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ENDOWING FUTURE HARVESTS: THE LONG-TERM COSTS OF CONSERVING GENETIC RESOURCES AT THE CGIAR CENTRES

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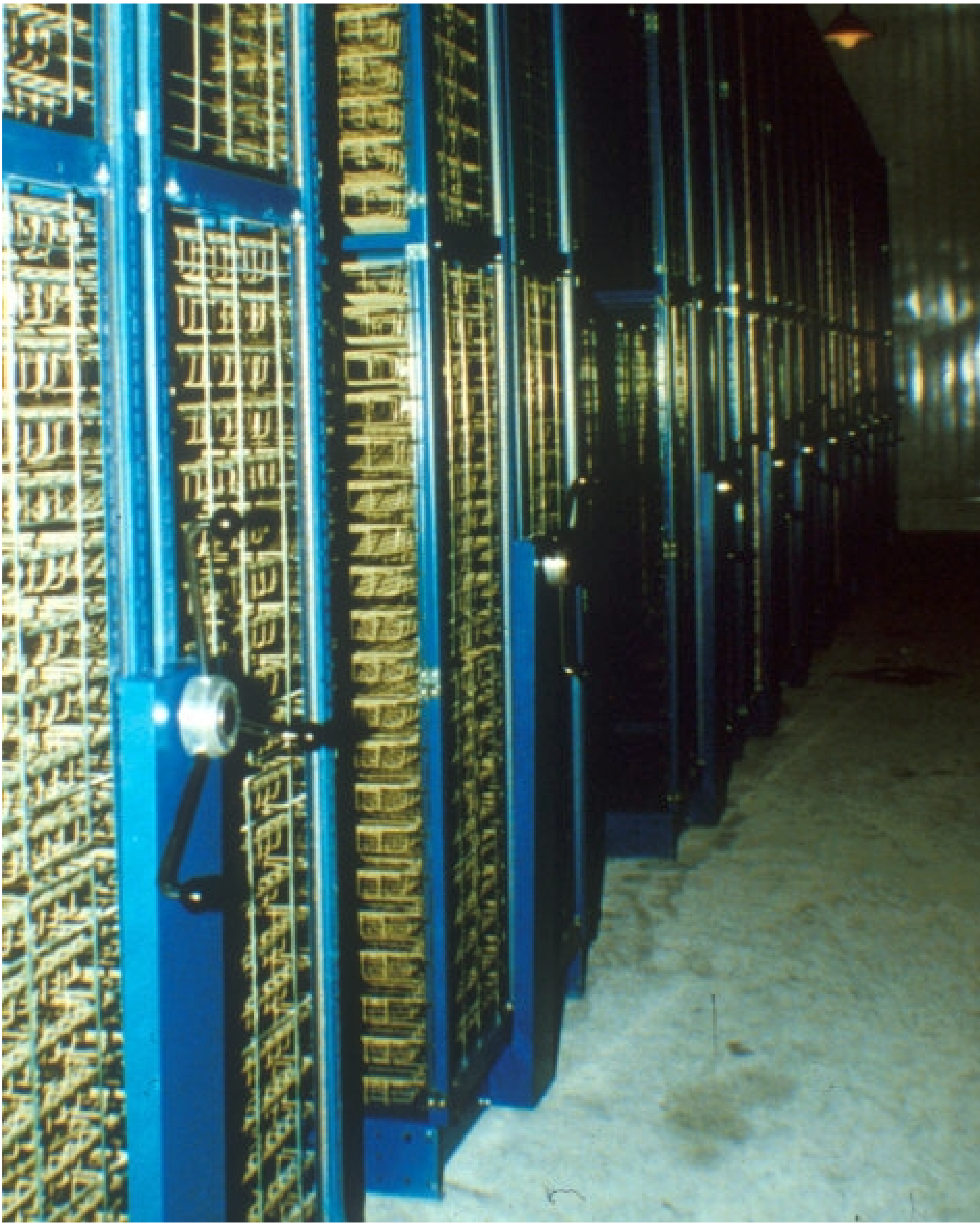

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HARVEST

ENDOWING FUTURE HARVESTS: THE LONG-TERM COSTS OF CONSERVING GENETIC RESOURCES AT THE CGIAR CENTRES

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A report prepared for the CGIAR System-wide Genetic Resources Programme by the International Food Policy Research Institute (IFPRI) in collaboration with the University of California, Berkeley

Bonwoo Koo is at the International Food Policy Research Institute as was Philip Pardey at the time this research was conducted (now at the University of Minnesota). Brian Wright is at the University of California, Berkeley.

The **Future Harvest** Centres comprise 16 food and environmental research organizations located around the world, which conduct research in partnership with farmers, scientists and policy-makers to help alleviate poverty and increase food security while protecting the natural resource base. The Centres are principally funded through the 58 countries, private foundations, and regional and international organizations that make up the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the World Bank.

The **System-wide Genetic Resources Programme** (SGRP) joins the genetic resources programmes and activities of the Future Harvest Centres in a partnership whose goal is to maximize collaboration, particularly in five thematic areas. The thematic areas — policy, public awareness and representation, information, knowledge and technology, and capacity-building — relate to issues or fields of work that are critical to the success of genetic resources efforts. The SGRP contributes to the global effort to conserve agricultural, forestry and aquatic genetic resources and promotes their use in ways that are consistent with the Convention on Biological Diversity. IPGRI is the Convening Centre for SGRP. The Inter-Centre Working Group on Genetic Resources (ICWG-GR), which includes representatives from the Centres and the Food and Agriculture Organization of the United Nations, is the Steering Committee.

The **International Food Policy Research Institute** (IFPRI) was established in 1975. IFPRI's mission is to identify and analyze alternative national and international strategies and policies for meeting food needs of the developing world on a sustainable basis, with particular emphasis on low-income countries, poor people, and sound management of the natural resource base that supports agriculture; to make the results of its research available to all those in a position to use them; and to help strengthen institutions conducting research and applying research results in developing countries. IFPRI is one of 16 Future Harvest agricultural research centers and receives its principal funding from governments, private foundations, and international and regional organizations, most of whom are members of the Consultative Group on International Agricultural Research.

The **International Plant Genetic Resources Institute** (IPGRI) is a Future Harvest Centre supported by the CGIAR. IPGRI's mandate is to advance the conservation and use of genetic diversity for the well-being of present and future generations. IPGRI's headquarters is in Maccarese, near Rome, Italy, with offices in another 22 countries worldwide. The institute operates through three programmes: (1) Plant Genetic Resources; (2) CGIAR Genetic Resources Support, and (3) the International Network for the Improvement of Banana and Plantain (INIBAP).

Citation:
Koo, Bonwoo, Pardey, Philip G., and Wright, Brian D. 2002. Endowing Future Harvests: The Long-Term Costs of Conserving Genetic Resources at the CGIAR Centres. International Plant Genetic Resources Institute, Rome, Italy.

ISBN 92-9043-520-8

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EXECUTIVE SUMMARY

The 11 CGIAR genebanks have grown considerably in size over the past few decades. They now conserve over 660,000 accessions (plant or seed samples) of crops grown mainly by poor people (such as cassava, millet, sorghum and cowpea), staple food crops grown throughout the world (such as rice, wheat and maize), and tree species used in agroforestry systems. This collection accounts for a sizeable share, perhaps 30 to 40%, of the unique entries in genebank collections worldwide. Conserving germplasm is a very long-term, if not *in perpetuity* (i.e., from now to eternity), proposition, and so the mismatch between the mainly annual funding support for this conservation effort and its very long-term nature and intent is a serious concern. An endowment or trust fund, the earnings from which would assure a funding stream to conserve this genetic material for all future generations, would judiciously match the duration of the funding commitments to the duration of the conservation commitments.

Our best estimate of the annual cost of conserving and distributing the genetic material presently held in the CGIAR genebanks is US$ 5.7 million per year. A commitment to underwrite these core genebank services for the benefit of *all* future generations could be met by setting aside a fund of US$ 149 million (invested at a real rate of interest of 4% per annum). Of this US$61 million (40 % of the total) would underwrite the CGIAR's current conservation activities in perpetuity and US$88 million (60 %) would maintain the distribution activities that provide germplasm to breeders, scientists, farmers and others worldwide.

These annual and in perpetuity estimates are sensitive to a number of factors, including the crop composition and size of the holdings, the number of samples distributed annually from the genebanks, the technology of germplasm storage, the rate of interest used to calculate the present value of distant future costs and various conservation protocols (especially the frequency with which aging seed samples are tested for viability and regenerated when necessary to maintain the vigor and size of the sample). The US$ 149 million conservation fund represents our best estimate, but with plausible variations in two key factors (interest rates and regeneration cycles), the size of the fund needed ranges from US$ 100 to US$ 325 million.

This funding is sufficient to support only *core* conservation and distribution activities currently undertaken by the CGIAR Centres. A key constraint to the effective use of genebank accessions for crop improvement and other purposes is the lack of information about the agronomic and genetic characteristics of the accessions. Although we have addressed the economics of this issue from a theoretical standpoint in another study, precise estimates of the costs are not available at this time. Nevertheless, a prudent strategy would be to complement the conservation fund costed here with comparable additional resources for characterizing the CGIAR collection to increase its value to plant breeding.

ACKNOWLEDGEMENTS

Throughout the course of this work we received a lot of valuable assistance from a lot people. Many CGIAR colleagues went out of their way to provide us with the information and data required to conduct the five genebank costing studies that are drawn together in this report. We would especially like to thank Paula Bramel, Daniel Debouck, Mike Jackson, Kameswara Rao, Bent Skovmand, Suketoshi Taba, Jan Valkoun and Eric van Dusen for their help in conducting these studies, and Samy Gaiji, Robert Guei, Jean Hanson, Geoffrey Hawtin, Quat Ng, Willy Roca, Suzanne Sharrock, Tony Simons and Jane Toll for providing additional data and reactions to earlier drafts of this paper.

This work was funded by the CGIAR System-wide Genetic Resources Programme (SGRP), with in-kind contributions from CGIAR Centres and additional support from the Swedish International Development Cooperation Agency (SIDA).

1. INTRODUCTION

Genebanks are a recent institutional innovation. For most of agriculture's 10,000-year history, it was farmers who saved seeds from one season for planting in the next. The idea of setting aside seeds from around the world in special facilities for future use by breeders and others did not really take hold until the early 20th century. Much of the credit for this idea and its implementation goes to the famous Russian biologist Nikolai Vavilov. During three decades of travel over five continents he amassed the largest collection in the world (at that time) of species and strains of cultivated plants and developed theories on how to use this material for breeding improved varieties (Reznik and Vavilov 1997). This collection formed the basis for the genebank now maintained at the N.I. Vavilov Research Institute of Plant Industry in St Petersburg, Russia.

Long-term germplasm conservation facilities are an even more recent phenomenon. Pistorius (1997, p.4) credits the National Seed Storage Laboratory (NSSL) at Fort Collins, Colorado, USA, created in 1958, as being the first such facility. Since then, a sizable investment has been made in collecting and conserving landraces (farmer-developed varieties) and wild and weedy species of crops in genebanks around the world. Motivating these investments were concerns that the genetic basis of agriculture (be it for commercial or subsistence production) was narrowing globally for many agricultural crops as genetically more uniform but superior-performing varieties developed with scientific breeding methods spread worldwide at an accelerating pace beginning in the 1960s.[1]

Since the 1970s, the 11 genebanks now maintained by the CGIAR (or CG for short) have become a pivotal part of a global conservation effort, currently holding over 660,000 accessions (plant or seed samples) of crops grown mainly by poor farmers (such as cassava, millet, sorghum and cowpea), staple food crops consumed worldwide (such as rice, wheat and maize) and tree species used in agroforestry systems. Of these 660,000 accessions, nearly 515,000 accessions are held in trust under agreements with the Food and Agriculture Organization of the United Nations (FAO). Having built this collection over the past three decades, the financial basis for conserving the material for all future generations is now being addressed.

At present the CG genebanks, like the CG generally, are financed from short-term (often year-by-year) pledges of support to the system and its centres by its members and from project funds with limited lives (sometimes five years, but often three or less). Germplasm conservation is a very long-term, if not *in perpetuity,* proposition, and so the mismatch between the short-term nature of the financial support and the long-term nature and intent of the effort is a serious concern. This paper describes our best estimates of the annual funds required to support the core conservation and distribution services provided by the CG genebanks, and uses these cost estimates to determine the size of endowment fund required to underwrite these core conservation services in perpetuity, along with the distribution efforts that ensure this material remains available on demand to breeders, scientists and others worldwide.

The basis for estimating the resource requirements is a series of detailed costing studies led by International Food Policy Research Institute (IFPRI) over the past several years in close collaboration with colleagues at five CG genebanks. These five genebanks accounted for 87%

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[1] Concerns about 'genetic erosion' (loosely, a narrowing of the genetic resource base used by farmers or breeders for improving crop varieties) were raised by NRC (1972) and Harlan (1972), among others. Using data for the past three decades (and especially the 1990s) on area-sown-to-varieties in developing countries (except China) and various metrics of 'genetic diversity' based on varietal pedigree information for CIMMYT-related spring bread wheats, Smale et al. (2001, p.25) conclude that "The data are not consistent with the hypothesis that the genetic base of CIMMYT germplasm has tended to narrow over time." This may in part reflect the extensive use CIMMYT breeders and their collaborators have made of landraces and other material collected from all over the world, precisely the same type of genetic material that is conserved in genebanks.

of the CG's germplasm holdings. Results from these studies are summarized in this report, together with the extrapolations made to develop a complete costing of the entire CG conservation and germplasm distribution effort.[2] The unique aspect of this study is that we developed an estimate of the current costs of conservation and used a set of plausible technical assumptions (based on present conservation practices) to derive the *in perpetuity* costs of conserving these seeds. The sensitivity of our baseline estimates to variations in key elements of the costing are also reported as a basis for setting targets for an endowment or stewardship fund to underwrite the CG's conservation effort over the very long run.

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[2] Extrapolating costs was not straightforward given the substantially different types of accessions held in the CG centres not directly costed, compared with those conventional crop accessions that make up most of the holdings in the centres we directly costed.

2. GENEBANK OPERATION AND COSTS

2.1 Genebank Services

For this costing analysis, we grouped the genebank operations into a set of three main services:

- conservation services
- distribution services
- information services

We take conservation services to include conserving agricultural genetic diversity in the form of a 'base collection' held in controlled environment conditions to maintain the stored plants (or plant parts) and seeds for use in the distant future. To fulfill this function properly requires maintaining healthy (free of disease) and viable germplasm in long-term storage, periodically checking the viability of the stored material (via germination tests) and regenerating it when required (planting the aged seeds and storing their progeny) and maintaining duplicates of the collection at other locations for safety reasons.

The distribution activities are geared to making accessions available upon request for current utilization. This typically involves maintaining an 'active collection' of germplasm in a medium-term storage facility from which samples of seed (or *in vitro* plantlets of crops that are usually vegetatively-propagated, such as cassava) are disseminated to researchers, crop breeders, farmers and other genebanks. Material stored in active collections typically requires more frequent regeneration than that in base collections because the environment in medium-term storage facilities is not as conducive to germplasm longevity (typically the temperature and humidity are not as low or as stable as in long-term stores because of more frequent access to retrieve samples for distribution) and germplasm sample sizes are eventually reduced as samples are shared with others to the point they must be replenished.

Basic conservation and distribution activities also require keeping track of the size and condition of each holding and documenting so-called passport data that indicates the source of the seed samples (for example, obtained from another genebank, institution or a field collection expedition) and their physical attributes (including plant height, seed characteristics such as size, colour, and shape, and evident pest and disease susceptibility). Much of this agronomic information is collected when the seeds are grown out in greenhouses or the field for disease screening or regeneration. There are additional information services that generate useful and reliably accessible information about each accession to expedite the use of material for crop-improvement or other research purposes. Some of this information is obtained by purposefully screening the genebank collection for accessions with resistance to certain pests and diseases (often by planting out samples in the field and exposing them to certain pests or diseases or other stresses like too much or too little water at certain stages of growth). Increasingly, modern biotechnology tools are also being used to collect data at the molecular level, identifying the genetic basis for certain traits and other genetic information deemed desirable in breeding programmes.

The demarcation between genebank and breeding functions is not always clear-cut. In some settings (such as in the CG centres, where the genebank activities form part of a more comprehensive research operation), some of the information services emanate from crop-breeding programmes. In other cases, some of the pre-breeding (e.g., molecular characterization) activities typically done as part of a breeding programme fall within the ambit of a genetic resource or genebank programme. To facilitate meaningful cross-centre comparisons that span a consistent set of core conservation activities, we confined the scope of our costing exercise to those functions that are essential for fulfilling the conservation and distribution demands placed on a genebank. Table 1 provides an overview of the functions that may form part of a genetic resource programme and identifies the subset of those activities included in our costing exercise. Notably, some management aspects deal with genetic resource issues not directly included in the conservation and distribution activities we costed. Thus only a share of the total management costs were included in our calculations.

Table 1. A categorization of genebank operations

Costed activities	Activities not costed
Management[1]	**Management**[1]
• Administrative tasks	• Administrative tasks
• Data-related activities[2]	• Data-related activities[2]
Conservation	**Information provision**
• Acquisition (including basic morphological and passport data)	• Characterization (additional morphological and molecular)
• Long-term storage	• Evaluation
• Safety duplication	• Pre-breeding
• Viability testing	• Other research
• Regeneration	
Distribution	**Other services**
• Medium-term storage	• Germplasm collection
• Dissemination	• Training
• Viability testing	
• Regeneration	

[1] Some management activities pertain to functions other than the conservation and distribution activities encompassed by our estimates. Based on advice from genebank managers around 80% of these costs were shared among conservation and distribution activities and the residual was attributed to other functions not costed here.

[2] Excludes system-wide documentation and dissemination of data (e.g., CG SINGER)

2.2 Understanding Genebank Costs

To structure the costing exercise we considered the genebank operations within a production economics framework, wherein *inputs* such as labour, buildings, equipment and acquired seeds are processed to produce *outputs* in the form of stored and distributed seeds and the information that accompanies them. Properly stored seeds and related information can be disseminated on demand for current use, or held in storage as use options that can be exercised, repeatedly if necessary, in future years. We also partitioned total costs into their variable (both labour and operational), capital (buildings and durable equipment) and quasi-fixed (senior scientific staff) components. Costs in each class were then summarized in terms of average and marginal costs.[3]

In our framework quasi-fixed inputs include the 'human capital' costs of the skilled labour and the scientific expertise such as the manager of a genebank and laboratory researchers. Technicians and temporary workers, or those paid on a daily basis, are treated as variable labour inputs. As a practical matter, we identified variable inputs as those that are sensitive to the size of the operation, capital inputs as those that are not and quasi-fixed inputs as a group of inputs that are neither fixed nor variable but 'lumpy.' A quasi-fixed input is lumpy in the sense that it is a discrete, indivisible unit that cannot be adjusted easily to match marginal changes in the extent of genebank operations; it is variable in that it is more easily adjusted (in discrete increments) than a capital item such as a building.

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[3] Average annual storage costs can be calculated as the *total* costs of storage in any year divided by the number of accessions in a storage collection. The marginal costs of storage would be the *increase in total* costs of storage that are incurred when an additional accession is added to the collection. See Pardey (1999 and 2000) for an elaboration of marginal costs in this context.

Aspects of Costing Genebanks

A premium was placed on collecting and assembling the cost data in ways that were consistent in scope and treatment among centres. To do so meant addressing several conceptual and practical issues.

Evolving protocols. During the period over which data were gathered, most genebanks were restructuring and reorganizing their operations, with consequent changes in some of their conservation protocols. In many cases these changes were stimulated by the findings of the 1995 SGRP review of the centre genebanks (SGRP 1996), in some other cases they represented plans put into practice by individual centres. For example, one genebank was reconfiguring its storage space across crops to more efficiently manage the space; another was building new structures to accommodate expanded operations. Cost profiles during a transitional period can be quite different from the structure of costs when operations are being managed in a steady state.[4] For this study we sought to compile and analyze the data for a 'representative' snapshot year, abstracting from the effects of abnormal one-off events and assuming away technological changes when projecting these representative costs forward to simulate costs incurred in future years.

Jointness/divisibility. The genebank is but one of many programmes in a CG centre. Typically, some of the services required for operating a genebank are provided centrally and shared with other programmes. For example, seed health testing units, field operation units and engineering units usually supply services to various programmes within a centre, thereby realizing economies of scale and other efficiencies. A genebank operating as a stand-alone facility would have to secure each of these services independently, leading to higher costs than those reported here assuming cost-sharing arrangements. This study treats the costs of the shared operations as being divisible among programmes and they are partially allocated to the genebank based on the genebank's share of the overall operation. The costs of other centrally provided services (such as security, building maintenance and library) that cannot be allocated in this way are included as prorated parts of overhead costs.

The issue of jointness also arises within the genebank operation. When accessions are regenerated due to either low viability or low stock, the general practice is to regenerate enough seeds for both the medium- and long-term storage, even though the purpose of the regeneration is to replenish seed stocks in only one part of the storage facility. This study assumes that the regeneration is performed for both purposes and the total costs of regeneration are allocated equally between conservation and distribution functions. Similarly, when seeds are packed after cleaning and drying, all the packing for different purposes (e.g., long- and medium-term storage, safety duplication, repatriation, distribution and so on) is done at the same time. Again, this study assumes that the packing is divisible and allocates the packing costs to different operations according to the amount of material and labour required for each purpose.

Quality of operation. The FAO/IPGRI (1994) genebank standards manual lays out two sets of conservation standards.[5] One is an 'acceptable standard' considered to be a minimal but adequate standard, at least for the short term. The other is a 'preferred standard' that describes the basic conservation conditions (based on scientific criteria) that give a "higher and thus safer standard". The funding realities are such that most CG genebanks have insufficient resources to satisfy all the criteria required to meet the preferred standard. Thus genebank managers are forced to continually juggle priorities, meeting some aspects of the preferred standard for some parts of the collection, implementing the acceptable standard for other

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[4] In any event, some aspects of most operations are always subject to change due to shifting demands and priorities placed on the genebank and technological changes; the distinction between transitional and steady state is thus a matter of degree.

[5] See also SGRP (1996) for a discussion of the status of the CG genebanks at that time.

aspects of the conservation effort and, in some instances, making do with less than acceptable standards.[6]

Meeting the preferred standard clearly costs more than maintaining the holding in acceptable condition.[7] Taking cost data at face value is thus tricky. A comparatively high cost for a certain operation in one genebank does not necessarily imply that this operation is being achieved with less efficiency than the same operation at a lower cost genebank. It might simply indicate a higher standard of operation. Because quality standards vary among centres and within centres over time, comparing costs on the premise that all-else-is-equal (including the quality of operations) can be quite misleading.

Capital costs. To estimate the annualized 'user-cost' of capital, we compiled information on the purchase price of each capital item and combined that with notions of the service profiles of each item[8] and the real rate of interest. Past capital purchases were made on different dates, so they were inflated forward using the most applicable price index series to express them in a set of base-year (taken to be the year 2000) prices. We also assumed a depreciation profile in which the capital good survives intact until the end of its life and then disappears all at once.[9] Annual depreciation costs are constant under this profile and so the annualized cost is easily calculated using the interest rate and service lives of each item. Equation (3) in Appendix A was used to derive the annual user cost of a capital item.

Dynamic costs and life-cycle considerations. The costs of some operations such as storage are incurred annually, while the costs of other operations such as regeneration are incurred periodically, say every 20 to 30 years, and the viability of a sample is tested every five years or so. Thus the conservation costs of a sample in any particular year depend on the time in storage and the status of the sample. Figure 1 illustrates an example of the profile of conservation costs incurred during the life cycle of an accession from introduction, expressed in present-value terms with a positive discount rate. When an accession is newly introduced into a genebank at time zero, it is typically regenerated and tested for viability and health, and the costs of conservation in that year are especially high. During a normal year when an accession is simply held in storage (such as time t_A in Figure 1), the conservation cost consists of only the long-term costs of storage. When an accession requires regeneration after failing a viability test, the costs in that year (time t_B in Figure 1) are higher than the cost at time t_A. Year t_C represents a year in which a sample successfully passes a viability test and requires no regeneration. Appendix A provides the formulas we used to calculate the present values of cost elements that are incurred repeatedly but at varying intervals. The present value of the costs of conserving an accession in perpetuity is obtained by summing all the areas (irrespective of their shading) of the bar graph in Figure 1.

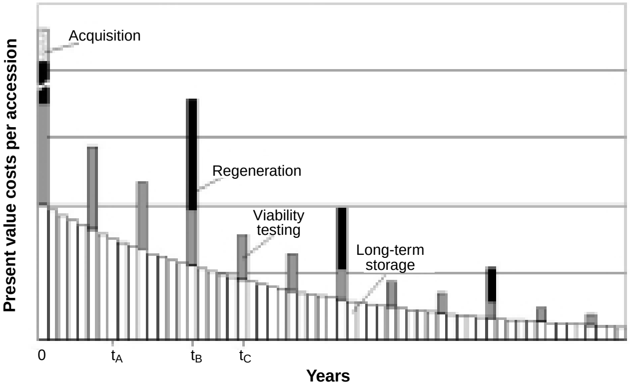

Figure 1. Profile of the present value of the conservation cost stream

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[6] Addressing this situation was the prime motivation for the study undertaken by SGRP (2000), which estimated the costs of upgrading the CG genebanks to uniformly preferred standards.

[7] The higher costs incurred in meeting the preferred standard are due to treating and documenting the conserved material with more care and completeness, thereby increasing the chances of long-term survival. There is also a cost trade-off over time; improving the quality of the conservation effort in the short run is likely to lower conservation costs in the future, in addition to lowering the risk of loss.

[8] The service lives of each item were set in accordance with the CG depreciation guideline–40 years for buildings, 10 years for equipment and so on.

[9] Economists typically call this a 'one-hoss-shay' depreciation profile (i.e., like a horse drawn buggy from days of old that provides more or less the same services year in and year out until one year when it is no longer usable).

3. COSTING THE CG GENEBANKS

3.1 The Collections Maintained by the CGIAR

By 2001, the 11 genebanks maintained by the CG centres held over 660,000 germplasm accessions of crops, forages and agroforestry trees (Table 2) — about 10% of the estimated six million accessions held in genebanks worldwide (FAO 1998).[10] Beginning in October 1994, the CG centres collectively agreed to place the genetic material held in their genebanks under the auspices of an 'in-trust' agreement with the FAO, with the intent of maintaining the collection in the global public domain. About 77% of the material held in the genebanks is now conserved under the terms of this in-trust agreement.[11] Material designated as part of the in-trust collection is made freely available, but with the stipulation that recipients agree not to seek intellectual property protection on any of the in-trust material obtained from CG centres.

As the world repository of germplasm for the poor, CG genebanks mainly hold landraces and wild species of crops (73% of their total holdings) that are especially important to people in developing countries, such as cassava, yam and chickpea, and crops grown worldwide, such as rice, wheat and maize. As the amount of material held in genebanks worldwide grew markedly in the past few decades (with new and expanding genebank collections drawing in accessions held elsewhere), the number of duplicates began to proliferate. FAO (1998) claimed the number of unique accessions held in *ex situ* collections worldwide in 1996 was between 1 to 2 million. Thus given the high proportion of landraces and wild species in the CG collection, the percentage of the world's unique *ex situ* accessions held in CG genebanks could be much higher than its share of the global *ex situ* collection (600,000 out of 6 million accessions).

Storing seeds and other plant material. Most of the accessions that produce storable seeds are placed in packets or small containers and stored in medium-term storage facilities (maintained at 0 to 5°C and 15 to 20% relative humidity) as an active collection. Most of this material is also kept in long-term storage facilities (held at colder temperatures, often in the range –18 to –20 °C) as a base collection. The expectation is that most seed samples (but, perhaps, not all, and so the need for monitoring) will remain viable for 20 to 30 years in medium-term storage and for up to 100 years in long-term storage, depending on the species, the initial seed quality and the specifics of the storage environment. Seed samples are checked for viability every 5 to 10 years and regenerated if the viability drops below a threshold level.

Vegetatively-propagated species (including crops such as cassava, potato and banana) are conserved as whole plants in field genebanks. They are also kept as live specimens, often maintained on a special growth medium in test tubes stored under warm, lighted conditions (23°C and 1500 to 2000 lux) in so-called *in vitro* genebanks. Plants in field genebanks can be readily characterized and evaluated but are susceptible to environmental variations and are increasingly difficult to distribute internationally due to increasingly stringent phytosanitary

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[10] The notion of an accession for tree germplasm is quite different from that normally applied to crop germplasm. At ICRAF, a single accession may either consist of seeds harvested from one tree in a single year, seeds harvested from one tree bulked across years, seeds from related half-sibling individuals bulked together, seeds from a population (provenance) of trees (20-200 trees) bulked together, seeds from a meta-population or seeds from inter-population hybrids. In contrast, crop germplasm is typically stored on an individual plant or varietal basis and thus crop collections appear more numerous. ICRAF holds approximately 10,000 accessions of orthodox tree species in their cold-storage facility, of which only 25 accessions are designated as in-trust (mainly because of the practicalities and costs involved in duplicate storage and regeneration of tree germplasm). For example, trees are perennial in nature and seed set may not begin for up to 15 years after planting. Additional logistical problems arise also due to their size, non-annual seed crops and poor synchronicity of flowering resulting in low effective population sizes.

[11] The intent was to designate all unencumbered accessions acquired by the centres prior to 29 December, 1993 (when the Convention on Biological Diversity came in to force). Hereafter, all genetic material was deemed subject to the sovereign rights clauses within the CBD, and so only material obtained after this date with the explicit understanding that it remain in the public domain could be so designated.

Table 2. Size and structure of the germplasm collection at the CGIAR centres, 2001

Centre (Location)	**Crop**	**Number of accessions**		
		In-trust	**Other**	**Total**
CIAT (Colombia)	Cassava	5,728	2,332	8,060
	Common bean	30,590	810	31,400
	Forages	16,339	7,845	24,184
	Total	**52,657**	**10,987**	**63,644**
CIMMYT (Mexico)	Wheat	79,912	75,000[a]	154,912
	Maize	20,411	4,675	25,086
	Total	**100,323**	**79,675**	**179,998**
CIP (Peru)	Potato	5,057	2,582	7,639
	Sweet potato	6,413	1,246	7,659
	Andean roots/tubers	1,112	383	1,495
	Total	**12,582**	**4,211**	**16,793**
ICARDA (Syria)	Cereal	54,218	5,795	60,013
	Forages	24,581	5,947	30,528
	Chickpea	9,116	2,103	11,219
	Lentil	7,827	2,135	9,962
	Faba bean	9,074	1,671	10,745
	Total	**104,816**	**17,651**	**122,467**
ICRAF (Kenya)	**Agroforestry trees**	**25**	**10,000[a]**	**10,025**
ICRISAT (India)	Sorghum	35,780	941	36,721
	Pearl millet	21,250	142	21,392
	Pigeon pea	12,698	846	13,544
	Chickpea	16,961	289	17,250
	Groundnut	14,357	985	15,342
	Minor millets	9,050	202	9,252
	Total	**110,096**	**3,405**	**113,501**
IITA (Nigeria)[b]	Bambara groundnut	2,029	—	2,029
	Banana	—	400	400
	Cassava	2,158	1,371	3,529
	Cowpea	15,001	1,000	16,001
	Soyabean	1,909	1,144	3,053
	Wild *Vigna*	1,634	50	1,684
	Miscellaneous legumes[c]	—	400	400
	Yam	2,878	822	3,700
	Total	**25,609**	**5,187**	**30,796**
ILRI (Kenya)	**Forages**	**11,537**	**1,667**	**13,204**
IPGRI/INIBAP (Italy)	***Musa***	**914**	**229**	**1,143**
IRRI (Philippines)	Cultivated rice	77,827	16,737	94,564
	Wild rice	2,790	1,778	4,568
	Total	**80,617**	**18,515**	**99,132**
WARDA (Côte d'Ivoire)[d]	**Rice**	**14,917**	**460**	**15,377**
CG total		**514,093**	**151,987**	**666,080**

Source: In-trust figures provided by IPGRI and totals provided directly from genebanks during 2001.

[a] Estimate provided by manager of ICRAF genetic resource programme.

[b] In addition to this material, IITA holds about 2500 accessions of maize and multipurpose trees.

[c] Includes African yam bean, Kersting's groundnut and various beans (e.g. lablab, jack and winged beans).

[d] The WARDA base collection is housed at IITA.

restrictions. *In vitro* genebanks store plants in controlled environments with less risk of natural disaster and facilitate the distribution of disease-free materials internationally. Another option that may become economically attractive for long-term conservation is to use cryoconservation techniques, conserving plant material (and even seeds for that matter) at extremely low temperatures (-196°C maintained with liquid nitrogen); some material is already stored this way. However, protocols for cryoconservation for many species (and even some genotypes within a species) are not fully elaborated and remain under active investigation.

The protocols used by ICRAF for conserving and distributing tree germplasm are quite different from the protocols generally used for crop species throughout the rest of the CG. Some tree species are kept as seed in cold storage (much like other crops, with the exception that the amount of material stored per accession is often vastly larger than for other crops), but other material is conserved in field genebanks and the bulk of the distributions are made from seed harvested from 'nuclear or catalyst stocks' maintained at various locations throughout the world.

Shipping seeds and other plant material. Complementing the conservation services, another important service provided by CG genebanks is to disseminate seed and other plant samples free of charge upon request. Samples for ready dissemination are maintained in medium-term storage as active collections, which require more frequent viability testing and regeneration than do long-term collections. Table 3 provides details on the material shipped from each CG genebank in the past seven years. The figures indicate the total number of samples distributed (i.e., including the samples shipped to those outside each centre as well as samples used for breeding and other purposes within each CG centre). From 1994 to 1999, over half a million samples were shipped by the CG genebanks (averaging more than 88,000 samples per year), of which more than half the samples were disseminated to breeders and other scientists working within each centre.

Most of the samples held in the CG genebanks are landraces and wild species.[12] This material is an important source of genetic diversity (and a potentially valuable source of novel and useful traits), but it is presently less amenable to ready utilization in crop breeding programmes. Demand for this type of material is thus lower than that for well-characterized and better-known breeding lines. While a very substantial number of samples have been shipped, the number of samples *per se* may not accurately indicate the utilization of this material. More complete information on the impact of this germplasm on crop-breeding efforts globally (as sources of new, desirable traits) and various other uses is needed to reasonably assess the use value of the material held in the CG genebanks.

3.2 CG Conservation Costs[13]

The structure of conservation costs critically depends on (i) the type of crops being conserved, (ii) institutional differences such as cost-sharing arrangements within each CG centre, and (iii) the local climate and general state of the infrastructure (such as electricity supplies, communications and international shipment options) available to each genebank. For example, regenerating cross-pollinating crops (such as maize, sorghum and pearl millet) or wild and weedy species is typically more complicated than regenerating self-pollinating cultivated

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[12] An exception is wheat at CIMMYT which includes a large proportion of improved material emanating from the centre's breeding programme.

[13] Prior genebank costing studies include Burstin *et al.* (1997), Epperson *et al.* (1997) and Virchow (1999). The current report builds on the costing methods described in Pardey *et al.* (1999 and 2001), which was the first study to comprehensively deal with the dynamics involved in costing the conservation activities of a genebank and to place those costs in an in-perpetuity framework.

Table 3. Number of samples disseminated from CGIAR genebanks, 1994-2000

		Number of samples						
Centre	**Crop**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**[b]
CIAT	Cassava	550	527	149	219	366	460	2,176
	Common bean	8,877	7,565	8,705	10,481	8,493	9,600	4,256
	Forages	3,231	1,133	1,320	1,053	518	525	517
	Total	**12,658**	**9,225**	**10,174**	**11,753**	**9,377**	**10,585**	**6,949**
CIMMYT	Wheat	2,244	460	1,835	9,974	22,105	6,512	na
	Maize	4,393	3,338	3,685	2,598	5,062	2,831	3,565
	Total	**6,637**	**3,798**	**5,520**	**12,572**	**27,167**	**9,343**	**3,565**
CIP	Potato	222	165	143	94	103	92	50
	Sweet potato	76	62	53	33	56	20	7
	Andean roots/tubers	3	-	3	-	-	-	5
	Total	**301**	**227**	**199**	**127**	**159**	**112**	**62**
ICARDA	Cereal	12,646	10,074	13,502	10,323	8,916	11,720	8,001
	Forages	8,883	7,983	9,246	8,777	7,696	9,178	5,193
	Chickpea	5,248	5,575	5,437	7,066	5,111	2,812	2,090
	Lentil	5,464	3,849	3,994	3,978	3,911	3,286	3,057
	Faba bean	412	2,393	1,601	1,434	3,917	3,306	2,286
	Total	**32,653**	**29,874**	**33,780**	**31,578**	**29,551**	**30,302**	**20,627**
ICRISAT	Sorghum	7,924	2,983	3,525	4,667	4,731	5,456	5,865
	Pearl millet	2,301	3,143	2,695	1,224	1,344	1,980	2,671
	Pigeon pea	6,520	2,206	2,866	1,014	962	1,595	2,657
	Chickpea	9,329	2,893	9,778	3,283	7,046	6,756	3,003
	Groundnut	6,180	3,737	3,443	4,787	2,475	5,604	4,872
	Minor millets	3,912	402	145	462	121	452	53
	Total	**36,166**	**15,364**	**22,452**	**15,437**	**16,679**	**21,843**	**19,121**
IITA	Bambara groundnut	118	50	147	19	29	16	14
	Cassava	347	330	690	1,871	1,211	461	493
	Cowpea	217	323	95	524	387	12,501	602
	Soyabean	198	894	2	22	111	202	17
	Wild *Vigna*	272	393	71	18	286	93	157
	Misc. legumes	318	148	136	94	96	34	38
	Yam	213	303	250	214	268	257	132
	Total	**1,683**	**2,441**	**1,391**	**2,762**	**2,388**	**13,564**	**1,453**
ILRI[a]	Forages	**2,355**	**2,240**	**1,591**	**1,954**	**2,267**	**2,139**	**1,313**
IPGRI/ INIBAP	*Musa*	**na**	**69**	**83**	**81**	**69**	**88**	**91**
IRRI[a]	Rice	**25,802**	**15,630**	**10,958**	**5,633**	**6,670**	**6,194**	**3,516**
WARDA	Rice	**304**	**718**	**622**	**2,437**	**312**	**123**	**126**
CG total[b]		**118,559**	**79,586**	**86,770**	**84,334**	**94,639**	**94,293**	**56,823**

Source: The data for ILRI and IRRI in year 2000 are obtained from SINGER database, and the remaining data from a survey of genebank managers undertaken by the authors.

[a] All ILRI and year 2000 IRRI data represent samples shipped externally from each centre.

[b] Year 2000 data missing wheat shipments from CIMMYT and may be an incomplete accounting of shipments from some other genebanks.

species.[14] Vegetatively-propagated species maintained *in vitro* as clones and in field genebanks are much more expensive to conserve than stored seeds. Besides these crop-specific aspects, differences in wage structures and the composition of labour (which are affected by local labour laws and practices) also have significant impacts on the overall costs. Moreover, if the local climate is inappropriate for regenerating some accessions, it may be necessary to plant them out at other locations.

Our basic approach was to estimate a representative set of baseline costs per accession in ways that would make it possible to evaluate the sensitivity of these baseline costs to differences in key crop-, location- and institution-specific factors. To systematically address these diverse factors within a reasonable timeframe, we conducted cost studies of five CG centres, standardizing as much as possible our treatment of the data to facilitate meaningful comparisons. The five centres are CIMMYT, CIAT, ICARDA, ICRISAT and IRRI, constituting nearly 90% of the total CG-held collection (578,742 out of 666,080 accessions, Table 2). Using the annual budgets for each genebank during 1998 and 1999 reported in SGRP (2000, Table 3, p.16), these five genebanks constituted about 55% of the total budget of the 11 CG genebanks (US$ 3.8 million out of US$ 6.9 million). But the scope of activities (and hence the functions funded from each genebank budget) varies from one genebank to another.

The case studies were conducted over several years—1996 data were used for CIMMYT, 1998 for ICARDA, 1999 for IRRI and ICRISAT and 2000 for CIAT. To control for the effects of inflation, we expressed all costs in year 2000 prices using a weighted average of the producer price index for the G7 countries constructed from data obtained from OECD (2000) and World Bank (2000).[15] Appendix Table 1 presents a breakdown of the baseline, per-accession costs for each operation, for each crop, for each centre. Some interesting comparisons are possible. For most crops at most centres the differences between medium- and long-term storage costs are much smaller than the differences in regeneration costs among crops, the general pattern being that cross-pollinating species (such as maize at CIMMYT and pigeonpeas at ICRISAT) and wild species (such as wild groundnut at ICRISAT or wild rice at IRRI) are much more costly to regenerate than other types of crops. The costs associated with vegetatively propagated crops (such as cassava at CIAT) are also comparatively high due to the intensity of labor required for subculturing. There are also significant locational-cum-institutional differences in the costs of regenerating crops; for instance wheat at CIMMYT versus ICARDA, forages at ICARDA versus CIAT, and chickpeas at ICRISAT versus ICARDA.

Table 4 reports the average costs of conserving (and distributing) an accession for one year.[16] Clearly the annual average cost depends on the crop in question and the state of the sample, including its time in storage, time from last regeneration or viability test, and the like. If an existing sample is known to be viable, it costs little to hold it over for one more year—less than US$ 2 per accession for most crops. However, if the sample requires regenerating because it failed a viability test, the holding costs increase substantially with the additional viability testing and regeneration costs. If the accession is newly introduced into the genebank (so that health testing is also required), the cost jumps even further and the variation in costs among crops increases. The structure of the distribution costs are similarly revealed in the two right-hand columns of Table 4.

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[14] It is crucial to regenerate material in ways that minimize the genetic drift from the planted to harvested sample. In promiscuously out-crossing plants like maize, this requires fairly elaborate procedures, like hand pollinating each plant and isolating the pollen of each plant by placing a cover over its tassels.

[15] The index was formed by taking a weighted sum of the national producer price indices for the G7 countries where the weights were the respective country shares in the seven-country GDP total. The index was 100.9 in 1996, 101.4 in 1997, 100.6 in 1998, 101.2 in 1999 and 104.4 in 2000.

[16] In this and all subsequent tables we opted not to round off our estimates to facilitate cross-referencing, but this should not be construed as implying any false precision.

Table 4. Average annual costs of conserving and distributing an accession

		Conservation cost[a]			Distribution cost[b]	
		Existing accession		New accession	Existing accession	
Centre	**Crop**	**w/o regeneration**	**w/ regeneration**	**w/ regeneration**	**w/o regeneration**	**w/ regeneration**
				(US$ per accession)		
CIAT	Cassava[c]					
	In vitro conservation		11.98	80.17		25.05
	Cryoconservation	1.23	43.06			
	Field genebank		7.28			
	Common bean	0.92	20.88	25.13	27.39	47.35
	Forages	1.12	34.61	38.85	51.86	89.35
CIMMYT	Wheat	0.48	4.47	8.21	4.57	8.57
	Maize	2.16	115.07	130.07	38.49	151.40
ICARDA	Cereal	0.47	6.86	17.02	4.25	10.65
	Forages	0.47	8.21	18.27	4.25	11.99
	Chickpea	0.47	8.76	19.36	4.25	12.54
	Lentil	0.47	10.74	21.57	4.25	14.53
	Faba bean	0.47	10.61	21.87	4.25	14.40
ICRISAT	Sorghum	1.32	11.89	32.65	4.09	14.66
	Pearl millet	1.32	27.48	49.81	4.09	30.25
	Pigeon pea	1.32	32.11	48.15	4.09	34.88
	Chickpea	1.32	12.71	27.48	4.09	15.48
	Groundnut	1.32	16.05	44.04	4.09	18.81
	Wild groundnut	1.32	126.45	162.47	4.09	129.22
IRRI	Cultivated rice	0.47	18.19	36.59	10.62	28.35
	Wild rice	0.47	58.61	74.47	10.62	68.76

Source: Authors' calculations.

Note: All costs are denominated in year 2000 US dollars.

[a] For conservation cost:

Existing accession without regeneration: C_A = long-term storage cost

Existing accession with regeneration: $C_B = C_A$ + (half of viability testing cost + half of regeneration cost)

New accession with regeneration: $C_C = C_B$ + (acquisition cost + duplication cost + characterization cost)

[b] For distribution cost

Existing accession without regeneration: D_A = medium-term storage cost + dissemination cost

Existing accession with regeneration: $D_B = D_A$ + (half of viability testing cost + half of regeneration cost)

[c] For *in vitro* conservation, the conservation cost includes half of storage cost and subculturing cost, and the distribution cost includes half of storage cost and dissemination cost.

Table 5 provides a representative snapshot of the total annual conservation and distribution costs incurred by each of the centres. The estimates for CIAT, CIMMYT, ICARDA, ICRISAT and IRRI were obtained directly and used as the basis for estimating the costs for the remaining six CG centres with active conservation programmes.[17] These costs include all the labour and operational costs incurred to provide core conservation and distribution services for one year, and an estimate of the annualized cost of the recurrent capital expenditures required to build and equip the genebanks. Based on the assumptions that underlie these estimates, the total annual cost for the CG genebanks is US$ 5.7 million. Table 5 illustrates that the number of accessions *per se* is not an especially good indicator of the comparative costs of conservation. There are many other factors—some intrinsic to the crop in question, others relating to locational and institutional aspects—that affect these costs.

Table 4 refers to the costs of conserving an accession for one more year, with the notion that decisions can be revisited the following year. However, the presumption is that the CG collection is being held for safe keeping for an indefinite future, so that an in perpetuity (i.e., from now to eternity) perspective on costs is more appropriate than a one-year perspective. Indeed the notion that the CG is guaranteeing safe keeping of these genetic resources for the common good, for both current and all future generations, is implicit in its in-trust commitments to the FAO. The cost of such a guarantee depends on a host of factors, not least the state of future conservation technologies, input costs (including the rate of interest used to calculate the present value of an indefinite future stream of costs), storage capacity vis-à-vis the size of the holding and regeneration intervals. Table 6 reports the present value of the average costs of conserving an accession in perpetuity, assuming per accession costs are constant over time

Table 5. Representative total annual CGIAR costs of conservation and distribution

		Cost (US$ per year)		
Centre	**No. of accessions**	**Conservation**	**Distribution**	**Total**
CIAT	63,644	354,159	573,444	927,603
CIMMYT	179,998	350,891	686,734	1,037,625
ICARDA	122,467	179,286	261,259	440,545
ICRISAT	113,501	347,224	419,244	766,468
IRRI	99,132	217,411	403,142	620,554
Others[a]	87,338	913,879	1,020,139	1,934,018
CG Total	**666,080**	**2,356,071**	**3,357,648**	**5,713,719**

Source: Authors' calculations.

Note: These estimates of annual total costs were based on the in-perpetuity costs given in Table 7. This method provides an annual average costs that implicitly takes account of differences in the long-term structure of the recurrent capital purchases for each of the genebanks and also recognizes that only a fraction of each centre's total holding is regenerated in any given year. Thus these costs are also sensitive to assumptions about the rate interest (here taken to be 4 % per annum) and the length of the regeneration cycles, among other things. All costs are denominated in year 2000 US dollars.

[a] Material in other centres mainly consists of vegetatively-propagated species, and we used the costs of maintaining cassava at CIAT as the basis for costing this material. Thus, some crop-specific characteristics of the vegetatively-propagated species may not have been considered here. The costs of conserving and distributing agroforestry material was based on data provided by the manager of the ICRAF genetic resources programme.

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[17] In section 4 below we sketch the basis for extrapolating costs to include all 11 CG genebanks.

in real (i.e, inflation-adjusted) terms and baseline conservation protocols are maintained throughout the entire period.[18] Here the present value represents the value of the stream of time-discounted future costs, recognizing that with positive interest rates a dollar expensed in the future is less costly than a dollar expensed today (because today's dollar could be invested and return more than a dollar in the future.)

For cassava, the present value cost of cryoconservation is lower than either *in vitro* conservation or a field genebank, implying potential cost saving from using this type of conservation method. The table also shows that the present value of distribution costs are generally higher than the present value of conservation costs. This is due to the more frequent regeneration and viability testing of seeds held in medium-term storage (from which distributed seeds are drawn) as well as the high

Table 6. Present values of the cost of conserving an accession in perpetuity

		Cost (US$ per accession)		
Centre	**Crop**	**Conservation**	**Distribution**	**Total**
CIAT	Cassava			
	In vitro conservation	291.00	263.06	554.06
	Cryoconservation	91.39		91.39
	Field genebank	189.25		189.25
	Common bean	61.86	160.34	222.21
	Forages	109.92	320.65	430.56
CIMMYT	Wheat	24.17	38.14	62.30
	Maize	214.44	476.25	690.69
ICARDA	Cereal	36.55	52.74	89.29
	Forages	38.02	55.92	93.94
	Chickpea	39.20	57.22	96.42
	Lentil	41.73	61.91	103.64
	Faba bean	42.02	61.60	103.62
ICRISAT	Sorghum	70.57	77.74	148.31
	Pearl millet	90.27	114.57	204.84
	Pigeon pea	89.37	125.51	214.88
	Chickpea	65.53	79.67	145.20
	Groundnut	82.64	87.55	170.19
	Wild groundnut	219.07	348.45	567.51
IRRI	Cultivated rice	54.97	101.33	156.31
	Wild rice	99.44	196.84	296.28

Source: Authors' calculations.
Note: For details on length of regeneration and viability testing cycles and other elements, see footnote 18 in text.
All costs are denominated in year 2000 US dollars.

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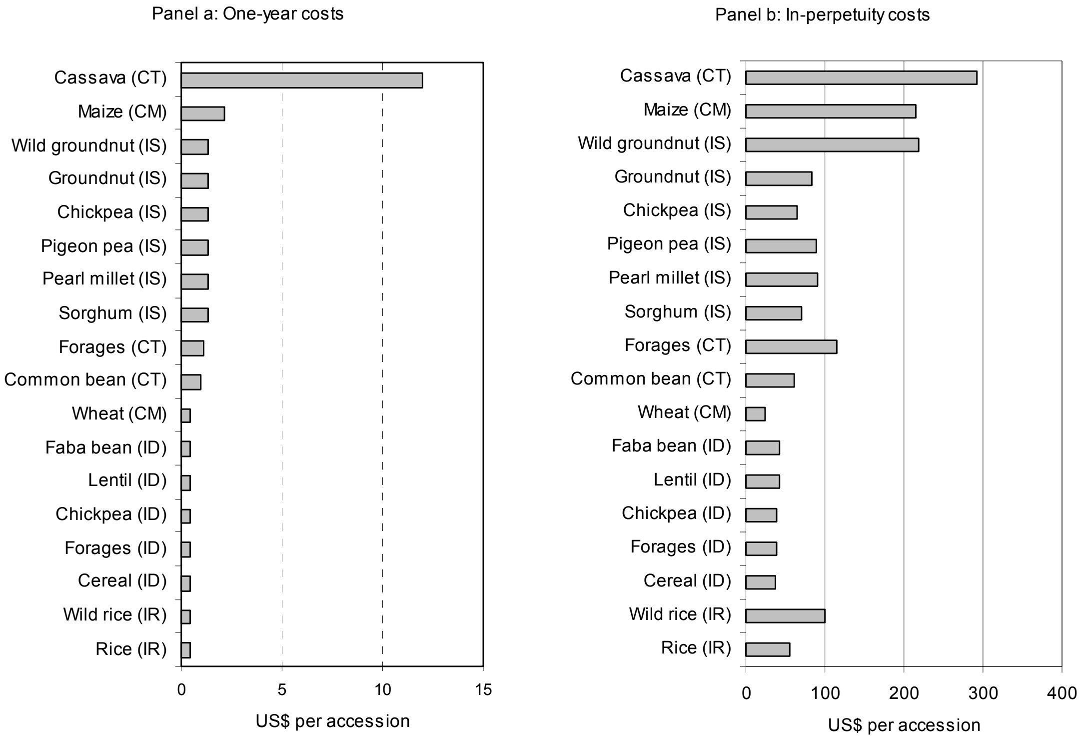
[18] The baseline assumptions for seed storage are (i) accessions in the medium-term storage are conserved for 25 years and those in the long-term storage for 50 years, (ii) viability testing is done every five years for seeds in medium-term storage and 10 years for those in long-term storage, (iii) an accession is disseminated once every 10 years and (iv) the presumed real interest rate is 4%. We also assume that all accessions are held both in medium- and long-term storage. For *in vitro* conservation of cassava, we assume that subculturing is done every 1.5 years. For cryoconservation, the storage life is assumed to be 100 years and the interval of viability testing is 10 years. The present values of the costs for each operation are calculated using the formula in Appendix A.

cost of dissemination *per se*. The right-hand column of total costs in Table 6 indicates the present-value cost of conserving an accession forever and maintaining the current average rate of dissemination for each accession over this same period of time. The crops conserved at CIMMYT represent the upper and lower bounds of the present value of total costs for all the crops in our study–US$ 62 for each accession of wheat and US$ 690 for each accession of maize.

Figure 2 compares the costs of conserving an accession for one year (panel a) with the present-value costs of conserving an accession in perpetuity (panel b). Simply holding a seed sample for one year (in which the sample requires no special treatment) costs less than US$ 1.50, except for maize, which costs US$ 2.16 per accession, and cassava conserved *in vitro,* which costs US$ 11.98 per accession. These storage costs consist mainly of the costs of electricity and the annualized capital cost of the storage facility, with a small expense for maintaining the storage equipment. The storage costs of crops at ICARDA are comparatively low due to its cheap labour and electricity costs, while costs are higher at ICRISAT, where electricity is expensive. The comparatively high cost of storing maize is due to its comparatively big seed size (less seed fits in a given storage space and more costly containers are required).

However, considering storage costs in perpetuity (which also include viability testing and regeneration costs) changes the ranking of costs. For example, the costs of forage conserved at CIAT and wild rice at IRRI are now higher than those of chickpeas or sorghum at ICRISAT due to the higher costs of regenerating forages and wild rice (repetitive costs that mount up over the longer term). As a rule, wild and weedy species and cross-pollinating crops that are relatively expensive to regenerate are more expensive in present-value terms when costs are cumulated over the long term.



Source: Authors' calculations.
Note: CT = CIAT, IS = ICRISAT, ID = ICARDA, CM = CIMMYT, and IR = IRRI. All costs denominated in year 2000 US dollars.

Figure 2. Comparison of one-year and in-perpetuity conservation costs.

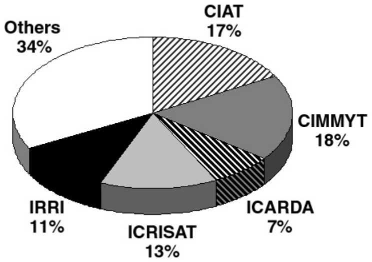
4. A CONSERVATION ENDOWMENT FUND

The present value of costs in perpetuity represents the amount of money that would need to be set aside (at, say, a 4% real rate of interest) to underwrite genebank activities at their current levels over the long term. We used the costing evidence in Table 6 as the basis for calculating the size of an endowment fund that would assure the conservation of the CG holdings for all future generations. To do this we presumed a particular correspondence between the per accession costs for crops we did directly cost and for those CG crops not included in our centre studies.[19] This method of extrapolating costs based on per accession cost might bias down the conservation costs for smaller genebanks since it may understate the costs of some indivisible capital equipment and facilities that are required regardless of the size of genebanks.

Because of the substantial differences in conserving and regenerating tree compared with conventional crop species, we relied on annual budget data and informed estimates from the manager of the ICRAF genetic resource programme to generate a proximate but representative estimate of the annual conservation, multiplication and distribution costs incurred by ICRAF. To maintain a headquarter operation (which includes a medium-term storage facility and ancillary buildings) and a wide network of on-farm conservation and regeneration sites in 10 countries around the world, the estimated total annual operating cost is about US$ 800,000, of which 80% was allocated to the conservation and distribution functions of ICRAF that were included in this study (and split 4:6 between these two functions).

Baseline estimates. Table 7 presents our best baseline estimates of the centre-specific and CG-wide endowment fund that would be sufficient to underwrite the CG's basic conservation and distribution functions at their present levels of activity into the indefinite future. Based on our assessment of the relevant costs, a US$ 149 million endowment invested at a real rate of interest of 4% per annum (or a nominal rate of, say, 7% if inflation is expected to average 3% per annum over the long run) would generate a real annual revenue flow of US$ 5.7 million, sufficient to cover the costs of conserving and distributing the current holdings of all 11 CG genebanks in perpetuity. About 20% of the endowment funds (nearly US$ 30 million) would be needed to underwrite the on-going purchases of equipment and genebank buildings as they need replacing. The rest would need to be set aside to meet the recurring non-capital costs.

Figure 3 illustrates the estimated centre-specific shares of this overall endowment fund. The conservation and dissemination activities undertaken by the five centres we directly costed (and that collectively conserve 87% of the CG's current germplasm holdings) could be supported with 66% of the total endowment fund, with the remaining 34% underwriting activities at the six centres we did not directly cost. These estimates indicate that 13% of the genebank holdings account for 34% of the total costs. This is because the vegetatively propagated material that constitutes a large part of the IITA, CIP and IPGRI/INIBAP collections and the tree species conserved by ICRAF are intrinsically costly to store and regenerate. CIAT and CIMMYT constitute 17 and 18% respectively of the total costs. Both centres are located in comparatively advanced developing countries in Latin America, where wage rates are comparatively high by developing country standards; they also maintain sizable holdings of crops that are intrinsically costly to conserve—specifically vegetatively-propagated cassava at CIAT and cross-pollinating maize at CIMMYT.



Source: Authors' calculations.

Figure 3. Centre share of total conservation costs of the CGIAR (total = US$149 million).

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[19] Specifically, we used CIAT's costs of conserving and distributing cassava as indicative of the corresponding costs for the root and tuber crops held at CIP, the *Musa* (banana) stored at INIBAP and the bananas, cassava and yams kept at IITA. Since the methods used to conserve these crops differ among centres, we used the *in vitro* and field genebank costs for the corresponding material held at CIP and IITA, and the *in vitro* and cryoconservation costs for the bananas stored at INIBAP. Rice costs at IRRI were deemed indicative of rice costs at WARDA, CIAT's forage costs were used to represent forage costs at ILRI, ICRISAT's chickpea costs were treated as equivalent to IITA's cowpea costs, while CIAT's bean and forage costs were treated as equivalent to IITA's soybean, miscellaneous legumes and wild *vigna* costs respectively.

Table 7. The Conservation Endowment Fund

			Cost (US$)		
Centre	**Crop**	**No. of accessions**	**Conservation**	**Distribution**	**Total**
CIAT	Cassava	8,060	4,607,383	2,120,296	
	Common bean	31,400	1,942,532	5,034,754	
	Forages	24,184	2,658,223	7,754,497	
	Total	**63,644**	**9,208,138**	**14,909,547**	**24,117,686**
CIMMYT	Wheat	154,912	3,743,844	5,907,775	
	Maize	25,086	5,379,326	11,947,314	
	Total	**179,998**	**9,123,170**	**17,855,089**	**26,978,259**
CIP	Potato	7,639	3,668,612	2,009,546	
	Sweet potato	7,659	3,678,217	2,014,808	
	Andean roots/tubers	1,495	717,970	393,281	
	Total	**16,793**	**8,064,800**	**4,417,635**	**12,482,435**[a]
ICARDA	Cereal	60,013	2,193,716	3,164,959	
	Forages	30,528	1,160,736	1,707,174	
	Chickpea	11,219	439,778	641,903	
	Lentil	9,962	415,729	616,747	
	Faba bean	10,745	451,478	661,945	
	Total	**122,467**	**4,661,437**	**6,792,729**	**11,454,166**
ICRAF	Agroforestry trees	**10,025**	**7,488,000**	**11,232,000**	**18,720,000**[b]
ICRISAT	Sorghum	36,721	2,591,397	2,854,548	
	Pearl/small millets	30,644	2,766,295	3,510,920	
	Pigeon pea	13,544	1,210,405	1,699,923	
	Chickpea	17,250	1,130,474	1,374,307	
	Groundnut	14,892	1,230,678	1,303,838	
	Wild groundnut	450	98,581	156,801	
	Total	**113,501**	**9,027,830**	**10,900,337**	**19,928,167**
IITA	Bambara groundnut	2,029	167,677	177,645	
	Banana	400	192,099	105,226	
	Cassava	3,529	1,694,794	928,353	
	Cowpea	16,001	1,048,621	1,274,799	
	Soyabean	3,053	188,871	489,526	
	Wild *Vigna*	1,684	185,100	539,967	
	Misc. legumes	400	43,967	128,258	
	Yam	3,700	1,776,917	973,337	
	Total	**30,796**	**5,298,045**	**4,617,111**	**9,915,157**[a]
ILRI	Forages	**13,204**	**1,451,339**	**4,233,806**	**5,685,145**[a]
IPGRI/ INIBAP	*Musa*	**1,143**	**437,070**	**300,682**	**737,752**[a]
IRRI	Cultivated rice	94,564	5,198,429	9,582,545	
	Wild rice	4,568	454,262	899,158	
	Total	**99,132**	**5,652,691**	**10,481,702**	**16,134,393**
WARDA	Rice	**15,377**	**845,314**	**1,558,212**	**2,403,526**[a]
CG total		**666,080**	**61,257,835**	**87,298,851**	**148,556,686**

Source: Author's calculations.
Note: All costs are denominated in year 2000 US dollars.

[a] Indirect estimates formed by extrapolating costs from crops and centres that were directly costed. For additional details underlying these estimates, see text footnotes 18 and 19.

[b] Indirect estimates based on aggregate cost data provided by ICRAF staff.

Sensitivity analysis. Our baseline cost estimates build on a number of assumptions made explicit above. Here we explore the sensitivity of the overall costs (in present-value terms) to changes in those elements of the costing framework thought likely to significantly affect the final figure.

Because the endowment fund represents the present value of the in-perpetuity costs it is designed to support, significant cost elements that repeat at regular intervals are likely to have a large effect on the estimated size of the endowment fund. Appendix Table 1 makes it clear that regeneration costs represent a significant share of the non-capital costs. Thus regenerating material at longer or shorter cycles will lower or raise costs accordingly. Interest rate is also a key component of any present value calculation; lower rates tend to raise the present value of future costs.

We tested the sensitivity of our best endowment fund estimate (US$ 149 million) to changes in these two elements by re-estimating the fund figure using the regeneration cycles given in Appendix Table 2 and several rates of interest. In scenario A, the storage lives are comparatively short, requiring more frequent regeneration and viability testing. For scenario C, the storage lives are much longer, and the cycles of regeneration and viability testing are thus less frequent. Scenario B represents a medium (and seemingly most plausible) regeneration cycle used to form the baseline estimates in Table 7. Figure 4 shows that with this combination of key assumptions the size of the endowment fund could be as low as US$ 100 million (under scenario C with a high, 6% rate of interest) or as high as US$ 325 million (under scenario A with a low, 2% rate of interest).

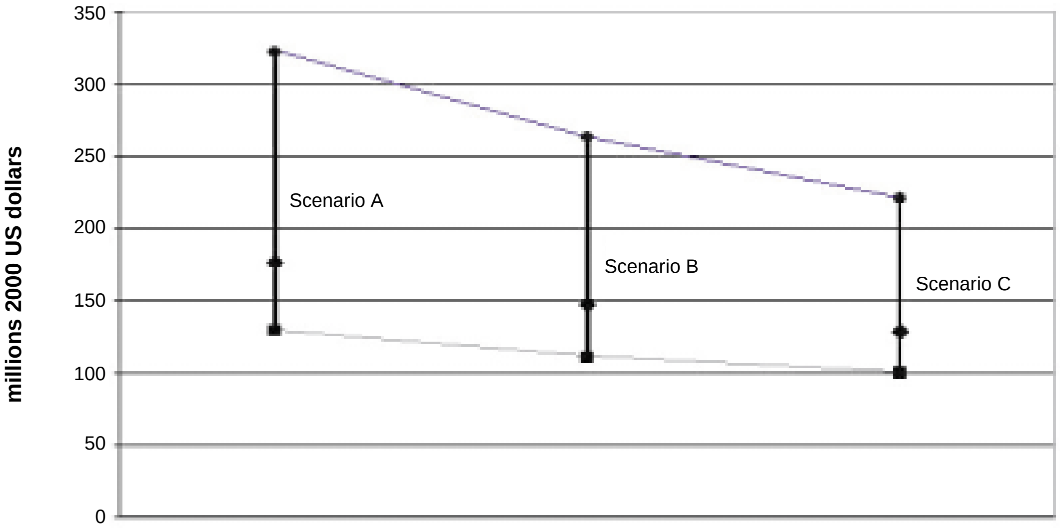

Figure legend	Interest rate	Length of regeneration and viability testing cycles[a]		
		Scenario A: short	Scenario B: medium	Scenario C: long
			(*millions 2000 US dollars*)	
●	2%	325	265	223
◆	4%	178	149	129
■	6%	130	111	100

Source: Authors' calculations.

[a] See Appendix Table 2 for details.

Figure 4. Sensitivity analysis of the conservation fund

5. FINAL CONSIDERATIONS

In setting a target for a conservation fund there are other things to consider; some that would decrease the size of the endowment compared with our best estimate, others that would increase it. Improvements in storage efficiencies due to technical change would likely lower costs in the future (but then again other techniques may reduce the risk of loss but increase costs). The costs presented above are based on data collected during a time of structural and operational changes for some CG genebanks. We tried to abstract from the cost implications of these changes, but on balance we are likely left with an upper-bound estimate of the relevant costs if the genebanks were to be operating in steady state. Pardey et al. (2001), using data from CIMMYT, illustrated that savings through potential economies of scale and size may be realized from consolidating genebank facilities.

There are some factors that would raise the endowment target. Our cost estimates were based on a steady-state continuation of the present level of activity into the distant future. Increasing the size of the collection or the number of samples distributed annually would obviously increase costs and the amount of funds required to support them. Conserving genetic material is a labour-intensive undertaking. If structural changes in developing-country labour markets cause local wage rates to rise the endowment fund would need to grow accordingly.

Moreover, our cost estimates include only those core activities required to conserve and distribute the CG holdings now and forever. Wright (1997) pointed out that the general lack of evaluation information on stored germplasm has severely limited its use in crop breeding and thereby curtails the demand for genebank material. Tanksley and McCouch (1997, p.1066) described how modern molecular biology techniques could be used to tap the 'wide repertoire of genetic variants created and selected by nature over hundreds of millions of years [that are] contained in our germplasm banks in the form of exotic accessions.' Costing the characterization activities that provide the molecular basis for modern breeding efforts and thereby greatly enhance conventional crop-breeding techniques is a tricky exercise, depending in part on the state and nature of the rapidly changing biotechnologies and the timing of their use (Koo and Wright 2000). In the absence of further detailed study, we believe it is prudent to match the resources devoted to conservation purposes with a comparable sum for their characterization and evaluation. This will greatly enhance the contribution of the conservation effort to the crop-breeding efforts of future generations worldwide.

Using germplasm conserved by the CG, crop breeders developed improved crop varieties that were taken up by farmers the world over. The result has been unprecedented increases in crop yields in the past several decades with benefits in the tens of billions of dollars for developing country producers (through increased productivity and lower costs of production) and consumers (through lower food prices and improved grain quality) (Alston et al. 2000). The benefits to the rich countries have been substantial too (for example, see Brennan and Fox 1995 and Pardey et al. 1996 for Australian and United States evidence respectively). There is no reason to think the flow of benefits will diminish any time soon: with little land left to bring into agriculture and a projected 3 billion increase in world population by 2050 (almost all occurring in poorer countries) yields must, and can, continue growing. This study provides a firm empirical basis for putting the CGIAR's conservation efforts on a firmer financial footing. If the future is anything like the recent past—and every indication is that it could be—setting aside $200-300 million to underwrite the CGIAR's genebank conservation and distribution efforts into the very distant future is a small down payment compared with the billions of dollars of benefits flowing from continued access to and use of this germplasm.

ACRONYMS

CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CIP	Centro Internacional de la Papa
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IPGRI/INIBAP	International Network for the Improvement of Banana and Plantain
IPGRI	International Plant Genetic Resources Institute
IRRI	International Rice Research Institute
NSSL	National Seed Storage Laboratory, USA
OECD	Organisation for Economic Co-operation and Development
SGRP	CGIAR System-wide Genetic Resources Programme
SINGER	CGIAR System-wide Information Network for Genetic Resources
WARDA	West Africa Rice Development Association

REFERENCES

Alston, J.M., C. Chan-Kang, M.C. Marra, P.G. Pardey, and T J Wyatt. 2000. A Meta-Analysis of Rates of Return to Agricultural R&D: Ex Pede Herculem? Research Report No. 113. International Food Policy Research Institute, Washington D.C.

Brennan, J.P., and P.N. Fox. 1995. Impact of CIMMYT Wheats in Australia: Evidence of International Research Spillovers. Economics Research Report No. 1/95. Wagga Wagga, Australia: New South Wales Department of Agriculture.

Burstin, J., M. Lefort, M. Mitteau, A. Sontot, and J. Guiard. 1997. Towards the assessment of the cost of genebanks management: conservation, regeneration, and characterization. Plant Varieties and Seeds 10:163–172.

Epperson, J.E., D. Pachico, and C.L. Guevara. 1997. A cost analysis of maintaining cassava plant genetic resources. Crop Science 37:1641-1649.

FAO. 1998. The State of the World's Plant Genetic Resources for Food and Agriculture. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.

FAO/IPGRI. 1994. Genebank Standards. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy, and IPGRI (International Plant Genetic Resources Institute), Rome, Italy.

Harlan, J.R. 1972. Genetics of disaster. Journal of Environmental Quality 1(3):212-215.

Koo, B. and B.D. Wright. 2000. The optimal timing of evaluation of genebank accessions and the effects of biotechnology. American Journal of Agricultural Economics 82(4):797-811.

National Research Council, Committee on Genetic Vulnerability of Major Crops. 1972. Genetic vulnerability of major crops. National Academy of Sciences, Washington D.C., USA.

OECD. 2000. Main Economic Indicators, CD-ROM version. OECD (Organisation for Economic Co-operation and Development), Paris, France.

Pardey, P.G., J.M. Alston, J.E. Christian, and S. Fan. 1996. Hidden Harvest: U.S. Benefits from International Research Aid. IFPRI Food Policy Report, Washington D.C. International Food Policy Research Institute.

Pardey, P.G., B. Koo, B.D. Wright, M.E. van Dusen, B. Skovmand and S. Taba. 1999. Costing the *Ex Situ* Conservation of Genetic Resources: Maize and Wheat at CIMMYT. EPTD Discussion Paper 52. IFPRI (International Food Policy Research Institute), Washington, D.C., USA.

Pardey, P.G., B. Koo, B.D. Wright, M.E. van Dusen, B. Skovmand and S. Taba. 2001. Costing the conservation of genetic resources: CIMMYT's *ex situ* maize and wheat collection. Crop Science 41(4):1286-1299.

Pistorius, R. 1997. Scientists, plants and politics: A history of the plant genetic resources movement. IPGRI (International Plant Genetic Resources Institute), Rome, Italy.

Reznik, S. and Y. Vavilov. 1997. The Russian Scientist Nicolay Vavilov. Preface to the English translation of N.I. Vavilov. Five Continents. IPGRI (International Plant Genetic Resources Institute), Rome, Italy.

Sackville Hamilton, N.R. and K.K. Chorlton. 1997. Regeneration of Accessions in Seed Collections: A Decision Guide. Handbook for Genebanks No. 5. IPGRI (International Plant Genetic Resources Institute), Rome, Italy.

SGRP. 1996. Report of the Internationally Commissioned External Review of the CGIAR Genebank Operations. IPGRI (International Plant Genetic Resources Institute), Rome, Italy.

SGRP. 2000. A Funding Plan to Upgrade CGIAR Centre Genebanks. Report of CGIAR System-wide Genetic Resources Programme, Rome, Italy.

Smale, M., M.P. Reynolds, M. Warburton, B. Skovmand, R. Trethowan, R.P. Singh, I. Ortiz-Monasterio, J. Crossa, M, Khairallah and M. Almanza. Dimensions of Diversity in CIMMYT Bread Wheat from 1965 to 2000. Mexico, D.F. CIMMYT, 2001.

Tanksley, S.D. and S.R. McCouch. 1997. Seed banks and molecular maps: unlocking genetic potential from the wild. Science 277:1063-1066.

Virchow, D. 1999. Spending on Conservation of Plant Genetic Resources for Food and Agriculture: How Much and How Efficient? ZEF Discussion Papers on Development Policy No. 16, Center for Development Research, Bonn, Germany.

Wright, B.D. 1997. Crop genetic resource policy: the role of *ex situ* genebanks. Australian Journal of Agricultural and Resource Economics 41(1): 81-115.

World Bank. 2000. World Development Indicators, CD ROM version. World Bank, Washington D.C., USA.

APPENDIX A: THE PRESENT VALUE AND ANNUALIZED COST OF RECURRENT CAPITAL AND OTHER EXPENSES

* The present value of an item with a service life of *n* years purchased at time zero for *X* dollars and repurchased every n^{th} year is given by

$$PV_0^n = X + \frac{X}{(1+r)^n} + \frac{X}{(1+r)^{2n}} + ... = X\left[1 + \frac{1}{(1+r)^n} + \frac{1}{(1+r)^{2n}} + ...\right]$$

(1) $$PV_0^n = \left[\frac{1}{1-a^n}\right]X$$ where $a \equiv \frac{1}{1+r}$ and *r* is the rate of interest.

For example, if regenerating an accession costs US$ 100 and it is done every 20 years from year zero, then the present value of the cost of regenerating the accession in perpetuity is US$ 183 at 4% interest rate.

* The present value of a service costing *Y* dollars purchased every year from time zero is given by

(2) $$PV_0^1 = \left[\frac{1}{1-a}\right]Y$$

For example, if it costs US$ 10 per year to store one accession of germplasm, the present value of the cost of storing that accession in perpetuity is US$ 260 at 4% interest rate.

* To calculate the annualized user cost *Y* of an item costing *X* dollars purchased every *n* years, we need to solve for *Y* in terms of *X* by setting $PV_0^1 = PV_0^n$ and rearranging terms

(3) $$Y = \left[\frac{1-a}{1-a^n}\right]X$$

For example, if a refrigerator costs US$ 2000 and its service life is 10 years, then the annualized user cost of the refrigerator is US$ 237 at 4% interest rate.

* The present value of an item with a service life of *n* years purchased at time *nth* year for *X* dollars and repurchased every *n* years is given by

(4) $$PV_n^n = \left[\frac{a^n}{1-a^n}\right]X$$

For example, if regenerating an accession costs US$ 100 and it is done every 20 years from year 20, then the present value of the cost of regenerating the accession in perpetuity is US$ 83 at 4% interest rate.

APPENDIX TABLE 1. THE COSTS OF EACH OPERATION FOR EACH CROP

Centre	Crop	Cost (US$ per accession)							
		Acquisition	Medium-term storage	Long-term storage	Viability testing	Regeneration	Characterization	Duplication	Dissemination
CIAT	Cassava								
	In vitro[a] conservation	68.19	3.09			20.87			13.07
	Cryoconservation			1.23	8.13	33.70			
	Field genebank[b]			7.28					
	Common bean		0.44	0.92	4.22	35.71		4.24	26.95
	Forages		0.65	1.12	15.08	51.91		4.24	51.21
CIMMYT	Wheat	3.30	0.37	0.48	1.36	6.63		0.44	4.20
	Maize	9.47	3.04	2.16	4.79	221.02		5.53	35.45
ICARDA	Cereal	6.10	0.55	0.47	2.70	10.09	1.55	2.51	3.71
	Forages	6.10	0.55	0.47	2.70	12.78	1.46	2.51	3.71
	Chickpea	6.10	0.55	0.47	2.70	13.88	2.00	2.51	3.71
	Lentil	6.10	0.55	0.47	2.70	17.85	2.22	2.51	3.71
	Faba bean	6.10	0.55	0.47	2.70	17.59	2.65	2.51	3.71
ICRISAT	Sorghum	5.27	1.51	1.32	1.26	19.88	11.10	4.39	2.58
	Pearl millet	5.27	1.51	1.32	1.26	51.05	12.67	4.39	2.58
	Pigeon pea	5.27	1.51	1.32	1.26	60.31	6.38	4.39	2.58
	Chickpea	5.27	1.51	1.32	1.26	21.51	5.11	4.39	2.58
	Groundnut	5.27	1.51	1.32	1.26	28.18	18.34	4.39	2.58
	Wild groundnut	5.27	1.51	1.32	1.26	249.00	26.36	4.39	2.58
IRRI	Cultivated rice	6.51	0.87	0.47	1.54	33.90	10.15	1.74	9.75
	Wild rice	6.51	0.87	0.47	1.54	114.74	7.62	1.74	9.75

Source: Authors' calculations.

Note: All costs denominated in year 2000 U.S. dollars.

[a] Acquisition costs for material to be held *in vitro* represents the costs of screening the health of the sample by disease indexing methods. Regeneration costs for material held *in vitro* represents the costs of subculturing the accession.

[b] As a practical matter, conserving cassava in a field genebank is more properly thought of as a medium-term undertaking, but we included it here under long-term storage to reflect its conservation intent. Most cassava is distributed in the form of *in vitro* samples. A few samples are distributed locally as cuttings direct from the field genebank, and the associated costs are subsumed in the storage costs reported here.

APPENDIX TABLE 2. OPERATIONAL CYCLES IN YEARS UNDER ALTERNATIVE SCENARIOS

	Scenario A	Scenario B	Scenario C
		(years)	
For seed storage			
Long-term storage regeneration cycle	30	50	100
Long-term storage viability testing cycle	5	10	10
Medium-term storage regeneration cycle	15	25	50
Medium-term storage viability testing cycle	5	5	10
Dissemination cycle	5	5	5
For *in vitro* conservation			
Subculturing cycle	1	1.5	2
For cryoconservation			
Regeneration cycle	50	100	150
Viability testing cycle	10	10	15

Source: FAO/IPGRI (1994), Sackville Hamilton and Chorlton (1997) and personal communication with CG genebank managers.

SGRP

ISBN 92-9043-520-8