Available online at www.sciencedirect.com
SCIENCE @ DIRECT®

AGRICULTURAL ECONOMICS

Agricultural Economics 29 (2003) 287–297

www.elsevier.com/locate/agecon

The economic costs of conserving genetic resources at the CGIAR centres☆

B. Koo[a,*], P.G. Pardey[b], B.D. Wright[c]

[a] International Food Policy Research Institute (IFPPI), 2033 K Street, NW, Washington, DC 20006, USA
[b] Department of Applied Economics, University of Minnesota, St. Paul, MN, USA
[c] University of California, Berkeley, CA, USA

Abstract

The 11 genebanks of the Consultative Group on International Agriculture (CGIAR) have grown considerably in size over the past few decades, currently holding about 666,000 accessions of germplasm. Conserving germplasm is a very long run, if not in perpetuity, proposition. The mismatch between the mainly annual funding support for this conservation effort and its very long-term nature and intent is a serious concern. Using the results of five CGIAR genebank case studies (accounting for 87% of the total CGIAR genebank holdings), we estimate the size of an endowment or trust fund that would be required to assure a funding stream to conserve this genetic material for future generations. The annual cost (in year 2000 US$) of conserving and distributing the genetic material presently held in all 11 CGIAR genebanks is estimated to be 5.7 million US$ (mUS$), which could be maintained for all future generations by setting aside a fund of 149 mUS$ (invested at a real rate of interest of 4% per annum). This would be sufficient to underwrite the costs for the CGIAR's current conservation activities in perpetuity (estimated to be 61 mUS$), as well as the cost of maintaining the distribution activities (88 mUS$) that provide germplasm to breeders, scientists, farmers and others world wide.

Keywords: Ex situ conservation; Genebank management; Conservation cost; Trust fund; CGIAR

1. Introduction

The importance of seeds to human life has been well recognised from time immemorial. But the notion of setting aside seeds in special facilities (denoted *ex situ* conservation) for use by plant breeders and others in the near and distant futures did not really take hold until the early 20th century. Much of the credit for this idea and its implementation is given to the famous Russian biologist Nikolai Vavilov. During three decades of travel over five continents in the 1920s and 1930s, 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). Since then, sizeable investments have been made in collecting and conserving landraces (farmer-developed varieties) and wild and weedy species of crops in *ex situ* genebanks around the world. Motivating these investments are concerns that the genetic basis of agriculture is narrowing globally for many agricultural crops, as genetically

☆ This work was funded by the System-wide Genetic Resources Program (SGRP), with in-kind contributions from the Consultative Group on International Agricultural Research (CGIAR) Centres and additional support from the Swedish International Development Cooperation Agency (Sida).
* Corresponding author. Tel.: +1-202-862-8184; fax: +1-202-467-4439.
E-mail address: b.koo@cgiar.org (B. Koo).

0169-5150/$ – see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/S0169-5150(03)00056-2

more-uniform but superior varieties developed with scientific breeding methods spread worldwide at a pace that began accelerating in the 1960s.[1]

The technology for storing genetic material for reproduction of plants (germplasm) has improved dramatically over the past several decades, with a corresponding increase in the number of *ex situ* conservation facilities. At present, it is estimated that global *ex situ* collections contain over 6 million samples (accessions) in more than 1300 genebanks worldwide, though this figure includes many duplicates (FAO, 1998). About 90% of these collections (mostly cereal and legumes) are conserved as seeds in seed genebanks, and the rest are in field genebanks (for trees and vegetatively propagated germplasm) or *in vitro* facilities (for vegetatively propagated plants and some fruits). About 10% of the total 6 million accessions are maintained within the centres of the Consultative Group on International Agricultural Research (CGIAR, or CG in short), most of them as 'in-trust' accessions for the international community.

Now that the coverage of the relevant crop diversity has expanded so dramatically, there is a need to establish a sound financial basis for conserving these impressive *ex situ* collections for all future generations. Most genebanks, including CG genebanks, are financed from short-term (often year by year) pledges of support, and the goal of conservation has often been subordinated to other activities like crop improvement and biotechnology research. The mismatch between the short-term nature of the financial support and the long-term (indeed indefinite) nature and intent of the conservation effort is a serious concern. The purpose of this paper is to estimate the size of the trust fund required to underwrite the conservation services provided by the global systems of CG genebanks. The unique aspect of this study is that we developed an estimate of the current costs of conservation and distribution, and used a set of plausible technical assumptions (based on present conservation practices) to derive the in perpetuity costs of conserving these seeds.

Some survey-based studies have attempted to estimate the cost of conserving germplasm (Burstin et al., 1997; Virchow, 1999), but subjective responses and excessively aggregated data often make comparisons across different environments difficult. On the other hand, a case study approach with on-site data collection and direct interviews provides more informative and accurate cost estimates (Epperson et al., 1997; Pardey et al., 2001). A series of detailed costing studies led by the International Food Policy Research Institute (IFPRI) has been conducted over the past several years in close collaboration with colleagues at five CG genebanks. This series of studies is built upon the framework described in Pardey et al. (2001), which was the first study to deal comprehensively with the dynamics involved in costing the genebank activities and to place those costs in an in-perpetuity framework. Results from these studies are utilised in modelling the costs of genebank management and in constructing a basis for the extrapolations made to develop a complete costing of the entire CG conservation and distribution effort. The cost estimates of different operations for each crop could provide the basis for answering many general operational issues, such as the choice of cost effective storage methods or the appropriate charge for distribution of germplasm as well as the fundamental rationale of *ex situ* conservation itself. For example, if the calculated cost of conservation is below the consensus minimal estimate of benefits, the cost calculation can be sufficient to justify the funding of continued conservation, without tackling the daunting, if not infeasible, task of estimating the full value of conserving germplasm in perpetuity.

2. Genebank operation and costs

2.1. Overview of genebank operations

Germplasm accessions in the form of storable seeds are kept in packets or small containers in a medium-term storage facility (maintained between 0 and 5 °C and 15–20% relative humidity) as an 'active'

[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 the outbreak of southern corn leaf blight in the 1970s, and addressed in NRC (1972) and Harlan (1972), among others. However, the seriousness of this issue varies from crop to crop. NRC (1972) found common beans to be "impressively uniform and impressively valuable", whereas Smale et al. (2003) conclude that "The data are not consistent with the hypothesis that the genetic base of CIMMYT germplasm (for wheat and maize) has tended to narrow over time." Genebanks help ensure that the genetic base of crop breeding does not rely solely on what is currently grown in farmers' fields.

collection. Typically, most of this material is also kept in a long-term storage facility (held at colder temperatures, often in the range -18 to $-20\,^{\circ}C$) as a 'base' collection. Seed samples in storage facilities are checked regularly for viability, usually every 5–10 years, and regenerated if the viability drops below a threshold level. The consensus is that most seed samples will remain viable for 20–30 years in medium-term storage, and for up to 100 years in long-term storage. Vegetatively propagated species (including crops such as cassava, potato, and banana) and some plants and trees with 'recalcitrant' seeds are conserved as whole plants in field genebanks or as live specimens in so-called *in vitro* genebanks which are maintained on a special growth medium in test tubes stored under warm, lighted conditions (23 °C and 1500–2000 lux). Plants stored in these types of genebanks are frequently regenerated (every 1–2 years) to maintain viable specimens. Another storage option that may become economically attractive for long-term conservation is to use cryoconservation techniques which conserve plant material at extremely low temperatures (at $-196\,^{\circ}C$ maintained with liquid nitrogen), and some material is presently stored this way.

Complementing the conservation services, genebanks also disseminate seed and other plant samples upon request, often with no charge. Samples for ready dissemination are maintained in medium-term storage as active collections or in *in vitro* storage. The CG centres collectively agreed to place the genetic material held in their genebanks under the auspices of an in-trust agreement with the Food and Agriculture Organization (FAO) of the United Nations in 1994, with the objective of maintaining the collection in the global public domain. Material designated as part of the in-trust collection is made freely available, with the stipulation that recipients agree not to seek intellectual property protection on the material. From 1994 to 1999, over half a million samples were shipped by the CG genebanks, averaging more than 94,000 samples per year (Table 1).

The genebank operations can be grouped into a set of three main services: conservation services, distribution services and information services. We take conservation services to include conserving agricultural genetic diversity in the form of a base collection to maintain the stored plants (or plant parts) and seeds for use in the distant future. This service requires placement of healthy (disease free) and viable germplasm in long-term storage, periodic checkup of the viability of the stored material and its regeneration when required, and maintenance of duplicates of the collection at other locations for added security. The distribution services are geared to making accessions available upon request for current utilisation. This typically involves maintaining an active collection of germplasm in a medium-term storage facility or as *in vitro* plantlets. Material stored in active collections typically requires more frequent regeneration as the environment within these storage facilities is not optimal for long-term conservation, and seed sample sizes are eventually reduced to the point they must be replenished. For example, the controlled temperatures and humidity are often not as low or as stable relative to the long-term conservation because of more frequent access to retrieve samples for distribution.

Conservation and distribution activities also require keeping track of the size and condition of each holding and documenting 'passport data' that includes basic information on the source of the seed samples and their physical attributes (including plant height, seed characteristics such as size, colour and shape, and evident pest and disease susceptibility). The purpose of these information services is to generate useful and reliably retrievable information about each accession to expedite the use of material for crop improvement or other research purposes. Some of this information is obtained by purposively screening the genebank collection for varieties with resistance to certain pests and diseases (often by planting out many varieties and subjecting them to infestation). 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 these services is not always clear-cut. In some settings (like 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 activities typically performed as part of a breeding programme (e.g., molecular characterisation) fall within the ambit of a genebank programme. To facilitate meaningful comparisons that span a consistent set of core conservation activities, we confined the study to those

Table 1
Size of the germplasm collection and dissemination at the CGIAR centres, 2001[a,b]

Centre (location)	Crop	Total number of accessions	Average annual dissemination (1995–1999)
CIAT (Columbia)	Cassava	8060	344
	Common bean	31400	910
	Forages	24184	8969
	Total	63644	10223
CIMMYT (Mexico)	Wheat	154912	3503
	Maize	25086	8177
	Total	179998	11680
CIP (Peru)	Potato	7639	4330
	Sweet potato	7659	1970
	Andean roots/tubers	1495	6
	Total	16793	6306
ICARDA (Syria)	Cereal	60013	10907
	Forages	30528	8576
	Chickpea	11219	5200
	Lentil	9962	3804
	Faba bean	10745	2530
	Total	122467	31017
ICRAF (Kenya)[c]	Agroforestry trees	10025	n.a.
ICRISAT (India)	Sorghum	36721	4272
	Pearl millet	21392	2077
	Pigeon pea	13544	1729
	Chickpea	17250	5951
	Groundnut	15342	4009
	Minor millets	9252	316
	Total	113501	18355
IITA (Nigeria)	Bambara groundnut	2029	52
	Cassava	3529	913
	Cowpea	16001	2766
	Yam	3700	258
	Others	5537	520
	Total	30796	4509
ILRI (Kenya)	Forages	13204	2038
IPGRI/INIBAP (Italy)	*Musa*[d]	1143	78
IRRI (Philippines)	Rice	99132	9017
WARDA (Côte d'Ivoire)[e]	Rice	15377	842
CG total		666080	94065

[a] Source: CIAT, ICRISAT, ILRI and IRRI from SINGER database, extracted March 2001. CIMMYT, CIP, ICARDA, ICRAF, IITA, INIBAP and WARDA obtained directly from genebank managers and represent late 2000/early 2001 totals.

[b] CGIAR: Consultative Group on International Agricultural Research; CIAT: International Center for Tropical Agriculture; CIMMYT: International Maize and Wheat Improvement Center; CIP: International Potato Center; ICARDA: International Center for Agricultural Research in the Dry Areas; ICRAF: International Centre for Agroforestry Research; ICRISAT: International Crops Research Institute for the Semi-arid Tropics; IITA: International Institute for Tropical Agriculture; ILRI: International Livestock Research Institute; IPGRI: International Plant Genetic Resources Institute; INIBAP: International Network for the Improvement of Banana and Plantain; IRRI: International Rice Research Institute; WARDA: West Africa Rice Development Association.

[c] Estimate provided by the manager of ICRAF genebank.

[d] Includes soyabean, wild *vigna*, banana, and miscellaneous legumes.

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

functions deemed essential for fulfilling the conservation and distribution demands placed on a genebank.

2.2. Aspects of costing genebank operations

To structure the costing analysis, we considered the genebank operations within a production economics framework, wherein inputs such as labour, buildings, equipment, and acquired seeds are utilized 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. Total costs are partitioned into their variable (both labour and operational), capital (buildings and durable equipment), and quasi-fixed (senior scientific staff) components, and costs in each class are then summarised in terms of average costs.

The protocols of operating a genebank and the corresponding costs vary considerably by the location and type of genebank. A premium was placed on collecting and assembling the cost data in ways that were consistent in scope and treatment among different genebanks. To do so meant addressing several conceptual and practical issues.

2.2.1. Evolving protocols

During the period over which data for case studies were gathered, most genebanks were restructuring and reorganising their operations, with consequent changes in some of their conservation protocols. For example, one CG 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.[2] This study sought to compile and analyse the data for a 'representative' snapshot year, abstracting from abnormal aspects and assuming away technological changes when projecting these representative costs forward to simulate costs incurred in future years.

[2] 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.

2.2.2. Jointness/divisibility

The genebank can be but one of many programmes in a large research centre, as is the case of CG centres. 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 or engineering units usually supply services to various programmes within a centre, thereby realising scale economies and other efficiencies. A genebank operated as a stand-alone facility would have to secure each of these services independently, most likely leading to higher costs than those reported here. 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.

2.2.3. Quality of operation

The FAO/IPGRI (1994) genebank standards manual lays out two sets of conservation standards. 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 conservation conditions (based on scientific criteria) that give a "higher and thus safer standard (p. 1)". Many genebanks often have insufficient resources to satisfy all the criteria required to meet the preferred standard, and genebank managers are continually forced to juggle priorities. Meeting the preferred standard clearly costs more than maintaining the holding in acceptable condition.[3] Because quality standards vary among centres and within centres over time, comparing costs on the premise that all-else-is-equal can be quite misleading.

3. Costing the CG genebanks

By early 2001, the 11 genebanks maintained by the CG centres held about 666,000 germplasm accessions

[3] The higher costs incurred in meeting the preferred versus acceptable standards 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.

of crops, forages and agroforestry trees (Table 1). As the world repository of germplasm for the poor, CG genebanks mainly hold landraces and wild species of crops (73% of the total) 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 last 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 and 2 million. 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 is certainly much higher than its share of the global *ex situ* collection.

3.1. Estimating costs of CG collections

The structure of conservation costs critically depends on: (1) the type of crops being conserved, (2) institutional differences such as cost-sharing arrangements within each CG centre, and (3) 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 species.[4] 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, at greater cost.

Our basic approach was to estimate a representative set of baseline costs per accession in ways that made it possible to evaluate the sensitivity of these baseline costs to differences in key crop-, location- and institution-specific factors. To address these diverse factors systematically within a reasonable timeframe, we conducted cost studies of five CG centres, standardising as much as possible our treatment of the data to facilitate meaningful comparisons. The five centres are CIMMYT (International Maize and Wheat Improvement Center), CIAT (International Center for Tropical Agriculture), ICARDA (International Center for Agricultural Research in the Dry Areas), ICRISAT (International Crops Research Institute for the Semi-arid Tropics) and IRRI (International Rice Research Institute), which comprise nearly 90% of the total CG-held collection (578,742 out of 666,080 accessions; Table 1). 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 US$ using a weighted average of the producer price index for the G7 countries constructed from data obtained from OECD (2000) and World Bank (2000).[5]

The first three columns of Table 2 report the average costs (inclusive of variable and annualised capital costs) of conserving and distributing an accession for 1 year.[6] 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 1.50 US$ per accession for most crops. However, if the sample requires regeneration 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. With the higher cost of storing samples in medium-term

[4] It is crucial to regenerate material in ways that minimise 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.

[5] For details on the price conversions, see Koo et al. (2002).

[6] 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 2
Average costs of conserving an accession for 1 year and in perpetuity[a]

Centre[b]	Annual cost ($ per accession)[c]			In-perpetuity cost ($ per accession)[d]	
	Conservation		Distribution	Conservation	Distribution
	Without regeneration	With regeneration			
CIAT					
Cassava					
In vitro conservation	11.98	25.05	291	263.06	
Cryoconservation	1.23	43.06	91.39		
Field genebank		7.28	189.25		
Common bean	0.92	20.88	47.35	61.86	160.34
Forages	1.12	34.61	89.35	109.92	320.65
CIMMYT					
Wheat	0.48	4.47	8.57	24.17	38.14
Maize	2.16	115.07	151.4	214.44	476.25
ICARDA					
Cereal	0.47	6.86	10.65	36.55	52.74
Forages	0.47	8.21	11.99	38.02	55.92
Chickpea	0.47	8.76	12.54	39.2	57.22
Lentil	0.47	10.74	14.53	41.73	61.91
Faba bean	0.47	10.61	14.4	42.02	61.6
ICRISAT					
Sorghum	1.32	11.89	14.66	70.57	77.74
Pearl millet	1.32	27.48	30.25	90.27	114.57
Pigeon pea	1.32	32.11	34.88	89.37	125.51
Chickpea	1.32	12.71	15.48	65.53	79.67
Groundnut	1.32	16.05	18.81	82.64	87.55
Wild groundnut	1.32	126.45	129.22	219.07	348.45
IRRI					
Cultivated rice	0.47	18.19	28.35	54.97	101.33
Wild rice	0.47	58.61	68.76	99.44	196.84

[a] Source: Koo et al. (2002). All costs are denominated in year 2000 US$.
[b] CIAT: International Center for Tropical Agriculture; CIMMYT: International Maize and Wheat Improvement Center; ICARDA: International Center for Agricultural Research in the Dry Areas; ICRISAT: International Crops Research Institute for the Semi-arid Tropics; IRRI: International Rice Research Institute.
[c] Based on the cost for existing material.
[d] Based on the cost of newly introduced material from acquisition.

storage and the addition costs of packing and shipping, the distribution costs are higher than the conservation costs.

These figures refer to the costs of conserving (and distributing) 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 perspective on costs is more appropriate than a 1-year perspective. 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.

The last two columns of Table 2 report the present value of the average costs of conserving an accession in perpetuity, assuming per accession costs are constant over time in real (i.e., inflation-adjusted) terms and baseline conservation protocols and technological levels are maintained throughout the entire period.[7] The table shows that the present values of distribution costs are generally higher than the present values 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 cost of dissemination per se. 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, i.e., 62 US$ for each accession of wheat and 690 US$ for each accession of maize.

Table 2 also indicates the difference of the cost in terms of the length of operation. Simply holding a seed sample for 1 year (in which the sample requires no special treatment) costs less than 1.50 US$, except for maize, which costs 2.16 US$ per accession, and cassava conserved *in vitro*, which costs 11.98 US$ per accession. These storage costs consist mainly of the costs of electricity and the annualised capital cost of the storage facility, with a small expense for maintaining the storage equipment. 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 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, vegetatively propagated crops, 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.

[7] The baseline assumptions for seed storage are: (1) accessions in medium-term storage are conserved for 25 years and those in long-term storage for 50 years, (2) viability testing is done every 5 years for seeds in medium-term storage and 10 years for those in long-term storage, (3) an accession is disseminated once every 10 years, and (4) the real rate of interest 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.

3.2. A conservation trust fund

We used the costing evidence in Table 2 as the basis for calculating the size of a trust 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. 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 trees 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 an approximate but representative estimate of the annual conservation, multiplication and distribution costs incurred by ICRAF. To maintain a headquarters 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 800,000 US$, of which 80% was allocated to the conservation and distribution functions of ICRAF that were included in this study (and split 2:3 between these two functions).

3.2.1. Baseline estimates

Table 3 presents our best baseline estimates of the centre-specific and CG-wide trust 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 149 mUS$ endowment invested at a real rate of interest of 4% per annum would generate a real annual revenue flow of 5.7 mUS$, sufficient to cover the costs of conserving and distributing the current holdings of all 11 CG genebanks in perpetuity. About 20% of the trust funds (nearly 30 mUS$) would be needed to underwrite the on-going purchases of equipment and genebank buildings as they require replacing. The rest would need to be set aside to meet the recurring non-capital costs.

Table 3
The conservation trust fund[a]

Centre[b]	Cost ($)			Share of total (%)
	Conservation	Distribution	Total	
CIMMYT	9123170	17855089	26978259	18
CIAT	9208138	14909547	24117686	16
ICRISAT	9027830	10900337	19928167	13
ICRAF	7488000	11232000	18720000	13
IRRI	5652691	10481702	16134393	11
CIP	8064800	4417635	12482435	8
ICARDA	4661437	6792729	11454166	8
IITA	5298045	4617111	9915157	7
ILRI	1451339	4233806	5685145	4
WARDA	845314	1558212	2403526	2
INIBAP	437070	300682	737752	1
Total	61257835	87298851	148556686	100

[a] Source: Koo et al. (2002). All costs are denominated in year 2000 US$.

[b] CIMMYT: International Maize and Wheat Improvement Center; CIAT: International Center for Tropical Agriculture; ICRISAT: International Crops Research Institute for the Semi-arid Tropics; ICRAF: International Centre for Agroforestry Research; IRRI: International Rice Research Institute; CIP: International Potato Center; ICARDA: International Center for Research in the Dry Areas; IITA: International Institute for Tropical Agriculture; ILRI: International Livestock Research Institute; WARDA: West Africa Rice Development Association; INIBAP: International Network for the Improvement of Banana and Plantain.

The last column of Table 3 shows the estimated centre-specific shares of this overall trust 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 trust 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 INIBAP collections and the tree species conserved by ICRAF are intrinsically costly to store and regenerate. CIAT and CIMMYT constitute 16 and 18%, respectively, of the total costs. Both centres are located in relatively advanced developing countries in Latin America, where wage rates are comparatively high by developing country standards; they also maintain sizeable holdings of crops that are intrinsically costly to conserve—specifically, vegetatively propagated cassava at CIAT and cross-pollinating maize at CIMMYT.

3.2.2. *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 trust 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 trust fund. Regeneration costs represent a significant share of the non-capital costs, and thus regenerating material at longer or shorter cycles will lower or raise costs accordingly. The interest rate is also a key component of any present value calculation; lower rates tend to raise the present value of future costs (but also reduce the cost of a given level of funding).

We tested the sensitivity of our best trust fund estimate (149 mUS$) to changes in these two elements by re-estimating the fund figure using various regeneration cycles and several rates of interest. In scenario A, the storage lives are comparatively short, requiring more frequent regeneration and viability testing. For scenario C, the storage lives are much longer, and the cycles of regeneration and viability testing are thus less frequent. Scenario B represents a medium (and seemingly most plausible) regeneration cycle used to form the baseline estimates in Table 3. With this combination of key assumptions, a sensitivity analysis reveals that the size of the trust fund could be as low as 100 mUS$ (under scenario C with a high, 6% rate of interest) or as high as 325 mUS$ (under scenario A with a low, 2% rate of interest).

4. Conclusion and caveats

In setting a target for a conservation trust fund there are many 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, while new 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 are likely left with an upper-bound estimate of the relevant costs if the genebanks were to be operating in steady state. Institutional initiatives could also be relevant. Using data from CIMMYT, Pardey et al. (2001) illustrated that savings through potential economies of scale and size may be realised 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 trust 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. 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 (Wright, 1997). 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 characterisation 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).

Crop breeders have developed improved crop varieties using germplasm conserved by the CG centres 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) (Evenson and Gollin, 1997; Alston et al., 2000; Gollin et al., 2000). The benefits to the rich countries have been substantial too (e.g., see Brennan and Fox, 1995; Pardey et al., 1996; for Australian and US evidence, respectively). There is no reason to think the need for a diverse base of germplasm will diminish any time soon: with little land left to bring into agriculture and a projected three billion increase in world population by 2050 (almost all occurring in poorer countries), yields must continue to be increased. 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 mUS$ to underwrite the CGIAR's genebank conservation and distribution efforts into the very distant future is a small down-payment compared with the benefits flowing from continued access to and use of this germplasm.

Acknowledgements

We thank Eric van Dusen, Bent Skovmand, Suketoshi Taba, Jan Valkoun, Mike Jackson, Kameswara Rao, Paula Bramel and Daniel Debouck for their help in conducting the CG Centre case studies that underpin this synthesis paper, and Samy Gaiji, Tony Simons, Jean Hanson, Willy Roca, Robert Guei, Quat Ng, Suzanne Sharrock, Jane Toll and Geoffrey Hawtin for providing additional data and comments on earlier drafts.

References

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

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

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

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

Evenson, R.E., Gollin, D., 1997. Genetic resources, international organizations, and improvement in rice varieties. Econ. Dev. Cult. Change 45 (3), 471–500.

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

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

Gollin, D., Smale, M., Skovmand, B., 2000. Optimal search for traits in *ex situ* collections of wheat genetic resources. Am. J. Agric. Econ. 82 (4), 812–827.

Harlan, J.R., 1972. Genetics of disaster. J. Environ. Qual. 1 (3), 212–215.

Koo, B., Wright, B.D., 2000. The optimal timing of evaluation of genebank accessions and the effects of biotechnology. Am. J. Agric. Econ. 82 (4), 797–811.

Koo, B., Pardey, P.G., Wright, B.D., 2002. Endowing Future Harvests: The Long-term Costs of Conserving Genetic Resources at the CGIAR Centers. International Plant Genetic Resource Institute (IPGRI), Rome, Italy.

NRC (National Research Council), 1972. Genetic Vulnerability of Major Crops. Committee on Genetic Vulnerability of Major Crops, National Academy of Sciences, Washington, DC.

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

Pardey, P.G., Alston, J.M., Christian, J.E., Fan, S., 1996. Hidden Harvest: US Benefits from International Research Aid. IFPRI Food Policy Report. International Food Policy Research Institute (IFPRI), Washington, DC.

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

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

Smale, M., Reynolds, M.P., Warburton, M., Skovmand, B., Trethowan, R., Singh, R.P., Ortiz-Monasterio, I., Crossa, J., Khairallah, M., Almanza, M., 2003. Dimensions of diversity in modern spring bread wheat in developing countries from 1965. Crop Sci. 42 (6), 1766–1799.

Tanksley, S.D., McCouch, S.R., 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. Centre for Development Research, Bonn, Germany.

World Bank, 2000. World Development Indicators. CD ROM Version. World Bank, Washington, DC.

Wright, B.D., 1997. Crop genetic resource policy: the role of *ex situ* genebanks. Aust. J. Agric. Resour. Econ. 41 (1), 81–115.