The price of conserving agricultural biodiversity

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The danger of excessive reliance by farmers and breeders on a narrowing genetic base was dramatized by the infestation of US hybrid corn with cytoplasm male sterility with southern corn leaf blight in the early 1970s (refs. 1, 2). This event catalyzed a worldwide effort to expand substantially the amount of agricultural biodiversity conserved *ex situ* in genebanks for use in crop breeding. Since then, modern biotechnologies that provide new and less costly ways of screening crop samples for useful traits have increased the usefulness of genebanks to breeders. The recent surge in interest in searching for valuable traits in conserved genetic resources has generated concerns about the sustainability of such conservation as a result of the mismatch between the generally short-term nature of the financial support for crop conservation and the long-term nature and intent of the effort. To sustain the long-term conservation and use of agricultural germplasm held in *ex situ* genebanks, a first step is to establish the cost of the necessary financial endowment. This article presents an estimate of this cost for the 11 genebanks now maintained by the Consultative Group on International Agricultural Research (CGIAR; Washington, DC) at their international crop-breeding centers.

CGIAR genebanks have become a pivotal part of the global agricultural genetic conservation effort. In 2001, they held about 666,000 germplasm accessions (plant or seed samples) of crops, forages, and agroforestry trees (see Table 1). As depositories of germplasm for the world's major food crops (especially those important to people in developing countries) and for many other regionally important staple crops, CGIAR genebanks are our natural starting point for a global conservation initiative.

But precisely how much does it cost to conserve this material now and into the distant future? Conservation costs depend on the type of crops, institutional arrangements, and the local environment. For example, regeneration (and minimization of genetic drift in the harvested sample) is typically more complicated for cross-pollinating crops or wild and weedy species than for self-pollinating cultivated species, and vegetatively propagated species, maintained *in vitro* as clones or in field genebanks, are also costly to conserve.

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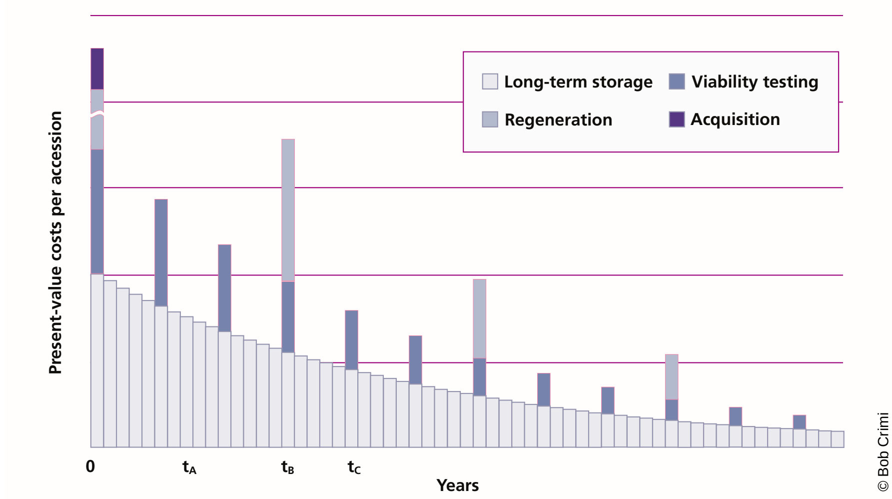

Figure 1. The cost of conservation. The graph profiles the present value of the stream of conservation costs at a typical genebank. The present values of cost elements $*X*$ that are incurred every year and every *n*th year are $X/(1-a)$ and $X/(1-a^n)$, respectively, where $a = 1/(1+r)$ and r is the interest rate. Details are presented in ref. 3.

Using detailed data collected from five CGIAR centers—the International Maize and Wheat Improvement Center (CIMMYT; El Batan, Mexico), International Center for Tropical Agriculture (CIAT; Cali, Colombia), International Center for Agricultural Research in the Dry Areas (ICARDA; Aleppo, Syria), International Crops Research Institute for the Semi-arid Tropics (ICRISAT; Patancheru, India), and International Rice Research Institute (IRRI; Los Baños, The Philippines)—that contain 87% of the CGIAR's germplasm, we have estimated the cost of sustaining the genebank operations at these centers in perpetuity. On the basis of these data, we have also identified similar conservation operations in the CGIAR's remaining six genebanks, and estimated their costs. The sum of all these calculations yields an overall estimate of the in-perpetuity cost of an endowment fund designated to sustain the CGIAR genebanks.

For our costing analysis, we grouped typical genebank operations into a set of three main services. First, conservation services maintain material in the form of a 'base collection' held in controlled environment conditions for use in the distant future. Viable and disease-free germplasm is placed in long-term storage, tested periodically for germination, and regenerated when necessary. All unique accessions are duplicated elsewhere for extra security. Second, distribution services make accessions available from an 'active collection' upon request for current utilization. From 1995 to 1999 the CGIAR centers shipped about 94,000 samples per year to researchers, crop breeders, farmers, and other genebanks worldwide (see Table 1). Finally, information services facilitate the use of material for crop improvement or other research purposes by providing detailed characterization and evaluation data.

The costs of many genebank operations, such as storage, accrue annually. On the other hand, the costs of other operations (e.g., regeneration) are incurred periodically, say every 20–30 years. 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 profiles conservation costs over the life cycle of an accession, starting from introduction, expressed in present-value terms with a positive discount rate. When introduced into a genebank at time zero, an accession 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 (e.g., at time t_A in Fig. 1), the conservation cost consists solely of 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 Fig. 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 (ref. 3). Distribution costs are treated similarly.

We calculate that simply holding a seed sample for one year (in which the sample requires no special treatment) costs less than $1.50 per accession per year for most crops, except for maize, which costs $2.16 per accession, and cassava conserved *in vitro*, which costs $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 ($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 ($1.32 per accession), where electricity is expensive.

Calculating the present value of conservation costs in perpetuity (including periodic viability testing and regeneration costs) changes the ranking, so that costs of forage crops conserved at CIAT ($89.35 per accession with regeneration) and of wild rice at IRRI ($68.76 per accession) are now higher than those of chickpeas or sorghum at ICRISAT ($15.48 and $14.66 per accession, respectively) because of the higher costs of repeated regeneration. As a rule, wild and weedy varieties, cross-pollinating crops, and vegetatively propagated crops that are relatively expensive to regenerate are more costly to conserve over the long term. Distribution costs are substantially higher than the conservation cost in present-value terms because of the more frequent viability testing and the additional regeneration costs associated with medium-term storage.

The present-value costs indicate that a $149 million endowment invested at a real (net of inflation) rate of interest of 4% per annum generates a real annual revenue flow of $5.7 million, sufficient to cover the costs of conserving and distributing the current holdings of all 11 CGIAR genebanks in perpetuity. About 20% of the endowment is needed to sustain the necessary capital equipment and buildings, and the rest to meet the recurring noncapital costs. The conservation and distribution activities undertaken by the five centers we directly costed could be supported with 66% of the total endowment fund, with the remaining 34% underwriting activities at the six centers we did not directly cost. About 13% of the genebank holdings account for 34% of the total costs, because of the high cost of storing and regenerating the vegetatively propagated materials that constitute large parts of the collections at the International Institute of Tropical Agriculture (IITA; Ibadan, Nigeria), International Potato Center (CIP; Lima, Peru), the International Network for the Improvement of Banana and Plantain (INIBAP; Montpellier, France), the West African Rice Development Association (WARDA; Abidjan, Côte d'Ivoire), and the International Livestock Research Institute (ILRI; Nairobi, Kenya), as well as the tree species conserved by the International Center for Research in Agroforestry (ICRAF; Nairobi, Kenya).

We tested the sensitivity of our baseline

Table 1. CGIAR germplasm holdings and distributions in 2001[a]

CGIAR Center (location)	Crop	Total number of accessions	Average annual dissemination
CIAT (Colombia)	Cassava	8,060	344
	Common bean	31,400	910
	Forages	24,184	8,969
	Subtotal	*63,644*	*10,223*
CIMMYT (Mexico)	Wheat	154,912	3,503
	Maize	25,086	8,177
	Subtotal	*179,998*	*11,680*
CIP (Peru)	Potato	7,639	4,330
	Sweet potato	7,659	1,970
	Andean roots, tubers	1,495	6
	Subtotal	*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
	Fava bean	10,745	2,530
	Subtotal	*122,467*	*31,017*
ICRAF (Kenya)	Agroforestry trees	10,025	NA
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
	Subtotal	*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
	Subtotal	*30,796*	*4,509*
ILRI (Kenya)	Forages	13,204	2,038
IPGRI/INIBAP (Italy)	*Musa* spp.	1,143	78
IRRI (Philippines)	Rice	99,132	9,017
WARDA (Ivory Coast)	Rice	15,377	842
CGIAR total		***666,080***	***94,065***

[a]For the analysis, costs in CIMMYT, CIAT, ICARDA, ICRISAT, and IRRI measured in different time periods were expressed as year 2000 prices using a weighted average of the producer price index for the G7 (highly developed) countries constructed by the authors. Source: Authors' survey and unpublished data provided by CGIAR centers. NA, Not available.

estimate ($149 million) to changes in interest rate and various cycles of genebank operations. If the interest rate is higher (6%) and accessions remain viable much longer (a possibility with modern technologies, which will take time to confirm), the size of the necessary endowment falls to as low as $100 million. Conversely, if the interest rate is 2% and viability testing and regeneration are more frequent, the required endowment increases to $325 million. (Note: Our 'short cycle' scenario entails regeneration cycles of 30 years for long-term storage and 15 years for medium-term storage of seeds, and the 'long cycle' scenario involves regeneration cycles of 100 years for long-term storage and 50 years for medium-term storage.)

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) from the unprecedented increases in crop yields that breeding efforts drawing on germplasm conserved in the CGIAR centers and elsewhere have brought about in the past several decades[4]. The benefits to the developed countries have been substantial too, as shown by evidence from both Australia[5] and the United States[6]. There is no reason to think the importance of diverse germplasm in ensuring increased food production will diminish anytime 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.

We costed the conservation of germplasm of staple food and feed crops held *ex situ* in CGIAR genebanks. Investment in characterizing and evaluating this material to allow optimal utilization[7] may be of a comparable magnitude, but may decline as biotechnology advances, so a delay of large evaluation investments may be justified[8]. But ensuring the sustainable conservation is a pressing concern. Setting aside $149 million to underwrite the CGIAR's genebank operations into the very distant future (or even $325 million if the cost of financing is lower) seems to be a small downpayment compared with the benefits of continued access to a diverse genetic base to support international advances in crop yields.

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