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CONSERVING GENETIC RESOURCES FOR AGRICULTURE: COUNTING THE COST

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As improved crop varieties developed by scientific breeding spread throughout the world in the latter half of the 20th century, the risk of excessive reliance by farmers and breeders on a narrowing genetic base was dramatized by the infestation and vulnerability of U.S. hybrid corn with cytoplasm male sterility to southern corn leaf blight. Events like this spurred worldwide efforts to greatly expand the amount of agricultural biodiversity conserved in genebanks. More recently, microarray and other modern biotechnologies that provide new and less costly ways of screening crop samples for useful traits have increased the value of conserved genetic resources and focused worldwide attention on access to and use rights of traditional crop varieties, or landraces, stored *in situ* (place of origin) or in *ex situ* genebanks worldwide.

The 11 genebanks maintained by the research centers of the Consultative Group on International Agricultural Research (CGIAR) conserve more than 666,000 accessions (plant or seed samples) of crops grown mainly by poor people, staple food crops grown worldwide, and tree species used in agroforestry systems. This collection constitutes a sizable share—perhaps 30 percent or more—of the unique entries in genebank collections worldwide. Conservation of this valuable germplasm should have a very long-term, if not perpetual, perspective. But funding for this long-term conservation service is currently provided on a precarious, year-by-year basis. This mismatch between the generally short-term nature of the financial support and the long-term nature and intent of the effort could threaten the security and future availability of this genetic material. A plan to judiciously match the duration of the funding commitments to the duration of the conservation commitments was unveiled at the World Food Summit in Rome in June 2002 and further elaborated at the World Summit on Sustainable Development in Johannesburg in August 2002. It involves an effort to tap private and public sources of support to establish a Global Conservation Trust (GCT) fund designed to sustain the long-term conservation and use of agricultural germplasm held in *ex situ* genebanks.

But just how costly is it to conserve genetic resources in genebanks and maintain their viability and sample sizes in perpetuity? In this brief we estimate the costs of conserving specific crop species in *ex situ* genebanks in perpetuity, including the costs of maintaining healthy and viable seeds and other plant breeding material (collectively called "germplasm") stored in the field or in vitro. We also show how these estimates change in response to variations among crops, conservation protocols, and institutional arrangements. The present value of these in-perpetuity costs indicates the necessary size of an endowment or trust fund that would furnish an income stream sufficient to underwrite long-term conservation efforts, thus keeping this valuable resource available for use in maintaining biodiversity and supporting plant breeding for the foreseeable future.

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The CGIAR Genebanks and Their Conservation Services

Since the 1970s the 11 genebanks now maintained by the CGIAR at its international crop-breeding centers have become a pivotal part of a global conservation effort. In 2001 the CGIAR genebanks held about 666,000 germplasm accessions of crops, forages, and agroforestry trees (Table 1). As the world repository of germplasm for the poor, CGIAR genebanks hold predominantly landraces and wild varieties of crops (73 percent 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 past few

Table 1—CGIAR germplasm holding and distributions

Center/location	Crop	Total number of accessions, 2001	Average annual dissemination, 1995-99
CIAT, Colombia	Cassava	8,060	344
	Common bean	31,400	910
	Forages	24,184	8,969
	Total	63,644	10,223
CIMMYT, Mexico	Wheat	154,912	3,503
	Maize	25,086	8,177
	Total	179,998	11,680
CIP, Peru	Potato	7,639	4,330
	Sweet Potato	7,659	1,970
	Andean roots/tubers	1,495	6
	Total	16,793	6,306
ICARDA, Syria	Cereal	60,013	10,907
	Forages	30,528	8,576
	Chickpea	11,219	5,200
	Lentil	9,962	3,804
	Faba bean	10,745	2,530
	Total	122,467	31,017
ICRAF, Kenya	Agroforestry trees	10,025	n.a.
ICRISAT, India	Sorghum	36,721	4,272
	Pearl millet	21,392	2,077
	Pigeon pea	13,544	1,729
	Chickpea	17,250	5,951
	Groundnut	15,342	4,009
	Minor millets	9,252	316
	Total	113,501	18,355
IITA, Nigeria	Bambara groundnut	2,029	52
	Cassava	3,529	913
	Cowpea	16,001	2,766
	Yam	3,700	258
	Others	5,537	520
	Total	30,796	4,509
ILRI, Kenya	Forages	13,204	2,038
IPGRI/INIBAP, Italy	Musa	1,143	78
IRRI, Philippines	Rice	99,132	9,017
WARDA, Côte d'Ivoire	Rice	15,377	842
CGIAR total		666,080	94,065

Source: Authors' survey and unpublished data provided by CGIAR centers.

Note: n.a. indicates not available.

decades, the number of duplicates proliferated. With only 1 to 2 million of the estimated 6 million accessions held worldwide deemed unique (FAO 1998), the high proportion of landraces and wild varieties in the CGIAR collection means its share of the world's unique ex situ accessions could be much higher—perhaps 30 percent or more—than its share of the global ex situ collection.

For our costing analysis, in consultation with genebank curators and breeders, we grouped typical genebank operations into three main services. Genebank services 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. Environmental conditions are typically 15 to 20 percent relative humidity and -18 to -20ºC for seeds, or 23ºC and 1,500 to 2,000 lux for vegetatively propagated material like yams and cassava held in culture mediums. Germplasm must be placed in long-term storage that is viable and disease-free; the viability of the stored material must be periodically tested, and, when indicated, viability must be restored by regeneration (planting the aged seeds and storing their progeny). For safety reasons, duplicates in the collection are periodically sent to other locations for storage.

To make accessions available upon request for current use, an active collection of germplasm is maintained in a medium-term storage facility from which samples of seed are available for dissemination to researchers, crop breeders, farmers, and other genebanks. From 1995 to 1999, the CGIAR centers shipped about 94,000 samples per year (Table 1). This material is an important source of genetic diversity and a potentially valuable source of novel and useful traits. Current use of this type of material is lower than for well-characterized and better-known breeding lines held by breeders, however, because promising traits are more difficult to identify and take time and effort to introduce into new cultivated varieties ("cultivars") distributed to farmers.

Active collections typically require more frequent regeneration than material held in base collections because the environment in medium-term storage facilities is not as conducive to germplasm longevity and germplasm samples eventually require replenishment. Most, but not all, seed samples will remain viable for 20 to 30 years in medium-term storage depending on the species, the initial seed quality, and the specifics of the storage environment.

Genebanks must maintain basic databases to indicate the source of the seed samples and their physical attributes. To facilitate the use of material for crop improvement or other research purposes, genebanks screen the collection for accessions with resistance to certain pests and diseases. Phenotypic information becomes increasingly valuable when coupled with the use of modern biotechnologies to identify the genetic basis for certain traits, along with other genetic information deemed desirable in breeding programs.

The Costs of Conservation Services in Perpetuity

The costs of some operations, such as storage, accrue annually, whereas the costs of other operations are incurred periodically—for example, every 5 years or so for the viability testing of samples and every 20 to 30 years for regeneration. 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 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 incurred 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. The present value of conserving an accession in perpetuity is obtained by summing all the areas (irrespective of their shading) of the bar graph in Figure 1.

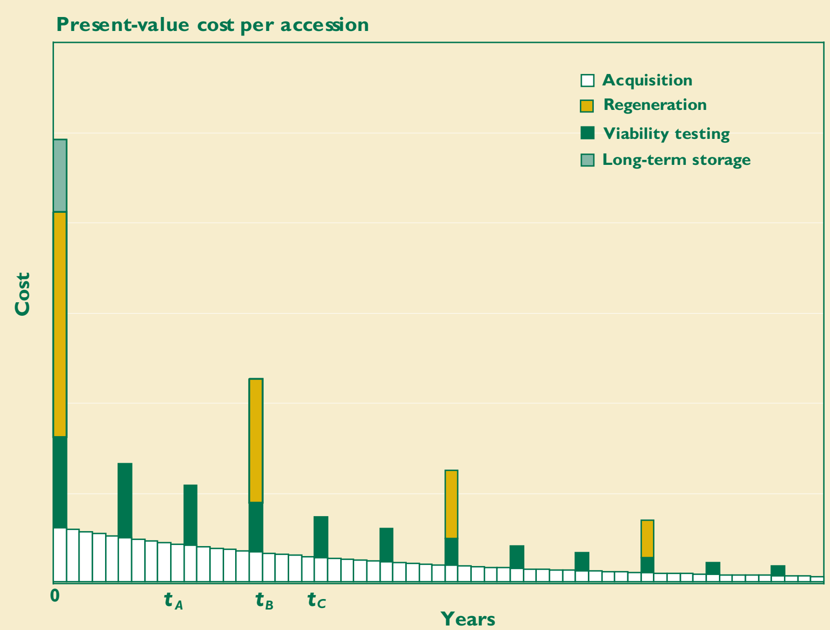
Conservation costs depend critically on (1) the type of crop being conserved, (2) institutional differences such as cost-sharing opportunities with other local activities, and (3) the local climate and the general state of the infrastructure (such as electricity supplies, communications, and international shipment options) available to each genebank. For example, regenerating cross-pollinating crops or wild and weedy species is typically more complicated than regenerating self-pollinating cultivated species. Vegetatively propagated species maintained in vitro as clones or in field genebanks are much more expensive to conserve than stored seeds. The local wage structure and the composition of the labor force (which are affected by a location's state of development and local labor laws and practices) also are important. Moreover, if the local climate is inappropriate for regeneration of some accessions, additional costs may be incurred by regeneration at other locations.

Our 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 address these diverse factors systematically within a reasonable timeframe, we conducted on-site cost studies of five CGIAR centers over several years, in close collaboration with center personnel, standardizing our treatment of the data as much as possible. The five centers, with the study dates, are the International Maize and Wheat Improvement Center (CIMMYT, 1998), the International Center for Tropical Agriculture (CIAT, 2000), the International Center for Agricultural Research in the Dry Areas (ICARDA, 1998), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, 1999), and the International Rice Research Institute (IRRI, 1999). The holdings of these five centers comprise nearly 90 percent of the total CGIAR-held accessions. To adjust 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 (highly-developed) countries constructed by the authors.

We found that simply holding a seed sample for one year (in which the sample requires no special treatment) costs less than US$1.50 per accession per year for most crops, 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 IRRI and ICARDA (US$0.47 per accession for crops kept at both locations) are comparatively low because of cheap labor and electricity costs, whereas costs are higher at ICRISAT (US$1.32 per accession) where electricity is expensive. The comparatively high cost of storing maize results from its comparatively large seed size (less seed fits in a given storage space and more costly containers are required).

Calculating the present value of conservation costs in perpetuity (including periodic viability testing and regeneration costs) changes the ranking. The costs of forage crops conserved at CIAT (US$89.35 per accession with regeneration) and of wild rice at IRRI (US$68.76 per accession) are now higher than those of chickpeas or sorghum at ICRISAT (US$15.48 and US$14.66 per accession, respectively) because of the higher costs of repeated regeneration of forages and wild rice. As a rule, wild and weedy varieties and cross-pollinating crops that are relatively expensive to regenerate are more costly to conserve over the long term. Conserving vegetatively propagated crops (such as cassava at CIAT at US$25.05 per accession) is also comparatively costly owing to the intensity of labor required for fre-

FIGURE 1 Profile of the present value of the conservation cost stream



quent subculturing of in vitro accessions or for annual replanting of field genebanks.

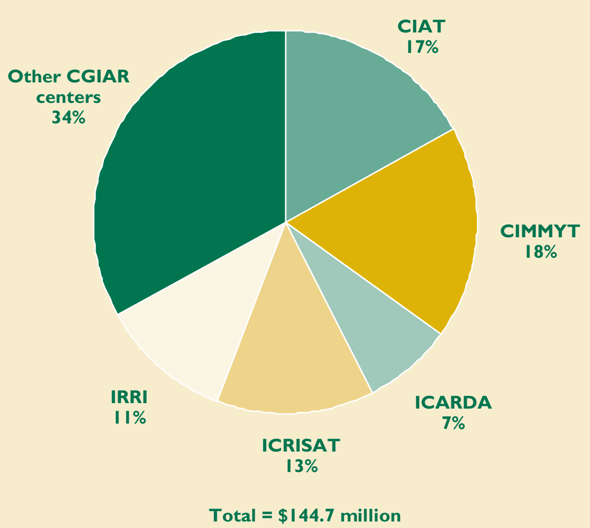
Our best baseline estimates of the present value of these in-perpetuity costs show that a US$149 million endowment invested at a real (net of inflation) rate of interest of 4 percent per year would generate a real annual revenue flow of US$5.7 million, sufficient to cover the costs of conserving and distributing the current holdings of all 11 CGIAR genebanks in perpetuity. About 20 percent of the endowment funds (nearly US$30 million) would be needed to underwrite the ongoing purchases of equipment and genebank buildings as they are replaced. The rest would need to be set aside to meet the recurring noncapital costs.

The conservation and distribution activities undertaken by the five centers we studied (which collectively conserve 87 percent of the CGIAR's current germplasm holdings) could be supported with 66 percent of the total endowment fund, with the remaining 34 percent underwriting activities at the six centers we did not study directly (Figure 2). These estimates show that 13 percent of the genebank holdings account for 34 percent of the total costs. This is because the vegetatively propagated material that constitutes a large part of collections of the International Institute of Tropical Agriculture (IITA), the International Potato Center (CIP), and the International Network for the Improvement of Banana and Plantain (INIBAP) and the tree species conserved by International Centre for Research in Agroforestry (ICRAF) are intrinsically costly to store and regenerate. CIAT and CIMMYT constitute 17 and 18 percent, respectively, of the total costs. Wage rates in Colombia and Mexico are comparatively high by developing-country standards, and major shares of the accessions at these genebanks are crops that are intrinsically costly to conserve—specifically, vegetatively propagated cassava at CIAT and cross-pollinating maize at CIMMYT.

A sensitivity analysis reveals that if the interest rate is higher (6 percent) and if accessions remain viable much longer (a possibility with modern technologies), making the cycles of regeneration and viability testing less frequent, the size of the necessary endowment falls to US$100 million. Conversely, if the interest rate is 2 percent and viability testing and regeneration are more frequent, the required endowment is US$325 million.

Our cost estimates include only those core activities required to conserve and distribute the CGIAR 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). 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" (Tanksley and McCouch 1997, 1006). Determining the cost of 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 on the optimal timing of their use (Koo and Wright 2000). In the absence of further detailed study, we believe it prudent to match the resources devoted to conservation purposes (estimated here) with a comparable sum for their characterization and evaluation. This step will greatly enhance the contribution of the conservation effort to the crop-breeding efforts of future generations worldwide.

FIGURE 2 Share of total CGIAR conservation costs, by center



Source: Koo, Pardey, and Wright (2002).

The Benefits of a Long-Term Commitment to Germplasm Conservation

These conservation costs need to be set against the tens of billions of dollars of benefits for developing-country producers (through increased productivity and lower costs of production) and consumers (through lower food prices and improved grain quality) that breeding efforts drawing on germplasm conserved in the CGIAR centers and elsewhere have brought about in the past several decades (Alston et al. 2000). There is no reason to think the importance of diverse germplasm in ensuring increased food production 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 continue to be increased. This study provides a firm empirical basis for ensuring in perpetuity the financial viability of the conservation efforts of the CGIAR centers. Setting aside US$200–300 million to underwrite the CGIAR's genebank conservation, characterization, evaluation and distribution efforts into the very distant future is a small down payment compared with the billions of dollars of benefits that will be generated by continued access to and use of this germplasm.

For a more detailed version of this summary, see Koo, Pardey, and Wright, 2002. http://sgrp.cgiar.org/SGRP-IFPRI.pdf

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