7 CIAT Genebank

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History of the CIAT Genebank

Established in Palmira, Colombia, in 1969, Centro Internacional de Agricultura Tropical (the International Center for Tropical Agriculture, known as CIAT) has worked to conserve and increase the productivity of beans, cassava, tropical forages and rice. Four programmes were initially established, with agronomy and breeding as the main components. The animal production programmes (cattle and pigs) were soon phased out, after which CIAT's activities concentrated on tropical pastures only, focusing on seed-based technologies that could be adopted quickly by farmers. Improved germplasm was produced through mass selection from germplasm collections or through plant breeding after the collections were evaluated.

Plant breeding requires large germplasm collections, but not much was known about their diverse agronomic traits or heritability in the 1970s. CIAT quickly accumulated thousands of accessions of beans, cassava and tropical forages as donations from other institutions. As the breeding programme developed, it became necessary to establish and maintain a separate germplasm collection. In 1977, the Genetic Resources Unit (GRU) was formally established (in a building originally designed as a slaughterhouse used by CIAT's animal production programme), and by 1988 the total collection grew from 17,000 to 40,000 accessions. Germplasm explorations for specific materials contributed substantially to the collection over this time.

The inherited facility was gradually modified and improved for seed conservation, and two cold-storage rooms and a drying room were built in 1990 with funding from the Italian government. Countries increasingly recognized the value of well-conserved and evaluated germplasm, and GRU operations continually improved. With the increasing demand for cassava and concern over the safety of disseminated materials, the entire cassava field genebank was progressively converted to an *in vitro* collection during 1980–1985,[1] and protocols for germplasm health testing were initiated (for example, thermotherapy – a means of heat-treating germplasm to rid it of diseases).

The FAO–CG in-trust agreement of 1994 reinforced the need for GRU to upgrade its operation (as stressed by external CG-genebank reviews in 1995, 1997 and 2000). The upgrades affected three areas: training staff, re-engineering operations and processes and improving facilities. A new, uniform computer system has also facilitated cross-checking to improve quality control, and a newly installed barcode system has reduced both the time needed to record data and the incidence of errors. Seed-drying and storage capacity has been increased and seed viability and *in vitro* laboratories have been modernized. The GRU also provided working training for 92 professionals in partner organizations during 1983–2000.

As of 2000, the total number of accessions conserved at the CIAT genebank was estimated at 56,138, including 31,880 accessions of *Phaseolus* beans, 18,178 of tropical forages and 6080 of cassava (clones of *Manihot*) (Table 7.1).[2] For cassava, the entire collection is maintained *in vitro*, as well as in a field genebank as backup (see more detail below). A small number of accessions (130) are also kept under cryoconservation (an experimental process described below). In addition, about 1000 accessions of wild cassava are conserved in cold storage as botanical seeds. All *Phaseolus* beans and forages are conserved in cold storage.[3]

Costing the CIAT Genebank

Capital input costs

Cassava

The *ex situ* conservation of cassava germplasm, though it is the only approach guaranteeing access to known traits, is hindered by several basic

Table 7.1. CIAT genebank holdings, 1978–2002.

	No. of accessions			
Year	Cassava	Beans	Forages	Total
1978	50	6,000	300	**6,350**
1980	702	14,626	5,033	**20,361**
1990	4,788	26,506	14,397	**45,691**
1995	5,707	27,918	15,157	**48,782**
1996	5,719	28,393	15,453	**49,565**
1997	5,719	28,623	15,748	**50,090**
1998	5,719	31,656	16,044	**53,419**
1999	5,719	31,880	16,339	**53,938**
2000	5,728	31,880	17,283	**54,891**
2001	5,728	31,881	18,228	**55,837**
2002	5,728	31,881	18,562	**56,171**

characteristics of the plant material – for example, it is highly heterozygous and outcrossing. Currently, four methods are used by the CIAT genebank to conserve cassava germplasm, each with various advantages and disadvantages: *in vitro* conservation of plantlets, field genebank, cold storage of botanical seeds and cryoconservation of shoot tips.

In vitro conservation is amenable to thermotherapy (mentioned above) and disease indexation (a form of health testing described below), so disease-free clones can be distributed internationally in an environment of increasingly strict quarantine requirements. However, *in vitro* collections require subculturing (regeneration in test tubes from plant tips) every 10–18 months to maintain viability. The field genebank is the only method that facilitates germplasm characterization and evaluation, but it is vulnerable to pests and diseases. The conservation of botanical seeds in cold storage can be comparatively cheap, but only two species (*Manihot esculenta* and *Manihot glazovii*) are considered 'orthodox' in that they can be successfully dried for long-term storage.[4] Cryoconservation of shoot tips would allow safe duplication (via the black-box method), but a protocol has yet to be established. Table 7.2 shows the capital costs required for different conservation methods.

Beans and forages

Table 7.3 indicates the capital input items needed for the conservation of bean and forage germplasm in cold storage, categorized by operation. Viability testing is conducted in a separate laboratory next to the GRU. Of note, the greenhouse represents a large capital investment even though most regeneration is done in fields, and Colombia's humidity makes seed-drying equipment all the more important.

Annual operating costs: cassava

Storage and subculturing

For storage, plants of each cassava accession (clones) are placed in five test tubes with a chemical medium and stored in a conservation room set at 23°C and 1500–2000 lux. Under these conditions, plantlets have an effective lifespan of only about 10–18 months (in contrast to the decades-long viability of seeds, as described in earlier chapters). Subculturing (as mentioned above) is a similar process conducted periodically to maintain the viability of each accession. Several shoot tips are extracted from plants and, once again, placed in test tubes with a chemical medium; however, before being stored they are maintained in a growing room for 3 months – a very labour-intensive process. A slow-growth method is currently being developed to increase the interval of subculturing. Table 7.4 shows the costs of storage and subculturing in the CIAT genebank.

Disease indexing

This is a process by which all incoming accessions are tested for various viruses and diseases to comply with the FAO agreement of a full-availability, disease-free collection. The meristem (or tip) of plants is extracted,

Table 7.2. Capital input costs (US$, 2000 prices) for cassava at the CIAT genebank.

		Replacement cost			Annualized cost[a]		
Cost category	Service life (years)	*In vitro*	Cryoconservation	Field genebank	*In vitro*	Cryoconservation	Field genebank
Storage		**35,613**	**17,646**	–	**2,708**	**692**	–
Conservation facility	40	21,645	–	–	1,052	–	–
Climate-control equipment	10	3,200	–	–	379	–	–
Cryoconservation equipment	100	–	17,646	–	–	692	–
Other equipment	10	10,768	–	–	1,277	–	–
Subculturing		**83,304**	–	–	**8,361**	–	–
Subculturing facility	40	21,645	–	–	1,052	–	–
Lab equipment	10	52,530	–	–	6,227	–	–
Other equipment	10	9,129	–	–	1,082	–	–
Disease indexation		**116,755**	–	–	**12,526**	–	–
Testing facility	40	21,805	–	–	1,059	–	–
Greenhouse	10	39,000	–	–	4,623	–	–
Lab/office equipment	10	53,783	–	–	6,376	–	–
Computer	5	2,167	–	–	468	–	–
Cryoconservation operation		–	**19,547**	–	–	**1,813**	–
Cryoconservation lab facility	40	–	7,215	–	–	351	–
Lab equipment	10	–	12,332	–	–	1,462	–
General capital		**62,188**	**4,969**	**4,969**	**5,747**	**514**	**514**
General facility	40	42,563	3,006	3,006	2,068	146	146
Other equipment	10	5,750	575	575	682	68	68
Computers	5	13,875	1,388	1,388	2,997	300	300
Total capital cost		**297,860**	**42,162**	**4,969**	**29,342**	**3,019**	**514**

Note: See Appendix B for further details.
[a]Calculated at a 4% interest rate using equation (3) in Appendix A.

Table 7.3. Capital input costs (US$, 2000 prices) for conserving bean and forage at the CIAT genebank.

Cost category	Service life (years)	Replacement cost	Annualized cost[a]
Medium-term storage		**232,360**	**17,703**
Storage facility	40	59,484	2,890
Storage equipment	10	52,633	6,240
Other equipment	10	43,243	5,126
Seed containers	50	77,000	3,447
Long-term storage		**143,214**	**12,181**
Storage facility	40	43,130	2,095
Storage equipment	10	44,133	5,232
Other equipment	10	31,843	3,775
Seed containers	50	24,108	1,079
Viability testing		**49,932**	**4,003**
Viability-testing facility	40	27,387	1,330
Testing equipment	10	22,545	2,673
Regeneration		**491,347**	**51,058**
Greenhouse	10	127,200	15,079
Field equipment	10	55,100	6,532
Seed-drying facility	40	18,118	880
Seed-drying equipment	10	108,333	12,843
Seed-processing facility	40	84,656	4,113
Seed-processing equipment	10	97,940	11,611
Seed-health testing		**168,467**	**17,345**
Seed-health testing facility	40	43,567	2,116
Greenhouse	10	13,000	1,541
Lab/office equipment	10	107,567	12,752
Computers	5	4,333	936
General capital		**139,125**	**14,389**
General facility	40	84,175	4,089
Other equipment	10	16,100	1,909
Computers	5	38,850	8,391
Total capital cost		**1,224,445**	**116,679**

Note: See Appendix B for further details.
[a]Calculated at a 4% interest rate using equation (3) in Appendix A.

placed in a medium, heat-treated for 3 weeks (40°C during day and 35°C at night) and grown in a greenhouse for 3 months before being tested. The current protocol involves three tests to detect different types of viruses.[5] Since the majority of the collection was not tested when it was introduced, indexing of all of CIAT's cassava materials began in 1996; the process was completed in 2001. Only two tests (enzyme-linked immunosorbent assay (ELISA) and grafting) were performed as of 2001, and the protocol of the new polymerase chain reaction (PCR) method is still being developed.

Dissemination

Dissemination of cassava is costly because a new set of clones must be subcultured each time a request is made. Two to five of the subculture test tubes

Table 7.4. Annual operating costs (US$, 2000 prices) for cassava at the CIAT genebank.

	In vitro			Cryoconservation			Field genebank		
Category	Labour	Non-labour	Capital	Labour	Non-labour	Capital	Labour	Non-labour	Capital
Storage	**3,514**	**7,880**	**2,707**	**836**	**366**	**692**	–	–	–
Management	2,880			685	–		–	–	
Electricity/supplies	–	6,459		–	300		–	–	
Overheads	634	1,421	–	151	66	–	–	–	–
(No. of accessions)	–	–	*(6,080)*	–	–	*(2,000)*	–	–	
Subculturing	**46,248**	**6,739**	**8,361**	**1,748**	**122**	–	–	–	–
Management	11,520	–		–	–		–	–	
Subculturing	26,388	5,524		–	–		–	–	
Viability testing	–	–		1,433	100		–	–	
Overheads	8,340	1,215	–	315	22	–	–	–	–
(No. of accessions)	–	–	*(4,290)*	–	–	*(300)*	–	–	
Disease indexation	**33,330**	**31,271**	**12,527**	–	–	–	–	–	–
Management	3,890	–		–	–		–	–	
Field operation	7,400	3,532		–	–		–	–	
Lab operation	16,030	22,100		–	–		–	–	
Overheads	6,010	5,639	–	–	–	–	–	–	–
(No. of accessions)	–	–	*(1,200)*	–	–		–	–	
Field maintenance	–	–	–	–	–	–	**26,816**	**5,563**	–
Management	–	–		–	–		7,005	750	
Land preparation	–	–		–	–		2,570	481	
Planting	–	–		–	–		2,115	352	
Field maintenance	–	–		–	–		3,698	2,237	
Harvesting							3,410	740	
Characterization	–	–		–	–		3,182	–	
Overheads	–	–	–	–	–	–	4,836	1,003	–
(No. of accessions)	–	–		–	–		–	–	*(5,230)*

Cryo-operation	–	–	–	**25,998**	**1,348**	**1,812**	–	–	–
Management				4,110	–				
Processing	–	–		17,200	1,105		–	–	
Overheads	–	–	–	4,688	243	–	–	–	–
(No. of accessions)	–	–		–	–	*(1,000)*	–	–	
Dissemination	**16,050**	**2,913**	–	–	–	–	–	–	–
Management	2,880	–		–	–		–	–	
Subculturing	8,796	1,672		–	–		–	–	
Packing/shipping	1,480	716		–	–		–	–	
Overheads	2,894	525	–	–	–	–	–	–	
(No. of accessions)	–	–	*(2,170)*	–	–		–	–	
General management	**29,152**	**12,091**	**5,746**	**4,274**	**902**	**514**	**4,274**	**902**	**514**
Managerial staff	23,895	–		3,503	–		3,503	–	
Office expenses	–	9,911		–	739		–	739	
Overheads	5,257	2,180	–	771	163	–	771	163	–
Total operating cost	**128,294**	**60,894**	**29,341**	**32,856**	**2,738**	**3,018**	**31,090**	**6,465**	**514**

Note: See Appendix B for further details.

are packed and shipped in polystyrene boxes by express courier service. As with the other CG genebanks, a phytosanitary certificate issued by the Colombian authorities and a material transfer agreement are included with the package (Roca *et al.*, 1984). Only indexed accessions are disseminated internationally to comply with quarantine requirements. An average of about 400–500 accessions were disseminated annually in the few years leading up to 2000; 2000 was an exception, with 2176 accessions disseminated in 54 shipments, the majority of which went to Thailand (see Table 7.6 below).

Cryoconservation

Cryoconservation enables long-term storage of cassava germplasm in a reduced space, at low cost, while maintaining its genetic integrity (Escobar *et al.*, 1997). Ongoing research focuses on establishing a basic cryoconservation protocol for cassava – the number and size of shoot tips, types of medium, levels of dehydration and so on. The first step is to propagate plantlets under culture conditions of 26–28°C and 12 hours of light per day (known as the 'photoperiod'). This takes about 2 months, after which the shoot tips are extracted, treated with sodium alginate and made to coagulate into tiny capsules (called beads or 'pseudo-seeds') through immersion in a calcium chloride solution. The beads are put in silica gel for 20 h to reduce the moisture content, and then 30 beads are packed in three small tubes of ten shoot tips each and stored in a tank filled with liquid nitrogen at a temperature of –196°C.[6] In this extreme environment, all biological activity is effectively halted, and the germplasm can be conserved for more than 100 years without maintenance. However, the recovery rate of shoot tips stored at this low temperature is one of the most difficult parts of current research.

As of 2000, 130 accessions were conserved in this way; and the number will increase up to 630 accessions (the size of the core collection at the time of this study). Various freezing methods have been attempted, and the cost data in Table 7.4 reflect the conservation protocols prevailing in 2000. Substantial resources have been allocated to basic research on cryoconservation rather than conservation *per se*, but the data in Tables 7.2 and 7.4 include only conservation-related cost estimates. A small tank (the size of a small refrigerator) can hold 2000 accessions (or 6000 test tubes) of cassava. To generate our storage cost estimates using this technique, we assumed that the tank was full.

Routine storage costs include labour for checking and filling the tank with liquid nitrogen and the material cost of liquid nitrogen.[7] The most expensive element of cryoconservation is preparing the pseudo-seeds before placing them in the storage tank. It is projected that two technicians can prepare about 1000 accessions per year, which is about the same throughput as regenerated seed.

Field genebank

Relying solely on *in vitro* methods – whereby just a few test tubes are used to store each accession – can be unduly risky; thus a field genebank is maintained as a safety backup and to enable characterization and evaluation of accessions. Once a complete evaluation of the collection is made and the protocol for cryoconservation is fully developed, the field genebank may become unnecessary, other than for occasional plantings to screen for new traits or maintain a few élite lines.

As of 2000, a total of 5230 cassava accessions were conserved on 5 ha and managed by the breeding programme in collaboration with the genebank. In 2000, the entire collection was cleared from the field to control chronic pest problems (whiteflies). Fallowing the field for a few months substantially reduces the whitefly population. The replanting cycle has been reduced from 2–3 years down to 1 year to solve the whitefly problem over the long run.[8] The annual operating cost of the field genebank in Table 7.4 is based on the new 1-year planting cycle; however, we did not include the costs of the major land-clearing activity conducted in 2000 because it was an atypical expense. Some of the cassava crops are sold to local companies after characterization or evaluation, but this revenue is also excluded from our cost calculations (about $250/ha).

Annual operating costs: beans and forages

Storage

The medium-term storage room holds 31,880 accessions of beans, 18,178 of forages and 1000 of wild cassava. About 40% of these collections are also stored long-term (12,705 accessions of beans and 7389 accessions of forage). Accessions are stored at the CIAT genebank for the same purposes as at the other genebanks already discussed: as a base collection for conservation; for dissemination on request; for viability testing; for safety duplication; and for repatriation or restoration upon request from the country of seed origin. All the newly harvested accessions are processed and stored in packets for these five different purposes.

Though there are separate medium-term and long-term storage rooms, the GRU plans to consolidate them to reduce costs, but the process of transferring samples from medium-term to long-term storage is necessarily gradual. Hence our cost estimates are based on the current dual storage arrangements (Table 7.5).

Germplasm-health testing

New accessions introduced at CIAT are first tested for disease by the Colombian quarantine unit located next to the GRU. Disseminated materials are tested by the Germplasm Health Laboratory (GHL). The testing is now performed immediately after regeneration and before storage, rather than prior to distribution. About 4000 bean and 1500 forage accessions are tested annually for two types of bacteria, three viruses and a fungus. This number includes both newly regenerated and existing stored samples.

Table 7.5. Annual operating costs (US$, 2000 prices) for bean and forage at the CIAT genebank.

	Bean				Forage			
Cost category	Labour	Non-labour	Subtotal	Capital	Labour	Non-labour	Subtotal	Capital
Medium-term storage	**3,315**	**2,344**	**5,659**	**11,145**	**1,951**	**1,380**	**3,331**	**6,557**
Storage management	1,813	–	1,813	–	1,067	–	1,067	–
Temperature control	902	1,920	2,822	–	531	1,130	1,661	–
Overheads	600	424	1,024	–	353	250	603	–
(Number of accessions)			*(31,880)*				*(18,180)*	
Long-term storage	**2,217**	**1,795**	**4,012**	**7,700**	**1,291**	**1,044**	**2,335**	**4,481**
Storage management	910	–	910	–	530	–	530	–
Temperature control	906	1,470	2,376	–	527	855	1,382	–
Overheads	401	325	726	–	234	189	423	–
(Number of accessions)			*(12,700)*				*(7,390)*	
Viability testing	**12,137**	**159**	**12,296**	**864**	**6,447**	**2,347**	**8,794**	**3,139**
Viability testing	9,940	130	10,070	–	5,280	1,922	7,202	–
Overheads	2,197	29	2,226	–	1,167	425	1,592	–
(Number of accessions)			*(5,000)*				*(1,000)*	
Regeneration	**123,355**	**38,860**	**162,215**	**31,859**	**92,566**	**33,923**	**126,489**	**19,198**
Field operation	72,560	21,389	93,949	–	54,840	21,465	76,305	–
Seed processing	28,468	10,437	38,905	–	20,972	6,318	27,290	–
Overheads	22,327	7,034	29,361	–	16,754	6,140	22,894	–
(Number of accessions)			*(5,220)*				*(3,160)*	
Dissemination	**62,778**	**9,383**	**72,161**	**8,673**	**7,681**	**1,236**	**8,917**	**8,673**
Management	5,132	–	5,132	–	628	–	628	–
Seed-health testing	45,390	7,055	52,445	8,673	5,554	863	6,417	8,673
Packing/shipping	893	630	1,523	–	109	149	258	–
Overheads	11,363	1,698	13,061	–	1,390	224	1,614	–
(Number of accessions)			*(4,250)*				*(520)*	
Duplication	**559**	**510**	**1,069**	–	–	–	–	–
Packing/shipping	458	418	876	–	–	–	–	–
Overheads	101	92	193	–	–	–	–	–
(Number of accessions)			*(2,180)*					
General management	**43,687**	**12,626**	**56,313**	**7,195**	**43,687**	**12,626**	**56,313**	**7,195**
Managerial staff	35,780	–	35,780	–	35,780	–	35,780	–
Other expenses	–	10,341	10,341	–	–	10,341	10,341	
Overheads	7,907	2,285	10,192	–	7,907	2,285	10,192	–
Total operating cost	**248,048**	**65,677**	**313,725**	**67,436**	**153,623**	**52,556**	**206,179**	**49,243**

Note: See Appendix B for further details.

The focus of the GHL has changed dramatically over the past few years. Until the mid-1990s, most of its operation was geared to testing bean and forage materials for the breeding programmes. Recently, however, germplasm exchange from the breeding programme has virtually halted, and over 90% of the health laboratory's operations were geared to the genebank. Research to establish new methods to test for the presence of key diseases in tropical pastures is integral to their work, and substantial resources have recently been spent for cassava indexation.

Viability testing

In addition to testing newly regenerated materials, delicate species (such as *Phaseolus coccineus*, *Arachis pintoi* and several grasses) are tested every 5 years for 20 years, hardier species are tested every 5 years for 30 years (except years 10 and 25) and the most durable species, such as woody-seeded legumes, are tested every 10 years from an initial testing in year 5. Once sufficient data have been accumulated, these protocols will be simplified.

Bean accessions are tested in sand-beds for cost efficiency; forages are tested using the conventional paper-rolling method accompanied by a tetrazolium test. Though only 3000 accessions were tested for viability in 2000, the cost elements in Table 7.5 are based on annual averages provided by the genebank manager (5000 for bean and 1000 for forage). As of 2000, 13,000 bean and 6600 forage accessions had undergone testing at CIAT.

Regeneration

Regeneration is conducted in several locations. Most field operations at Palmira (CIAT headquarters) are undertaken by CIAT's field unit on a charge-back basis. However, the genebank uses its own labour and other resources to regenerate genetic material at Palmira along with field activities in other locations, such as Popayan, Quilichao and Tenerife.[9] A total of 8380 accessions of beans and forages (5220 beans and 3160 forages) were regenerated during 2000. Material is usually processed and packed the year after it is harvested to allow for the lengthy drying period. For the purposes of costing, however, we assumed that all the regenerated accessions were cleaned, dried and packed in the same year.

Dissemination and safety duplication

A total of 6949 accessions were disseminated to users around the world in 2000. The GRU ships requested material every 2–3 weeks, while backup duplicates are shipped every 2–3 years. In 2000, 2180 bean accessions were prepared for safety duplication to Brazil and Costa Rica, and held for later shipment. Limited duplication activities occurred for beans and forages in 2000, so the data in Table 7.5 are estimates based on averages over several prior years. Table 7.6 shows the number of disseminated samples in the years leading up to and including 2000.

Economic Analysis

Representative annual costs of conservation

The total annual cost of conserving and distributing cassava at CIAT is estimated at $295,207, of which 74% consists of the cost of *in vitro* conservation and the rest is equally divided between cryoconservation and the field genebank (Table 7.7). In addition, the total annual cost of conserving and distributing bean and forage germplasm at CIAT is $636,583. Together with the annual costs of maintaining cassava germplasm, the total cost of maintaining the current collections of CIAT germplasm per year is estimated at

Table 7.6. Dissemination of germplasm from the CIAT genebank, 1994–2000.

Crop/recipient	1994	1995	1996	1997	1998	1999	2000
Cassava	**550**	**527**	**149**	**219**	**366**	**460**	**2,176**
CIAT/CG	80	192	5	138	278	422	1,936
NARS	470	321	82	46	57		201
Private		9	3	7	7		10
Others		5	59	28	24	38	29
Bean	**8,877**	**7,565**	**8,705**	**10,481**	**8,493**	**9,600**	**4,256**
CIAT/CG	6,007	7,383	6,355	6,339	2,931	8,327	1,468
NARS	2,860	76	1,334	2,727	3,653		2,275
Private	10			4	9		11
Others		106	1,016	1,411	1,900	1,273	502
Forage	**3,231**	**1,133**	**1,320**	**1,053**	**517**	**525**	**517**
CIAT/CG	2,018	632	742	216	200	235	136
NARS	538	312	445	349	121		73
Private	28	89	28	3	20		
Others	647	100	105	485	176	290	308
Total	**12,658**	**9,225**	**10,174**	**11,753**	**9,376**	**10,585**	**6,949**

NARS, National Agricultural Research System.

Table 7.7. Annual total (US$, 2000 prices) and average (US$ per accession, 2000 prices) costs of each operation at the CIAT genebank.

Cost category	Number of accessions	Total capital cost	Total quasi-fixed cost[a]	Total variable cost	Average capital cost	Average quasi-fixed cost	Average variable cost
Cassava		**32,874**	**70,448**	**191,885**	**17.60**	**27.86**	**110.10**
***In vitro* conservation**		**29,341**	**49,300**	**139,888**	**14.74**	**15.72**	**74.76**
Storage	6,080	3,282	6,160	9,358	0.54	1.01	1.54
Subculturing	4,290	11,809	29,931	47,801	2.75	6.98	11.14
Disease indexation	1,200	13,101	4,403	64,323	10.92	3.67	53.60
Dissemination	2,170	1,149	8,806	18,406	0.53	4.06	8.48
Cryoconservation		**3,019**	**9,674**	**25,918**	**2.76**	**9.95**	**30.35**
Storage	2,000	744	1,218	501	0.37	0.61	0.25
Viability testing	300	51	382	2,006	0.17	1.27	6.69
Cryo-operation	1,000	2,224	8,074	23,411	2.22	8.07	23.41
Field genebank		**514**	**11,474**	**26,079**	**0.10**	**2.19**	**4.99**
Field maintenance	5,230	514	11,474	26,079	0.10	2.19	4.99
Bean		**67,436**	**80,688**	**233,039**	**10.61**	**15.65**	**46.39**
Medium-term storage	31,880	12,224	7,599	6,509	0.38	0.24	0.20
Long-term storage	12,700	8,060	2,906	3,922	0.63	0.23	0.31
Viability testing	5,000	1,584	5,225	12,701	0.32	1.05	2.54
Regeneration	5,220	34,737	35,468	149,273	6.65	6.79	28.60
Dissemination	4,250	10,471	27,695	58,544	2.46	6.52	13.78
Duplication	2,180	360	1,795	2,090	0.17	0.82	0.96
Forage		**49,242**	**53,412**	**152,766**	**32.76**	**35.34**	**72.69**
Medium-term storage	18,180	7,636	6,687	5,090	0.42	0.37	0.28
Long-term storage	7,390	4,841	2,442	2,709	0.66	0.33	0.37
Viability testing	1,000	3,858	3,712	10,713	3.86	3.71	10.71
Regeneration	3,160	22,076	29,306	122,524	6.99	9.27	38.77
Dissemination	520	10,831	11,265	11,730	20.83	21.66	22.56
Total cost		**149,552**	**204,548**	**577,690**			

Note: As of 2000, 6080 accessions of cassava (5730 FAO-designated and 290 non-designated accessions) were conserved. For *in vitro* conservation, genebank management costs are allocated as follows for the ICRISAT genebank: storage (10%), subculturing (60%), disease indexation (10%) and dissemination (20%); for cryoconservation, genebank management costs are allocated as follows: storage (10%), viability testing (10%) and operation (80%). For bean and forage, management costs are allocated according to the following percentages: medium-term storage (15%), long-term storage (5%), viability testing (10%), regeneration (40%), duplication (5%) and dissemination (25%). There was no duplication for forages during the sample period, so the cost for beans was used as a proxy.

[a]Total quasi-fixed costs include the costs of senior scientific and technical staff.

$931,790 (Table 7.7). Figure 7.1 shows that almost two-thirds of this annual expense involves variable costs, such as labour and non-labour (62%), while less than a quarter of the total cost is related to capital (16%).

Economic costs

Annual average costs

Annual average costs of conserving cassava vary considerably according to the method used to conserve the material. The cost of conserving an existing cassava accession *in vitro*, including storage and annual subculturing, is $10.34, and the corresponding cost for a new accession is as high as $67.61 due to the cost involved in health testing. We estimate the cost of distributing an *in vitro* sample to be $22.88 per accession, which includes the costs of subculturing, packing and shipping. The with- and without-regeneration cost differentials are more significant for cryoconservation: it costs only $0.86 to conserve an accession for a year if it does not require regeneration or viability testing, while the cost jumps to $40.31 if the sample requires regeneration. The cost of conserving accessions in the field genebank at CIAT is estimated as $7.18 per accession per year, making this the cheapest option for conserving cassava germplasm in the short run if regeneration is required (Table 7.8).[10]

The average costs of conserving seed samples at the CIAT genebank for 1 more year are just 54 cents for beans and 70 cents for forages; if regeneration is needed, the costs increase to $20.03 for beans and to $31.93 for forages; and if the accession is newly introduced in the year in question it costs

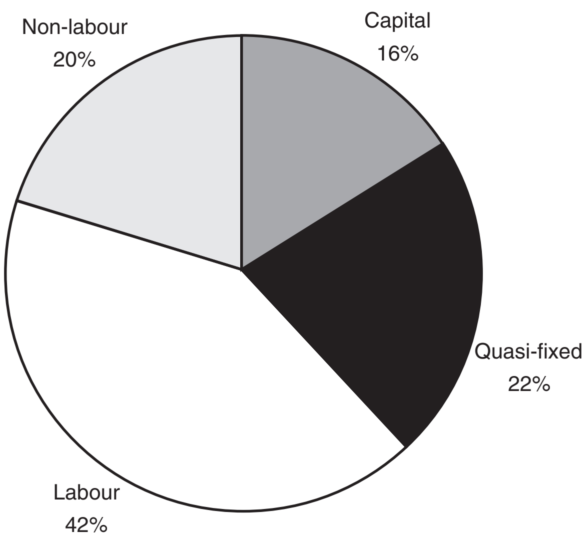

Fig. 7.1. Representative annual costs of maintaining the CIAT genebank holdings. Share of conservation and distribution costs by cost category (US$931,790, 2000 prices).

Table 7.8. Average costs (US$ per accession, 2000 prices) of conserving and distributing a cassava accession for 1 year at the CIAT genebank.

	In vitro		Cryoconservation		
Cost category	Existing accessions	New accessions	Without regeneration	With regeneration	Field genebank
Conservation					
Storage[a]	1.28	1.28	0.86	0.86	7.18
Subculturing[b]	9.06	9.06			
Viability testing				7.96	
Regeneration (cryoconservation)				31.49	
Disease indexation		57.27			
Conservation cost					
In vitro	**10.34**	**67.61**			
Cryoconservation			**0.86**	**40.31**	
Field genebank					**7.18**
Distribution					
Storage	1.28	1.28			
Subculturing	9.06	9.06			
Dissemination	12.54	12.54			
Distribution cost	**22.88**	**22.88**			

[a]Storage costs for the field genebank are the same as the cost of field maintenance.
[b]Storage and subculturing costs for *in vitro* are allocated equally between conservation and distribution.

$25.40 for beans and $48.14 for forages. Similarly, the cost of distributing an accession is $20.73–$40.22 for beans and $44.87–$76.10 for forages depending on whether regeneration is required (Table 7.9).

Average costs in the long run

Under the same baseline assumptions as those used in previous chapters, the average cost of conserving an existing cassava accession in perpetuity is $268.73; for a new accession it is $326.00. A substantial portion of these costs (87% and 72%, respectively) is the cost of subculturing. This suggests that the slow-growth method mentioned earlier (currently being researched to reduce the time required for subculturing) could save considerable conservation costs. The in-perpetuity cost of distributing an accession from the *in vitro* collection is estimated at $307.38, assuming it is disseminated once every 10 years, the contemporary average rate (Table 7.10).

The cost structure of cryoconservation is very different from that of *in vitro* conservation. *In vitro* conservation requires a relatively modest, but frequent, cost of subculturing to maintain the germplasm's viability ($9.06 per accession), while cryoconservation costs $31.49 per accession for regeneration. However, germplasm stored using cryoconservation methods is infrequently regenerated – perhaps only once in every 100 years – whereas subcultured material is regenerated every year, or every other year if the slow-growth method is used. Thus, the in-perpetuity cost of regeneration is only $32.12 under cryoconservation (with 4% interest rate), compared

Table 7.9. Average costs (US$ per accession, 2000 prices) of conserving and distributing a bean or forage accession for 1 year at the CIAT genebank.

Cost category	Existing accessions		New accessions (with regeneration)
	Without regeneration	With regeneration	
Conservation cost			
Bean	**0.54**	**20.03**	**25.40**
Long-term storage	0.54	0.54	0.54
New introduction			
Initial viability testing			3.59
Initial duplication			1.78
Viability testing		1.79	1.79
Regeneration		17.70	17.70
Forage	**0.70**	**31.93**	**48.14**
Long-term storage	0.70	0.70	0.70
New introduction			
Initial viability testing			14.43
Initial duplication			1.78
Viability testing		7.21	7.21
Regeneration		24.02	24.02
Distribution cost			
Bean	**20.73**	**40.22**	
Medium-term storage	0.44	0.44	
Dissemination	20.29	20.29	
Viability testing		1.79	
Regeneration		17.70	
Forage	**44.87**	**76.10**	
Medium-term storage	0.65	0.65	
Dissemination	44.22	44.22	
Viability testing		7.21	
Regeneration		24.02	

with $235.55 for *in vitro* conservation (Table 7.10). Assuming that the viability of germplasm is tested every 20 years, the estimated in-perpetuity cost of cryoconservation increases to $69.11, still substantially lower than the corresponding $268.73 cost of the annually subcultured material.[11] The in-perpetuity, present-value cost of the field genebank is relatively high, at $186.69 per accession, because of recurrent annual planting and harvesting.

As shown above, the average cost of cryoconservation is comparatively high in the short run, but it is the most cost-efficient conservation option in the long run. It should be noted, however, that each conservation method has its own technical and economic pros and cons. Furthermore, conserving material *in vitro* is a prerequisite for storing samples in a cryoconservation environment; thus *in vitro* capabilities must be maintained for newly introduced material even if the option to cryoconserve material is chosen.

Table 7.10. Present values (US$ per accession, 2000 prices) of conserving and distributing a cassava accession in perpetuity at the CIAT genebank.

	In vitro			Cryoconservation			Field genebank		
Cost category	2%	4%	6%	2%	4%	6%	2%	4%	6%
Conservation									
Storage	65.08	33.18	22.54	43.84	22.35	15.19	366.20	186.69	126.85
Subculturing[a]	462.05	235.55	160.06						
Viability testing[b]				24.34	14.64	11.57			
Regeneration[c] (cryoconservation)				36.53	32.12	31.58			
Disease indexation	57.27	57.27	57.27						
Conservation cost									
In vitro									
Existing accession	**527.13**	**268.73**	**182.60**						
New accession	**584.40**	**326.00**	**239.87**						
Cryoconservation				**104.71**	**69.11**	**58.34**			
Field genebank							**366.20**	**186.69**	**126.85**
Distribution									
Storage	65.08	33.18	22.54						
Subculturing	462.05	235.55	160.06						
Dissemination[d]	69.80	38.65	28.40						
Distribution cost	**596.93**	**307.38**	**211.00**						

Note: Some figures in this table were calculated using equations (1) and (2) in Appendix A.
[a]From the time of acquisition, subculturing for *in vitro* occurs every year.
[b]Viability testing for cryoconservation occurs every 20 years.
[c]Regeneration for cryoconservation occurs every 100 years.
[d]Dissemination of an accession occurs every 10 years.

For beans and forages, viability testing is assumed to take place every 10 years for the base collection and every 5 years for the active collection; the regeneration interval is 50 and 25 years, respectively; and an accession is assumed to be disseminated once every 10 years. Using the baseline 4% interest rate, the average cost of conserving an existing bean accession in perpetuity is $20.90; for forages it is $37.36; for a newly acquired accession,

Table 7.11. Present values (US$ per accession, 2000 prices) of conserving and distributing a bean or forage accession in perpetuity at the CIAT genebank.

	Existing accession			New accession		
Cost category	2%	4%	6%	2%	4%	6%
Conservation						
Beans						
Long-term storage	27.42	13.98	9.50	27.42	13.98	9.50
New introduction						
Initial viability testing				3.59	3.59	3.59
Initial duplication				1.78	1.78	1.78
Viability testing	8.19	3.73	2.27	8.19	3.73	2.27
Safety duplication	1.05	0.29	0.10	1.05	0.29	0.10
Regeneration/viability testing (50 years)[a]	10.46	2.90	1.02	28.16	20.59	18.71
Conservation cost	**47.12**	**20.90**	**12.89**	**70.19**	**43.96**	**35.95**
Forages						
Long-term storage	35.54	18.12	12.31	35.54	18.12	12.31
New introduction						
Initial viability testing				14.43	14.43	14.43
Initial duplication				1.78	1.78	1.78
Viability testing	32.94	15.02	9.12	32.94	15.02	9.12
Safety duplication	1.05	0.29	0.10	1.05	0.29	0.10
Regeneration/viability testing (50 years)	14.20	3.93	1.38	14.20	3.93	1.38
Conservation cost	**83.73**	**37.36**	**22.91**	**99.94**	**53.57**	**39.12**
Distribution						
Bean						
Medium-term storage	22.57	11.51	7.82			
Viability testing	17.22	8.27	5.30			
Dissemination[b]	112.95	62.54	45.95			
Regeneration/viability testing (25 years)	17.16	7.72	4.36			
Distribution cost	**169.90**	**90.04**	**63.43**			
Forage						
Medium-term storage	33.04	16.84	11.44			
Viability testing	69.30	33.29	21.33			
Dissemination	246.15	136.30	100.14			
Regeneration/viability testing (25 years)	23.30	10.49	5.92			
Distribution cost	**371.79**	**196.92**	**138.83**			

Note: Some figures in this table were calculated using equations (1) and (2) in Appendix A.
[a]Regeneration costs include germination testing after regeneration; regeneration for distribution commences at the 25th year, and then occurs every 50 years.
[b]Dissemination is assumed to occur every 10 years.

the cost ranges from $43.96 for beans to $53.57 for forages. The costs of distributing an accession – $90.04 for beans and $196.92 for forages – are much higher, given the higher costs of maintaining the active collection and the additional costs of disseminating samples (Table 7.11).

Total costs in the long run

Table 7.12 presents the total costs of maintaining the current collection at the CIAT genebank. If all the cassava accessions (6080 accessions) are conserved *in vitro*, the total conservation cost in perpetuity is $2,366,887, including the capital cost. The corresponding figures for maintaining the complete cassava collection using cryoconservation methods are $655,669, and $1,150,596 for material kept in a field genebank. Taking into account the cost of distributing samples from *in vitro* ($1,898,776) and presuming all the accessions were conserved using all three techniques yields an in-perpetuity cost of $6,071,928 for cassava.[12]

The total cost of conserving and distributing the current collection of bean and forage germplasm in perpetuity is estimated at $3,756,450 for beans and $4,857,797 for forages. Labour and operating costs (designated as non-capital cost in Table 7.12) to conserve the entire holdings of beans and forages in perpetuity amount to $7,687,771, while the corresponding capital cost accounts for only $926,476 (Table 7.12).

Notes

[1]Plants conserved *in vitro* can be maintained free from disease contamination, enabling safe dissemination.

[2]The accession numbers used for our cost estimates were developed in November 2000 and represent estimates of the size of the entire CIAT holdings as of mid-2000. The data in Table 7.1 were compiled in April 2003 and include only FAO-designated cassava and forage material.

[3]All collections are conserved under medium-term conditions. As of 2000, about 40% of the total collection was conserved in the long-term storage room. A few forage species (fewer than 20 accessions) are also maintained in a field genebank because they do not produce enough seed for storage.

[4]In general, conservation of cassava as seeds would allow the conservation of specific genes but not necessarily the range of genotypes found within a given species. For wild species of *Manihot*, however, a cost-effective and successful method is to conserve well-dried botanical seeds in long-term storage because the alleles present in a source population can best be preserved in this way (though sample frequencies may vary in comparison with the original populations).

[5]The tests are the enzyme-linked immunosorbent assay (ELISA) method for cassava common mosaic virus (CCMV) and cassava X virus (CsXV), the grafting method for frog skin disease (FSD) and the polymerase chain reaction (PCR) method for cassava vein mosaic virus (CVMV).

[6]Only a few can be recovered from each plantlet (usually three or four), so several plantlets are needed.

[7]Many research units at CIAT use liquid nitrogen, and there was a proposal to purchase liquid nitrogen-producing equipment and generate it in-house. This equipment

Table 7.12. Total costs of conservation and distribution in perpetuity at the CIAT genebank.

Crop	Number of accessions	Per-accession cost (US$ per accession, 2000 prices)			Total cost (US$, 2000 prices)		
		Conservation	Distribution	Total	Conservation	Distribution	Total
Cassava	6,080	**524.53**	**307.38**	**831.91**	**4,173,152**	**1,898,776**	**6,071,928**
In vitro		**268.73**	**307.38**	**576.11**	**2,366,887**	**1,898,776**	**4,265,663**
Non-capital		268.73	307.38	576.11	1,633,890	1,868,896	3,502,786
Capital		–	–	–	732,997	29,880	762,877
Cryoconservation		**69.11**	–	**69.11**	**655,669**	–	**655,669**
Non-capital		69.11	–	69.11	420,208	–	420,208
Capital		–	–	–	235,461	–	235,461
Field genebank		**186.69**	–	**186.69**	**1,150,596**	–	**1,150,596**
Non-capital		186.69	–	186.69	1,135,063	–	1,135,063
Capital		–	–	–	15,533	–	15,533
Bean	30,900	**25.19**	**96.38**	**121.57**	**778,260**	**2,978,190**	**3,756,450**
Non-capital		20.90	90.05	110.95	645,842	2,782,500	3,428,342
Capital		4.29	6.33	10.62	132,418	195,690	328,108
Forage	18,180	**43.61**	**223.60**	**267.21**	**792,791**	**4,065,006**	**4,857,797**
Non-capital		37.37	196.93	234.30	679,307	3,580,122	4,259,429
Capital		6.24	26.67	32.91	113,484	484,884	598,368
All crops	**55,160**	**593.33**	**627.36**	**1,220.69**	**5,744,203**	**8,941,972**	**14,686,175**

would reduce the cost of liquid nitrogen dramatically. Currently, the cost includes transportation from the local vendor and insurance.

[8]Now, all the accessions are planted in April and harvested in February of the following year.

[9]The site at Tenerife, which has been used to regenerate about 4000 bean accessions annually, was abandoned in mid-2000 for security reasons.

[10]CIAT maintains its field genebank for conservation and other (e.g. crop breeding and characterization) purposes. Consequently our per-accession estimates of the respective conservation costs are likely to be lower than if the field facilities were operated solely for conservation purposes (i.e. they reflect some savings because of economies of scale and scope).

[11]Because cryoconservation is still experimental, CIAT initially plans to test the viability of cryoconserved accessions every 5 years, but with an expectation that the viability testing interval will lengthen to 20 years.

[12]Another option is to conserve the cassava collection *in vitro* for medium-term storage and cryoconserve the material designated for long-term storage. Using this protocol, the total cost of conserving CIAT's current cassava holdings in perpetuity would be $4,921,333.