germplasm soon led to the establishment of guidelines for safe movement of germplasm in 1988. These guidelines, revised in 1996 are still followed in the genebank activities (Diekmann and Putter 1996). One of the first viruses recognized to pose risks for the distribution of banana germplasm was the Banana bunchy top virus (BBTV). As safety measures, restrictions on the distribution of materials originating from countries where the virus was known to be endemic were applied. Later, methods were developed to detect the virus in *in vitro* material, and therapy methods became available to eliminate the virus from the material. The first accessions were virus-indexed in 1989. Since 1994, full virus-indexing has become a pre-condition for the distribution of germplasm, and since 2001 the whole collection held at ITC is virus-indexed.

In the beginning of the 1990s, another group of viruses caused severe concerns, the Banana streak viruses (BSVs). These viruses are commonly integrated in the banana genome of varieties carrying the B genome, including plantains (AAB genome). Although methods for the detection of the viruses are available, up to the present there is no possibility of virus therapy for BSV-infected germplasm[3]. Therefore, this germplasm, although conserved at ITC is not available for distribution.

In 1994, all genebanks of the CGIAR, including the ITC, were placed under the auspices of FAO, ensuring that the germplasm remains in the public domain, accessible for all interested users. Also from that date on, the genebanks assumed the commitment to conserve the germplasm 'in trust' for the long term. In order to fulfil its commitments for safe conservation of the diversity of *Musa* genetic resources, ITC collaborates closely with partner collections for safety duplication of its accessions at CIRAD in Guadeloupe and France.

Based on the ITPGRFA (FAO 2001) a standard material transfer agreement (SMTA) was developed, to be signed by every recipient of germplasm from ITC as well as ITC signing an SMTA for receiving germplasm from other institutes. The SMTA indicates the rights and obligations linked to the reception of germplasm. One important aspect is the obligation of sharing any benefits from commercial use of the germplasm or research products with those populations in the country of origin who contributed to the selection and conservation of the germplasm.

[3] However, the episomal form of the virus can be cleaned (Helliot et al. 2002; 2003).

In 1996, the *Musa* Germplasm Information System (MGIS) was launched, an electronic database to access information about *Musa* accessions in 18 genebanks worldwide, of which ITC is the largest and the only genebank operating at a global level. The MGIS database contains passport information and minimum descriptors for the accessions held in the genebanks. A recently released updated version was expanded to include representative sets of pictures for the characterization of the accessions. Also, links to geographic information are included, allowing mapping of the origin of the different accessions.

The ITC played a crucial role in enabling the International *Musa* Testing Programme (IMTP), organized by INIBAP in three phases, starting 1987, 1997 and 2001. In multiple environments worldwide, representing different growing conditions, new banana varieties were tested against reference varieties and cultivars for resistance to BLSD, Panama disease (*Fusarium oxysporum*) and agronomic performance. All materials used in the standard experimental design of IMTP first passed through ITC, where they were checked for plant health and subsequently multiplied to supply the partner organizations participating in IMTP.

Since its establishment, the ITC was strongly involved in organizing, coordinating and encouraging research on *Musa* germplasm. The most important research fields have always been the development of methods for virus-indexing and therapy, as well as the improvement of conservation methods. In 1984, the development of methods for conserving *Musa* germplasm in frozen state commenced with support from KULeuven. Over a period of ten years, protocols for cryopreservation of *Musa* germplasm were developed, tested and improved, later supported by the Directorate General for Development Cooperation (DGDC) through INIBAP. In 1995 the first consolidated cryopreservation method was available (Panis et al 2005). In 2003 the systematic cryopreservation of the ITC collection started with project funds from the GATSBY Charitable Foundation. Later, the World Bank, continued to support the cryopreservation, and in 2008 the Trust joined the Bank and the DGDC in funding *Musa* germplasm cryopreservation as a safe long-term conservation method.

This brief overview of the development of the ITC illustrates the central role of the genebank for the conservation of *Musa* genetic resources and for the distribution of germplasm to the community of *Musa* researchers and producers. Although unique among the *Musa* genebanks in its size and global mandate, the ITC is closely interlinked with partner collections and cooperates in terms of research and capacity building in conservation methods and safety duplication of the collection. ITC has strong relationships with regional collections in Asia, Africa and Latin America, where specific local germplasm is conserved and the multiplication for distribution of germplasm in the regions is carried out.

Chapter 3. Theoretical background and conceptual framework of impact assessment of ITC

The aim of this chapter is to provide a comprehensive conceptual framework for the evaluation of costs and benefits of the ITC. Although the scope of the empirical analysis is confined to the analysis of costs and user assessment of the service, it is useful to provide a more comprehensive theoretical framework including the identification of impacts and methods for their economic evaluation. This will allow a broader perspective for the discussion of the empirical results presented in the later chapters.

The chapter is structured as follows: in the next section, the overall objectives, the activities and routine operations of the ITC are explained giving a guideline to structure the cost analysis and facilitate the identification of outcomes and impacts. Indicators for the description of the outcomes of each activity are defined as the basis for the empirical analysis in Chapter 5. After that, the methodology for the cost analysis is provided, followed by a section that discusses approaches to evaluate the impacts of the ITC and the values of the germplasm in the collection. Then the database and methods of analyses used in this study are described. Finally, an outlook is given on further research on the quantification of impacts, delineating possible empirical case studies.

3.1 The ITC, objectives, activities and operations

Worldwide about 60 genebanks or collections of *Musa* germplasm exist, of which the ITC is the largest one, operating on a global level. In 1994, an agreement was signed between FAO and IPGRI, placing the collection under the auspices of FAO, as part of the international network for *ex situ* collections The *Musa* germplasm collection designated under this agreement is held in trust for the benefit of the international community. The central role of the ITC in the efforts to conserve *Musa* germplasm and promote its use on a global level with support of the Trust is outlined in the document on the Global conservation strategy for *Musa* germplasm (INIBAP 2006). In this document, the main tasks of the ITC in the regional and global networks of *Musa* research and breeding are described as the provision of a safety backup for national or regional collections and as a clearing house, providing virus-indexed, healthy germplasm to users worldwide.

These tasks reflect the two overall objectives of the ITC:

1. Contribute to the secure, sustainable and long-term conservation of the entire *Musa* genepool
2. Maintain genetic resources and related information in the public domain and provide a service for the safe movement of *Musa* germplasm.

As a guideline to structure the analysis of costs and impacts, the different genebank activities and operations are grouped according to the two objectives

as illustrated in Table 3.1. Also, output indicators are listed, which facilitate the description of the results of the respective activity.

Table 3.1. Genebank objectives, activities and output indicators

Objective	Activities	Output indicators
Conservation	Medium-term storage	Number of accessions stored
	Long-term storage	Number of accessions stored, probability of recuperation
	Safety duplication	Number of accessions duplicated
	Rejuvenation/regeneration	% of collection rejuvenated in adequate time period, % of accessions true-to type in field verification (genetic integrity)
	Collection & acquisition of new materials	No. of accessions introduced over time
Use	Information management	Completeness of data: 1) Number of accessions with Passport data 2) Number of accessions characterized (minimal and full set of morphological descriptors, minimum set of photos, molecular characterization data 3) No. accessions evaluated for biotic/ abiotic stress/agronomic performance/ micronutrient contents in fruits
	Germplasm health management	Number of accessions available for international distribution (disease free)
	Germplasm distribution	Number of requests per year, Number of accessions distributed, % of collection used Number of recipient countries % consumer satisfaction response

3.1.1 Conservation

ITC has a mandate to conserve germplasm of *Musa* and *Ensete* in trust. The collection comprises at present 1212 accessions, including wild *Musa* species (15%), landraces from all diversity centres of the crop (75%) and improved varieties from breeding programmes (10%).

Conservation of a seedless crop, which can only be propagated vegetatively, is much more demanding in terms of storage and maintaining viability as compared to seed crops. At the ITC, the germplasm is held in tissue culture (shoot-tip culture) under slow-growth conditions. It requires constant monitoring and periodical subculturing of the stored propagules. Tissue culture

has several advantages over *in vivo* conservation methods, such as in the field collections where fully developed plants are maintained. Tissue culture occupies less space, and the controlled growth conditions avoid infestation of the germplasm with pests and diseases, as well as climate shocks, which may affect field collections. Planting material for distribution can be obtained much faster than from field plants and due to aseptic growth conditions, the health status, once determined, can be guaranteed. One drawback of storing germplasm as tissue culture is that the material might be subject to somaclonal variation through spontaneous genetic modification. Therefore, rejuvenation and verification of the trueness-to-type of the conserved germplasm has to be performed periodically. These activities which require planting in the field are carried out in collaboration with partner collections in the Philippines, Cameroun, Uganda, Honduras and Guadeloupe. The data from the regeneration plots allow drawing conclusions on the quality of the conservation, since the plants in the field are evaluated against reference plants in order to identify potential off-types or mislabelled accessions.

The rejuvenation and field verification has resulted in the replacement of the stored germplasm of all virus-free accessions in the medium-term storage (MTS) collection by newly initiated tissue cultured for which the authenticity and conformity has been confirmed. As outlined in Table 3.1 this is an indicator for the quality standards implemented in the conservation of germplasm.

Cryopreservation or storage in liquid nitrogen provides a way of safe long-term conservation with minimal probabilities of deteriorating and losses of germplasm. In collaboration with KULeuven, ITC has already introduced a large share of its accessions into cryopreservation. Two different cryopreservation protocols are used, according to the requirements of the different cultivars (Panis et al. 2008). Due to the long and laborious process and hence high costs for the introduction of germplasm into the cryopreservation, the long-term storage in liquid nitrogen is currently not used as a substitute for the *in vitro* MTS collection, but rather serves as a back-up reserve. To what extent the replacement of *in vitro* conservation with cryopreservation is economically viable, will be determined in the cost analysis (Chapter 7 of this study). As further safety measure, a duplicate of the cryopreserved part of the collection is held at the Institut de Recherche pour le Développement (IRD), Montpellier, France. The outputs of the long-term storage activity are accessions of *Musa* germplasm stored in liquid nitrogen. Up to now, 600 accessions are stored in liquid nitrogen, 490 of which have safety duplicates at IRD in a black-box collection. At the ITC, a minimum standard of 95% probability of recuperation of the cryopreserved accessions is applied, which indicates the high quality and safety level of long-term storage.

The ITC manages a continuous process of expanding and complementing the collection with new germplasm, especially in the area of wild *Musa* species. As outlined in the global conservation strategy, there are about 300 to 400 cultivars known to be still missing from the collection, mainly germplasm from Asia, including *Callimusa* from Borneo, *balbisiana* types from India and China, as well as other wild types from Thailand, Indonesia and the Pacific (INIBAP 2006). It is expected that especially the wild types, which are still under-represented in the collection, contain interesting traits with high future use value for banana breeding, such as tolerance to drought or cold. Missing and under-represented diversity is introduced to the collection via national collections. If new material is discovered for example in a collecting mission, it is first planted in the national collection for characterization and description; from there it is then sent to ITC to be introduced into *in vitro* culture and subject to health checks, virus indexing and therapy, if necessary.

There are different ways to categorize the materials for the purpose of measuring the benefits. Understanding the conservation tasks as "making sure that germplasm is not extinct / permanently lost to human use", the accessions could be grouped according to their risk of extinction without *ex situ* conservation. Some of the cultivars, especially the improved materials, are held by the public or commercial breeding programmes that released them. Other varieties including landraces may be cultivated widespread and have a high probability to survive even without *ex situ* conservation efforts. Other accessions may represent germplasm with high risk of getting extinct in its habitat; this may especially be true for some of the wild species.

3.1.2 Distribution of healthy germplasm

The facilitation of exchange of *Musa* germplasm is the second major objective of the genebank. The ITC distributes a free of charge sample of five tissue culture plantlets of the required accessions to anyone who requests it for research, breeding and conservation purposes. The distribution is conditional on the health status of the accessions, i.e. only germplasm free of diseases is given out. Within the context of the ITPGRFA, the recipient of the germplasm has to sign an SMTA, stating that the material will be used for non-commercial purposes only, or will respect the intellectual property rights and share the benefits with the owner of these rights in case of commercial use.

The output of this activity is the supply of germplasm for anyone who wants to use it for research, breeding or conservation purposes. Quantitative output indicators for the distribution of germplasm are, for example, the number of requests per year and the number of accessions distributed per year. The share of the collection which is used over time can be seen as one indicator for the relevance of the collection and its distribution service.

For the distribution service, two management activities are essential: the health management and the documentation management. For the health management, substantial effort goes into the testing of newly introduced germplasm on viruses, following the FAO IPGRI Technical Guidelines for safe movement of germplasm (TGSMG - Diekmann and Putter 1996), and in case of infection, into therapy to clean the germplasm. Most of this work is carried out by contracted specialized laboratories.

However, there a major issue impeding that the entire collection is virus free. This problem is related to the BSVs which are integrated in the genome of banana. These viruses may or may not be expressed in plants with a B-genome. *In vitro* conditions are a factor that could increase the probability of the virus to be expressed. The episomal form of the virus may cause damage in terms of yield losses when infected plants are cultivated in the field. Actually, no therapeutic techniques are available to clean tissue cultures from the integrated form but for genotypes with exclusively the A-genome, effective remediation is possible.

Adequate documentation of the germplasm held in the ITC contributes to an increased use and a rationalized management of the genetic resources. The basic documentation related to the germplasm held at ITC is the passport data of the accessions. Since the field regeneration activity started, characterization data using a minimal set of descriptors were systematically generated for accessions undergoing verification in the field. Each accession is also documented with a set of pictures illustrating its typical characteristics. Evaluation data, which actually contribute most to a targeted use of the germplasm in the collection, are still scarce and collected on an ad hoc basis. Also, the management of the accessions in the genebank, such as the history of all genebank processes applied to the material is documented. The collected data include subculturing, monitoring, health testing, rejuvenation, as well as shipment data about when and where the accession has been distributed. This information can be important to any users of the material and ensures the high quality of conservation with transparent handling procedures, reducing the probability of mislabelling and off-types. The information is processed in MGBMS, the genebank management system of the ITC. All ITC accessions are also represented in the MGIS, which holds passport and characterization data of more than 5000 *Musa* accessions maintained in 18 genebanks around the world. This data is publicly accessible through the Internet (http://www.crop-diversity.org/banana/). Within the context of its documentation management, ITC is involved in organizing and coordinating characterization of *Musa* germplasm. In collaboration with partner institutes, field characterization is carried out in the framework of the rejuvenation activities and molecular characterization using DArTs and SSR-markers is conducted. Within the IMTP project, evaluation data of subsets of accessions in the ITC collection is generated in worldwide, multiple-site testing.

With regards to the objective of exchange of germplasm, the accessions held at ITC could be categorized either in terms of demand by the users, according to the frequency of request, or in terms of the availability elsewhere. For example, some varieties may be easily available from other sources, while some material might be supplied exclusively by ITC.

3.1.3 Reference collection

As the world's largest collection of *Musa* germplasm with international recognition, ITC plays an important role for the research community as a reference collection. Although this is not directly related towards an activity or genebank operation, this is an important function, given the characteristics of the crop and a large number of synonym names for cultivars and varieties of *Musa*. The use of ITC accession numbers to refer to the specific germplasm or clone used for an investigation ensures that research findings are reproducible. The citation of ITC codes in publications about *Musa* germplasm related research could be interpreted as the output or result of ITC providing the function of a reference collection.

The set-up of a set of reference accessions for taxonomical studies, held at ITC is a separate activity, but related to the role of the ITC of being a reference collection in its whole. These reference accessions are a set of 36 accessions, which have been defined by the Taxonomy Advisory Group[4] (TAG) established in 2006. They have been planted out in the field in several field collections and serve as a tool for the standardized classification of the edible bananas and as reference for the identification of synonyms or verification of germplasm.

3.2 Concepts for measuring the costs of conservation

For the analysis of the costs of conservation of crop genetic resources, three major approaches can be distinguished in literature: the evaluation of country-level expenditure on the conservation of crop genetic resources, the evaluation of costs of national conservation systems for specific crops, and the analysis of costs of individual genebanks.

As an example for the first approach Virchow (1999) used survey data for an inter-country comparison of expenditure on conservation, estimating cost-effectiveness in terms of cost per accession conserved in genebanks. The expenditure estimates include the direct spending of public and private entities for *in situ* and *ex situ* conservation, as well as bilateral or multilateral financial

[4] The Taxonomy Advisory Group (TAG) was established to provide guidance on the implementation of the Global Conservation Strategy for *Musa* and to offer expert advice on issues constraining the use and conservation of bananas and plantains. The group consists of a growing community of experts, researchers and collection managers who operate through an open, web-based discussion forum. The TAG held its first meeting in Cameroun in 2006 and a second meeting in India in 2008.
(Source: http://bananas.bioversityinternational.org/)

support provided for conservation. Indirect expenditure considered in this study is constituted of opportunity costs, for example for the conservation of wild habitats or forgone benefits of on-farm conservation when the conserved varieties are less profitable than others.

With respect to the quality of conservation, a number of quality indicators were defined and merged into an index. Countries were then ranked according to quality and costs of conservation. This approach allows some conclusions about the effectiveness of different conservation systems and provides starting points for further detailed analysis of the different systems and their components. For example, economies of scale could well be observed, i.e. that the per accession costs decrease significantly with the total number of accessions conserved in a system. However, an assessment of cost-effectiveness in terms of a ranking of countries based on such survey data is more difficult for countries with different cost and quality levels. Also, the comparison is hampered by the large differences in the data quality obtained from the countries (Virchow 1999).

A more detailed perspective on the costs of a conservation system on national level is provided in country studies. In their study of conservation of crop genetic resources in Kenya, for example, Andama and Wandera (2003) compare the costs of different conservation methods, including field banks, on-farm conservation and seed banks for five different crops. Using cost data from a survey among institutes involved in *ex situ* conservation, they estimate average conservation cost per method and crop. Studies in India (Saxena et al. 2003) and Colombia (Moreno 2003) use similar approaches to analyze the costs per crop in the respective national conservation systems. As countries with centres of origin or centres of diversity of different crops, the costs of acquisition of new accessions in collecting missions are an important share of the national expenditure on conservation of crop genetic diversity, including wild relatives of the crops. Such analyses are helpful to determine the costly components of different conservation methods and analyze the cost-effectiveness of the system.

In the context of the establishment and implementation of the Trust, studies have been conducted to quantify the costs of conserving the existing genetic diversity in the CGIAR genebanks on the long term (see for example Koo et al. (2004). The studies following the genebank approach are based on cost accounting of different cost categories including capital costs for infrastructure and long-term equipment, variable non-labour costs for laboratory supplies and consumables, and labour costs. The aims of the Trust are to provide long-term funding to the conservation of crop genetic resources, to promote the strategic planning for effective and economically viable conservation on a global level and support the development and implementation of efficient conservation management and technologies (Trust 2006). The analysis of the costs of the genebank operations serves in the organization of the genebank operations and

for the planning of funding requirements. Also, information is provided on potential areas of rationalization.

3.3 Measuring the impact of ITC

Most empirical studies on the benefits of conservation of crop genetic resources have focused on the valuation of the use of genebank material in the breeding process. While this is probably the core task and core objective of the analyzed large seed banks, for *Musa* germplasm at the ITC, the use in breeding programmes is not the most frequent purpose for request, due to the particular physiology of the crop. Although breeding is one important purpose for using *Musa* germplasm from ITC, a significant portion of the germplasm is also used directly in the evaluation and selection of cultivars or varieties for production or for fundamental research. Therefore, for the evaluation of the costs, benefits and impacts of the collection at ITC, it is useful to develop a framework for the assessment, considering the range of activities at ITC to fulfil its objectives and the outcomes delivered. A distinction will be made between the approaches of economic valuation of crop genetic resources and the conceptualization of measuring the impacts of the genebank work. It is argued that the impacts of the conservation and distribution of germplasm in a genebank are not equal to the economic value of the genetic resources conserved. Only for specific accessions, the impact can be measured by quantifying the economic value. In the next section, first a brief overview of economic valuation of crop genetic resources is given (section 3.3.1). Then the concepts for the evaluation of the different types of impacts that can be expected from the ITC based on the description of objectives and activities are discussed in more detail (section 3.3.2).

3.3.1 The economic valuation of crop genetic resources

There is a growing body of literature on valuation of crop genetic resources. Both the value of crop genetic resources in genebanks and in the field have been of interest. For a general conceptualization of the types of values to be measured, Koo and Smale (2003) provide a taxonomy of values distinguishing between current use value, expected future use value and option value. Current and future use values refer to the contribution of a certain crop genetic resource to the improvement of crop production either in the present or in response to an anticipated problem that will occur in the future, for example if current disease resistance will be overcome by the pathogen. The option value in contrast to the expected future use value, refers to the possibility of finding useful genes to cope with unforeseeable future shocks and challenges (Pearce and Moran 1994; Koo and Smale 2003). Non-use values (Krutilla 1967), a concept often applied in the valuation of natural resources, are rarely referred to in the context of crop genetic resources, since the use by humans is the characteristic of crops.

The measurement of current use values is based on market prices of the product. Examples for empirical applications are the study of Pardey et al. (2006)

on sources of benefits from new varieties in Brazil and the study of Evenson and Gollin (1997) on the contributions of IRRI to productivity improvements in modern rice cultivars using genealogical analysis. Also Johnson et al. (2003) used a genealogical approach to identify the contribution of germplasm from different origins to productivity gains in bean production in Latin America. Comparisons of the benefits derived from domestic genetic resources with those from material from foreign sources show that the international exchange of germplasm facilitated through the Centro Internacional de Agricultura Tropical (CIAT) genebank has greater benefits, even for countries whose bean varieties are mainly based on endemic germplasm. Such analysis is especially helpful in articulating implications of a benefit-sharing system in the context of the ITPGRFA. The authors conclude that the free exchange of germplasm has higher returns than for example a 10% royalty on the productivity benefits attributed to the contribution of a country's genetic resources to an improved variety, even for those countries with high diversity of germplasm for the specific crop.

Gollin et al. (2000) analyzed current use values applying a search theoretic framework, focusing on the questions of optimal size of a genebank, and the pay-offs of searching for specific traits of germplasm stored in the genebank. They showed that the value of accessions in a large genebank can be significant, even if they remain unused for many years.

The quantification of expected future use values is often based on the expected demand for new resistance genes for crop diseases and the probability of finding these in the germplasm conserved at a genebank. In their study on the expected benefits of adding more accessions to the national US germplasm system Zohrabian et al. (2003) applied a maximum entropy approach to this research question. They found that the lowest benefit estimate by far exceeded the highest cost estimate of conservation of an additional accession in the US genebanks, demonstrating that the conservation of germplasm in this case is a high return investment.

Referring to unforeseeable shocks, the option value of germplasm is difficult to determine by definition, although it is probably one of the most important reasons why investments in the *ex situ* conservation of germplasm are made. One approach for the measurement of option values is to analyze farmers' choices with regards to the trade-off between the cultivation of high yielding modern crop varieties and traditional landraces. The productivity gains that they are willing to forego can be interpreted as their valuation of the benefit of diversity of crop genetic resources (Brush and Meng 1998; Drucker et al. 2001). This valuation includes aspects of expected future use values as well as of the option values of the germplasm they conserve.

It should be noted that all these value concepts are based on economic utility theory, which represents the idea that values are based on individuals' choices

between bundles of goods in order to pursue their wellbeing (= maximize utility). Gowdy (1997) criticizes the exclusive focus on this value concept when assessing the value of biodiversity, of which crop genetic resources are part. He emphasizes the basic life-supporting function of biodiversity and argues that there is no substitute for this function, which leads him to the conclusion that no meaningful economic value can be placed on a particular species. The perception that a valuation based on individuals' choices in markets does not provide sufficient information for decision making on the conservation is supported by the study of Koo and Wright (1999). In their review of case studies valuing genetic resources and biodiversity, they show that in many instances, the magnitude of biodiversity products' market values are not high enough for a merely economic justification of the conservation of these resources as for example in the case of pharmaceutical use and crop genetic resources for agriculture. They conclude that tangible market values are only a small part of the total value of biodiversity.

Nevertheless, the economic valuation of crop genetic resources conserved in a genebank is not equal to the valuation of biodiversity as a whole, and is justified and necessary in view of limited resources available for conservation. As stated by Brown (1990), there is no way to decide not to value genetic resources, since all choices about conservation efforts imply a value judgment.

3.3.2 The impact of the ITC and its valuation

The values of the germplasm held at ITC are difficult, if not impossible to quantify in a comprehensive way. However, a closer analysis of the functions and the types of germplasm conserved reveals the different types of impacts created by the ITC and provides entry points for their evaluation. In this section, it is argued that the impact of a genebank is not equal to the value of the germplasm conserved there. For the evaluation of the impact, the relevant question is "what would the world look like if the ITC did not exist?" The analogy of a genebank to a library (Brown 1990) provides useful insights for such analysis. The impact of a library would probably be overestimated, if all the benefits from the knowledge provided by the books stored there would be assigned to it. At least for those books that are easily available in a bookshop, the impact of the library is confined to making it cheaper to access them. Following this analogy, the yield improvements of poor farmers in developing countries due to a banana hybrid obtained from ITC can probably only partially be attributed to the impact of ITC, if these hybrids could also have been obtained from the breeder. In this case, the role of the ITC is to save the costs of accessing the germplasm from the other sources.

Another important reason to distinguish between the value of the crop genetic resources *per se* and the impact of ITC arises from the fact that *ex situ* conservation is not a complete substitute to conserving germplasm in situ. While

the populations in situ are continuously evolving and adapting to an ever changing environment, the germplasm in the genebank is not changing over time5 (Iriondo et al. 2008). Another issue is the question whether the accessions stored in the genebank represent the total diversity of the *Musa* species and how to complete the collection. In the following sections, concepts and approaches to the valuation of the impact of ITC are discussed according to the different functions.

3.3.2.1 The impact of germplasm conservation

The evaluation of the benefits from conserving *Musa* germplasm is closely related to the challenge of measuring the value of crop genetic resources as discussed above. ITC conserves crop genetic resources which have current use value through the contribution to improved germplasm for cultivation, with desired tastes, processing quality, yields, resistance to biotic and abiotic stress and other agronomic characteristics. Future use values are derived from the expectations that the collection hosts germplasm with resistance genes or other traits that will be useful for future demands. The germplasm held at ITC also has an option value, based on the belief that a greatest possible diversity of *Musa* germplasm will provide an asset to cope with future shocks, like climate change, the consequences of which and the challenges for agriculture are not yet foreseeable.

The contribution of the ITC to the conservation of *Musa* germplasm depends on how probable it is that the crop genetic resources would be lost if not conserved in the ITC collection. Therefore, it is useful to divide the collection into three categories, as shown in Table 3.2. There are varieties that are widely cultivated, maybe in many countries and the germplasm or the planting material is commercialized by breeders, for example modern hybrids or even genetically modified varieties. For this germplasm it is reasonable to assume that there is no risk of extinction in the short or medium term. The current use value of this material is very high, while the option value may be low, because the germplasm is selected and bred to encounter current challenges in crop production. In order to assess the impact of the conservation of these cultivars at the ITC, the counterfactual has to be identified. By definition of this category of germplasm, the germplasm would not easily be lost, even if not conserved at ITC. Hence, the impact of ITC can be assumed to be rather low.

They have a high current use value, since they represent the characteristics highly preferred in the communities where they are grown, especially in terms of consumption qualities, as shown by Bellon et al. (1998) for Philippine rice farmers.

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[5] At least under optimal conditions, the conserved germplasm is expected not to change. In practice, mutations are possible and there may even be a selection pressure according to the storage conditions. For the in vitro collection of ITC, mutations and the development of off-types can be an issue and considerable efforts are made to detect and to avoid this problem.

Table 3.2. Approaches to the valuation of the impact of ITC on the conservation of *Musa* germplasm according to the risk of extinction

Category of germplasm	Current and expected future use value	Option value	Counterfactual	Valuation of ITC impact
Widespread cultivation, commercialization of germplasm, no risk *in situ*	High	Low	Widespread cultivation, no risk of extinction	Low value of conservation
Local cultivation, no commercial-ization of germplasm, certain risk *in situ*	High	High	Decline in cultivation, eventually loss of specific germplasm	Value of conservation increasing over time. Value of on-farm conservation: Farmer willingness to forego yield Benefits of genetically modified varieties: consumer willingness to pay.
No cultivation, no commercialization of germplasm, high risk or already extinct *in situ*	Low	High	Loss of crop genetic resource highly probable	Expected future use value, option value

The option value of such varieties may also be high, since much of this germplasm has not been evaluated under different conditions and interesting traits may still be discovered in the future. What now would happen to these landraces if not conserved at the ITC? For different crops it could be shown that the diversity of landraces grown by the farmers in the centres of origin of the crops declined, for example after the introduction of modern cultivars, like in the case of potatoes in the Peruvian Andes (Brush et al. 1992), or of wheat in Turkey (Brush and Meng 1998). Another risk factor for the conservation of landraces *in situ* could be the occurrence of new pests and diseases. Kalyebara et al. (2008) document for example the effect of BLSD and Fusarium wilt (FW) as production constraints for the traditional East African Highland Cooking Bananas in Uganda and Tanzania and the spread of Banana Xanthomonas wilt (BXW) has been described as a major threat to banana production in that region (Abele et al. 2007).

As a consequence, the value of the conservation of this germplasm at ITC is high and increasing over time with declining diversity *in situ*. One approach to the valuation of traditional cultivars and landraces is to measure the yield of modern varieties that farmers are willing to forego when they prefer to continue

the cultivation of lower yielding traditional cultivars (Brush and Meng 1998). Also, the difference in output price between traditional and modern cultivars on local markets, which can be observed e.g. for the traditional type of cooking bananas - a group of cultivars commonly referred to as Matooke in local language - versus modern hybrids in Uganda and Tanzania, can be interpreted as an indicator of the value of the germplasm. Another starting point for the valuation of these genetic resources is found in the work of Kikulwe et al. (2008) who assess the costs and benefits of a genetically modified traditional cooking banana. The impact of ITC in this case is conservation of the germplasm used in conventional and biotechnological breeding.

The third category of germplasm held at ITC is plant material which is not cultivated, for example wild species, which are often found in endangered habitats, or landraces which are no longer grown by farmers. The current use value of this germplasm is probably low; however, it is believed to have a high option value. Many of the accessions in this category are exclusively conserved at ITC, so the counterfactual would be the loss of this material for any future use. Since the option value refers mainly to the possible discovery of genetic traits relevant for future uses, the search theoretic approach to valuation as used by Gollin et al. (2000) could be applied for the germplasm in this category. Determinants of the value of the material would include the distribution of desirable traits. However, in absence of criteria, which specific traits will be of interest in the future, an ex-ante quantification of the pay-offs of the conservation is hardly feasible.

3.3.2.2 The impact of the distribution of germplasm and facilitation of germplasm exchange

For germplasm that is more or less easily available from other sources, such as commercial breeders or national/regional collections, the most realistic counterfactual scenario is that the users would resort to these sources of the germplasm. While some of these potential sources might also provide the germplasm free of charge, it is probable that additional costs occur. First, there could be costs of information search. Since all potential alternative sources of *Musa* germplasm are smaller collections, the costs of seeking the information can assume to be higher as compared to ITC. Second, according to the source, there are shipment costs of other fees for the receipt of the germplasm. Third, depending on the source, additional costs may be involved in testing the health status of the material or acquiring health certificates, if required for import procedures. Additional quarantine costs and the cost of the time delay for using the material may occur and have to be accounted for in this approach. It is possible that some users of ITC lack the funds to cover the costs involved in receiving germplasm from other sources. In these cases, it might be necessary to apply the opportunity cost approach. The opportunity cost approach is also relevant, if less stringent

health management procedures are applied by other providers of germplasm, and hence the users inadvertently introduce new diseases into a banana producing region. However, in practice, cases may be very rare where the introduction of a new disease can be traced back to a single identifiable point of entry so that the quantification of the contribution of ITC to the control of movement of diseases might remain rather speculative. Yet, it should be mentioned, that in some countries, ITC is the only accepted source of new germplasm due to the health status guarantee. In this case, the estimation of opportunity costs as described above for the distribution of germplasm can be applied.

For the evaluation of the ITC function to facilitate the exchange of healthy germplasm and to distribute it on request to anyone who wants to use it free of charge, two main concepts can be used, based on the relevant counterfactual situation:

1) The transaction cost approach is based on the concept that ITC decreases the transaction costs, which the users would incur to obtain the desired germplasm from other sources. Transaction costs for virus indexing would also occur in the case that alternative sources would not guarantee the health status of the material.

2) Where no alternative sources of the germplasm exist, the opportunity cost approach can be used to measure the foregone benefits if the germplasm could not be received from ITC.

In order to identify the appropriate approach, it is again useful to consider different categories of germplasm distributed by ITC as shown in Table 3.3.

The second category of germplasm is material, which may not be available from other collections or breeding programmes, but only from *in situ* sites, where it is cultivated or from the natural habitats. These could be specific landraces or wild *Musa* species in accessible habitats. The counterfactual situation, in which this material cannot be received from ITC, would be that those who wish to receive this germplasm have to go to the field to collect this germplasm for themselves. Hence, the transaction costs saved through using the ITC service include the costs of the collection mission like seeking the information where the germplasm is located, travel costs, opportunity costs of labour, fees and charges for export and import permits of the germplasm, health checks of the material and the time delay to receive the material. Since many users of the ITC are from developing countries and face tight budget constraints, the more realistic counterfactual would probably be that such germplasm would not be used at all, if not available from ITC. Hence the same valuation method has to be used than that for the next category of germplasm material which is exclusively available from ITC. The benefits from the use of this material can be assessed using an opportunity cost approach, i.e. the costs of non-use.

Dependent on the type of use of that material, different valuation method can be applied. All research and dissemination projects that lead to increased production of bananas could be valuated by the market value of the additional output. Resistance to pests and diseases can be valued either by summing up the costs of alternative pest management technology, e.g. pesticide application and all related costs, or by estimating the yield loss prevented through the resistance traits, multiplied by the net value of the produce.

The use of germplasm in breeding programmes to create improved varieties also can be valued by the contribution to production, including benefits for processing industry. According to the magnitude of changes in the production, output prices could also change so that producer and consumer surplus measures have to be used.

Table 3.3. Evaluation approaches of distribution function, according to availability of the germplasm elsewhere

Category of germplasm	Counterfactual	Transaction costs	Opportunity costs
Germplasm available from other providers	Users are able to receive germplasm from elsewhere	Search and information costs Fees and charges to purchase material Health certificates Quarantine, time delay for starting the project	Relevant only in special cases, if users would be unable to pay the costs involved in receiving germplasm from elsewhere Or Costs of introduction of new diseases if users inadvertently use infested germplasm from other sources
Germplasm only available from *in situ* locations	User collect germplasm from farmer fields/the wild or are unable to access germplasm	Costs of collecting missions and permits to export/import germplasm Virus indexing/therapy	Foregone benefits from receipt of germplasm depend on type of use: e.g. in *Musa* production Avoided yield losses/avoided pesticide applications Yield increases Research and capacity building Broader genetic base for breeding
Germplasm exclusively provided by ITC	Users are unable to access germplasm	Not applicable	

Conservation and distribution of germplasm are highly dependent on the accompanying documentation management activities. It is difficult to imagine how a germplasm collection without the basic documentation might be of much use to breeders, producers and researchers. The counterfactual scenario probably would be a much lower rate of use of the collection, since potential users would

be unable to identify the germplasm of their interest. Those who would use the germplasm would have to spend much time on investigating about basic characteristics, resulting in time delays to produce other research outputs.

3.3.2.3 The impact of a reference collection

The impact of ITC in terms of a reference collection for the banana science community is related to research with germplasm. The existence of a unique identifier of an accession in the ITC code, allows publishing reproducible research results, which also allows the validation of published results. Hence, duplication of research efforts can be avoided and researcher can build upon the work of others more easily. The impact hence consists in savings in time and costs and more progress in answering research questions. However, such impacts are difficult to quantify, since the counterfactual is not clear in the specific case. If disease resistance to a specific race of a pathogen is analyzed without giving a unique identifier, other researchers who wish to follow up on these experiments would have three options: Obtain the germplasm from those who did the first study; rely on the assumption that the material, with the same cultivar name which they plan to use is in fact the same germplasm; or first repeat the experiments with their own material and then go ahead with further research. However, these counterfactual scenarios are highly hypothetical. Also, research questions are commonly developed based on previous results so that the precise description of the material in previous investigations is simply a condition for the development of a follow-up study or repetition of experiments.

The unique identification and the general availability of the germplasm also offer the possibility of multilocational testing of germplasm. An example for this is the IMTP.

As qualitative indicators of the impact of a reference collection of *Musa* germplasm, the number of publications and types of publications based on research with ITC accessions and the range of topics covered are used.

Chapter 4. Methodology

4.1 The outputs and impacts of ITC

For the analysis of the work carried out at the ITC as presented in this study, a distinction is made between the *outputs* of the activities pursued and the *impacts*. Outputs refer directly to the respective activities of conservation and distribution of germplasm, as outlined in section 3.1. The immediate products from these activities can be described using qualitative and quantitative output indicators. Impacts are only indirectly created through the genebank activities, when the outputs are used by different actors to achieve certain objectives. Therefore, the analysis of impacts cannot be immediate and considers the actors utilizing the genebank outputs, their contribution to achieve the desired impact and the factors that favour or constrain the achievement.

In this study, emphasis is given first to the description and analysis of the outputs of the genebank activities. The conservation is described by the number of accessions held in the collection and their classification in terms of wild species, landraces/cultivars and improved varieties. Indicators like health status, rejuvenation and safety duplication in long-term storage give an overview of the quality standards of conservation. The distribution activity and its outputs are documented by the number and the types of germplasm distributed, preferred accessions, the share of the total collection distributed, and data on the recipients of the germplasm.

From this description of the genebank outputs, the next methodological step taken towards an evaluation of impacts is the evaluation of the service provided by the ITC through its users, based on direct feedback from its users or clients. An assessment of the quality of different aspects of the service and the comparison with other sources of germplasm is presented. Information on the utilization of the germplasm by the clients then indicates what types of impacts have been created and gives first hints at the magnitude of some of the impacts. An in-depth analysis or even quantification of these impacts are beyond the scope of the study, however, an outlook on possible case studies for the impact assessment is given, based on the empirical results.

4.2 Analysis of costs

In the analysis of the costs, in this study, the genebank approach is applied, following Koo et al. (2004). Cost accounting includes all capital costs for infrastructure and equipment, variable costs for supplies and consumables and labour costs for management, administration and technicians. Also, overhead costs, paid to the hosting institute at KULeuven are accounted for in order to obtain a comprehensive estimate of the total annual costs of the genebank operations.

In order to estimate the long-term costs of maintaining the genebank operations, the in-perpetuity costs for infrastructure and equipment were

calculated, assuming an average period of utilization for any asset and the re-investment in an identical item.

Where possible, costs were directly attributed to the different activities namely the introduction of new accessions, medium term storage of established accessions *in vitro*, the lyophilized leaf tissue collection, the distribution of accessions including the multiplication, handling and shipment costs and long-term storage including multiplication, preparation for the cryopreservation protocols and maintenance in liquid nitrogen.

Capital items used exclusively for one of the activities, for example tanks for cryopreservation or lyophilizers and freezers for the leaf tissue, were included in the cost estimates for these activities. The remaining capital costs for infrastructure and laboratory equipment used for several activities were attributed according to the estimated share of use for each of the activities.

Labour costs for technicians were estimated for each activity, based on records and experience of labour requirements for the specific tasks within the activity. Labour costs for general management, documentation and research were recorded separately and not included in cost estimates of the different activities.

Costs for contracted services were included according to their relevance for the activities, for example, virus indexing for the introduction of new accessions or greenhouse services for the regeneration activity.

An overall cost estimate is provided based on prices in 2007 and standard operations for the current genebank size, as an estimate of funding requirements for maintaining the genebank service at an adequate quality level of performance. Additionally, in scenario analyses, estimates about costs for increasing the number of accessions in the collection over a period of ten years are made, based on estimates for the implementation of a global conservation strategy for *Musa* and complementing the coverage of the *Musa* diversity.

The implications of such expansion of the collection for the per-accession cost for different genebank activities and of the measures for the rationalization of the collection are analyzed using scenario analysis.

4.3 Data used in this study

The presented study draws on a number of different data sets, which will be briefly described in this section:

1) Survey of literature on genebank economics.
2) Genebank generated data managed in the MGBMS, providing key indicator information about the conservation and use of the ITC in terms of:
    a. information on the diversity of germplasm held in the collectionand its health status,
    b. the history of shipments of germplasm since the inception of ITC,

c. receipts of the germplasm and short feedback on the quality of received materials,
d. data on ITC users,
e. data on the intended use of the distributed germplasm by recipients.

3) Information of the costs of the genebank operations from genebank records.

These data serve as the basis for the analysis of costs as outlined above. Additional information of costs was obtained from other sources, for example suppliers of laboratory equipment.

4) Survey of literature referring to ITC accession codes.

5) Users' survey.

A survey among users of the ITC was conducted applying two different procedures: 15 key informants were interviewed, following a semi-structured set of questions. These interviews were administered personally or by phone. The phone interviews were followed up, such that the notes taken during the interview were then sent out per e-mail for approval of the respondent.

The topics discussed during the interviews included the perceptions on the role and the functions of the ITC and on the availability of information about germplasm at ITC. Further questions were asked about the use of the materials received from ITC and the benefits derived. Finally, the respondents were asked to evaluate the service provided by the ITC and to suggest improvements.

The observations from these interviews were then used to design a structured questionnaire for an online survey among all users of the ITC since 2000.

Therefore, from the ITC shipment data, all users who had received germplasm were identified. They were contacted by e-mail and provided with the link to the survey. The survey was offered in English and Spanish language. A total of 218 contact e-mails were sent out, 182 invitations to the English survey and 36 to the Spanish one. A problem was that many e-mail addresses were no longer valid, for example if the person who had requested the germplasm from ITC had changed his working position. Of the Spanish contacts, 17 e-mails were not valid and 59 of the English contacts. For these invalid contacts, contact addresses in the organizations of the users were looked up in the data base BRIS (http://bris.inibap.org/) and new invitation e-mails for the survey were sent out. For those respondents with limited access to the internet, the questionnaires were sent as pdf per e-mail attachment on request, and returned by fax. A total of 63 responses were received corresponding to a response rate of 27%. While this is an acceptable response rate for an online/e-mail survey, for the interpretation of results it has to be considered that those users with positive experiences could be more inclined to respond than those less satisfied.

The data from the interviews with key informants and from the online survey are mainly of qualitative character, indicating the range of different purposes for which germplasm is used and the variety of products that have resulted from the use of germplasm. The client groups of ITC and their needs and perceptions are characterized in more detail. Also, areas of potential improvements in the service are identified, based on problems reported by the users and their suggestions of possible solutions.

From the users' perceptions about the impacts they were able to achieve based on the receipt of germplasm, preliminary benefit estimates can be derived. This information, combined with information about potential alternative sources of germplasm is then used to identify the counterfactual for more detailed case studies on the impacts of ITC in further studies.

Chapter 5. The distribution of *Musa* germplasm since the foundation of the ITC

This chapter presents the description of the distribution activity based on information managed in the genebank database (MGBMS) using key figures for the availability of germplasm for dissemination at ITC, the germplasm health status, demand for traits and distribution of germplasm and a brief characterization of users of ITC.

5.1 Collection holdings at ITC and its health status

Currently, the ITC holds 1212 accessions of *Musa* germplasm, including representatives of 19 wild species, cultivated forms with accessions belonging to 15 groups and 40 subgroups as well as improved varieties represented by diploids (11 accessions), triploids (25 accessions), tetraploids (81 accessions).

The ITC first obtained germplasm from different field collections and later from a number of collecting missions in Asia and East Africa (see Table 5.1). All banana breeding programmes also provided improved material to ITC, for example for the purpose of evaluation of varieties in IMTP. This has been an important factor to make improved varieties available for small scale farmers all over the world.

Finally, accessions are being sent to ITC by other collections, botanical gardens or even private persons interested in collecting.

The availability of germplasm for international distribution is determined by its viral health status. The ITC has always adopted the most restrictive principle that only germplasm that is fully indexed following accepted testing methods (FAO/IPGRI TGSMG) and found to be free of virus and virus-like particles can be released for international distribution.

Until 1992, introductions were indexed for Cucumber mosaic virus (CMV), BBTV and Banana bract mosaic virus (BBrMV). Most of the new acquisitions were received as virus-tested negative materials through the virus indexing centre (VIC) of the Queensland Department of Primary Industries and Fisheries (DPI), Australia. The diagnostic tests to detect viruses were based on serological methods using ELISA and symptom observations during a growth period of 12 months in the VIC screen house.

The procedure was repeated at a second indexing centre in confirmation of the indexing results obtained by the first facility.

In 1994 the TGSMG for *Musa* (Diekmann and Putter 1996) were revised and updated. In the meantime new viruses, BSV and Banana mild mosaic virus (BanMMV) had been described and detection methods developed. Initially, this resulted in a drop back of the available number of accessions from the collection for distribution, since all accessions needed to be virus-indexed, based on the

new protocols. However, since also the testing period at the indexing facilities was shortened and the requirement to double check the materials had become redundant because of the high reliability of the testing methods used, backlogs were made up over a period of seven years (1995-2002), (Figure 5.1, for details see Table B.1, Appendix B).

Table 5.1. Number of accessions at ITC by source and type of genotype

Type of source	Donor	# accessions	Genotypes
Field collections	FHIA, Honduras (1988)	126	wild/cultivated forms
	IITA, Nigeria (1986-1987)	115	AAB-plantain
	IRAZ, Burundi (1987)	54	EA-Highland bananas
	CIRAD, Guadeloupe (1987-1990)	233	wild/cultivated forms
	CATIE, Costa Rica (1986-1989)	23	cultivated forms
Collecting missions	Papua New Guinea (1989-1990)	278	diploid wild/cultivated forms
	Vietnam (1996)	43	wild/cultivated forms
	Tanzania (2002)	21	EA-highland bananas
	DR Congo (2005)	38	semi-dwarf plantains
	Tanzania (2005)	36	EA-highland bananas
Breeding programmes	CARBAP, CIRAD, EMBRAPA, FHIA, IAEA, IITA, INIVIT, TBRC	117	Improved high yielding and disease resistant cultivars.
Others (other collections, botanical gardens, private persons, ...)		157	wild/cultivated forms

By 2005, the whole collection was fully indexed. Hence the indexing activity was focused on the new incoming accessions. A large portion (34.6%) of the collection had been found virus-infected, mainly by BSV (episomal form) in a single or mixed infection with BanMMV. Most plantains, and other natural germplasm as well as improved germplasm with a B-genome of which it is known that they carry the integrated form of a BSV virus are categorized as unavailable for distributions.

In the same period therapeutic techniques were developed for CMV, BBTV, BanMMV and the episomal BSV form, present in A-genome accessions. This has resulted in recent years (2006-2008) in the release of an extra 100 accessions that were cleaned.

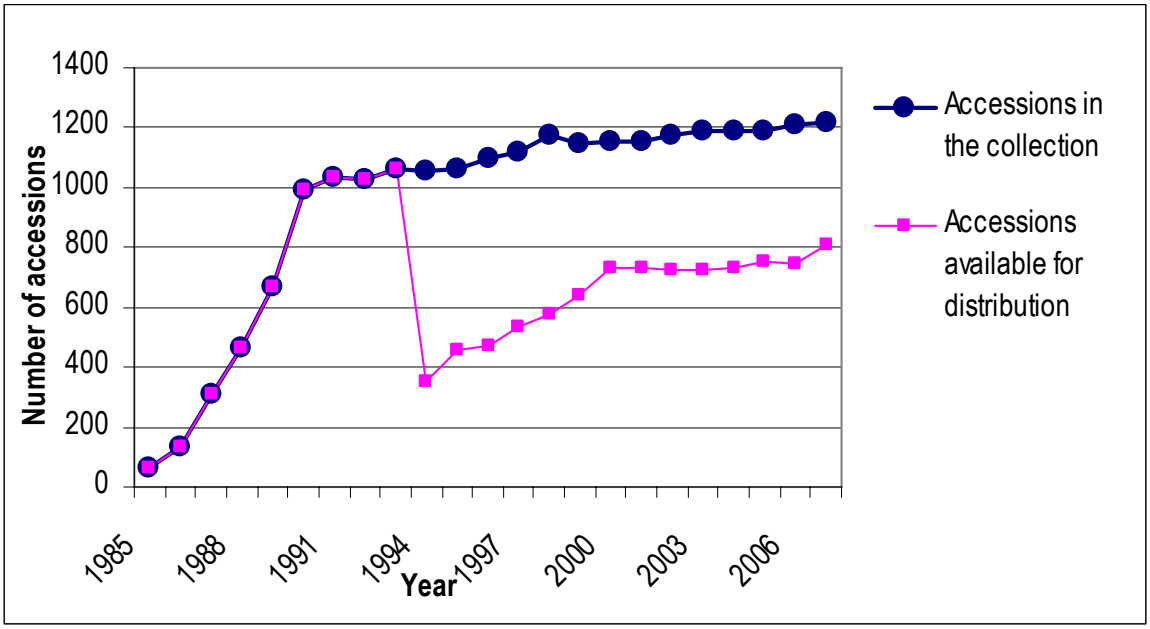

Figure 5.1. Number of accessions in the collection and available for distribution

Currently, the collection holds a total of 1212 accessions among which 810 (66.8%) accessions are classified as virus-negative and hence available for distribution, while 368 (30.4%) are virus positive and cannot be distributed. This latter group mainly contains improved germplasm and cultivars with the B-genome. For a number of 34 (2.8%) recent introductions virus indexing is pending (Figure 5.2).

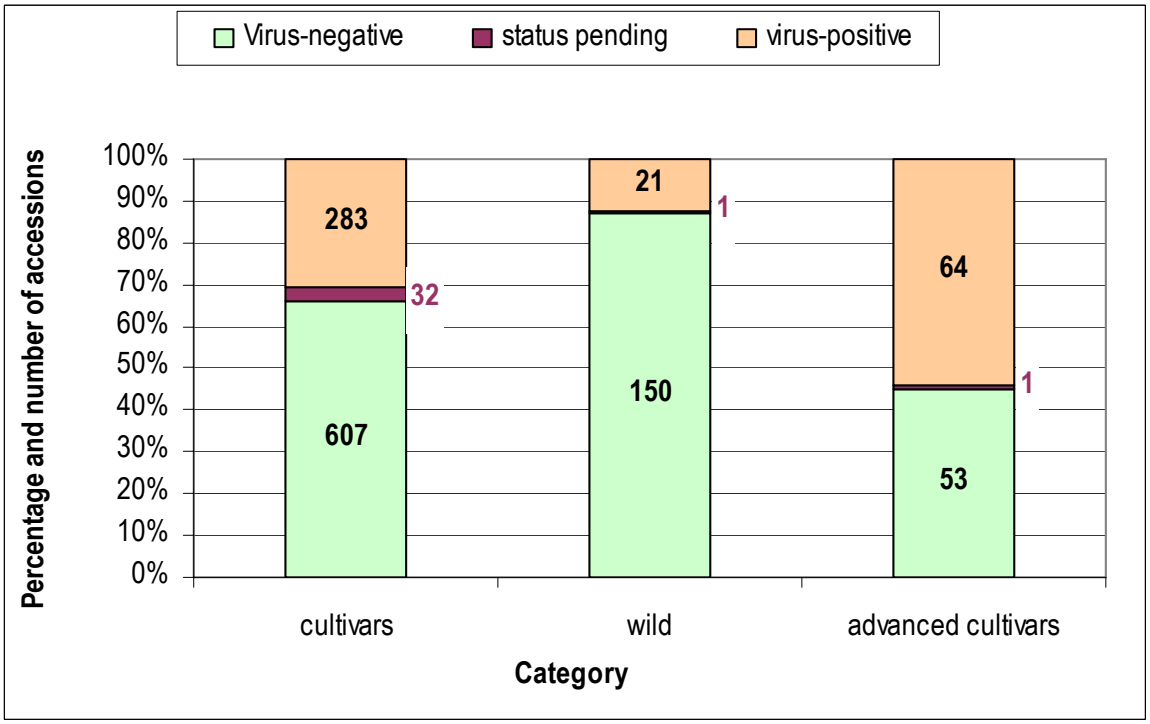

Figure 5.2. Health status of different categories of germplasm in the ITC collection

5.2 Distribution of germplasm since 1985

Analysis of the export data of the past two decades showed that half of the distributions concerned the supply of samples used for studies and activities that underpin the genebank operations. The largest fraction is used in field and laboratory characterization (contributing to an improved documentation status of the collection) health testing of the accessions (virus indexing and therapy), trait evaluation of germplasm within the framework of IMTP, taxonomic studies (MGIS), and safety duplication off-site of the MTS collection (Figure 5.3).

The other 50% of the disseminated samples are supplied upon request to scientists for their banana research, evaluation, conservation and breeding activities. The service is free of charge and therefore the supply is restricted to a limited number of five samples per accession. In the following, distribution always refers to the supply to external users.

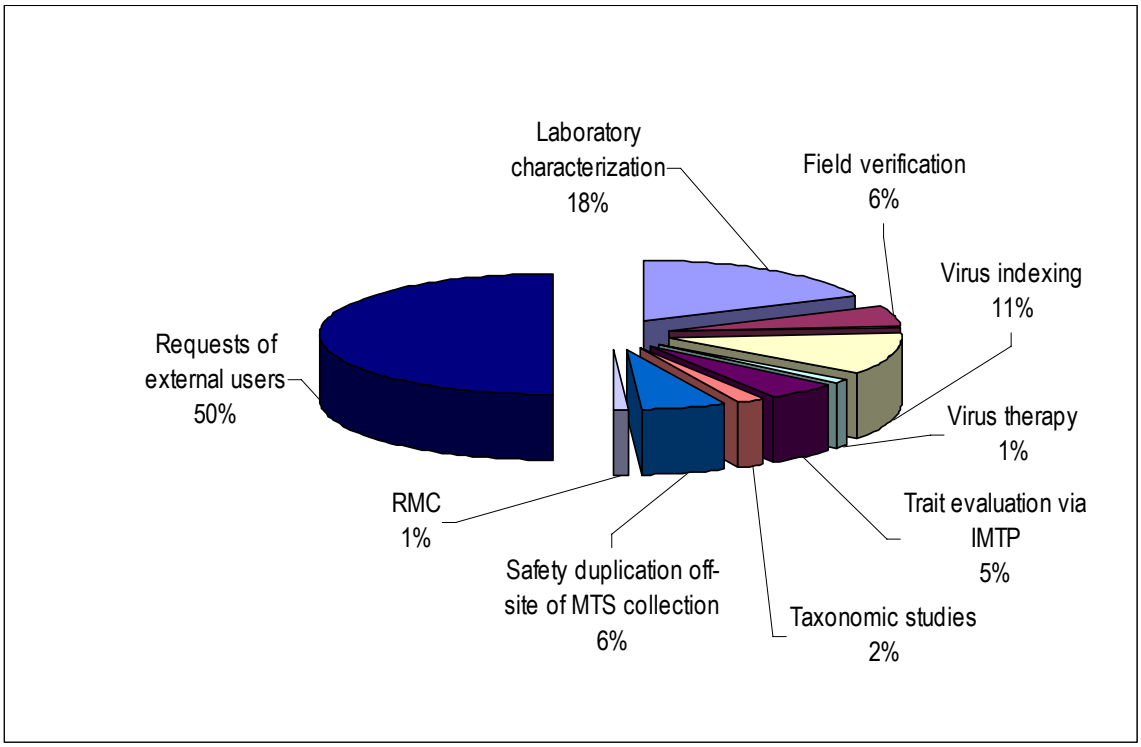

Figure 5.3. Distribution of accessions for genebank services and external users

The genebank receives 70-100 requests annually for germplasm. In response, over the past 22 years, samples of 8353 accessions were shipped to scientists based in 103 different countries in the world. Peaks in the supply of germplasm in 1997 and 2001 are due to the supply of materials for IMTP trials (Figure 5.4).

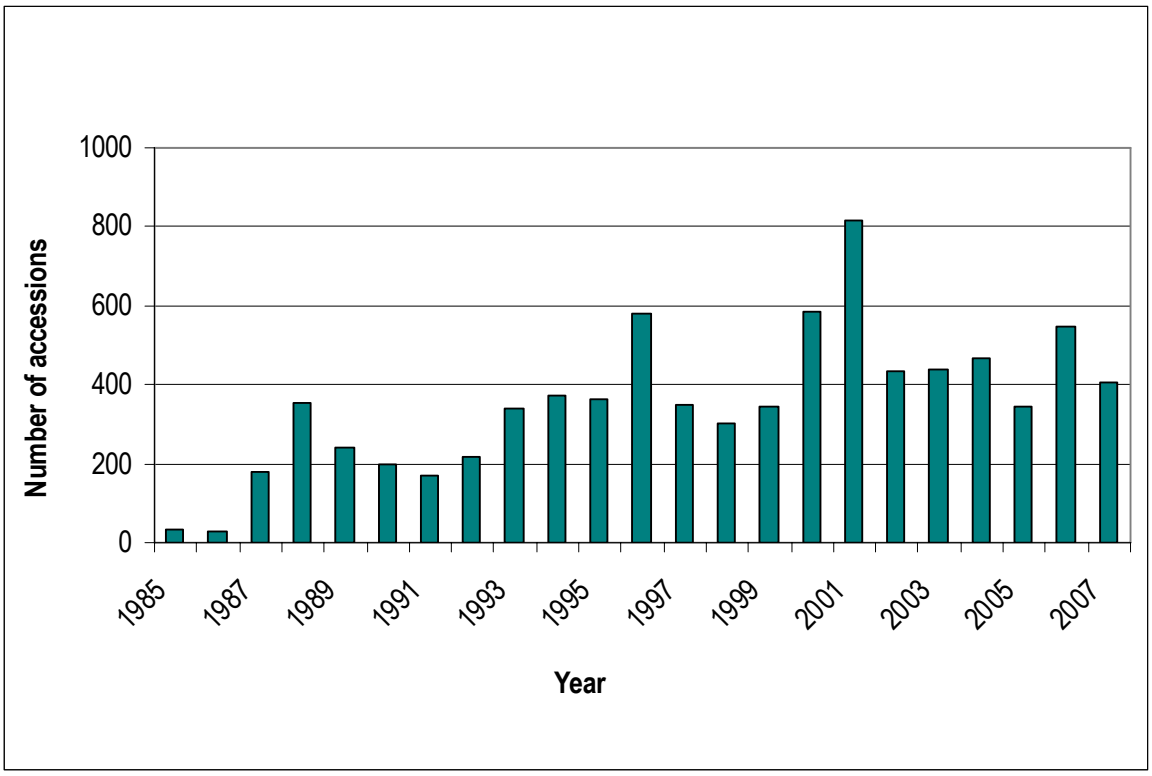

Figure 5.4. Yearly number of accessions distributed since 1985

The number of demanded accessions per request varies considerably. On average eight accessions are supplied. Larger sets of samples are sometimes requested by universities and advanced research institutes for molecular (genetic and characterization) studies.

Because of financial constraints (labour and shipping costs) the supply is usually restricted to a maximum of 35 accessions in agreement with the requestor, however in exceptional cases higher numbers are made available. In the latter case, it is agreed with the requestor to reduce the number of supplied samples per accession, in order to compensate for the preparation and shipping costs.

The analysis of the distribution data shows a steady increase in the demand by external users for samples of *Musa* genetic resources over the years (Table B.1 in Appendix B). At the same time a slight increase in the number of different accessions requested occurred, which is likely to be related to an increasing number of accessions that became available for users after virus indexing (data 1994-2007). However, many accessions are still poorly documented in MGIS, with only passport data available, which in some cases is incomplete. This may result in underutilization of the available diversity. An intensification of the characterization activity in recent years and an increased effort to document each accession with a minimum set of pictures will contribute to a better documentation status of the preserved genetic resources. Better documentation is

expected to result in an increased demand for a broader spectrum of materials for utilization in the coming years.

The utilization ratio of the collection at ITC is significantly higher as for the average of only 10% of all genebanks as reported by FAO (1997). Since its establishment, 1026 different accessions representing 75% of the total genetic resources ever kept at ITC have been accessed at least once by user. Looking at the yearly use of the collection the analysis of the number of distributed accessions revealed an average utilization ratio[6] of 22% (Figure 5.5). Considering only the fraction of the collection that is accessible for distribution, samples of 33% of the available accessions (tested negative) are distributed.

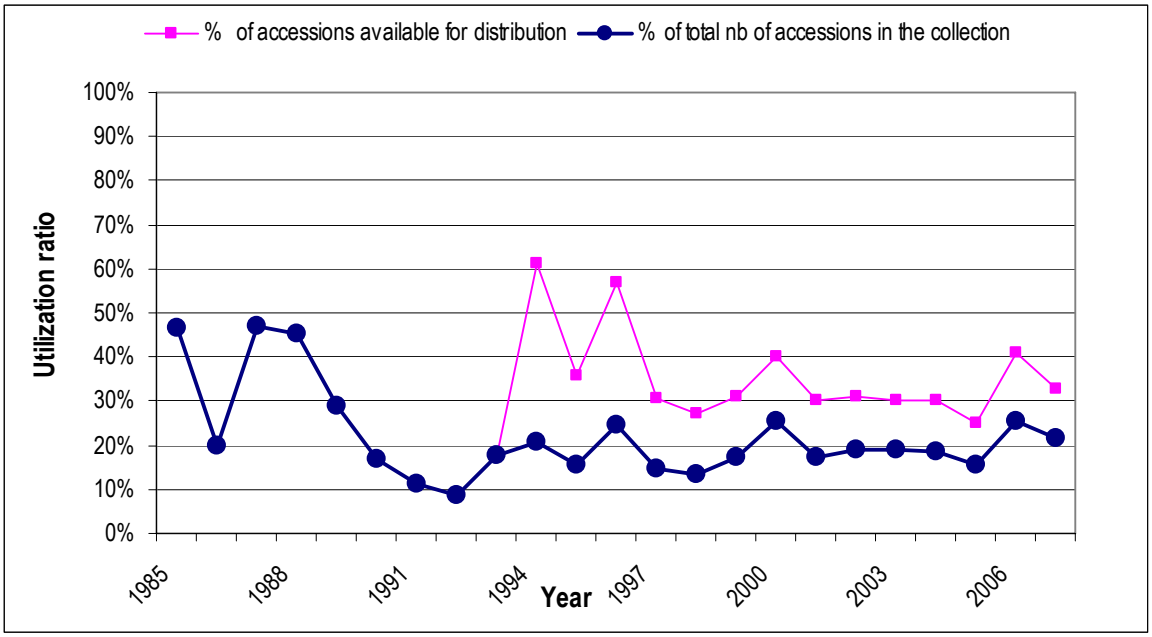

Figure 5.5. Yearly utilization ratio[6] of the collection

5.3 The users of ITC

Analysis of the distribution records kept over the past 22 years revealed that the *Musa* germplasm is intensively requested by different types of users, with most of them being active in the public sector. The germplasm distribution service answers mainly demands from users in developing countries (62%). The remaining 38% of the distributed germplasm is destined for developed countries. Figure 5.6 shows the overall distribution of germplasm since 1985 according to the geographical regions. The figure gives an indication of the importance of

[6] The utilization rate is calculated as number of distributed accessions in the respective year divided by the total number of accessions in the collection (blue line) or divided by the number of accessions available for distribution (virus-indexed, red line) in that year. Until 1998, before virus-indexing techniques were available, all accessions in the collection were available for distribution.

research in the banana growing zones with equally one quarter distributed to each of the banana areas: the Americas (North, Central and South America), Asia and the Pacific and the African continent (12% to West and Central Africa and 15% to East-Africa). Only one quarter of the germplasm samples are destined for users in Europe, mainly at universities and advanced research centres. Details about the distribution to the regions in different years are provided in the appendix B (Table B.2).

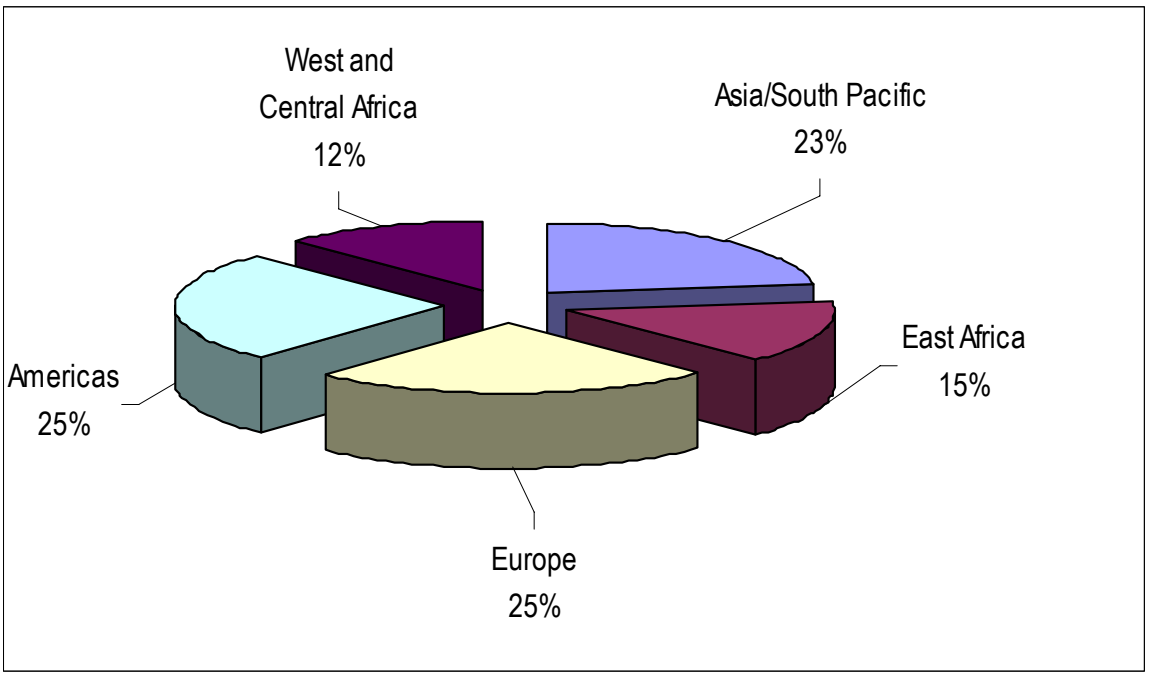

Figure 5.6. Geographical distribution (export per region)

Figure 5.7 shows the users by type of organization. National institutions of agricultural research and advanced research institutes including universities, both in developed and developing countries are the largest groups of recipients. Samples of *Musa* accessions are also frequently used by other international agriculture centres including the CGIAR[7] centres, where the materials are used for breeding activities or added to their collection. The ITC also distributes materials to commercial companies and regional organizations like the Institut de recherches agronomique et zootechnique (IRAZ), the Centre africain de recherches sur bananiers et plantains (CARBAP), while not more than 5% were distributed to non-affiliated users, NGOs and other kinds of organizations, mostly in search of materials with superior productivity related traits and disease resistance traits.

[7] CGIAR centres which have received germplasm are IITA (813 accessions), CIAT (17 accessions) and Bioversity International/IPGRI (13 accessions).

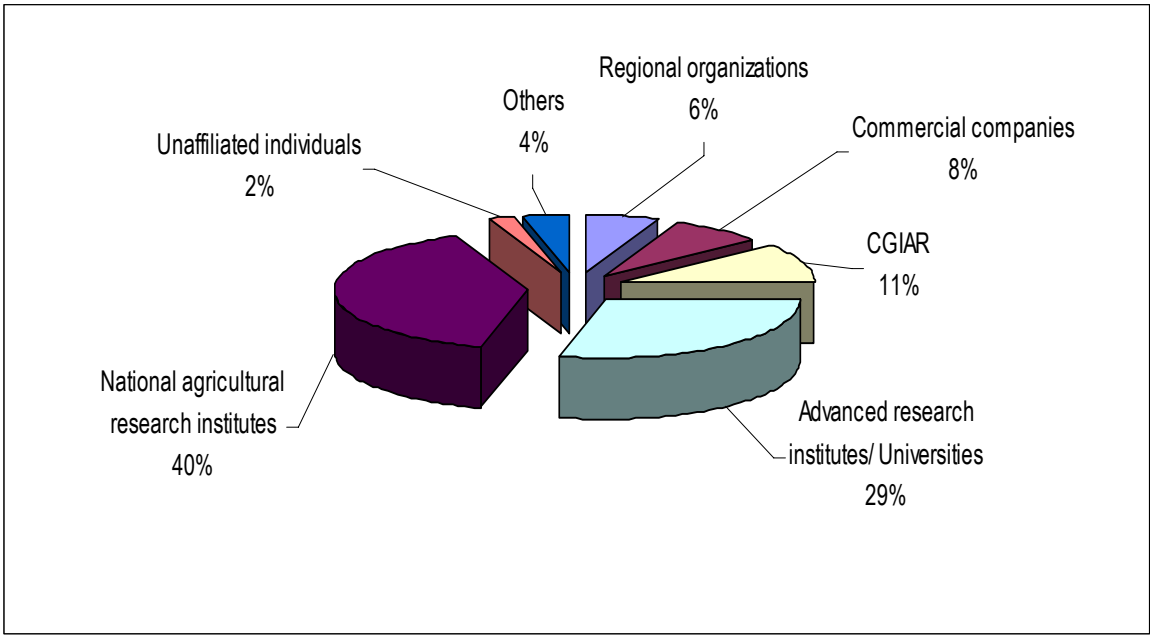

Figure 5.7. Users of ITC by type of organization

5.4 What kind of germplasm is requested? For what purpose?

Nearly two thirds of the demands concerned cultivated forms, landraces mainly of local importance, and cultivars that are widely grown and intended for trait evaluation, mainly biotic stress resistance or tolerance and agronomic traits and fruit quality. Improved cultivars from breeding activities are demanded for their superior yield and disease resistance characteristics and account for 20% of the distributed materials, while 17% of the disseminated germplasm are wild relatives, serving as a source of potential valuable genes in breeding activities and for fundamental taxonomic/phylogenetic studies (Figure 5.8).

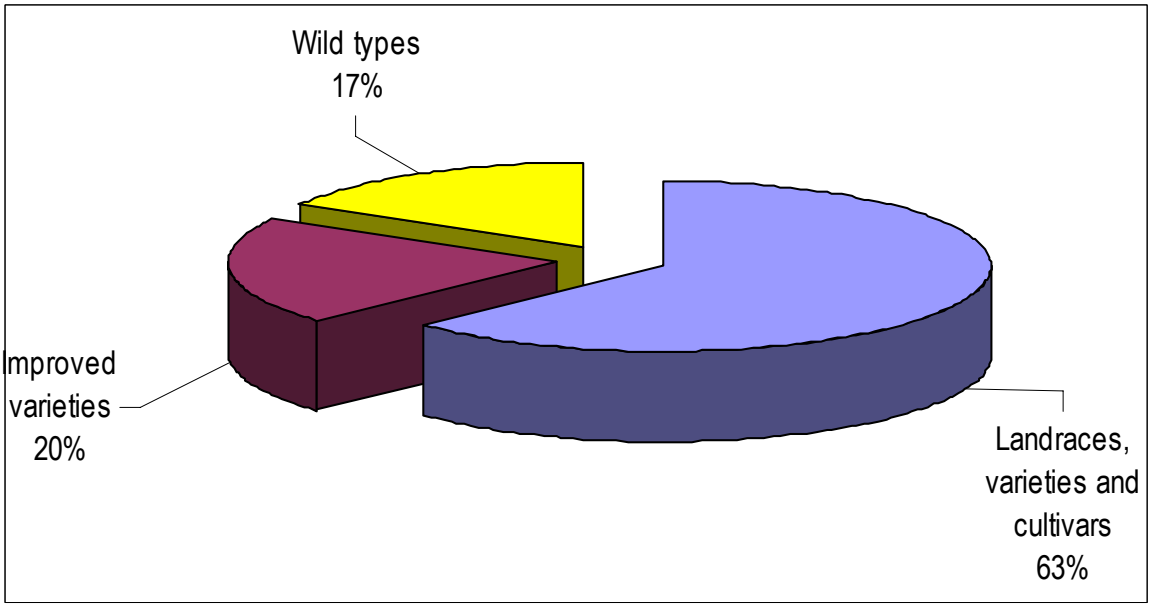

Figure 5.8. Share of different categories of germplasm distributed

The distribution of germplasm of different categories is related to the diversity of germplasm in the collection (Figure 5.9). Landraces, traditional varieties and cultivars are the largest category held at ITC. Demand for improved materials has been relatively high, compared to the low numbers of accessions represented at ITC. This may be explained by the fact that the improved materials have been evaluated more intensively and much more information about agronomic traits and resistance to biotic and abiotic stresses is available, as compared to the other categories.

The utilization ratio per category illustrates the constant and high interest in wild species for breeding and fundamental research (Figure 5.10).

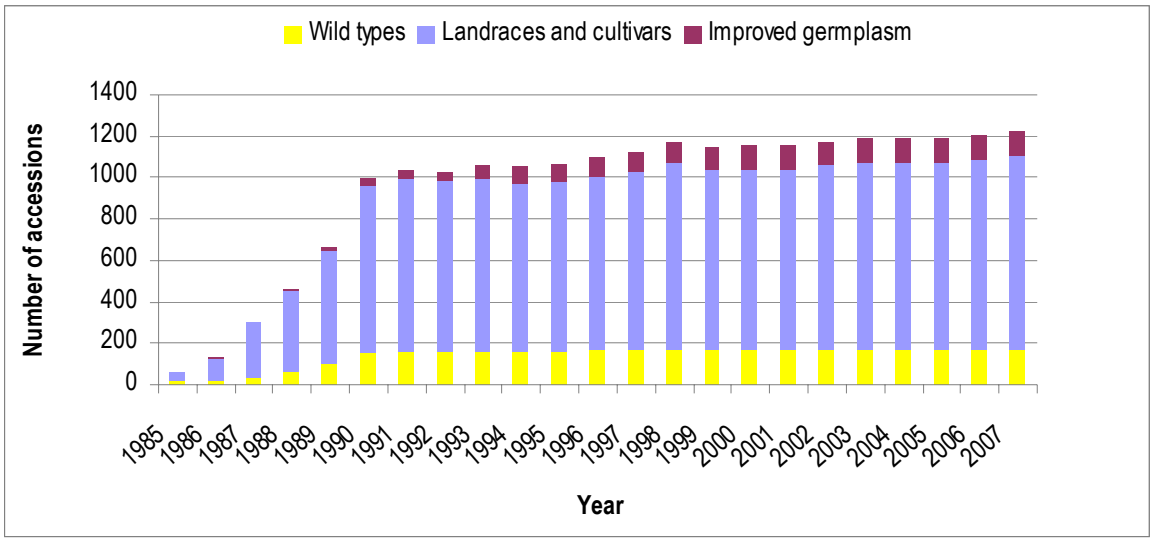

Figure 5.9. Collection holdings of different categories of germplasm over time

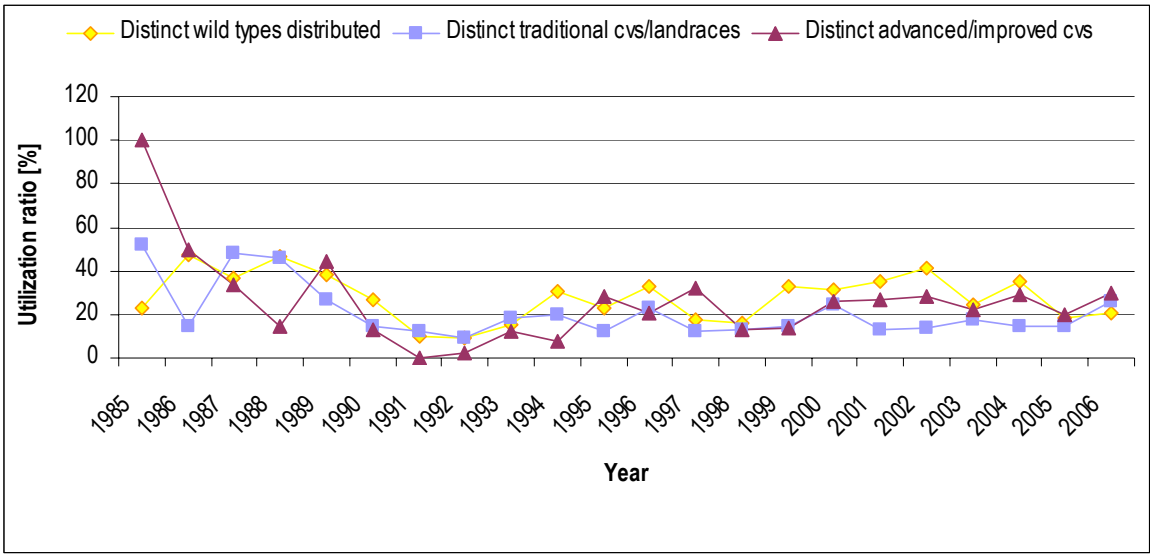

Figure 5.10. Utilization ratio as number of different accessions distributed per category of germplasm

Analysis of the frequency of distribution of individual accessions shows that BLS resistance and higher productivity are the most demanded traits in cultivated materials. Particularly, a whole range of improved varieties from the Fundación Hondureña de Investigación Agrícola (FHIA) breeding programme, with BLSD resistance were widely distributed. The cultivar 'Yangambi km5', that is known to be highly resistant to BLSD, resistant to Sigatoka leaf spot and FW race 1 and to nematodes, is frequently demanded, followed by accessions of the commercial AAA-cultivars ('Cavendish' and 'Gros Michel' subgroup). Table 5.2 shows how over time the demand for improved germplasm has increased (from 0% to 77% total requests), together with a general increase in the number of accessions distributed (from 87 to 564).

In terms of the type of material, the ITC distributes proliferating tissue cultures, which require handling in *in vitro* laboratories, and rooted plantlets suitable for direct transfer to a nursery. The largest share of requests has been for proliferating tissue cultures, indicating the availability of laboratory facilities (Figure 5.11). Since 2006, lyophilized leaf tissue can also be requested for molecular studies (DNA). The collection of freeze-dried leaf samples was established to serve molecular researchers. Since then demand has been growing and reached about 16% of total distributed samples in the period 2003 to 2007 (see Figure 5.11). Demand is expected to increase further, as the number of accessions and genetic diversity represented in the lyophilized collection will increase.

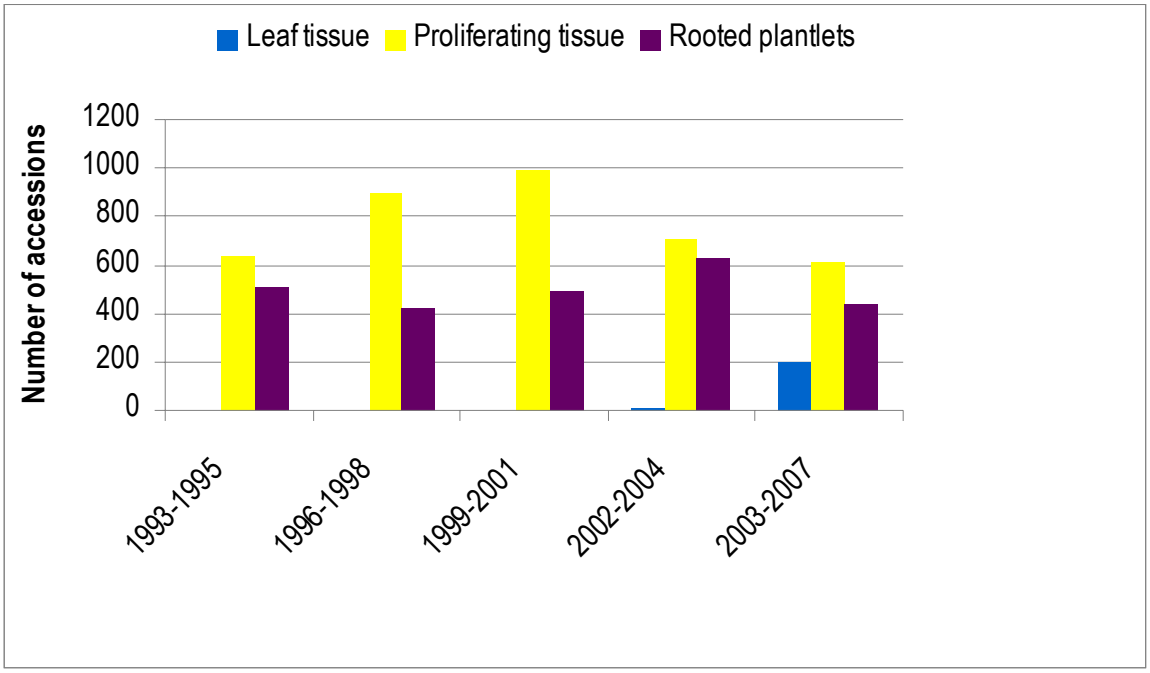

Figure 5.11. Types of materials distributed

Table 5.2. The 10 most frequently demanded accessions over five-year periods

Period	ITC code	Name	Group,subgroup Species, subspecies	Type	Frequency of distribution
1985-1990	0101	Fougamou 1	ABB 'Pisang Awak'	cv	16
	0010	Bluggoe	ABB 'Bluggoe'	cv	12
	0107	Figue Sucrée	AA 'Sucrier'	cv	11
	0061	*Musa basjoo*	*Musa basjoo*	w	9
	0124	Yangambi km5	AAA 'Ibota'	cv	9
	0001	Pisang Lilin	AA 'lidi'	cv	8
	0043	Champa Nasik	AAAA 'Gros Michel der.'	cv	8
	0048	Valery	AAA 'Cavendsih'	cv	8
	0213	Pisang Awak	ABB 'Pisang Awak'	cv	8
	0249	Calcutta 4	*M. acuminata* ssp. *burmannicoides*	w	8
1991-1995	0504	FHIA-01	AAAB	Imp	47
	0505	FHIA-02	AAAB	Imp	47
	0506	FHIA-03	AABB	Imp	46
	1123	Yangambi km5	AAA 'Ibota'	cv	41
	0653	Pisang Mas	AA 'Sucrier'	cv	29
	0249	Calcutta 4	*M. acuminata* ssp. *burmannicoides*	w	24
	0650	Pisang Ceylan	AAB 'Mysore'	cv	24
	0472	Pelipita	ABB 'Pelipita'	cv	21
	0570	Williams (Bell, South Johnstone)	AAA 'Cavendish'	cv	18
	1138	Saba	ABB 'Saba'	cv	18
1996-2000	1123	Yangambi km5	AAA 'Ibota'	cv	58
	0504	FHIA-01	AAAB	Imp	55
	1256	Gran Enano	AAA 'Cavendish'	cv	46
	1265	FHIA-23	AAAA	Imp	40
	1297	TMBx 5295-1	AAAB	Imp	39
	0506	FHIA-03	AABB	Imp	38
	0505	FHIA-02	AAAB	Imp	36
	1122	Gros-Michel	AAA	cv	32
	1296	TMBx 1378	ABBB	Imp	32
	1293	TMPx 4479-1	AAAB	Imp	30

Table 5.2. The 10 most frequently demanded accessions over five-year periods (cont'd)

Period	ITC code	Name	Group,subgroup Species, subspecies	Type	Frequency of distribution
2001-2005	1332	FHIA 21(#68)	AAAB	Imp	71
	1265	FHIA-23	AAAA	Imp	65
	1418	FHIA 25	AAB	Imp	61
	0504	FHIA-01	AAAB	Imp	57
	1319	FHIA 18	AAAB	Imp	56
	1123	Yangambi km5	AAA 'Ibota'	cv	55
	0249	Calcutta 4	*M. acuminata* ssp. *burmannicoides*	w	52
	1264	FHIA-17	AAAA	Imp	50
	1344	CRBP 39	AAAB	Imp	50
	0506	FHIA-03	AABB	Imp	47

Chapter 6. Utilization of germplasm and impacts created

In this chapter, details on the utilization of germplasm by the clients of ITC are presented and the impacts that have been created based on the receipt of the germplasm are described. Related to the utilization of germplasm in research projects is the use of ITC codes in publications for reference. Therefore an indicative literature review is provided in this chapter to describe the impact of ITC with respect to the function as international reference collection. The chapter is divided into three sections, first, the qualitative analysis based on interviews with key informants (15 respondents); second, and more quantitative results from a formal survey among users of the ITC, who received germplasm in the time period between 2000 and 2007 (63 respondents); and third the results of the literature review.

6.1 Key informants

The objective to have personal interviews with key informants was to obtain an overview of perceptions of the role and the service provided by ITC. Personal interviews were conducted in August 2007 during the meeting of the Banana Research Network for Eastern and Southern Africa (BARNESA) in Dar Es Salaam, Tanzania and a visit to the Crops Research Institute (CRI) in Kumasi, Ghana in March 2008. Other interviews were conducted by phone during March to May 2008. The respondents for the key interviews were chosen based on recommendations by the regional coordinators of the banana research networks in Southeast Asia (BAPNET), Africa (BARNESA and MUSACO) and Latin America (MUSALAC). The sample includes seven respondents from East and Southern Africa, two from West Africa, five from South East Asia and the Pacific and one from the US.

The interviews were semi-structured, following an outline that covered the following topics:

- Perceptions on the role and functions of ITC
- Use of ITC and purpose of requesting
- Impacts and beneficiaries
- Evaluation of service provided
- Perceptions on information available
- Germplasm from other sources
- Suggestions for improvements of the service provided.

Since the sample of respondents is not representative and the questions could change according to the focus of the respondent, in this section, a summary and overview of the responses is reported. These qualitative results were used to

design the questionnaire to be applied to the larger sample of the survey presented below.

6.1.1 Perceptions of the role and functions of ITC

The importance of ITC is seen in the central role of the genebank in the conservation of *Musa* germplasm on a global level, pointing to the safety and reliability of the conservation *in vitro* and cryopreservation and the size of the collection. All respondents acknowledged that the ITC collection is the largest collection of *Musa* germplasm on a global level. However, with regards to the diversity conserved, several respondents expressed their concern that the collection does not yet represent the genetic diversity of banana sufficiently and should be expanded in a strategic way, especially with regards to wild *Musa* species.

In terms of the germplasm distribution activity of ITC, the fact that the material is virus-indexed and is accompanied with the respective documentation was most important to the respondents. They also stressed the relatively easy and cheap access. Many pointed out that ITC for them was the only source of germplasm where material was supplied free of charge. This aspect was especially important to scientists from national agricultural research institutions in developing countries. Two respondents mentioned the well-defined legal framework for sending and receiving germplasm as important to them.

Interestingly, several respondents, although mentioning the free and easily accessible distribution service provided by ITC, stated that they would prefer the germplasm to be conserved within the regions, feeling that access would still be easier. This might be related to the preferences for conservation in the field in national or regional collections and the possibility for the researchers to visit and see the plants before requesting it for own use.

6.1.2 The use of ITC and purpose of requesting germplasm

The most frequent purpose of using germplasm from ITC mentioned by the key informants was the evaluation of agronomic traits, especially disease resistance, and the subsequent distribution of promising cultivars to farmers for local consumption and domestic markets. Disease resistant material was seen as an important measure for preventing the spread of new diseases. The aim to increase production of bananas with good processing qualities was mentioned by four respondents. Other objectives included the use of the germplasm in breeding programmes, and the completion of the own collection. Congruent with the purposes of utilization of the germplasm, the most interesting materials for the key respondents were: improved cultivars like the FHIA or other hybrids; landraces with preferred taste for local consumers and clones with specific disease resistance characteristics.

6.1.3 Impacts and beneficiaries of germplasm received

The ultimate beneficiaries of the germplasm received from ITC, according to the respondents have been farmers and especially small scale farmers. However, it was also pointed out that the research institutions benefited in terms of easier access to a diversity of banana germplasm. One respondent from East Africa pointed out that there was no other way to access improved and superior banana germplasm except from ITC, because no individual breeding programme could be maintained and other sources of elite germplasm were perceived as too expensive.

The impacts created refer to increased banana yield and disease prevention. For several countries, respondents stated that the use of virus-indexed material from ITC helped to prevent the spread of new diseases, as compared to germplasm from other sources. Often, increased production at the farmer level was reported to lead finally to higher farm incomes, where surpluses could be sold via local markets. It was also mentioned that the supply to the processing industry for products such as chips and juices was improved, which in the long term benefited all actors in the value chains, including producers and consumers.

Another type of impact was created in the field of research and capacity building. Some respondents referred to student's thesis on MSc and PhD level with ITC materials, others mentioned general progress of knowledge available for example on banana diseases or molecular characterization.

6.1.4 Evaluation of service provided

The service provided by ITC was rated "very good" by most respondents. In some cases, problems were encountered with establishing the material in the field, including slow growth and deficient root system development. Some materials were even lost before they could be used. One respondent felt that more samples per accession should be provided, to reduce the risk of loss of material. In some specific cases, off-types were reported by the respondents. Difficulties with establishing the *in vitro* plantlets in the nurseries and finally in the field may also be one of the reasons, why some respondents expressed a preference for having regional field collections, as mentioned above.

In some cases, infection with BSV was reported even for fully indexed germplasm. This can be explained by the virus characteristics: Some accessions (with B-genome) that were tested virus-negative, when cultured *in vitro*, may develop BSV infection after. This is also mentioned in the germplasm accompanying health statement document. While some respondents advocated more scrutiny to avoid the spread of the virus, others saw the problem in the national quarantine, where the germplasm had tested positive. They would still have wished to receive the germplasm and even proposed to skip testing by national authorities, once the accessions are virus-indexed by ITC.

The requesting procedure was perceived as adequate by most respondents.

6.1.5 Perceptions regarding information availability

A major weakness of ITC was perceived in the area of information availability about the germplasm held at ITC. Respondents found it difficult to select germplasm for their purposes, expressing the need for much more characterization and especially evaluation data. Disease resistances, the reaction of cultivars to different climatic and soil environments and tolerance to abiotic stress are of high interest for those who aim at providing farmers with improved/better adapted varieties. It was also mentioned that good photos of bunches and plants as well as data on nutritional qualities and taste would be very helpful. The information sources used by the respondents include catalogues like *Musa*logue[8] and the online database MGIS. Some respondents expressed a preference for electronic sources in the internet; others have only limited access to the internet and rely on hard copies. Several respondents indicated that MGIS was useful to them to look up where to access the germplasm, once they had decided which accessions to request. For the identification of suitable germplasm for their purposes, MGIS was perceived as less helpful. Several respondents rely on conferences, meetings and personal communication to identify germplasm of interest for them.

6.1.6 Germplasm from other sources

For most respondents (13 out of 15), ITC was the most important and most recent source of germplasm. However, germplasm was also received from other collections, either the national collections or other international collections like CIRAD, from breeding programmes such as IITA and FHIA, or even from own collecting missions. Several respondents stated that they avoided requesting material from sources other than ITC because of the risk of viruses or diseases.

Yet, there is germplasm which respondents would wish to receive but is not available from ITC. The most important reasons included backlogs in virus-indexing at the time when they requested the material or the BSV problem, which renders the accessions unavailable for distribution. Also, reference was made to potentially interesting germplasm not yet covered in the collection, for example, clones with specific disease resistance or cultivars mainly from some Asian countries, which has not yet been shared with ITC.

6.1.7 Suggestions for the improvement of service

Suggestions were made with regard to the conservation, distribution and information activities of the genebank.

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[8] Musalogue is a catalogue of Musa germplasm articulating the diversity of the Musa genus, produced by Bioversity International (formerly INIBAP/IPGRI) in collaboration with CIRAD; CTA; CARBAP; NARO, Uganda; NRCB, India, and QDPI, Australia- see:
http://bananas.bioversityinternational.org/files/files/pdf/publications/musalogue2.pdf

Concerns were raised about the fact that the germplasm at ITC is conserved *in vitro* only, which might lead to the development of off-types. Respondents suggested establishing reference collections in the regions, with the most important accessions backed-up in field conservation. Also, several respondents pointed out that ITC should be pro-active in expanding the collection, especially targeting wild species, which were felt to still be underrepresented.

For the distribution, concerns were raised about the health status of the collection with respect to BSV. One issue is the fact that a significant part of the collection is not available for distribution due to BSV infection. The other concern is that the virus may be found even in accessions that are healthy according to virus indexing.

Those respondents who had reported about problems with cultivating the germplasm received from ITC proposed to increase the sample size per accession. They also proposed changes in the cultivation measures to enhance the development of the root system. Also, some respondents expressed a need for capacity building for tissue culture of *Musa* germplasm in the regions and suggested that ITC and Bioversity supported such activities.

With respect to information management and availability, closer collaboration with other collections of *Musa* germplasm was proposed. Respondents suggested creating channels for regular updates on the ITC activities and new germplasm available, for example electronic newsletters. Another suggestion was that a new edition of the *Musa*logue and updated versions of MGIS on the internet and as compact disks to be made available.

The role of Bioversity, namely the Bioversity Commodities for Livelihoods programme (formerly INIBAP) in organizing banana research networks was underlined explicitly by several respondents. They pointed out that the conservation of *Musa* genetic resources should not rely only on one genebank, but the collaboration with national partners and collections was crucial to secure the standard of conservation as well as to maintain close relations with the users of ITC and meet the demand for germplasm.

6.2 The survey respondents

Of the 63 respondents who answered the on-line survey, a relatively large share is from Europe or North America. The second largest group is from Asia and the Pacific, followed by Africa and Latin America. That Europe and the US are overrepresented in the survey respondents may be related to easier access to electronic communication, however the list of respondents' countries demonstrates that respondents in less-favoured countries also could be reached for example in Burundi, Haiti, Madagascar, Marshal Islands or Democratic Republic of Congo.

Table 6.1. Respondents of the on-line survey according to region

Region	Number of respondents	% of respondents	Number of different countries
Latin America and the Caribbean	7	11.1	7
West and Central Africa	4	6.3	3
East and Southern Africa	6	9.5	5
Asia and the Pacific	12	19.0	9
Europe and North America	21	33.3	11
No data	13	20.6	n.a.
Total	**63**	**100**	**35**

The distribution of respondents by type of organization corresponds roughly with the profile of users as registered in the ITC export data (see section 4.3). The response rate of national research institutes (15.3%) is relatively lower; however these institutes are well represented in the sample of key informants.

Table 6.2. Survey respondents according to type of organization

Type of organization	No of respondents	% of respondents
Advanced research institute	6	9.5
University	21	33.3
National research institute	9	14.3
Genebank	1	1.6
Non-governmental organization	2	3.2
Farmer	1	1.6
International Agricultural Research Centre	4	6.3
Commercial company	5	7.9
Unaffiliated individual	2	3.2
No data	12	19.0

Most of the respondents have executive positions in their organization, as professors, senior scientists, and directors of the research programme or head of the research unit or company.

6.2.1 Utilization of germplasm

The most frequently mentioned purposes for requesting germplasm were the multiplication for dissemination and the evaluation of agronomic traits, which then often was linked to the dissemination of selected superior cultivars (Figure 6.1).

This illustrates that banana breeding is carried out by few organizations only and for many countries, ITC is the only viable access to improved germplasm, as already explained by some of the key informants (see above). Morphological or molecular characterization was another frequently mentioned purpose for which germplasm was requested from ITC. About 9% of the respondents mentioned to have used the materials for breeding or evaluation for breeding purposes.

Approximately equal proportions of the respondents were involved in applied and fundamental research and conservation activities, the latter include in field conservation as well as *in vitro* and to a minor extent cryopreservation (Figure 6.1).

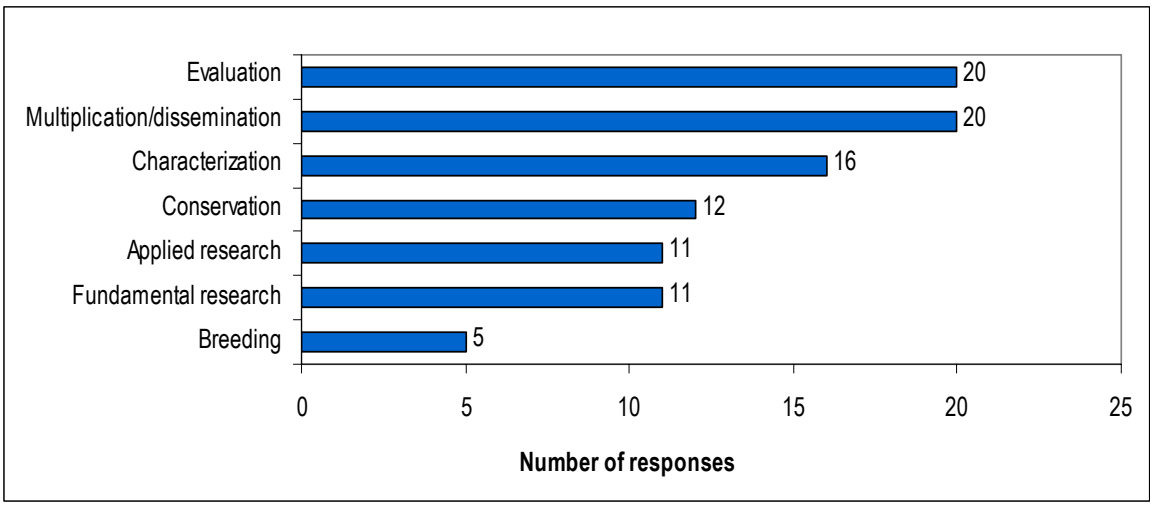

Figure 6.1. Purposes of germplasm request (*Multiple answers possible*)

For those evaluating germplasm for agronomic traits, the most frequently mentioned trait was tolerance to biotic stress (30%), including diseases like *Mycosphaerella* leafspot and Fusarium wilt and other pests, for example nematodes (Figure 6.2). The adaptation of the material to specific local conditions and consumer acceptability ranked second in evaluation interests (24%), followed by yield characteristics (15%) and tolerance to abiotic stress like wind, cold and drought tolerance (13%). Other traits of interest refer to fundamental research questions (13%) like the physiology of the development of the root system as an example. Pre-breeding evaluation studies were mentioned by 5% of the respondents.

Germplasm requested for dissemination was distributed either directly to farmers or alternatively to extension services and NGOs for further distribution.

More than 50% of the respondents, who received germplasm from the ITC in the past seven years, are still keeping the germplasm (Figure 6.3). A minor share of respondents explained that the original research projects are still ongoing (two respondents); others indicated that the germplasm will be useful for future

studies or that conservation of germplasm is part of the mandate of the institute. For maintaining the germplasm, most respondents plant it in the field and in the greenhouse. Many respondents also have the capacity to maintain the germplasm *in vitro*, often with the aim to back up the field material.

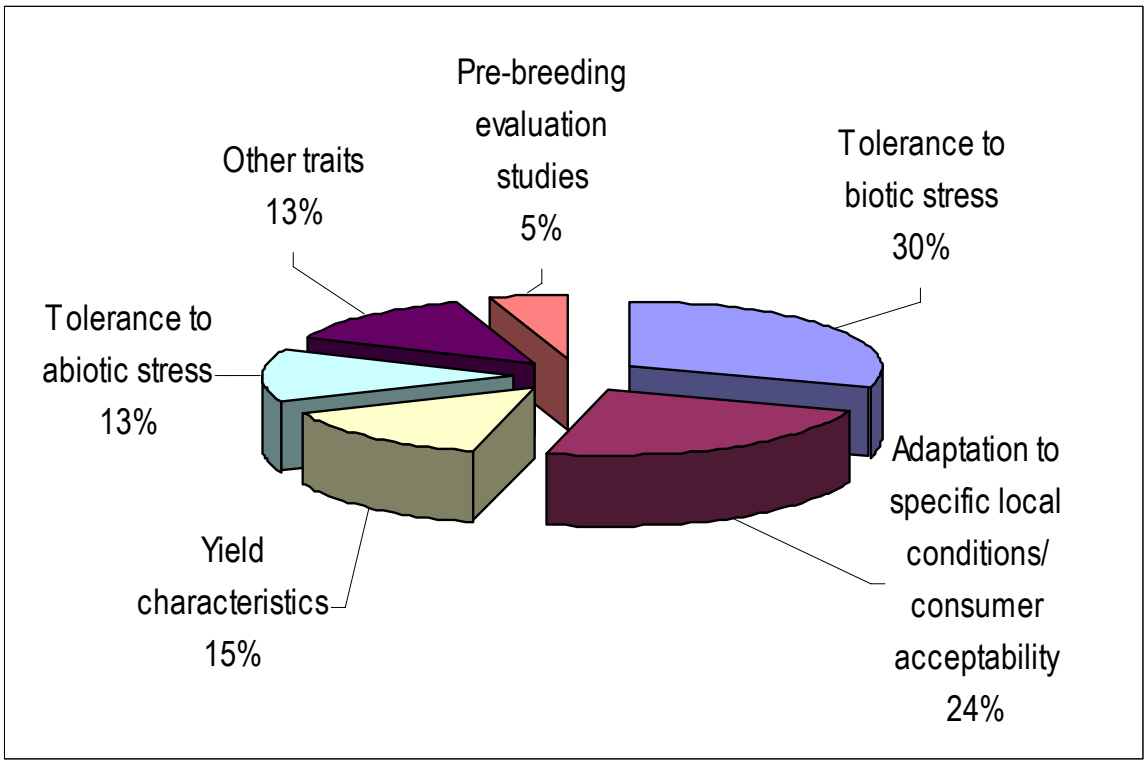

Figure 6.2. Traits of interest in germplasm evaluation

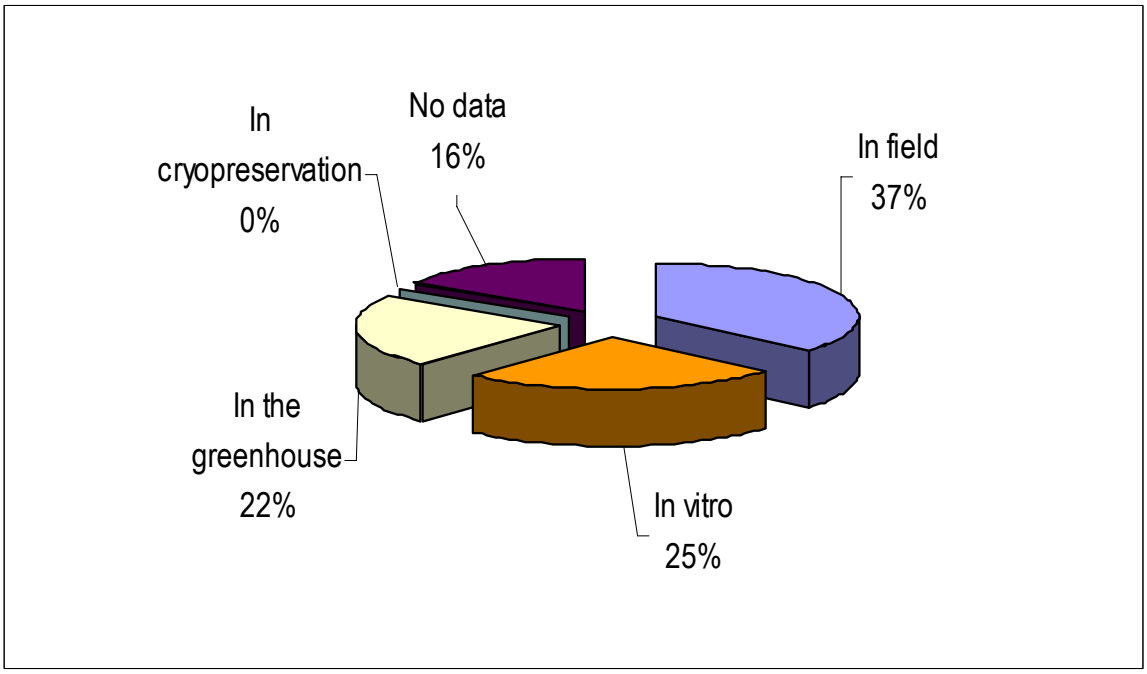

Figure 6.3. Germplasm conservation methods

Of those institutes who discarded a proportion or all of the germplasm received from ITC, some changed or terminated their research programme. Others lost germplasm due to problems encountered in tissue culturing the germplasm, or destroyed trials after discovering virus infection.

6.2.2 Outcomes and types of impact of germplasm from ITC

In this section, the outcomes of the research carried out with germplasm from ITC and the expected impacts are described. When asked to identify the beneficiaries from the receipt of the germplasm, most of the respondents focus on banana farmers, either as direct or indirect beneficiaries (Figure 6.4). Direct benefits to farmers are created through the distribution of improved planting material. Indirectly, farmers benefit from the results of research projects, on the medium or long term. In the sector of banana industries, more benefits were seen by the respondents for the producing industries than for banana processing industries. About 13% of the respondents indicated benefits also for the consumers. However, many respondents (46%) pointed out that the primary beneficiaries of their research were not the actors of the banana value chain (farmers, processing industries, consumers) but rather other researchers or the banana scientific community, yet maintaining the vision of long-term benefits to farmers, for example with respect to using their results for identifying possibilities of genetic improvement.

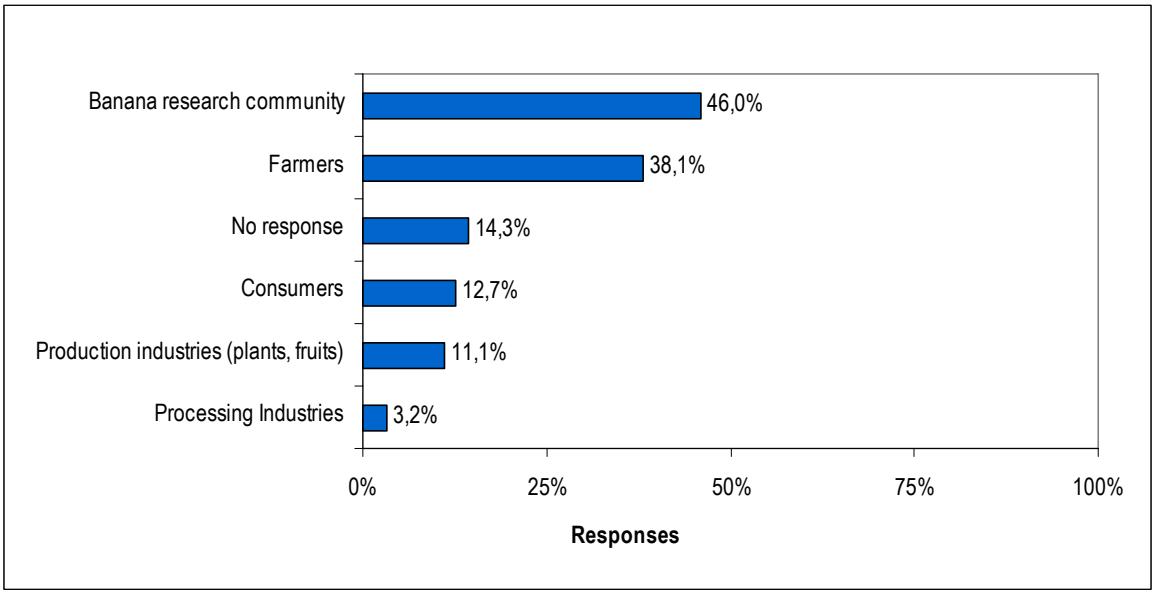

Figure 6.4. Germplasm beneficiaries as indicated by survey respondents

The range of answers to the question of how many farmers might have benefited from the germplasm received, shows the very different visions of the respondents about the impact. Some included only those farmers who directly collaborated in a project, mentioning for example only 12 or 50 farmers who

benefited. Others are more confident about up-scaling impact, stating that many or even all banana farmers of the country benefited. In total, 23 respondents from different countries gave estimates of numbers of beneficiaries. Summing up these estimates, more than 76 000 farmers have benefited over the last 7 years. Another three respondents did not give an estimate but indicated that "many" or even "all farmers in the country" have benefited. The interpretation of the answers to this question can only be a minimum estimate or an indication that significant impacts have been created in many countries, given that the survey covers only a period of seven years and many users have not responded to the survey. For example, it has been documented that about 0.5 million farmers benefitted from the distribution of improved germplasm from ITC during 1995 to 2004 in Kagera Region, Tanzania (De Weerdt 2003).

The products of the research carried out by the respondents include new varieties that were developed (6 respondents), evaluation of existing varieties and release for use in the country (8 respondents) and publications (18 respondents). For 11 respondents, the germplasm was received too recently to report on any products yet.

Only one third of the respondents gave some kind of feedback to Bioversity and formerly INIBAP about the research outcomes. The feedback was given in forms of personal communication and e-mails, presentations in meetings and conferences and through sharing of publications. This scarce feedback by the users is probably one of the reasons for the difficulties to demonstrate the impacts created by the ITC. There are no formal or systematic ways to collect feedback from the users and hence to document the outcomes and impacts created. In order to facilitate better documentation, it might be useful to provide more formal procedures to encourage users to report on their work. Also, with regard of the perceived lack of evaluation data as mentioned by the key informants, the results from evaluation trials carried out by different users could be highly useful in upgrading the documentation status of the collection.

The types of impacts created refer to agronomic improvements like higher yield and reduction of losses to pests and diseases. Avoiding introducing new diseases into a country or a region was mentioned as impact by 25% of the respondents. Other types of impacts reported by the respondents refer to research outcomes such as improved knowledge about the *Musa* genome and diversity, and other topics for fundamental research and capacity building.

As an example, one respondent reported on the research on virus indexing methods and virus therapy. The result of applying his research findings is the increased availability of virus free germplasm from ITC. Pre-breeding studies provide another example, which resulted in the identification of parent lines in the breeding process.

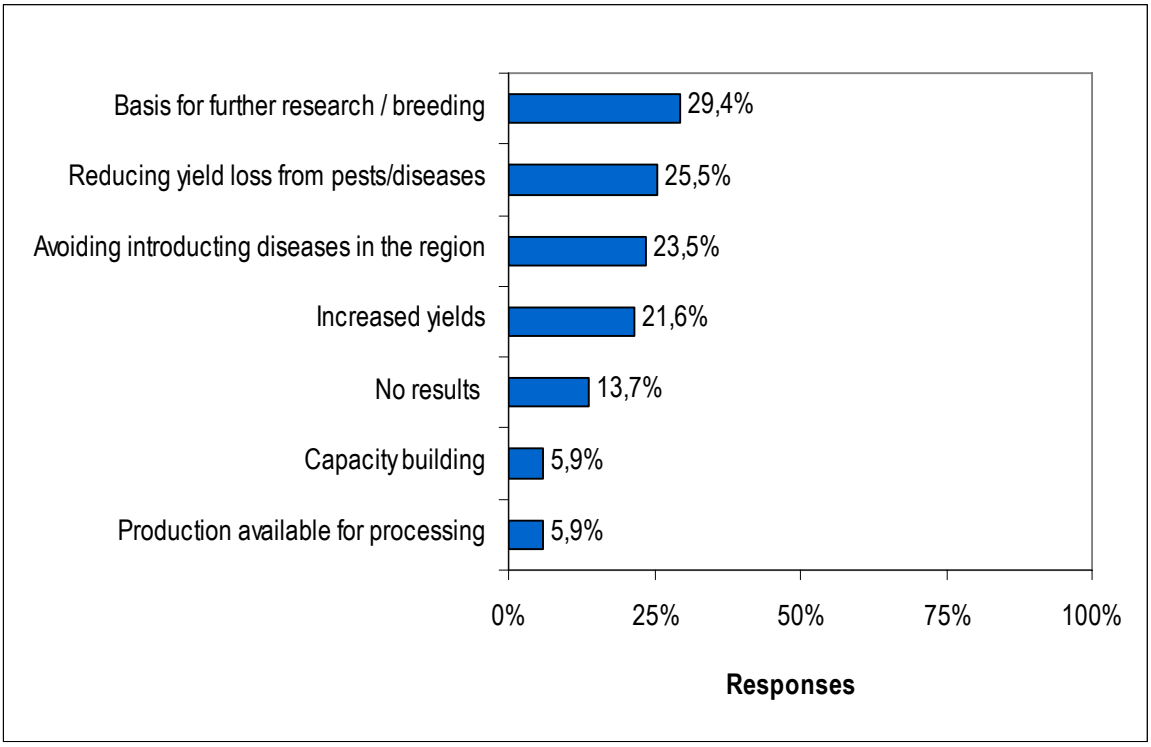

Figure 6.5. Germplasm impacts (*Multiple responses possible*)

When asked how the work would have been affected if there had not been access to germplasm from ITC, about 38% of the respondents said that they would not have been able to carry out their research or development project. Another 22% of respondents pointed to severe difficulties in organizing research including time delays and increased costs to find the germplasm from other sources. Two respondents indicated that quarantine regulations in their countries prohibited any introduction of banana germplasm except from ITC. That research results would not be internationally comparable if they had not used accessions from ITC was mentioned by 4% of the respondents. Another aspect mentioned by about 21% of respondents was that the diversity of banana germplasm available for breeding or for use by farmers would be much more limited without access to the ITC distribution service. About 11% of the respondents stated that their work would not or nearly not have been affected and they would have been able to pursue the germplasm equally easy from other sources (Figure 6.6).

With regard to the demand for germplasm, the responses obtained in the survey differ from the distribution data: According to the genebank shipment records, more cultivars and landraces are distributed, however survey respondents requested more improved materials. When ranking according to importance for their own work, respondents rated improved materials and landraces as equally important, followed by wild species. Only a few researchers work with *Ensete*.

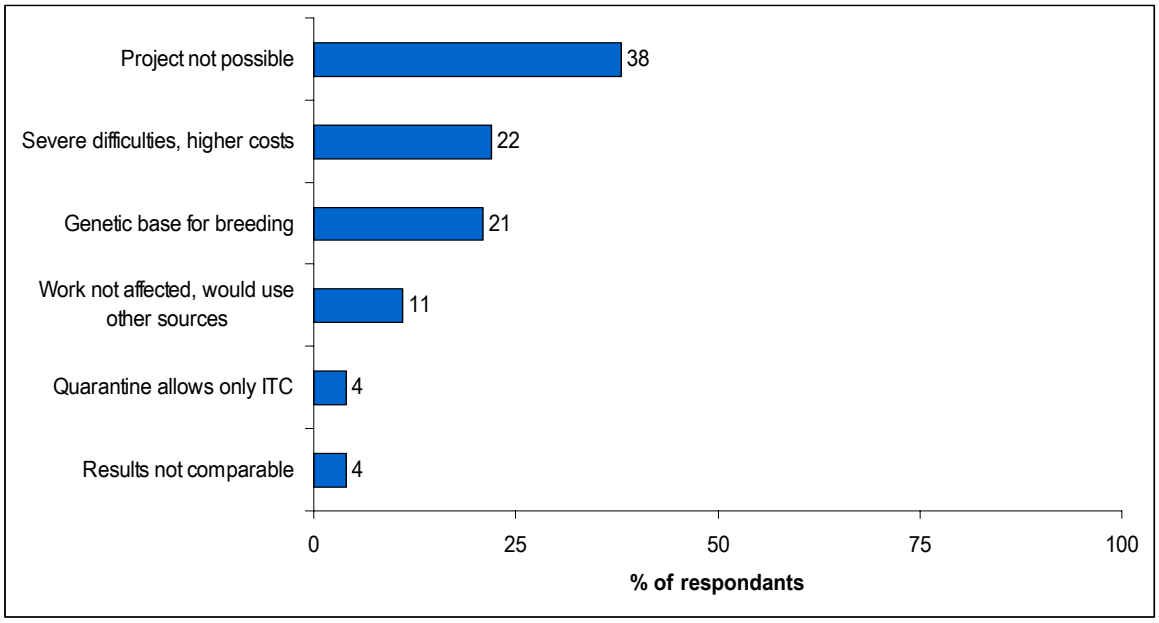

Figure 6.6. How would your work have been affected without access to ITC?

Interestingly, when asked for future demand, respondents anticipate increased importance and interest for wild species, thinking that ten years in the future, wild species will be equally important than improved germplasm and landraces.

When looking at the details of characteristics of *Musa* germplasm that will be interesting in the future, tolerance to pests and diseases remains the most important trait, followed by abiotic stress traits, like wind, salinity and drought tolerance Agronomic characteristics like yield and early flowering and fruit production are also rated high. Less attention is paid to post harvest characteristics and the nutritional value of the crop, although some respondents stressed the importance of taste and consumer acceptability (Figure 6.7).

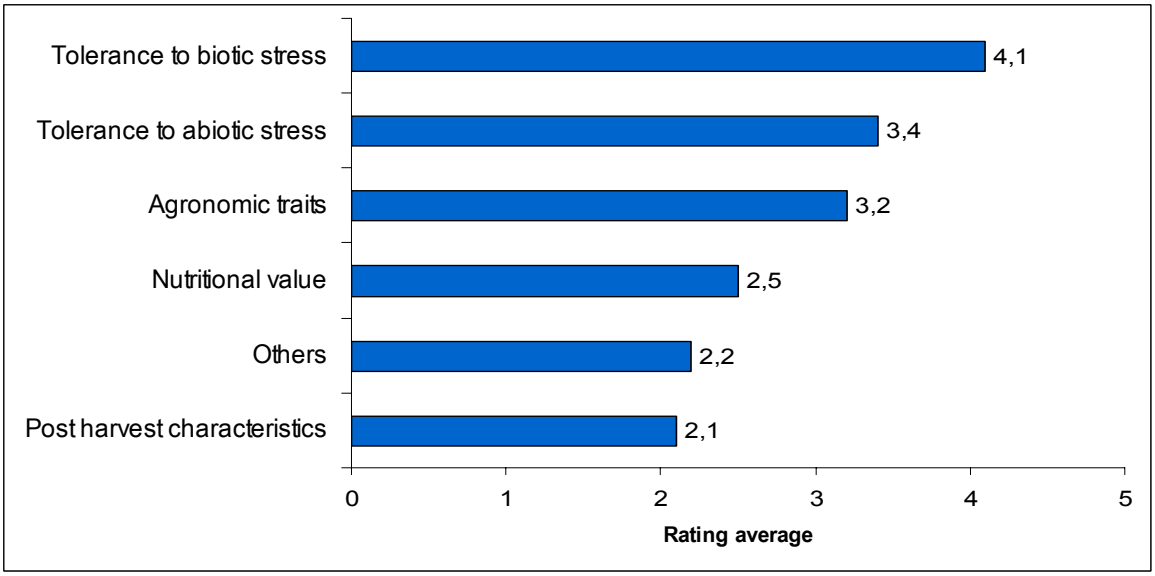

Figure 6.7. Important germplasm traits in the future

6.3 Literature on research with germplasm from ITC

For the review of literature citing ITC codes to refer to the germplasm used in a research project, two aspects are considered: the use of a set of 36 accessions, which are explicitly defined as a taxonomical reference collection, and the more general scenario that research is done with any germplasm received from ITC or identified by its ITC accession code.

The rationale for the selection of a reference collection of 36 accessions is based on *Musa* taxonomy with the objective to harmonize taxonomy and identify synonyms. The selection is not related to the frequency of the germplasm. The search in the Musalit[9] database reveals that since 1998 at least 39 publications in international literature made reference to one ore more of the selected reference accessions. In order to find the citation of the ITC code, it was necessary to review the contents of all potentially relevant publications, therefore, in this first step of analysis, the search was confined to the Musalit database and the results are to be interpreted as indicative, not as an exhaustive review. Of these publications, 14 are articles in international peer reviewed journals, 25 are available as conference proceedings, PhD theses, technical guidelines or research reports published by INIBAP-IPGRI/Bioversity. Most of these publications deal with characterization and genomic analysis, which is related to the objective of the selection of the set of reference accessions. Other research topics covered in the literature are methods for the detection of viruses; the interactions of the germplasm with pathogens, like the fungi causing BLS and FW or nematodes; and to a lesser extent the evaluation of agronomic traits. The large majority of the publications deals with fundamental research with the objective of progress in biological science and biotechnology as well as in research methods.

Considering the ITC function of a reference collection in a broader sense, all publications referring to any *Musa* germplasm with the ITC accession code are potentially included in the literature review. With a full text search in the Musalit database for publications citing ITC accession number, a total of 69 publications are found. That these however present a rather small portion of publications on research with ITC germplasm is indicated by the results of literature search in "Google scholar". Using full text search, 590 publications were found for "*Musa*, ITC" of which 91 cited ITC accession codes in the article. The topics of the publications include: molecular characterization; genome-related research and sequencing; virus detection and therapy; conservation methods *in vitro* or in cryopreservation; plant-pathogen relationships and host plant resistance; agronomic evaluation and response to management practices; the diversity of

[9] Musalit is a searchable bibliographic database containing more than 10 000 references and abstracts of documents on bananas and plantains in English, French and Spanish. Musalit is maintained by the Commodities for Livelihood Programme, Bioversity. see http://musalit.inibap.org/

banana including the geographical distribution; nematodes and root health; soil-root interaction; propagation methods and banana taxonomy.

A more detailed review of the publications, for example including the analysis of the types of accessions used and the frequency of citation for different topics is beyond the scope of the present study. In order to assess the impact of the ITC function as a reference collection on progress in fundamental and applied research, an in-depth literature analysis can be proposed. Such analysis would illustrate the use of previous studies for follow-up studies as indicated by cross-referencing of articles, as an example.

Yet, the presented results of the literature overview show that ITC provides an important service to the *Musa* research community by offering the possibility of unique identification of germplasm.

6.4 Summary

The results from the survey among users and interviews with key informants show that both the conservation and the distribution of *Musa* germplasm at ITC are highly appreciated throughout the community of banana researchers. They demonstrate the central role of ITC on a global level to ensure the long-term conservation of the largest possible diversity of *Musa* germplasm. The distribution of guaranteed healthy germplasm has enabled and facilitated a large body of research and played an important role in the implementation of banana-related development projects. For the quantitative evaluation of the impact of ITC, the reported impacts indicate that the most important fields where impacts have been created are:

a) The dissemination of superior germplasm to small-scale farmers with expected positive effects on their productivity. The extent of the impacts on poor farmers' income will depend also on the available markets and infrastructure for processing. Several respondents mentioned that positive effects have been created along the value chain of production and processing of bananas.

b) Research on resistance/tolerance to economically important banana pests and diseases. Research questions for the evaluation of impact include how to value the growing body of research results of germplasm evaluation for example generated in the International *Musa* Testing Programme, and the contribution of ITC.

c) The impact of and the contribution of ITC to breeding of superior banana germplasm.

d) The valuation of fundamental research carried out with materials from ITC. Here, impacts include the use of ITC codes for the identification of the germplasm, the generation of technologies for virus testing and therapy, improved understanding of banana physiology, plant pathogen relationships and breeding techniques.

The survey results also give some indications on the approaches to define a counterfactual situation for studies evaluating the impact of the distribution of germplasm by ITC. Based on respondents' perceptions, how their work would have been affected, had they not been able to receive germplasm from ITC, in many cases, the counterfactual can be defined using the opportunity cost approach, considering that the research or development project would not have been carried out without the ITC, for example in countries with a strict quarantine, where the ITC is the only legal source for banana germplasm. Some respondents stated that they would not have been able to carry out their work, even in countries with possible access to germplasm from other sources. In such a case, an impact assessment study would have to evaluate the plausibility of different counterfactuals, including the hypothetical transaction costs to obtain the germplasm from elsewhere.

Several respondents, especially those involved in research, directly mentioned the high transaction costs they would have incurred for searching and obtaining the germplasm from other sources. A study assessing the impact of ITC in the field of applied and fundamental research would have to use methods to quantify the costs of time delays in different research.

Chapter 7. Evaluation of service provided by ITC and comparison to other sources of *Musa* germplasm

This chapter presents an evaluation of the ITC services in terms of germplasm dissemination, information availability and a comparison to other sources of *Musa* germplasm. The results presented in this chapter are based on the on-line survey among users, described above. For the general evaluation of the service, as an additional data source, receiving reports of users of the ITC were analyzed. As part of the standard procedure of shipment of germplasm, recipients are asked to fill out receiving report forms to acknowledge the receipt of the requested germplasm and to provide feedback on the conditions of the germplasm on arrival as well as any problems encountered related to mailing service, phytosanitary documents/protocols and custom related issues.

7.1 Perceptions of the role of ITC

As a starting point to ask for the evaluation of the services, survey respondents were asked about a ranking of the different activities and functions of the ITC according to perceived importance.

Results show that the conservation of the diversity of *Musa* on the long-term is seen as the most important activity of the ITC by most respondents (Figure 7.1, for more details see Table B.4 in Appendix B). This clearly corroborates the view of the key informants, presented above, who appreciated the safe long-term conservation as key function of the ITC.

Not surprisingly, the distribution of clean and healthy *Musa* germplasm is rated equally important, indicating that the purpose of conservation is necessarily the use of the conserved diversity. The role as facilitator of the international exchange of germplasm is related but not equal to the distribution activity. The exchange of germplasm is an important factor to enable farmers in poor countries to access superior banana varieties. Also, for breeders, the participation in the exchange of germplasm and the supply of germplasm to ITC can pay off, since it helps them to evaluate their varieties in a large range of environments and growing conditions, for example in the framework of IMTP.

The function of ITC as a reference collection is mainly important for researchers, whose results are internationally comparable, if they use material from ITC. The provision of germplasm related information is considered important, but to a much lesser extent than the other functions of ITC. Other functions mentioned by respondents are supporting collaborations, collecting data on comparative evaluation of the accessions and making it available to a broader public and the work on the identification of synonyms and verification of the genetic identity of the germplasm in the collection.

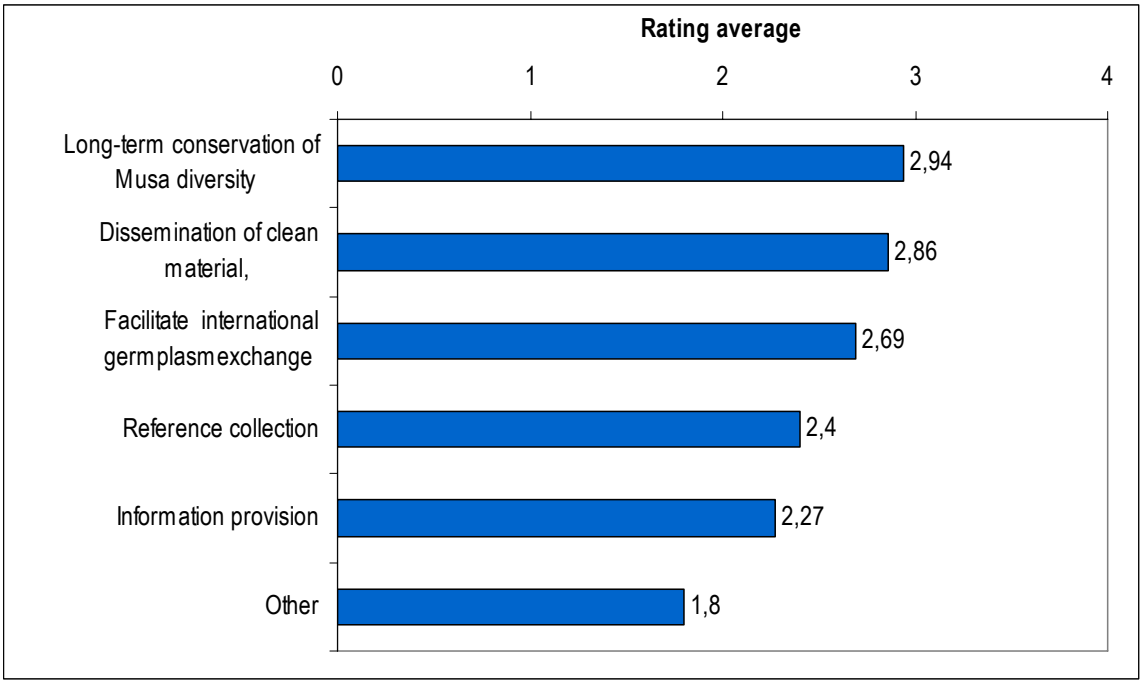

Figure 7.1. Perceived most important function or role of the ITC

7.2 Information and documentation

Most of the 60 respondents (87.5%) perceived the available information about germplasm as sufficient for their selection of germplasm. This result however may be positively biased, since only users of ITC were included in the sample, who somehow managed to select their germplasm. Those who miss information hint at too many empty data fields in the MGIS database. Information about male and female fertility as well as evaluation of agronomic traits such as resistance against biotic and abiotic stress and yield data was also missed by the respondents.

Of the available information sources, direct inquiries to ITC or Bioversity scientists as well as personal communication are most important for the respondents to select germplasm. This indicates that the expertise of the ITC and other Bioversity staff is highly appreciated and well accessible to users. However, it also indicates inefficiencies of the more systematic information systems about *Musa* germplasm, for example MGIS, which seemed to be of limited use for many respondents and received the lowest average rate of all sources. Scientific publications and conferences play an important role for the selection of germplasm. Also, similar to the perceptions of the key-informants (see section 6.1.2) the germplasm catalogues, for example *Musa*logue were appreciated as useful by many respondents, who liked especially the photos provided in these catalogues (Figure 7.2, for details refer to Table B.5 in Appendix B).

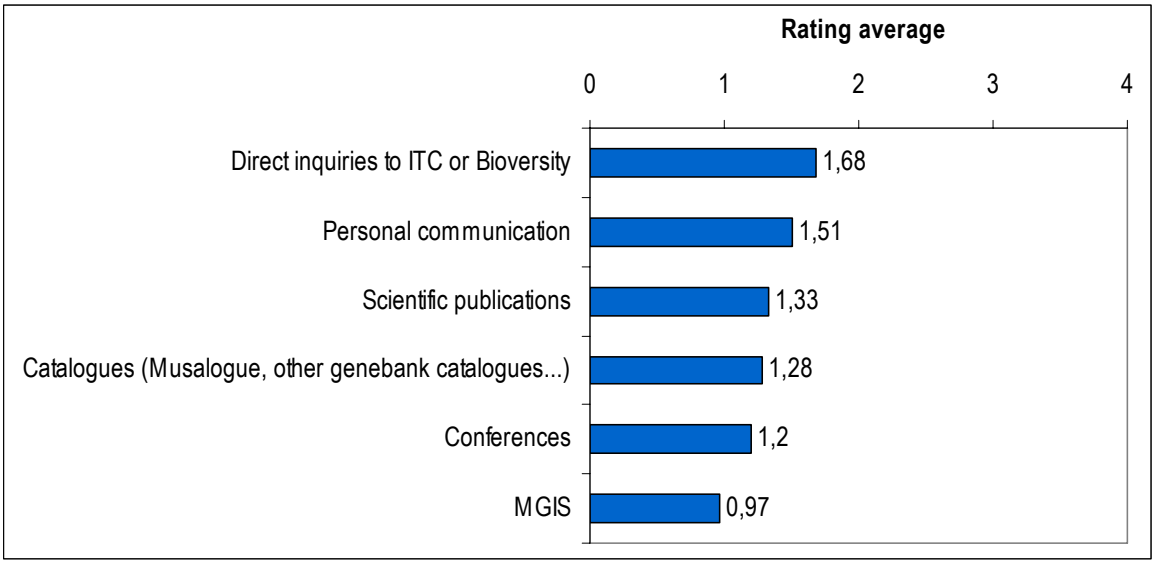

Figure 7.2. Information sources used to select needed germplasm /usefulness

7.3 General evaluation of service

A first impression of the quality of service provided by the ITC is derived from the analysis of receiving reports by users. These reports are filled out immediately after receipt of germplasm and refer directly to the conditions of the germplasm on receipt and any problems encountered during shipment.

To assess the satisfaction of the users with the service, the comments from the recipients are grouped into three categories (Figure 7.3): About 48% were very satisfied with the shipments, expressed in comments like "very good service, excellent conditions, thank you very much, no problems encountered, everything okay".

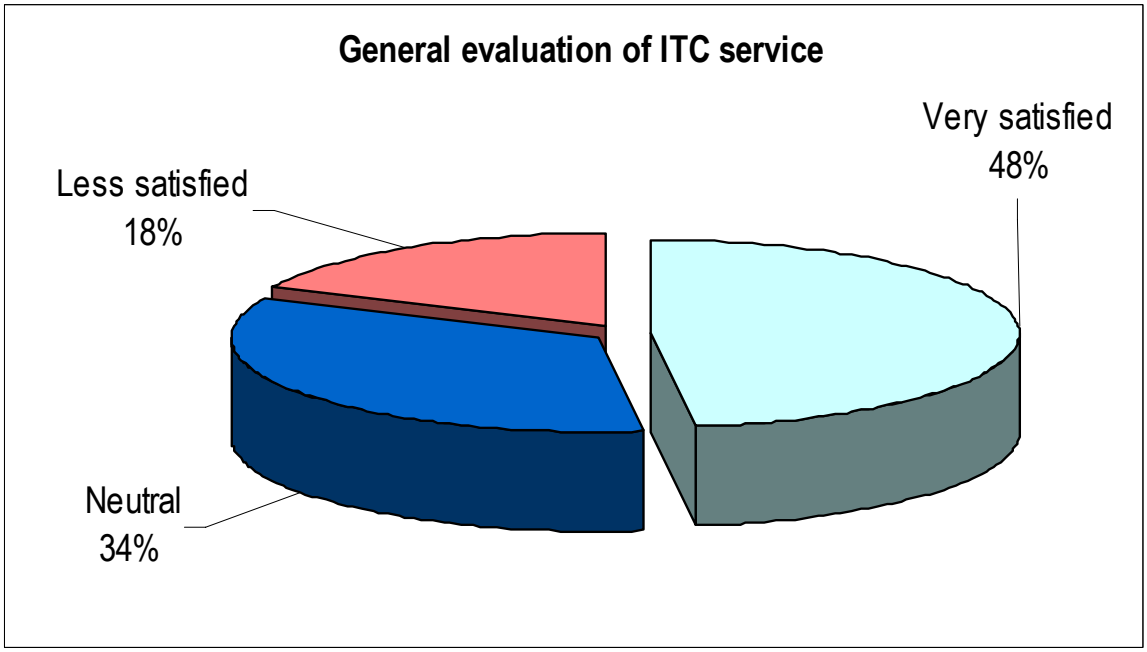

Figure 7.3. Satisfaction with received germplasm samples

Another 34% of the reports were neutral, without any particular comments and without problems reported either. Less satisfied were 18% of the recipients, reporting problems with the shipment either due to shortcomings of the ITC or due to external factors that were not within the control of ITC, such as problems with shipment conditions or delays in national customs.

The delivery time of germplasm depends on the type of material requested, and the availability of the necessary legal and phytosanitary documents, including the plant import permission, issued by the importing country. Once the request is made and the signed SMTA is provided to ITC, the delivery time for proliferating shoot tip cultures is about two months, for individual rooted plantlets four months and for freeze dried leaf tissue two weeks. In order to keep the journey as short as possible and minimize the risk of deterioration, germplasm samples are usually shipped through express mail services provided by the postal system for European destinations. For non-EU destinations, air courier services are used (DHL or FedEx). Occasionally, the samples are picked up at the ITC and hand carried to their destination by the requestor or by an intermediate person (4%). On average, the shipments take 6 days to arrive at their destination, 84% arrived before or on the 10th day. No shipment has taken more than 30 days to arrive. In almost every occasion, the delay in delivery was due to the slow completion of custom formalities and phytosanitary control of the material. In other cases the delay in delivery is caused by the remote location of the destination (e.g. Marshall Islands).

Among the respondents of the on-line survey, the satisfaction with the distribution service of ITC was very high. The requesting procedure was perceived as adequate (good or sufficient) by all respondents. More than 97% of respondents were satisfied with the health status and the general quality of the germplasm (Table 7.1), indicating that in general there are no problems with the viability of the germplasm or with contamination and that the accessions supplied are true-to-type. Some respondents would like to get more or better documentation supplied with the germplasm, although 90% of the respondents valued this aspect as good or sufficient.

With respect to the quantity of the materials supplied, there are a number of respondents wishing to receive more samples per accessions, a suggestion also expressed by some of the key informants during their interviews. The diversity available for distribution is largely perceived to be good or sufficient, although there might be still unsatisfied demand, as indicated by "poor" evaluations. These respondents may have special interest in those varieties which are unavailable due to BSV infestation of in wild *Musa* species.

Table 7.1. Evaluation of ITC germplasm distribution service

Answer options	Good 4	Sufficient 3	Poor 2	N/A 1	Rating average
Health status of the available germplasm	42	6	1	0	3.8
Germplasm accompanying documentation	27	18	4	1	3.5
Requesting procedure (effectiveness/helpfulness/delivery time)	30	21	0	0	3.6
Quantity of materials supplied	29	15	6	1	3.5
Quality of tissue cultures supplied (viability/contamination/trueness–to-type)	39	11	1	0	3.7
Diversity available for distribution	24	16	3	5	3.5

Respondents also mentioned different types of constraints that prevented them from using ITC: 9 respondents (14.2%) referred to national regulations of phytosanitary quarantine or germplasm import; Four respondents indicated their concern about the infection of interesting germplasm with BSV, expressing their wish that infested accessions become available soon; One respondent reported to have received germplasm that developed BSV symptoms and had to destroy the trials. As stated in the health documentation, this is a scenario that cannot be avoided given that the virus is integrated in the banana genome and can eventually be expressed after *in vitro* conservation.

One of the respondents reported about the difficulties for his institute to obtain the permit to sign the SMTA and questioned why this was a requirement also for receiving lyophilized leaf tissue.

Nineteen percent of the respondents made suggestions for improving the service. They covered a broad range of topics, such as to improve the documentation of the germplasm by adding more evaluation data. Related to information and documentation, one respondent made the suggestion of posting regular newsletters informing about newly available accessions and incoming evaluation data.

The idea to support the establishment of field collections in the different regions as satellite distribution centres for germplasm was brought up. It should be noted that such systems exist throughout Asia, where in different countries a national germplasm repository, multiplication and dissemination centre was established for ITC as well as for local germplasm. Also, the Secretariat of the Pacific Community (SPC) in Fiji and CARBAP in Cameroon act as regional multiplication centres for ITC. And in the global conservation strategy for *Musa*, the concept of supporting regional collections for distribution of germplasm is advocated (INIBAP 2006).

One proposal was made to expand the collection in order to increase the diversity available. Other suggestions referred to increase the number of samples per accession distributed to increase the probability of survival of the received plantlets, and to provide more services such as ploidy and molecular characterization. While the whole collection is checked for ploidy, complete molecular characterization will probably not be feasible to implement for financial reasons, given the fact that the supply of germplasm is free of charge at the moment. Instructions on the handling of *in vitro* plants are routinely included in the shipping documents. Maybe they need to be revised and users be encouraged to clarify any doubts immediately in order to increase survival rates. For those users requiring larger amounts of germplasm, reference is made to commercial *in vitro* suppliers or the regional multiplication centres.

That in general the respondents showed high degrees of satisfaction is underlined by the statement of 80% of respondents who recommended the ITC service to others and 84% who are planning to request germplasm from ITC again in the future.

7.4 Other sources of germplasm

Fifteen percent of the respondents indicated that there was germplasm they would wish to receive but was unavailable from ITC. The materials of interest mentioned were wild species, local germplasm from India, Mexico and Thailand and specific improved varieties or resistant clones, for example from breeding programmes. Only 4 of these respondents (40%) were able to obtain the materials from other sources, in one case from a commercial tissue culture laboratory, others even in form of own collecting mission in the countries of origin or from project partners. This shows that most of the varieties which are not available from ITC are not easily obtained from other sources.

However, many respondents reported on the use of other sources of *Musa* germplasm. About 60% of the respondents have received germplasm from elsewhere. The most important alternative source for *Musa* germplasm are national or regional collections but commercial providers and tissue culture laboratories are important sources of germplasm too. Other international organizations, namely the IITA in Africa have a banana breeding programme and are active in disseminating banana germplasm for multisite testing (Figure 7.4).

The comparison between ITC and other sources of germplasm may not be representative, since not all respondents who had used other sources of germplasm gave a comparative evaluation of the services. For those 13 respondents who answered this question, the services of ITC are mostly valued as similar or in some cases better than the other sources. Specific evaluation were asked for the following aspects: diversity available for distribution, requesting procedures, cost of the germplasm, restrictions on the use of the germplasm, quality and health status of the material received, quantities supplied and the

documentation accompanying the shipment. The diversity available for distribution is clearly highest at ITC as compared to all other sources, however, the other sources were sufficient for some respondents and one pointed out that the alternative source had other diversity than available at ITC. The requesting procedure was perceived as similar to the ITC by 50% of the respondents, while the other 50% found the procedure elsewhere easier, however without indicating the details.

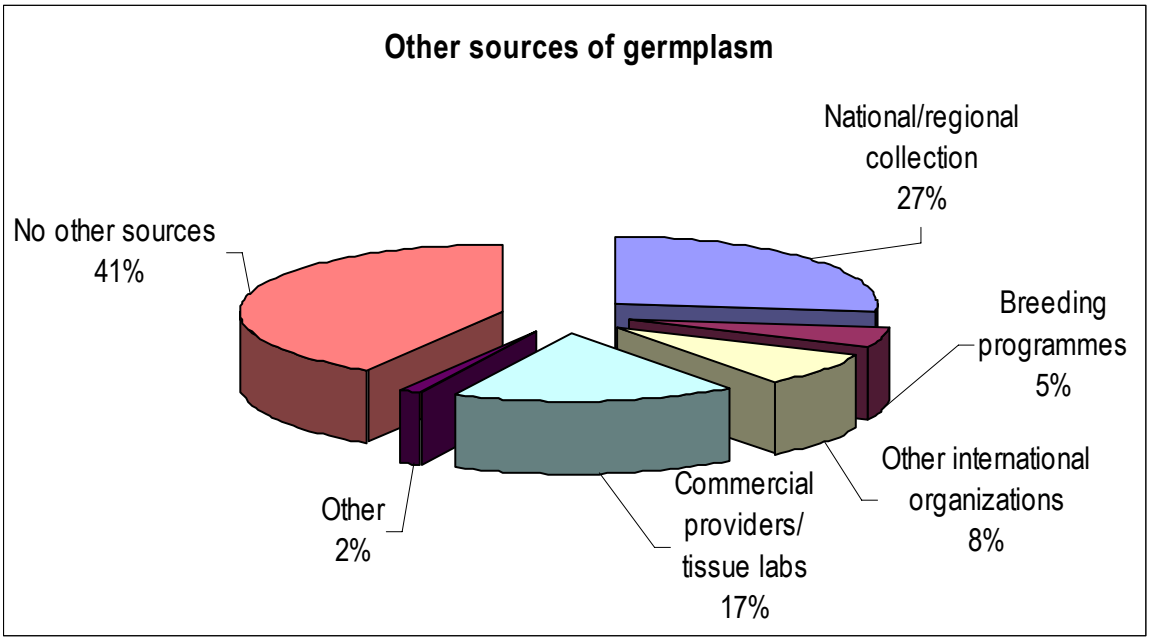

Figure 7.4. *Musa* germplasm sources other than ITC

Many other sources, especially national or regional collections provide germplasm free of costs for the requestor, as does ITC. Some respondents reported to have bought germplasm for prices they perceived as high, one paid less than 1 US$ per plant, another reported of costs between 15 to 20 US$ per bud from a commercial laboratory. The costs are directly related to the quantities supplied: Those who pay for the service receive the quantity they request, while the free services supply generally a limited number of samples.

Restrictions on the use of the germplasm are imposed by public providers, most of which give out germplasm for research purposes only, although one respondent indicated that restrictions were less severe than for material from ITC. Commercial providers have no specific restrictions on the use of the materials.

All respondents valued the quality of the materials supplied by ITC as similar or superior than germplasm from other sources. The same holds for the health status. The time for sending is largely similar to the ITC.

Interestingly, respondents pointed out that in terms of documentation, ITC provides the most complete service as compared to other sources, although in

questions before, respondents had suggested how to improve the documentation of the germplasm, indicating the general difficulty of genebanks and germplasm providers to achieve complete documentation.

7.5 Summary

In general there is a high degree of satisfaction with the services provided by ITC. Suggestions for improvement of the service refer to the potential expansion of the collection in order to represent better the global diversity of *Musa* germplasm. Especially wild *Musa* species and specific germplasm from several Asian countries are perceived to be still lacking in the ITC collection.

Other suggestions hint at the lack of available information about the germplasm. There is a high need for more evaluation data for the accessions held at ITC. The current formal information systems like MGIS and catalogues need to be updated continuously. It was suggested to circulate regular updates of the information available and also on new accessions available for distribution, for example in form of an electronic newsletter (see recommendations in Chapter 9).

Chapter 8. The costs of conservation and distribution of *Musa* germplasm at ITC

For the planning and evaluation of the ITC, information about the full operating costs of the genebank is important. The situation of the ITC is special among the genebanks of the CGIAR in several ways. It is located in a non-banana cultivating country in Europe, which is a major strength in terms of exchange of germplasm, but also has implications for the cost structure in terms of costs for labour, which maybe more expensive. For other supplies however access is probably easier than in a developing country. The ITC is hosted at the Laboratory of Tropical Crop Improvement of the KULeuven and is closely interlinked with the hosting institute, which provides infrastructure, services and exchange of technical and scientific know how. This does not only imply a significant co-financing (no rent is charged for laboratories, growths chambers and storages rooms) but also secures the flow of operations, dealing with peaks in labour demand and leverages research activities at ITC. The ITC forms part of Bioversity's Commodities for Livelihoods programme and shares the decentralized *modus operandi* focusing on networks. Many genebank activities are carried out as contracted services, or in close collaboration with partner collections, which also influences the cost structure thus that capital costs are reduced and instead costs for contracted services are incurred.

Another special characteristic of ITC concerns the nature of the germplasm it conserves. The *Musa* germplasm collection is an *in vitro* collection of plants, which implies much higher requirements for maintenance and is much more labour intensive compared with storing seeds of crops like rice, maize or wheat (Engels and Visser 2003).

Figure 8.1 illustrates the flow of operations at the ITC. The heart of the ITC is the medium-term storage of the accessions *in vitro*. From here, materials are sent for characterization, regeneration, distribution on request and for cryopreservation. Not included here is the provision of prerequisites for new accessions, before they are considered for inclusion into the collection, such as basic morphological characterization and passport data. The shaded boxes in Figure 8.1 show the operations performed by service providers or carried out in collaboration with other *Musa* genebanks.

The cost analysis is structured according to the activities and operations performed to achieve the main objectives outlined above.

Variable, capital of fixed and quasi-fixed costs are identified, following the approach proposed by Koo et al. (2004) and Koo and Smale (in Engels and Visser 2006). This facilitates the calculation of the annual average costs of the different activities of ITC as well as the annualized capital costs, which are important information to plan a sustainable medium and long-term funding.

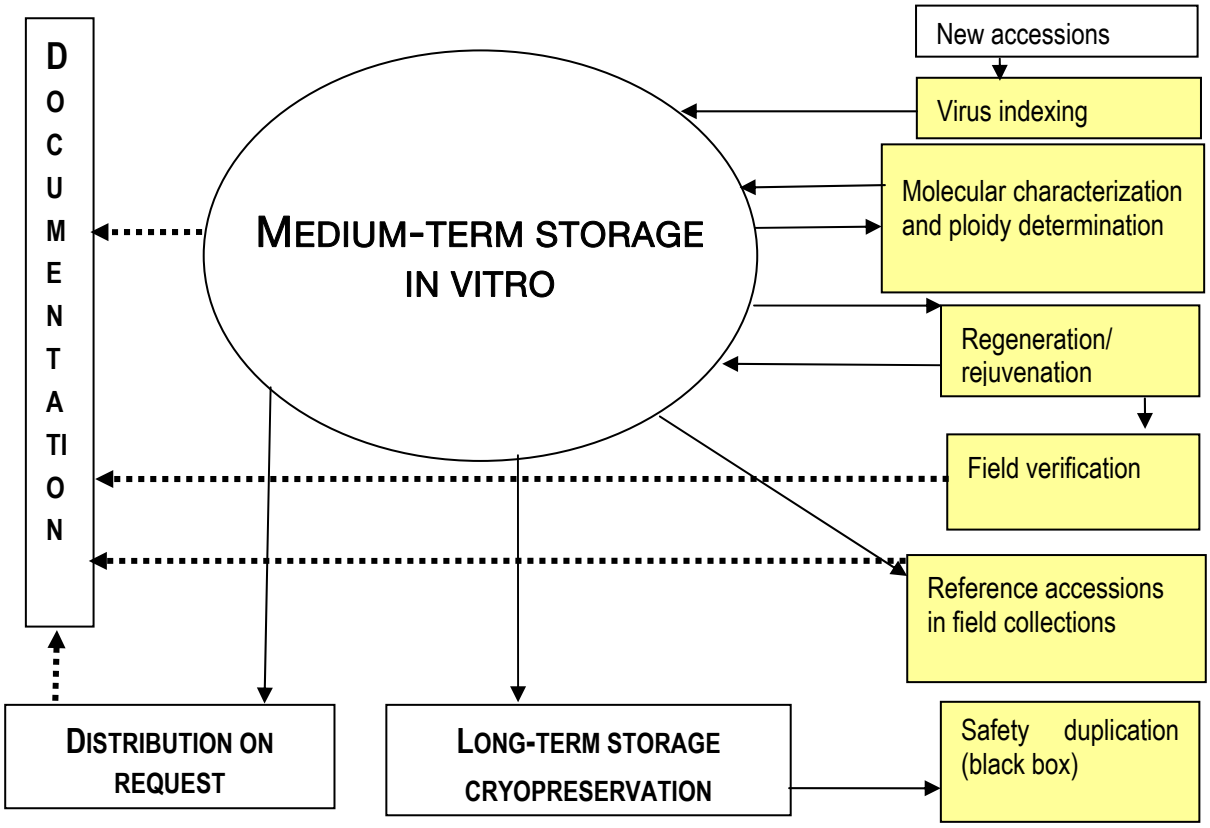

Figure 8.1. Flow of operations in ITC

Variable costs refer to all cost items that vary with the size of the operation, like materials used, power, labour inputs of technicians or temporary workers. Capital or fixed costs are largely independent of the size of the operations, like infrastructure, storage facilities, and laboratory equipment. Costs that are neither variable nor fixed but lumpy are classified as quasi-fixed costs. They include skilled labour, the management and scientific expertise.

While variable and quasi-fixed costs, especially labour inputs are easily converted into annual costs, the capital costs have to be annualized, considering the inflation adjusted purchase price, the life of service of capital items and the interest rate. In order to estimate the capital costs of laboratory equipment, the replacement costs in prices of 2007 were considered and annualized following the methodology of Koo et al (2004) (see Appendix C, Equation 1 and 2). An interest rate of 4% was applied, based on an average of long-term interest rates in the OECD Euro area (OECD 2008). Inflation was not considered in the cost estimates.

The detailed cost analysis of the different genebank activities is then used to perform a sensitivity analysis. Scenarios include an increase or a decrease in the size of the medium-term collection, an increase in the use of the collection and different options for rationalization.

8.1 Capital input costs

The medium-term collection of *in vitro* plants (MTS) lies at the heart of the germplasm collection at ITC. All of the currently 1212 accessions are held as proliferating shoot cultures under slow growth conditions, with a temperature of 16°C and reduced light conditions of 25 µmol/m²/s (24h/24h) (Van den houwe et al. 1995).

The size of the MTS room is 26 m². It accommodates 13 culture racks with 6 fixed shelves each and can hold 1404 accessions[10]. It is equipped with climate-control equipment. A growth room with similar equipment is used for the tissue culture initiation of accession, annual subculturing of accessions from the MTS collection and for multiplication and regeneration of samples for distribution. The size of the growth room is 16 m². The room holds 6 culture racks with a capacity of 18 000 individual test tubes or 750 accession racks. The culture room is kept constantly at a temperature of 28°C and light intensity of 63 µmol/m²/s permanently.

For long-term storage in liquid nitrogen (LTS), the storage facility currently comprises 3 storage tanks with a capacity of 300 accessions with about 120 meristems each. The plant materials in preparation for cryopreservation, and for viability testing after cryopreservation, occupy the same culture room as the materials for MTS. A second culture room, where cultures can be grown in darkness, is also in use for proliferating tissues for cryopreservation.

The tissue culture laboratories and ancillary facilities are used for all tasks related to preparation of growth media, handling and preparation of the cultures for MTS and LTS as well as for multiplication for distribution of germplasm. Equipment includes an autoclave, a medium dispenser, refrigerators, laminar airflows, a dishwasher, microscopes and other essential *in vitro* laboratory items. Laboratory space and parts of the equipment are shared with the KULeuven Laboratory of Tropical Crop Improvement. The costs of the infrastructure and basic services are not included in the capital costs, but are (partially) covered by the overheads paid to KULeuven as explained below. For shared equipment, like for example the autoclave, the share of use attributable to ITC is included in the costs. For the purpose of estimating the costs of the different activities of MTS, LTS and distribution, the capital costs for laboratory equipment are distributed according to the approximate share of uses. In 2007, the share for MTS was 50%, for LTS 40% and for distribution 10%.

For the infrastructure, no capital costs are shown, since they are part of the infrastructure of the KULeuven and provided at a cost of 17% overheads on the full costs of the ITC. These overheads also cover basic supplies, logistics and services

[10] In 2011, the ITC will move to new facilities within KULeuven, where MTS room will have a capacity to store at least 2000 accessions according to current plans of expanding the collection.

related to infrastructure, such as electricity, water, insurances, maintenance and cleaning service.

A greenhouse is needed for regeneration of germplasm, backing up accessions at risk of loss and rescuing contaminated accessions. Currently, the greenhouse area used by ITC for this purpose has a capacity of 200 potted plants. Additional space can be hired, in adjacent greenhouse compartments if needed. The greenhouse space and supplies are rented from KULeuven Faculty of Bioscience Engineering.

The ITC also maintains a collection of lyophilized leaf tissue, which is obtained during the periodic regeneration of germplasm. Capital goods for this part of the collection include a lyophilizer and two deep-freezers of -20°C and other two devices of -80°C, to store the lyophilized leaf tissues. Finally, capital costs also are required for the general management and documentation. The items include the office space and equipment, computers and software. Next to the office, one room is made into a shipping area (packing of germplasm for distribution).

The capital costs are calculated based on estimated replacement costs in 2007 Euros and estimated service life in years, applying a discount rate of 4%.

Table 8.1. Annual user costs of capital items for different activities[1] (2007 prices in Euro)

Use of equipment	Annual user costs
Laboratory, general	23,681.39
Leaf bank	3,475.38
Data management	3,631.40
MTS specific	1,672.48
Cryopreservation specific	4,408.43
Total annual capital costs	36,869.08

[1] For detailed list, see Table A in Appendix.

8.2 Annual operating costs

The ITC is currently in a phase of expanding the collection. Within the framework of the Trust project at least 200 accessions will be introduced in the coming two years and further completion of the collection is expected in the medium term. In the following sections, all cost estimates are based first on the current situation in 2007.

8.2.1 Medium-term storage

Medium-term storage of *Musa* germplasm *in vitro* requires periodical subculturing. For each accession, 20 cultures are maintained. Subculturing of an accession is required on average each 12 months, with a range of 4 to 22 months, according to genetic composition of the accession. Monthly monitoring of the quality of the stored germplasm is required and tubes with contaminated, necrotic or otherwise damaged cultures are removed. Accessions are also inventoried in terms of available replicate cultures and when the number of cultures falls to twelve, subculturing is

carried out. For subculturing, *in vitro* material is transferred to new, sterile medium and kept for three weeks in the growth room at a temperature of 28°C and light conditions of 63 μmol/m²/s permanently. Costs of laboratory consumables are relatively low, compared to the labour costs of the laborious process of secure maintenance of *in vitro* plants. It is estimated that one laboratory technician can handle about 1000 accessions per year if exclusively working on MTS, including media preparation, recycling of cultures and monitoring accessions.

8.2.2 Regeneration and field verification

In recent years several projects have been carried out for successive regeneration and rejuvenation of all accessions (tested virus negative) according to the number of subculturing they already passed. Regeneration and rejuvenation is a time consuming process, requiring about two years per accession. It includes the multiplication of the tissue material and transfer of the plants in the greenhouse. After nine months, the plants are decapitated to stimulate sucker growth. When sufficient new shoots of adequate size have developed fresh tissue cultures are established to replace the old *in vitro* material. Also planting material is sent to partner collections for field regeneration and verification of its trueness-to-type. The germplasm is planted in the field to be compared to reference plants of the respective accession. At least two years are required for field verification, since during the first year growth might still be affected by post *in vitro* effects. Due to labour availability and limited greenhouse capacity, no more than 50 accessions can be rejuvenated per year at the ITC, unless extra greenhouse space is rented. It is projected that by 2010 all virus-free accessions will have been regenerated according to current standards of a maximum of 10 annual subculture cycles between regenerations. For the cost calculations it is assumed that every year about 10% of the collection will be regenerated. However, it has to be noted that virus infected material cannot be regenerated in the field because of quarantine restrictions.

The data from the field characterization collected in the course of the regeneration project will contribute to a significant upgrade of the documentation status of the ITC collection, which is expected to contribute to a more targeted use of germplasm and an increase of the utilization rate of the germplasm.

8.2.3 New accessions

New accessions enter the collection usually through field collections in the country of origin. If new germplasm is discovered, the first step is to plant it in the field in the country of origin so it can be described and characterized. Upon acceptance of the SMTA established in the Treaty by the germplasm provider and Bioversity, samples of the new accessions can be sent to ITC, where it is introduced into tissue culture and checked for asepsis, bacterial or other pathogen contamination and eventually remediated. The number of new introductions is very variable (and difficult to predict) in different years. In 2007, 70 new accessions were added to the collection, but in previous years the annual acquisition of new accessions was less

than 20 accessions. It is expected that in the coming years the collection will further expand, filling the existing gaps in representation of diversity; an estimated average of 80 accessions per year will be introduced.

8.2.4 Long-term storage in cryopreservation

For long-term storage, newly acquired or recently rejuvenated accessions are multiplied *in vitro*. Two different protocols are used to put banana germplasm to cryopreservation, based on the type of tissue to be frozen- proliferating meristems (scalps) or apical individual meristems (Panis et al. 2008). For the first method, meristem proliferation is stimulated by using *in vitro* medium with high contents of cytokinins. These can then be cut relatively easily and enter a process using specific media to cryoprotect the tissue. For the method using apical meristems, rooted plantlets have to be produced and the apical meristem obtained from each. The step of excising the meristem from the plant is the decisive and most labour-intensive step. After that, these meristems are prepared for cryopreservation using a similar process as for the other method. Cryopreservation is a time consuming process: On average preparation of material including the multiplication takes between 4 to 6 months, but that can be longer for different cultivars.

The two protocols differ in recovery rates after cryopreservation: The apical meristems have regeneration of up to 80% of material, while for the other method the post-thaw recovery is highly variable. Yet proliferating meristems are usually the first method chosen, since it requires significantly less labour input. The method works well for AAB and AAA dessert bananas and AAB plantains. AAA highland bananas and the wild relatives (*Musa acuminata*) however do not respond well to the proliferating meristem method and need to be subject to the apical meristem protocol.

In order to achieve high safety standard of LTS, three repetitions are done for each accession. Each repetition contains about 60 meristems. One part of the sample remains stored in liquid nitrogen, while another part is thawed to check the regeneration rates. The standard used at ITC is that there should be a probability of at least 95% that at least one plant can be reproduced from each repetition. If this cannot be guaranteed, the repetition is discarded and the process starts all over again. Two repetitions with a total of four samples are maintained at the ITC, while one repetition is sent to IRD, Montpellier, France as a safety back-up stored in a black-box collection.

Germplasm is cryopreserved at a rate of 50 accessions per man-year. Half of the collection is safely stored in liquid nitrogen but the remaining 600 accessions still need to be processed for long-term storage. At the moment 3 technicians are working in the cryopreservation of 125 accessions. Two technicians are full time involved in tissue culture and one person is also half-time time busy with organizing and planning the work and experiments, checking survival rates and

data management and processing. The estimated costs per accession represent an average cost of the two methods.

The collection expansion scenario foresees that in the next 10 years, all new accessions in MTS are gradually also introduced into LTS, at a rate of 80 accessions per year. Once the accessions are stored in liquid nitrogen, minimal maintenance input is required to check and fill-up the liquid nitrogen level in the tanks.

8.2.5 Distribution of germplasm

For the distribution of germplasm, material has to be multiplied first[11]. A sample of the accession in MTS is transferred to the growth room for subculturing and according to the type of material requested; rooted plantlets or proliferating tissue cultures are grown. For each accession, five plantlets in Cultusaks® on rooting medium or five multiple shoot cultures contained in plastic culture vessels on multiplication medium are prepared for shipment. The multiplication and preparation of germplasm for shipment takes an average of two to four months. For frequently requested accessions, ready-to-send material is kept at the ITC. With the current demand for germplasm of about 400 to 500 accessions by external users per year, multiplication and preparation of shipments including related administrative work requires 1.5 man-year. It is expected however, that demand for germplasm will increase in the next years. This will be related to the expansion of the collection with more accessions available for distribution. Also, current efforts of upgrading the documentation status of the collection through characterization and data from field evaluation will contribute to increased distribution.

8.2.6 Documentation and information management

The documentation management refers to all genebank operations. Since five years, a data management system with barcodes is introduced to rationalize the gene banking documentation management. The database system (MGBMS)[12] was developed in-house, specifically for the needs of the *in vitro* genebank of ITC.

Passport data, health status information and distribution data of the accessions captured in MGBMS feeds directly into a broader information system, the MGIS which includes passport data and characterization data of 6000 *Musa* accessions from 18 participating collections. Indirectly, the ITC is connected to the CGIAR System Wide Information Network of Genetic Resources (SINGER), sharing the ITC accession information through MGIS.

Currently, 20% of the time of a full-time technician is used for data entry and 30% of a database developer's time is required for technical support for the system. Additional data management related to the ITC collection (incl. management of

[11] Different from seed crops, where a stock of seed for distribution is produced during periodical regeneration, in vitro materials are not stored for distribution but multiplied upon request.

[12] *Musa* Genebank Management System by its acronym.

characterization and evaluation data in MGIS) is performed in the Bioversity office in Montpellier, the costs of which are not included in our estimates.

8.3 Costs for external services

One important characteristic of the ITC is its decentralized way of operation. Instead of investing in the complete set of genebank related facilities, for example for virus indexing, these specific tasks are performed by contracted service providers. For the virus indexing, ITC sends the germplasm to one of three virology laboratories at DPI, Australia; CIRAD, France; or Plant Protection Research Institute (PPRI), South Africa, who provide this service.

Since 2002, the complete collection has been virus indexed according to current standards; hence virus indexing is required only for new accessions or for those that underwent virus therapy.

For new accessions, a preliminary virus check (pre-indexing) has been introduced, an early and rapid screening of new introduction using PCR techniques. The aim of this activity is to identify virus free plant material among the different samples of a new accession, for inclusion into the collection. If viruses which can be eliminated through virus therapy are found during pre-indexing, material is sent for therapy directly. This increases the chance that virus-free germplasm is introduced in the genebank, and allows for cost reduction in double indexing, pre- and post-therapy. After therapy, indexing is still required to confirm the health status. If the pre-indexing results are negative, the material is sent immediately for full indexing for confirmation of its health status.

Other areas where ITC uses contracts with partners for genebank operations are characterization and field verification. Field verification is carried out either by partner institutes in the country of origin of the accession or by other collections holding the mother plants in the field. The cytological characterization to determine the ploidy of an accession is carried out at the Institute of Experimental Botany (IEB) in Olomouc, Czech Republic, and for molecular characterization material is analyzed using SSR-markers at CIRAD, France or IEB. After validation of the genotyping technique, in 2009, it is planned to develop a *Musa* Genotyping Centre (MGC) hosted by IEB to perform molecular characterization of any plant material to be acquired by ITC. In addition this MGC will provide genotyping services to any *Musa* researchers wishing to confirm the identity of a particular genotype (this last service is on a cost-recovery basis). One full-time technician is required to do flow cytometry analysis, DNA extraction and molecular characterization using SSR and ITS markers for an estimated 200 samples/year. The annual operating costs for the ITC in 2007 are shown in Table 8.2

8.4 Economic analysis

In 2007, the total estimated annual costs of operating ITC was 751,702 Euros. However, 2007 may not reflect a “typical” year for a longer-term perspective. There

were more new introductions than in other years. Also the cryopreservation of the whole collection is still in process so that more accessions are included in this activity than will be in the future.

Table 8.2. Current annual operating costs (2007 prices in Euro)

Activity	Number of accessions	non-labour variable costs	Labour costs	Annualized capital costs
Laboratory tasks				
Introduction of new accessions	70	2,800	9,295	
Maintenance of accessions (MTS)	1,182	11,420	58,157	12,714
Regeneration	50	3,100	11,727	-*
Cryopreservation	125	5,769	100,000	14,579
Safety duplication of accessions	192	2,650	0	
Germplasm distribution	550	16,500	27,433	2,543
Leaf bank	120	289	1,625	3,328
Stock	23	507	2,206	
Genebank supportive research		0	20,000	
Greenhouse renting + supplies*		3,000		
Management				*3,631*
In vitro collection	1,182		42,235	
LTS management + training			45,000	
Germplasm dissemination management	550.00		60,643	
Database management			45,000	
General genebank management			45,000	
Financial administration			45,000	
Contracted services				
Germplasm health testing				
virus indexing	70	22,750		
virus therapy	14	6,852		
pre-indexing	70	10,500		
Characterization				
field verification/ morpho characterization	50	3,750		
ploidy (cytology)	70	1,400		
molecular (SSR)	70	1,400		
Total per category		***92,687***	***513,322***	***36,472***
Total cost	642,481			
Total cost including overheads to KULeuven 17%	**751,702**			

* For regeneration, infrastructure and services are contracted from KULeuven and appear therefore in greenhouse renting and supply. Greenhouse is only required for regeneration.

In a more typical year, about 25 accessions are newly introduced; hence health testing and cryopreservation are necessary only for these new introductions. The rejuvenation activity is up date for all accessions, and about 80 accessions per year will be regenerated in a typical year. With more data on the frequency of mutations and the frequency of subcultures, the time intervals for regeneration might be extended in the longer term.

In a typical year, the total annual cost for the current size of the genebank operations is about 650,000 Euro (Table 8.3). In terms of an endowment fund or capital stock to cover costs in perpetuity, a capital of 16,886,537 Euro is required, based on an interest rate of 4% per year. Further scenario calculations are based on the results for this typical year (reference year).

The largest share of cost is represented by labour costs (Figure 8.2). This has several reasons, first the maintenance of the collection as *in vitro* plants with relatively short cycles of subculturing and permanent revision of the plant material is highly labour-intensive as compared to seed banks, where germplasm can be stored for extended periods of time and intervals for regeneration are much longer. Second, labour is expensive due to the highly specialized tasks in the *in vitro* laboratories as compared for example to maintenance in field genebanks. Third, compared to the countries where the other CGIAR genebanks are located, Belgium is a country with relatively high labour costs.

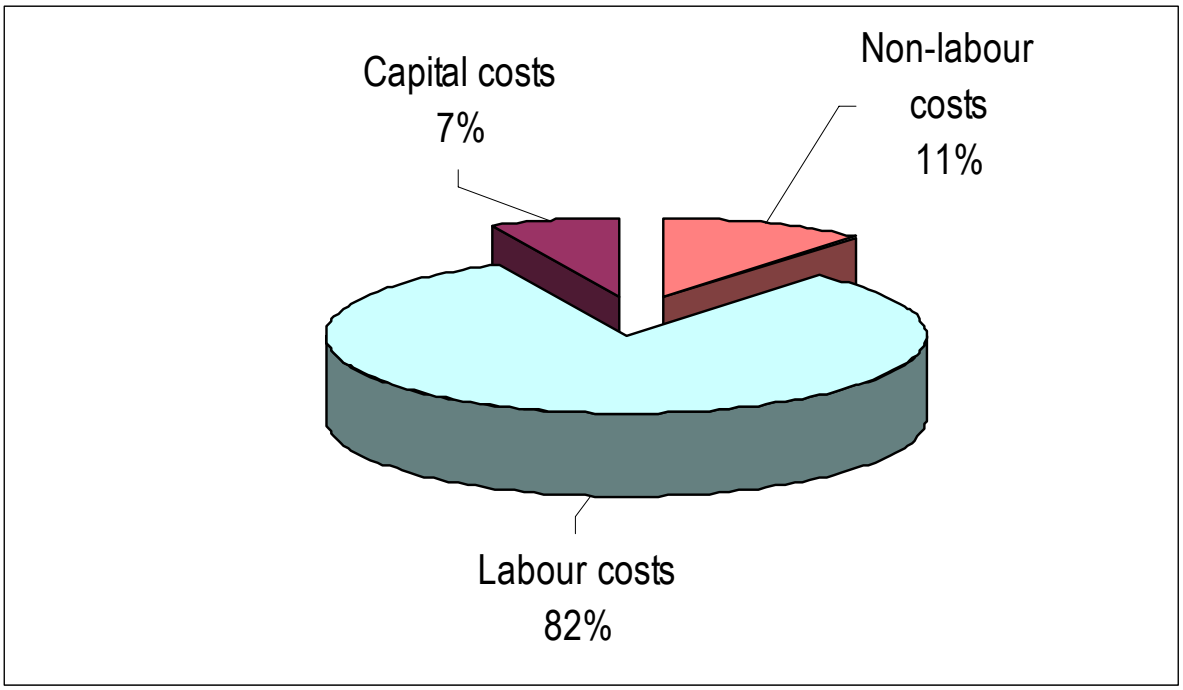

Figure 8.2. Genebank annual maintenance costs breakdown

Table 8.3. Average annual cost of genebank operations in 2007 prices (Euro) *with current size and standards and typical year.*

Activity	Number of accessions	non-labour variable costs	Labour costs	Annualized capital costs
Laboratory tasks				
Introduction of new accessions	25	1,000	3,320	
Maintenance of accessions (MTS)	1,200	11,594	59,043	17,799
Regeneration	80	4,960	18,764	
Cryopreservation	50	2,307	40,000	9,494
Safety duplication of accessions	50	690	0	
Germplasm distribution	550	16,500	27,433	2,543
Leaf bank	120	289	1,625	3,328
Stock	25	551	2,397	
Genebank supportive research			20,000	
Greenhouse renting + supplies		3,000		
Management				*3,631*
In vitro collection	1,200		42,879	
LTS management + training			45,000	
Germplasm dissemination management	550		60,643	
Database management			45,000	
General genebank management			45,000	
Financial administration			45,000	
Services				
Germplasm health testing				
virus indexing	25	8,125		
virus therapy	5	2,447		
pre-indexing	25	3,750		
Characterization				
field verification/ morpho characterization	80	6,000		
ploidy (cytology)	25	500		
molecular (SSR)	25	500		
Total per category		***62,214***	***456,103***	***36,472***
Total cost	555,113			
Total cost including overheads to KULeuven 17%	**649,482**			

8.4.1 Costs per activity and accession

For the calculation of the per-accession costs of conservation, three different activities are considered: The maintenance in MTS, in cryopreservation and the introduction of a new accession to the collection, which is relevant for either type of conservation.

The costs for the introduction of a new accession include tissue culture supplies, labour for the establishment of the tissue culture as well as contracted services for health checks and characterization. The introduction phase for an accession ends with the confirmation of its health status.

Table 8.4. Cost of introduction of new accessions to ITC, in 2007 prices (Euro).

Cost item	Price per accession
Introduction of new accession supplies	40.00
Introduction of new accession labour	132.79
Health testing/therapy	572.89
Characterization	115.00
Total cost	**860.68**

Average annual costs and in-perpetuity costs of the conservation of *Musa* accessions *in vitro* in MTS are shown in Table 8.5. The costs of managing and subculturing of accessions in MTS are estimated on an annual basis, since on average, the accessions are subcultured after 12 months. Regeneration is only necessary every ten years. For the capital costs for laboratory equipment, the average annual depreciation was calculated and attributed such that 50% of total costs are charged to the conservation *in vitro*.

Table 8.5. Average annual costs and in-perpetuity costs for medium term conservation per accession, in 2007 prices (Euro)

Cost category	Average annual costs	In-perpetuity cost
Supplies	9.66	251.20
Regeneration	6.20	191.10
Laboratory equipment	12.03	312.70
Labour subculturing	49.20	1279.20
Labour regeneration	23.20	722. 95
Labour management	35.73	929.04
Total	**136.02**	**3686.19**

In view of the high costs of maintenance of *Musa* as *in vitro* plants in MTS, long-term conservation of *Musa* accessions in liquid nitrogen has been considered as a probably lower cost alternative, since maintenance costs are relatively low (see Table 8.6). Accessions, once stored in LTS do not require subculturing, and the time period for regeneration is estimated to be around 100 years. Also, contamination with pathogens or other potential risks of growing *in vitro* plants is minimal or non-existing if germplasm is stored in frozen state, which is therefore seen as a very safe conservation technology.

Table 8.6. Average annual costs and in-perpetuity costs for long-term storage in cryopreservation, in 2007 prices (Euro)

Cost category	Introduction of accession into LTS	Maintenance in LTS	In-perpetuity costs
Supplies	59.95		59.95
Labour	800.00		800.00
Specific laboratory equipment	30.95		30.95
Share of general laboratory equipment	45.49		45.49
Labour, management	360.00		360.00
Energy and liquid nitrogen		5.21	135.41
Total per accession	**1296.39**		**1431.80**

The analysis of the costs per accession shows that in comparison to MTS, the LTS requires a high investment in the first year, which is the labour-intensive step of preparing the material and freezing it. In the long run, maintenance costs are low (based on estimated of IRD, where safety duplicates of the cryopreserved accessions are stored, the annual costs for maintenance per accession are 5.21 Euro for infrastructure, energy supply, liquid nitrogen and labour for regular checks). The in-perpetuity costs of LTS per accessions are much lower than for MTS. Assuming that for MTS, regeneration will be carried out in the 10th year, the time period, when the cumulative costs of MTS become equal/higher than LTS, is 15 years. If stored for a longer time period, LTS becomes the cheaper option for conservation. Yet, the comparison of costs of LTS and MTS applies only for conservation. It has to be noted that cryopreserved material is not available for distribution, therefore currently all accessions in LTS continue to be stored *in vitro* as well. Unlike frozen seeds, the regeneration of cryopreserved tissue into viable plants is a lengthy process and requires the re-establishment of the tissue as *in vitro* material, which then would be multiplied for distribution. Hence, the elimination of accessions from MTS, which are also maintained in liquid nitrogen, would affect either the availability for distribution or lead to increased costs for thawing material. As shown in the previous chapters, the utilization ratio of ITC has been high in the past, with 80% of the available accessions requested at least once. Also trends in the demanded traits change over time, so the future demand for accessions is practically unpredictable.

Also, further research on characterization, virus elimination and evaluation is not possible in LTS, thus limiting the possible information upgrade for accessions exclusively stored in liquid nitrogen.

The distribution of germplasm to users all over the world is a key activity in the mandate of the ITC. The service is free for the users, i.e. the costs are completely covered by the ITC budget (Table 8.7). The costs include management of requests and SMTAs, laboratory work for the multiplication of the requested accessions, packaging and shipping costs. Currently, a stock of frequently requested accessions is maintained ready to distribute, which not only speeds up the service, but also allows reducing costs through planning of laboratory work.

In view of the objective of ITC to conserve *Musa* germplasm to make it available for use, LTS and MTS cannot easily be traded-off in terms of costs (Table 8.8).

8.4.2 Scenario analysis: Expansion of the collection

One realistic scenario for the further development of the *Musa* collection at ITC is a stepwise expansion of the collection over the next 10 years to reach a total of approximately 2000 accessions. The basis of this scenario is the high interest in completing the collection in terms of wild *Musa* species and filling gaps is representation of some geographical under-representation of cultivated materials, as well as the progressive implementation of the Treaty with financing by the Trust, to acquire and conserve a number of *Musa* landraces as safety back-up for national or regional collections, where the germplasm so far is maintained in field banks only, with all the associated risks.

For this scenario, it is assumed that over ten years, every year 80 new accessions are added to the collection, including the health checks and basic characterization (laboratory and field). Assuming that cryopreservation of the whole collection will be achieved before this expansion; the annual investment in cryopreservation corresponds to the 80 new acquisitions per year. Regeneration of the new accessions is only required after 10 years from introduction, hence during the expansion phase, this activity includes yearly 100 accessions from the existing collection. It is anticipated that the current investment in field verification and upgrade in the documentation status of the collection, as well as the expansion of the collection are both factors that will increase the demand for germplasm, so that a steady increase in the distribution activity up to 1200 accessions per year after 10 years may be expected.

Expanding the collection to 1600 accessions, corresponding to year 5 of the expansion phase, would require additional investments in laboratory equipment, such as culture racks, laminar airflow benches, freezers and tanks for cryopreservation. For the further expansion it is assumed that an additional investment of similar magnitude will become necessary in year ten, when the collection reaches a stable size.

Table 8.7. Average annual costs and in-perpetuity costs of distributing one accession, in 2007 prices (Euro)

Cost category	Annual average costs	Cost of distribution activity in perpetuity
Supplies	30.00	780.00
Stock	22.06	573.51
Labour	49.88	1296.81
Management (labour)	110.26	2866.75
Share of general lab equipment cost	5.17	134.40
Total per accession	**217.36**	**5651.47**

Table 8.8. Present value of in-perpetuity costs of MTS, LTS, distribution and management of ITC in 2007 prices (Euro)

Activity	Number of accessions	In perpetuity costs per accession	Total present value
Introduction of new accession	25	22,377.80	559,445
Conservation MTS	1200	2757.21	3,308,653
Conservation MTS, new accession	70	1117.29	1,340,745
Conservation LTS	1200	29,049.47	726,237
Distribution	550	5541.22	3,047,670
Management	1	5,872,536.73	5,872,537
Overheads	1	2,408,643.91	2,408,644
Grand total			**17,263,930**

Table 8.9 (see page 79) shows the average annual costs in 2007 prices at different points of time during the expansion phase as well as for managing the collection at a stable size of 2000 accessions. Due to changes in the size of the different activities, the allocation of capital costs also changes over time. While for the first years of the expansion phase, the shares of the activities are calculated as in the typical year with 70% for MTS, 20% of LTS and 10% for distribution, from the 5th year on, the distribution activity increases and hence the use of laboratory equipment for distribution related tasks. Therefore, the weights in the 5th year are 60% for MTS, 20% for LTS and 20% for distribution.

For the typical year after the expansion, when the collection has reached a stable size, cryopreservation will require much less laboratory work, so the allocation of capital costs is 65% for MTS, 10% for LTS and 25% for distribution.

The results of this scenario simulation (Table 8.10) show that moving from 1200 to 2000 accessions would result in additional average annual costs of about 227,000 Euro. The present value of the sum of estimated annual total costs during the expansion phase is about 7.7 million Euros. Considering the total costs of maintaining the collection at current size during the same time period, the additional funds necessary for the expansion is 1.4 million Euros.

The expansion of the collection up to 2000 accessions conserved and 1200 accessions distributed per year has implications for the costs per accession, considering that by then the laboratory equipment and infrastructure will be used at full capacity. The comparison of per accession costs for MTS and distribution activity between the current and the expanded size of the collection shows that reductions in costs are moderate for both, MTS with savings of about 15 Euro and distribution with only 2 Euro (Table 8.10).

Table 8.10. Average annual costs per accession in MTS and for distribution, different scenarios, 2007 prices (Euro)

Activity	Current size	Expanded collection
Medium term storage		
Average annual costs	136.02	121.67
Present value of in-perpetuity costs	3,686.19	3,306.54
Distribution		
Average annual costs	217.36	215.14
Present value of in-perpetuity costs	5,651.48	5,593.77

Table 8.9. Expansion of the collection from 1200 to 2000 accessions over 10 years: Average annual costs in 3 different years during the growths phase and at steady state with 2000 accessions, in 2007 prices (Euro)

	Year 1			Year 5			Year 10			Year 11		
Activity	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**
Tissue culture laboratory work												
Introduction of new accessions	80	3,200	10,623	80	3,200	10,623	80	3,200	10,623	25	1,000	3,320
Maintenance of accessions (MTS)	1,200	11,420	59,043	1,600	15,227	78,724	1,920	18,272	78,724	2,000	19,033	98,405
Regeneration	100	6,200	23,455	100	6,200	23,455	100	6,200	23,455	200	12,400	46,910
Cryopreservation	80	3,692	64,000	80	3,692	64,000	80	3,692	64,000	25	1,154	20,000
Safety Duplication of accessions	80	1,104		80	1,104		80	1,104		25	345	
Germplasm distribution	800	24,000	39,902	1,000	30,000	49,877	1200	36,000	49,877	1,200	36,000	59,853
Leaf Bank	80	193	1,083	80	193	1,083	80	193	1,083	100	241	1,354
Stock	20	441	1,918	30	662	2,877	40	882	2,877	40	882	3,836
Genebank supportive research		3,000			3,000			3,000			3,000	

Table 8.9. Expansion of the collection from 1200 to 2000 accessions over 10 years (cont'd)

	Year 1			Year 5			Year 10			Year 11		
Activity	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**
Management												
In vitro laboratory management			47,859			55,566			59,771			48,612
LTS management + training			45,000			45,000			45,000			45,000
Germplasm dissemination management			88,208			110,260			132,300			132,312
Database management			63,000			63,000			63,000			63,000
General genebank management			45,000			45,000			45,000			99,000
Financial admin			45,000			45,000			45,000			99,000
Greenhouse renting + supplies		3,000			3,000			3,000			3,000	
Depreciation Equipment												
Lab equipment MTS		12,552			17,151			20,844			20,844	
Lab equipment LTS		9,429			10,817			8,999			8,999	
Lab equipment distribution		2,510			5,717			8,017			8,017	

Table 8.9. Expansion of the collection from 1200 to 2000 accessions over 10 years (cont'd)

	Year 1			Year 5			Year 10			Year 11		
Activity	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**	**# acc**	**non-lab**	**labour**
Depreciation Equipment (cont'd)												
Lab equipment leaf bank		3,328			3,328			3,328			3,328	
Office Equipment		3,631			3,631			3,631			3,631	
Services												
Virus indexing and therapy		45,831			45,831			45,831			14,322	
Field verification		7,500			7,500			7,500			15,000	
Ploidy and SSR characterization		3,200			3,200			3,200			1,000	
Total operating cost		**144,232**	**534,091**		**163,455**	**594,466**		**176,895**	**647,390**		**152,198**	**720,601**
Total operating cost including overheads paid to KULeuven		**793,638**			**886,767**			**964,413**			**1,021,175**	

8.4.3 Scenario analysis: Reduction of plants per accession in MTS

In MTS, the standard procedure is to maintain 20 replicate cultures per accession. Currently, at ITC, trials are carried out to test the possibility of reducing the number of plants per accessions to 12. Potential savings in costs refer to the consumption of tissue culture supplies and labour. The trials will have to show whether or to what extent the reduction in plants per accession increases the risk of loss of the accession, requires more frequent monitoring or leads to shorter intervals between subculturing, which would increase rather than decrease costs for such a scenario. To calculate potential cost savings, it is thus assumed here that labour for managing and supervising the collection remain constant while labour for subculturing is reduced. The results (Table 8.11) show that savings in average annual costs are about 20 Euro at the current size of the genebank with 1200 accessions. For an expanded genebank, the rationalization of MTS in terms of reducing the number of plants results in savings of about 12 Euros. Combining the 2 scenarios, an expanded, rationalized medium-term collection would cost about 25 Euros less per accession.

Table 8.11: Average annual costs per accession in MTS, 20 or 12 plants per accession, for different scenarios, 2007 prices (Euro)

Size of collection	Current size		Expanded collection	
No. of accessions in MTS	1,200	1,200	2,000	2,000
Plants per accession	20	12	20	12
Average annual costs	136.02	116.58	121.67	109.76
Present value of in-perpetuity costs	3,686.19	3,174.14	3,306.54	2,996.93

8.4.4 Scenario analysis: Substitution of medium-term conservation by cryopreservation

As explained above, it is very difficult to trade off between MTS and LTS in terms of giving up the one-to-one principle that all accessions stored in LTS are also maintained in the *in vitro* collection. However, one rationalization strategy could be to separate the active collection in MTS from the long-term collection in liquid nitrogen. This would require a decision about germplasm that will not be available for distribution for a certain time period at medium term.

In general, it is very difficult to predict the demand for a specific accession, and as shown in the distribution data, the majority of available accessions (80%) have been requested in the history of ITC. More information about accessions in terms of identification of duplicates, characterization and

especially evaluation data would probably allow selecting accessions, which could be eliminated from MTS.

However, there is a considerable share of accessions, which are not available for distribution because of virus problems for which no therapy is actually available. These accessions can only be regenerated in the greenhouse and not in the field because of the risk of spreading the virus. Therefore, cryopreserving them has priority, to avoid degeneration in long-term when kept in culture under slow growth conditions. Although some of this germplasm is needed for virus-related research, is it reasonable to assume that distribution will remain restricted in foreseeable time.

Therefore, a possible scenario for rationalization is the exclusive maintenance of the virus infected germplasm in LTS and its elimination from MTS. In Table 8.12, the potential cost savings per accession eliminated from MTS over different time periods are shown. The initial investment of introducing the accessions into cryopreservation is not considered, since the accessions are already cryopreserved, or will be cryopreserved irrespective of the possible removal from MTS.

The potential cost savings are high but depend however on the time period considered (Table 8.12). One factor which could impact on the relevant time period is the Bioversity moratorium on the distribution of virus-infected (BSV) *Musa* germplasm, which is currently under discussion. In that case, the materials would be released for distribution on the shorter term, without the need for therapy.

Table 8.12. Cost savings through elimination of accessions from MTS, in 2007 prices (Euro)

Type of cost	Base year	Year 5	Year 10	Year 15	Year 20
Present value of annual costs/accession in MTS	136.28	112.01	92.06	75.67	62.20
Cumulative present value/accession in MTS		606.68	1105.34	1515.19	1852.06

Chapter 9. Conclusions and recommendations

The results in this study allow drawing a number of conclusions about the evaluation of performance of the ITC through its users and deriving recommendations for further improvements. The conclusions and recommendations summarized in this section cover the aspects of general performance indicators, the evaluation of service through users of ITC, recommendations for the improvement of the service, economic aspects using cost indicators, possibilities of reduction of costs and suggestions for areas needing further investment of funds.

Box 9.1. List of recommendations

1. Expand the collection, especially with respect to wild species.
2. Encourage stakeholders to share germplasm to complete the collection.
3. Establish/ support existing regional collections for easier access and back-up function.
4. Continue with cryopreservation for backing-up the whole collection.
5. Use regeneration and field verification project as starting point for further research on maintaining genetic integrity and avoid off-types.
6. Improve documentation: upgrade with characterization and evaluation data and photos.
7. Better links between ITC and MGIS, updates and user-friendliness of MGIS.
8. Encourage more systematic feedback from users about germplasm evaluation results.
9. Establish regular updates on ITC activities, new germplasm or new information about germplasm available.
10. Reconsider moratorium on the distribution of BSV infested accessions; investigate trade-off between risks and benefits, probably country and case-specific.
11. Consider sets of accessions to be exclusively held in cryopreservation and eliminated from *in vitro* collection.
12. Invest in characterization (morphological and molecular) and evaluation in order to increase germplasm use and to allow for rationalization.

9.1 General performance and impacts

The presented study gives an overview of the performance of ITC since its beginnings, with a more detailed view on the time period since 2000.

The presented data show a continuous increase in the genebank activities in terms of the size of the collection, the number of accessions available for distribution and in samples of germplasm distributed. Currently the collection of ITC includes 1212 accessions, of which 810 are available for distribution. In recent years, an average of 550 samples of accessions has been distributed to external users. In terms of the diversity distributed, about 33%

of the available accessions or 22% of the total number of accessions have been distributed every year.

The quality standards of the genebank activities have also increased over time, based on research achievements with regards to virus indexing and therapy and new technologies made available for the conservation of germplasm. All accessions at ITC are virus indexed and it is guaranteed that no infected germplasm is distributed. The quality of medium-term storage as *in vitro* cultures has been improved through rejuvenation of all accessions. The regeneration and field verification of rejuvenated accessions in reference collections is expected not only to further confirm the authenticity and the trueness-to-type of the conserved germplasm, but also to upgrade the documentation with actualized characterization and evaluation data, which in the medium term is expected to lead to an increase in utilization of the collection.

The development of protocols for the long-term storage of *Musa* germplasm in liquid nitrogen, and the increasing number of accessions thus cryopreserved, lead to increased safety of the conservation of germplasm. Safety duplication of cryopreserved germplasm has been set up. This is an important back-up of the *in vitro* collection and reduces the risks of loss of accessions for example through contamination or mutations induced through the *in vitro* conservation.

9.2 Evaluation of service and suggestions for improvements through users of ITC

Since its foundation, the ITC distributed germplasm to more than 100 different countries. The survey results presented in this study are based on responses of 63 users in 35 different countries. Survey respondents reported a high degree of satisfaction with the service provided and highlight the role of ITC as most important source of new *Musa* germplasm for research as well as for the distribution of improved germplasm to farmers. The respondents appreciated the diversity available for distribution, which they rated as unique among *Musa* genebanks and the accessibility of germplasm due to the free-of-charge service. The health status of the received material and the related health certificates are of high value to the users. In some countries, the ITC is the only possible source of *Musa* germplasm given strict quarantine regulations. Thirty-eight percent of the survey respondents pointed out that they would not have been able to carry out their research or development projects without having access to the germplasm from ITC. Germplasm is requested from ITC for different purposes, for example for breeding, fundamental research, characterization and evaluation as well as direct dissemination to farmers. For a number of countries, ITC is the only viable source of superior *Musa* germplasm. Impacts created by the use of germplasm from ITC include yield increases, benefits along the value chain including

processing, prevention of yield losses through the introduction of varieties with resistance or tolerance to abiotic stress and to pests and diseases. Based on only the small sample of 60 survey respondents, a rough estimate of at least 76 000 farmers have benefited indirectly over the last 7 years from the distribution of germplasm from ITC. Providing access to a broad genetic diversity of *Musa* and the unique identification of accessions, ITC facilitates applied and fundamental research on bananas.

However, with respect to the distribution service, many survey respondents mentioned to be concerned about the issue of banana viruses integrated in the banana genome (BSV). Two major perspectives were raised: firstly, the risks of the unintentional spread of the virus, through negatively indexed germplasm, which nevertheless can develop virus symptoms; secondly, the limited availability of a relatively large group of accessions due to infestation with BSV and the interest in the potential benefits from the use of this germplasm. These contrasting views are being discussed and important arguments exist for both options: to maintain or to relax the moratorium on the distribution of affected germplasm (see InfoMus@ 2008). It is recommended to carry out further research to assess risks and benefits and to reconsider the moratorium when new results or arguments are available.

In addition to the distribution of germplasm, the users stressed the importance of the conservation of germplasm, especially as safe back-up of national or regional field collections. In this context, users perceived cryopreservation as an important innovation for the long-term conservation of *Musa* germplasm, which they thought of as potentially interesting also for other collections.

The suggestion of providing more support to regional collections and distribution centres or establishing them where missing is currently being addressed in the framework of the global *Musa* conservation strategy, supported by the Trust.

Suggestions were made with respect to the diversity available for distribution from ITC. Respondents expressed their interest in a wider diversity of wild *Musa* species, which were perceived to be still underrepresented in the collection of ITC.

Other suggested improvements refer to the information availability about the conserved germplasm. There is a need for more evaluation data in order to support the selection of germplasm for specific purposes. The users expressed their preference for characterization data including good photos. Also, they suggested regular updates on new evaluation results and new germplasm available. This could be implemented using existing communication channels in the ProMusa network (http://www.promusa.org/), probably in combination with an e-mail newsletter for those users of ITC who may have limited access to internet resources. Other improvements in the availability of information are

outside of the responsibility of ITC, but are currently being addressed by working groups within Bioversity, such as a new, user-friendlier version of the MGIS database including a set of photos for characterization, and the publication of the results of the last IMTP phases in user-friendly formats.

Other suggestions that were raised by some of the users may not be feasible for cost reasons, such as the provision of a higher quantity of plants per accession. If the reason for such suggestions is the perceived risk of loss of samples during multiplication, a possible solution is to provide more information on handling and multiplication of the tissue culture material. For users who need multiplication services, it may be possible to provide more plants at a cost, or to refer to tissue culture laboratories in the respective country/region.

9.3 Cost analysis

The cost analysis shows that the conservation of *Musa* germplasm is relatively expensive. This is mainly due to the need of *in vitro* conservation as compared to crops of which seeds can be stored over several years. The average annual cost of conserving one accession of *Musa in vitro* is about 136 Euro. For the distribution of one accession, about 217 Euro are needed. The reason for these high costs is that *in vitro* culture with the regular need for subculturing is very labour intensive. The comparison of results of this study with data on *in vitro* conservation of cassava germplasm at CIAT shows that labour input for the *in vitro* conservation is similar for cassava and banana (Koo et al. 2004). However, labour is far more expensive in Belgium than in Colombia, so that the cost estimates for the medium term storage of banana germplasm *in vitro* per accession are significantly higher than for cassava.

The results presented in Chapter 8 demonstrate that cryopreservation cannot be a substitute for *in vitro* culture due to the high initial costs of about 1300 Euro to introduce an accession of banana germplasm into long-term storage in liquid nitrogen. This result supports the current strategy of using cryopreservation for safe long-term storage backing up the *in vitro* collection. However, cryopreservation could play an important role for the rationalization in two ways. Firstly, if it was possible to agree on a set of accessions, which will not be distributed for a minimum time period of 20 years, these accessions could be exclusively conserved in long-term storage, thus saving about 136 Euros per accession or year. Possible criteria for the selection of such a set of accessions could be, for example, the infestation of the germplasm with viruses for which currently no therapy is available, or groups of genetically very similar accessions, of which only few representative accessions be kept for distribution. Secondly, the safety back-up in long-term storage allows rationalizing the medium-term collection so that the number of *in vitro* cultures can be reduced from currently 20 to 12 samples per accession, as already established in trials. For the current size

of the collection of about 1200 accessions and 900 accessions cryopreserved to date, approximately 18 000 Euros[13] could be saved. As shown in the cost estimates for an increased size of the collection with about 2000 accessions, the savings per accessions would be lower, but still amount to a potential 24 000 Euros per year[14].

For a number of genebank operations, for example for virus indexing, molecular characterization, regeneration and field verification, the ITC collaborates with external service providers, instead of maintaining own infrastructure. This strategy seems to pay-off in terms of cost savings, since the size of these operations has largely varied over time. The introduction of new accessions, which require virus indexing and probably therapy, has been variable in the past. For a period of 10 years from now, an average of 80 accessions is assumed to be introduced into the collection, however, actual numbers may differ from year to year making it difficult to plan the capacity for own virus indexing facilities.

9.4 Recommendations for further investment

There are already plans for further investments for improved conservation *Musa* germplasm at the ITC, like an expansion of the collection from the currently 1200 accessions to about 2000 accessions, based on the numbers of accessions known to be lacking and on estimates of existing wild species which still have to be collected in their geographical origin. This expansion of the ITC collection not only corresponds to the interest expressed by the users of getting access to a broader diversity of wild species. Also, the ITC has the mandate and commitment to conserve these accessions and make them available in the public domain as specified in the Treaty and supported by the Trust. The results of the cost analysis show that such an expansion would require an investment of about 1.4 Million Euro over 10 years. After this time period, the total annual operating costs are estimated to increase by about 220 000 Euros, as compared to the current situation.

Additional investments can be recommended in the area of characterization and evaluation of the germplasm. The benefits for the users are obvious: a better information basis for the selection of germplasm may lead to an increased demand and to cost reductions for germplasm evaluation for the individual user, resulting in greater impact of the distribution of germplasm from ITC. Considering the high number of users carrying out evaluation trials with ITC germplasm, a strategy should be set up to encourage feedback of research results from users to ITC and to capture more

[13] About 20 € per accession, see Table 8.11, multiplied by 900 accessions.

[14] About 12 € per accession, see Table 8.11, multiplied by 2000 accessions.

evaluation data in the documentation systems. This would be closely linked to the current efforts of improving and upgrading MGIS.

In the context of the rationalization of the ITC, additional characterization and evaluation data could be used to identify duplicates in the collection as well as to select sets of accessions for which it would be sufficient to be conserved in long-term storage as explained above. More information about the accessions, organized in a user-friendly manner also could reduce the number of specific personal inquiries to the genebank manager asking for recommendations for the selection of germplasm. This could be an important aspect in view of the challenge to coordinate and organize the increase in the size of the collection.

9.5 Outlook for further research topics: quantifying the impact of the ITC

Based on the types of impacts described by the survey respondents in this study, and considering the conceptual framework outlined in Chapter 3, a number of topics for empirical case studies can be identified, aiming to quantify some of the impact created by the ITC in terms of conservation and distribution of *Musa* germplasm and through its role as a reference collection.

The distribution of germplasm is probably the most obvious activity creating quantitative impacts for farmers. Many survey respondents reported increases in banana yields and the prevention of yield losses due to pests and diseases, based on the introduction of new varieties obtained from ITC. The contribution of the ITC to such positive effects can be identified based on the question whether the germplasm would have been available from other sources or not. If the varieties could have been provided by other sources, the comparison of transaction costs for the different possible sources would be the correct approach to quantify the impact. For varieties, where ITC is the only possible provider or in countries, where import from other sources than ITC is prohibited, the opportunity costs of not carrying out the project need to be measured. A prominent case, where large-scale adoption of varieties introduced from ITC and significant yield effects have been adopted is the Kagera region in Tanzania. Between 1997 and 2002, a number of improved varieties and disease-resistant cultivars have been disseminated to farmers, accompanied by a widespread farmer-to-farmer diffusion. Impacts in terms of increases in incomes, including the poorest stratum among the farmers have already been documented (Bese 2008). For the attribution of the project impacts to the distribution through ITC, it would be necessary to analyze which varieties had the strongest effects, and which would have been the possibilities and related costs of sourcing them from elsewhere.

For the conservation of germplasm, it would be interesting to focus on the traditional cultivars and landraces, which form the largest category of

germplasm in the ITC collection. Many of these cultivars are still being cultivated by farmers in East Africa (East African Highland bananas) and in Asia and the Pacific. Yet, due to rising pests and disease pressure, climate change and changing land-use patterns, many of these cultivars can be considered at risk of extinction, if not conserved in the genebank. In their regions of origin, these traditional cultivars are usually preferred by consumers for their tastes and processing qualities and hence fetch higher prices in the local markets than newly introduced, improved varieties. For the valuation of these genetic resources held at ITC, a case study could be carried out, compiling market information of price differences between traditional and new bananas, paid in local markets e.g. in East Africa and in the Asian and Pacific region and aggregate these value over the respective market volumes. The aggregated, observed willingness to pay for traditional banana cultivars by consumers could be interpreted as one important value-component of the conservation of this germplasm.

For the third area, where the ITC is expected to create tangible impacts, the role as a reference collection, providing unique identifiers for genetic material used in research, the transaction cost approach could be applied. Results of the survey among ITC users revealed that researchers are aware of saved transaction costs, because the use of ITC materials allowed them to base their research design on previous results, saving time and resources to start with basic trials and characterizations. Based on an analysis of literature where ITC codes are cited, a survey among researchers could be used to identify, to what extent germplasm from ITC facilitated research and especially follow-up studies building upon previously published results. This information then could be used for an assessment of the transaction costs saved through the use of ITC materials.

These briefly described possible case studies refer to the main activities and objectives of the ITC, and may be the most feasible examples for quantitative impact assessment. Topics for further studies could include the valuation of wild species conserved at the ITC, considering their utilization in breeding programmes, or further cases where ITC has facilitated the introduction of new varieties for release to farmers, resulting in prevention of pests and diseases or yield increases.

In view of the large number of ITC users in more than 100 different countries, and considering the range of different types of impacts created through the ITC activities, it is unlikely to achieve a comprehensive quantitative impact assessment of the ITC. The proposed case studies however could be used as examples for the magnitude of impacts of the different activities and for the different settings where germplasm from ITC is used.

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Appendix A. Survey on the use of *Musa* germplasm from Bioversity International Transit Centre (ITC) Belgium

1. The use of germplasm from ITC and its impact

Please note:

Use the comment boxes if you want to give details for shipments you received in different years.

It is possible to exit the survey and come back later, using the same link, in case you want to update your responses or complete the survey later.

1. For what purpose did you request germplasm from ITC?
   - o Breeding/Evaluation for breeding
   - o Multiplication and further dissemination
   - o Evaluation of agronomic or other traits
   - o Characterization (morphological, molecular, …)
   - o Fundamental Research
   - o Applied Research
   - o Conservation *in vitro*
   - o Conservation in field
   - o Cryopreservation

2. If Evaluation: What specific traits are you looking for?

3. For what purposes was the germplasm actually used?
   - o As intended
   - o Additional uses, please specify

4. Do you still keep the germplasm received from ITC? please give reasons:
   - o Yes
   - o No
   - o Some were discarded

Reasons

5. If yes to question 4: How do you keep the germplasm?
   - o In field
   - o *In vitro*
   - o In the greenhouse
   - o In cryopreservation

6. Have you distributed/shared the germplasm to/with additional users in your own institute?
   - o Yes
   - o No

7. Has the germplasm directly been passed on to other institutes, groups or growers? If yes, to whom?

- No
- Research institutes
- NGO
- Extension units
- Growers
- Commercial organization

8. Who are the beneficiaries from the receipt of the germplasm or any research that has resulted from the receipt of the germplasm?

- Farmers
- Processing industries
- Production industries (plants, fruits)
- Consumers
- Others (please specify)

9. If farmers were beneficiaries, please estimate how many farmers benefited from the germplasm or related research.

10. What have been the products of the research for which the germplasm from ITC was used?

- New variety developed
- Release of newly introduced variety
- Publications
- Other (please specify)

11. Did you provide feed-back on the research product/outcome of the use of the germplasm to Bioversity? In what form?

12. What have been the main impacts of the germplasm received from ITC of from research that has been carried out?

- Increased yields
- Reductions of yield loss from pests/diseases
- Avoidance of the introduction of diseases into the region/country
- Production available for processing
- Other (please specify)

13. How would your work be affected if you did not have access to germplasm from the ITC?

2. Types and traits of germplasm

14. Which cultivar types have been most important for achieving the objectives of your programme or institute?

Cultivar type	Relevant for own work (yes or no?)	Please rank according to importance for your own work (1 = most important)
Local cultivars/landraces		
Improved material/hybrids		
Wild *Musa* species		
Ensete		

15. Which cultivar types do you think will be most important for achieving the objectives of your programme or institute in the next 10 years from now?

Cultivar type	Relevant for own work (yes or no?)	Please rank according to importance for your own work (1 = most important)
Local cultivars/landraces		
Improved material/hybrids		
Wild *Musa* species		
Ensete		

16. Which traits of *Musa* varieties do you think are most important to you in the future? (please rank, 1 = most important)

- Nutritional value
- Tolerance to biotic stress
- Tolerance to abiotic stress
- Agronomic traits
- Post harvest characteristics
- Others (please specify)

3. Availability and quality of information about Musa germplasm

17. What information sources do you use to select the germplasm you wish to receive for your work and how useful do you find them? (please tick)

Information source	Very useful	Useful	Sometimes useful	Not useful	Don't know
MGIS					
Catalogues (e.g. *Musa*logue, other genebank catalogues)					
Direct inquiries to ITC or Bioversity					
Personal communication					
Scientific publications					
Conferences					
Other					
Please specify					

18. Do you think that the information from the above mentioned sources is sufficient to select germplasm?

- o Yes
- o No

19. If "no"- what information do you think is missing?

4. The role of ITC and evaluation of its service

20. In your opinion, what is the most important function or role of the ITC?

Function	Very important	Important	Less important	Not important
Long-term conservation of the diversity of *Musa*				
Facilitate the international exchange of germplasm				
Dissemination of clean material, free of pests and diseases				
Information provision				
Reference collection				
Other				
Please specify				

21. How do you perceive the ITC germplasm distribution service in terms of the following aspects?

Aspect	Good	Sufficient	Poor	N/A
Health status of the available germplasm				
Germplasm accompanying documentation				
Requesting procedure (effectiveness/ helpfulness/ delivery time)				
Quantity of materials supplied				
Quality of tissue cultures supplied (viability/ contamination/ trueness-to-type)				
Diversity available for distribution				

22. Are there any constraints that prevent you from using the ITC service? And how might they be resolved?

23. Do you have suggestions, how ITC might improve its service?

24. Did you recommend the ITC distribution service to others?

- Yes
- No

25. Will you request more germplasm from the ITC in the future?

5. Other sources of Musa germplasm

26. Is there any germplasm you wish to receive but cannot obtain from ITC? Please specify

27. Are/were you able to get it from other sources? If yes, from where?

28. Have you received germplasm from other sources? If yes, from whom?

- National/regional collection
- Breeding programmes, which
- Other international organizations
- Commercial providers/tissue labs
- Other (please specify):

29. How do the other sources of germplasm compare in the service they provide? Please explain

Aspect	Explanation
Diversity available	
Procedures for requesting	
Costs for receiving germplasm	
Restricted use	
Quality of material received	
Health status/ health certificate	
Time for sending	
Documentation of germplasm	
Quantities supplied	
Other aspects	

6. Some general questions about you and your organization

30. What type of institute is your organization?

- Advanced research institute
- University
- National research institute
- Genebank
- Non-governmental organization
- Farmers
- International Agricultural Research Centre
- Commercial company
- Unaffiliated individual

31. In which region is your organization located?

- Latin America and Caribbean
- West and Central Africa
- East and Southern Africa
- Asia and the Pacific
- Europe and North America

32. In which country?

33. What is your position in your organization?

34. Do you have any further comment or suggestion?

Appendix B. Details on genebank holdings and distribution

Table B.1. Number of accessions in the collection and available for distribution

1	2	3	4	5	6	7
Year	No. of accessions in collection	No. of accessions available for distribution	Total No. of accessions distributed	No. of distinct accessions distributed	% of accessions available (5/3)	% of total No. accessions (5/2)
1985	60	60	32	28	47%	47%
1986	132	132	27	26	20%	20%
1987	307	307	178	144	47%	47%
1988	467	467	356	211	45%	45%
1989	670	670	247	194	29%	29%
1990	991	991	210	165	17%	17%
1991	1036	1036	169	115	11%	11%
1992	1030	1030	219	91	9%	9%
1993	1065	1065	340	186	17%	17%
1994	1052	352	372	216	61%	21%
1995	1062	456	362	163	36%	15%
1996	1096	472	581	268	57%	24%
1997	1121	536	351	163	30%	15%
1998	1173	580	300	157	27%	13%
1999	1150	643	345	199	31%	17%
2000	1153	735	587	294	40%	25%
2001	1153	735	816	201	30%	17%
2002	1174	723	432	223	31%	19%
2003	1186	725	441	223	30%	19%
2004	1186	734	469	222	30%	19%
2005	1189	754	342	187	25%	16%
2006	1207	748	547	307	41%	25%
2007	1219	808	408	265	33%	22%

Table B.2. Distribution of germplasm according to geographical regions

Year	Asia/South Pacific	East Africa	Europe	Americas	West and Central Africa	Grand total
1985	12				20	32
1986					27	27
1987			19	16	143	178
1988	5	97	14	128	112	356
1989	28	58	13	47	101	247
1990	37	42	47	50	34	210
1991	12	5	101	13	38	169
1992	47	48	59	65		219
1993	10	63	141	99	27	340
1994	107	40	55	78	92	372
1995	103	48	107	91	13	362
1996	40	27	177	260	77	581
1997	56	42	173	67	13	351
1998	78	9	136	52	25	300
1999	121	110	63	36	15	345
2000	199	69	154	107	58	587
2001	401	63	111	170	71	816
2002	126	65	65	123	53	432
2003	123	80	103	120	15	441
2004	134	125	99	111		469
2005	11	90	129	91	21	342
2006	77	47	84	317	22	547
2007	134	54	150	50	20	408
Grand total	**1861**	**1182**	**2000**	**2091**	**997**	**8131**

Table B.3. Future importance of *Musa* variety traits (1 = most important)

Answer options	1	2	3	4	5	6	Rating average	Rank	Response count
Tolerance to biotic stress	22	8	3	2	2	1	1.9	1	38
Tolerance to abiotic stress	9	12	5	6	1	3	2.6	2	36
Agronomic traits	5	10	11	9	2	0	2.8	3	37
Nutritional value	7	4	8	7	12	2	3.5	4	40
Others	2	1	2	0	0	4	3.8	5	9
Post harvest characteristics	1	3	7	9	12	1	3.9	6	33

Table B.4. Importance of different ITC roles or functions (1 = most important)

Functions of the ITC	Very important	Important	Less important	Not important	Rating average
Long-term conservation of the diversity of *Musa*	46	3	0	0	1.06
Dissemination of clean material, free from pests and diseases	42	7	0	0	1.14
Facilitate the international exchange of germplasm	34	13	1	0	1.31
Reference collection	21	24	2	0	1.60
Information provision	16	24	4	0	1.73
Other	1	3	0	1	2.20

Table B.5. Perceived usefulness of different information sources for selection of germplasm

Answer options	Very useful	Useful	Sometimes useful	Not useful	Don't know	Total respondents	Rating average
Direct inquiries to ITC or Bioversity	22	11	3	0	4	40	1.32
Personal communication	26	8	5	1	1	41	1.49
Scientific publications	20	14	5	1	0	40	1.67
Catalogues (*Musa*logue, other genebank catalogues…)	17	14	6	1	1	39	1.72
Conferences	10	8	8	1	3	30	1.8
MGIS	10	10	11	3	3	37	2.03
Other	5	3	0	0	1	9	1.22

Appendix C. Costing of genebank activities

Equation 1: Calculation of present value of costs C_0 of capital items with service life of n years, price of X Euro at time zero and repurchased every nth year, considering the interest rate r.

$$C_o = \left[\frac{1}{1-a^n}\right]X \text{, with } a = \frac{1}{1+r} < 1,$$

Equation 2: Calculation of annualized user cost A of capital items repurchased every nth year at a price of X Euro, considering interest rate r.

$$A = \left[\frac{1-a}{a-a^n}\right]X \text{, with } a = \frac{1}{1+r} < 1$$

Table C.1. Capital costs and in-perpetuity annual user costs for laboratory equipment, in 2007 prices (Euro)

Equipment	Purchase unit cost	Quantity	Expected service life	In-perpetuity annual user costs
Laboratory				
Analytical balance	2752.09	1	10	326.26
Balance	600.00	1	10	71.13
Magnetic stirrer/heater	446.28	1	10	52.91
Heating mantle	502.14	1	10	59.53
pH-meter	1149.16	1	5	248.20
Medium dispenser	1983.49	1	5	428.41
Autoclave	100 000.00	0.5	10	5927.45
LAF table (laminar airflow)	7438.08	4	10	3527.11
Bunsen burners	322.32	8	10	305.68
Glass bead sterilizer	918.55	8	5	1587.16
LAF chairs	371.90	8	10	352.71
Binocular	991.74	2	10	235.14
Culture racks	1487.62	12	15	1543.82
Incubator	1537.20	1	10	182.23
Medium "mini-wash	198.35	1	5	42.84
Test tubes	0.67	5000	5	723.56

Table C.1. Capital costs and in-perpetuity annual user costs for laboratory equipment (cont'd)

Equipment	Purchase unit cost	Quantity	Expected service life	In-perpetuity annual user costs
Caps	0.15	5000	4	198.67
Test tube racks	12.40	150	10	220.50
Refrigerator	495.87	2	10	117.57
Freezer - 20 degree	619.84	3	10	73.48
Dishwasher	4958.72	1	10	587.85
Dissecting instruments	49.59	8	3	137.46
Incubator	12 000.00	1	10	1422.59
Water softener	1250.00	0.5	10	74.09
Stove	1284.0	0.3	10	45.66
Min-max thermometers	21.45	6	5	27.80
Cooking recipient	60.00	2	5	25.92
Electric timer	23.19	6	5	30.05
Table on rollers	200.00	6	10	142.26
Vacuum pump	800.00	1	10	94.84
TL light	1.04	465	1	483.6
Filters for LAF table	1239.68	1	1	1239.68
Glassware	1239.68	1	5	267.75
Depreciation general laboratory				**23 681.39**
Medium-term storage				
Culture racks in MTS room	1487.62	13	15	1672.48
Depreciation MTS specific				**1672.48**
Leaf bank				
Lyophilizer	14 876.16	1	10	1763.55
Freezer - 20 degree	619.84	2	10	146.96
Freezer - 80 degree	13200.20	1	10	1564.87
Depreciation leaf bank specific				**3475.38**

Table C.1. Capital costs and in-perpetuity annual user costs for laboratory equipment (cont'd)

Equipment	Purchase unit cost	Quantity	Expected service life	In-perpetuity annual user costs
Data management				
Computers	2000.00	4	3	2771.91
Printer + SQL server + scanner	1500.00	1	5	323.98
Barcode reader and printer	2479.36	1	5	535.51
Depreciation data management				**3631.40**
Cryopreservation specific				
Cryotank (300 acc.)	8000.00	4	15	2767.42
Dry shipper + transportation box	4000.00	1	5	863.95
Liquid nitrogen	0.40	6250	5	539.97
LN transportation tank	1000.00	2	10	237.10
Depreciation LTS specific				**4408.43**

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