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COSTING THE *EX SITU* CONSERVATION OF GENETIC RESOURCES: MAIZE AND WHEAT AT CIMMYT

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ABSTRACT

Worldwide, the number of genebanks and the amount of seed stored in them has increased substantially over the past few decades. Most attention is focused on the likely benefits from conservation, but conserving germplasm involves costs whose nature and magnitude are largely unknown. Because more resources spent on conserving germplasm often means less spent on characterizing the collection or using the saved seeds in crop-improvement research, knowledge of the costs of germplasm conservation has important, possibly long run, R&D management, policy, and food-security consequences. Moreover, these costs place a lower bound on the benefits deemed likely to justify the expense of saving this seed.

In this paper we compile and use a set of cost data for wheat and maize stored in the CIMMYT genebank to address a number of questions. What is the cost of storing an accession of either crop for one more year, or, equivalently what is the benefit in terms of cost savings from eliminating duplicate accessions from the genebank? Relatedly, what is the cost from introducing a new accession into the genebank, given the decision to store it is revisited after one year? Does it make economic sense for CIMMYT to discard accessions that may be available elsewhere? As an extension of this line of inquiry it is possible to value the benefits from either consolidating genebanks or at least networking existing banks to reduce or eliminate duplicate holdings not needed for backup safety purposes. We present estimates of the size and scale economies evident in the CIMMYT operation as a basis for assessing the economics of consolidation.

Genebanks represent a commitment to conserve seeds for the very long-run. In this study we report on these long-run costs for the CIMMYT genebank—costs that are sensitive to the interest rate used and the protocols for periodically replenishing accessions that are shared with others or regenerating accessions whose viability gradually diminishes with age. We estimate that under baseline assumptions the present value of conserving the existing accessions in perpetuity at CIMMYT is $7.95 million—$4.42 million for storing the 17,000 maize accessions and $3.53 million for the 123,000 wheat samples. Maintaining the current level of effort to disseminate accessions free-of-charge to those who request them would cost an additional $3.07 million in perpetuity. Contrary to popular perception, conserving seeds (like R&D more generally) is much more of a labor or human-, not physical-capital intensive, undertaking. On an annualized basis, physical capital represents 22 percent of the costs of conservation, labor about 60 percent, with operational costs making up the remaining 18 percent. Much of the labor takes the form of a quasi-fixed input—the human capital embodied in senior scientific and technical genebank staff is a lumpy labor input that is not especially sensitive to changes in the size of the holding.

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1. INTRODUCTION

The technology for storing germplasm in modern, long-term, *ex situ* conservation facilities has improved dramatically over the past several decades, and the number of such facilities has expanded greatly. But the focus on improved performance and capacity expansion has left key management-relevant questions neglected. These include:

- What should be conserved?
- How much should be conserved?
- Where should it be stored and regenerated when required?
- How is conserved germplasm used?
- How should it be used?

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These questions all have economic dimensions, and answering them with any precision is problematic.[1] It includes estimating the marginal benefits of conserving each type of genebank accession, but quantifying the benefits of such conservation is particularly difficult. One reason is that attributing an appropriate part of the agronomic improvement in a plant to the use of conserved germplasm is a daunting, if not intractable, inferential challenge (see, for example, Pardey et al. 1996). Second, many modern genebank facilities are so new that insufficient time has elapsed for breeders to establish a useable time series of realized gains attributable to their establishment.

Beyond immediate agronomic values that are in principle estimable, conservation of crop genetic diversity yields an option value for responding to currently unidentified future demands. It also offers, to some people at least, an “existence value;” some people will report they are better off for knowing crop biodiversity is being conserved rather than lost, quite apart from the production role of the germplasm involved. Though methodologies are available to assess these values, empirical results are bound to be very imprecise.

A complete economic approach to the above questions would weigh the benefits of conservation against the costs involved to arrive at a net benefit assessment. On the benefit side, the empirical difficulties imply that any acceptable evaluation would involve significant expense in time, talent, and money. The cost side, on the other hand, predominantly involves items that are at least estimable in principle from historical data

[1] Frankel, Brown, and Burdon (1995) offer some technical (noneconomic) perspectives on many of these same issues.

of existing genebank and related operations. If the total and marginal costs of the genebanking operations are estimated, and are judged to be less than any reasonable lower-bound estimate of the corresponding benefits, then it may not be necessary to confront the challenge of estimating the latter more precisely to justify the existence and size of the genebank.

The foregoing rationale motivates this study of the cost of *ex situ* conservation. The example we consider is the genebank facility at Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), the International Maize and Wheat Improvement Center headquartered at El Batan, Mexico. The CIMMYT case offers an instructive opportunity for comparing the management of two different types of germplasm—maize and wheat—by two different crop programs housed under the same roof.

Because the germplasm banks are inextricably linked to the rest of the CIMMYT crop-improvement programs, it is difficult to identify precisely the costs of the bank itself. In effect, this study will look at the basic activities required to conserve an *ex situ* collection—including the storage of the germplasm, regeneration of accessions, and data management aspects—as well as the seed health and other activities related to the introduction of new accessions and the dissemination of conserved material to plant pathologists, entomologists, breeders, and other genebank facilities. Other areas of germplasm management that are also discussed but not explicitly considered here are the cost of collection, comprehensive evaluation, and utilization in breeding. We use methods that are designed to furnish upper bounds on the relevant cost concepts as conservative thresholds for the benefits needed to justify the gene-banking operation as a whole, as well as conservation of additional accessions.

2. HISTORY OF THE CIMMYT COLLECTIONS

2.1 THE MAIZE COLLECTION

The CIMMYT maize holdings are based on a collection first assembled as part of the joint Rockefeller Foundation-Government of Mexico program initiated in 1943 to improve the productivity of basic food crops in Mexico.[2] An Office of Special Studies (OSS) was formed within the Mexican Ministry of Agriculture to carry out this program of research, which paired overseas (mainly United States) scientists with scientists from Mexico. In 1947, the Department of Experiment Stations was reorganized to form the Institute of Agricultural Research, which in 1961 merged with the Office of Special Studies to become Mexico's first national agricultural research agency, the Instituto Nacional de Investigaciones Agrícolas (INIA) under the auspices of the Ministry of Agriculture.[3]

A Mexican seed bank was established in 1944 by the OSS and by 1947 its maize collection had grown to more than 2,000 samples (mainly landraces).[4] The publication of characterization and evaluation details about these landraces (Welhausen et al. 1952)

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[2] Fitzgerald (1986) describes some of the details of the Mexican program in its formative years.

[3] See Venezian and Gamble (1969) for more details on the early institutional development of the Mexican agricultural research system.

[4] As described by Wellhausen (1988, p. 26), "Seeds of collections made in 1943-45 were first stored at room temperature in a temporary adobe building constructed at Chapingo (El Horno), pending the completion of a more permanent refrigerated storage facilities in 1946. Temperature in this building varied from a low of about 15 °C in winter to a high of about 22 °C in summer. Seed stored under these conditions in capped jars at 8 % moisture (air-dried) maintained its viability for about five years."

sparked the formation of a U.S. National Academy of Sciences (NAS)–National Research Council (NRC) initiative in the early 1950s to further collect and preserve indigenous strains of maize throughout Latin America, as well as to collect material from the United States and Canada. The NAS–NRC effort assembled nearly 11,000 samples. Seeds from Mexico, Central America, and the Caribbean region were stored in the Mexican genebank in Chapingo maintained by OSS and continued to be operated by them until 1959. Original varieties of local maize were also stored in Brazil (Piracicaba) and Colombia (Medellen). Small samples of each collection were housed in backup storage facilities in Glenn Dale, Maryland, and later shipped to the National Seed Storage Laboratory (NSSL) in Fort Collins, Colorado, (NAS-NRC 1954 and 1955).

The closure of the OSS, and the subsequent transfer of its maize holdings to the newly formed national research agency (known by its spanish acronym, INIA), coincided with the launch of the Inter-American Maize Program. This program, a joint venture between the Government of Mexico and the Rockefeller Foundation, regenerated and duplicated the entire INIA collection. The program also regenerated part of the Latin American NAS–NRC collection, which was shipped from the NSSL facility in Fort Collins to Mexico and formed the basis of the CIMMYT maize collection.

CIMMYT participated in various maize collection expeditions in Mexico and the Andean region in the late 1960s. Maize collection expeditions sponsored by the International Board for Plant Genetic Resources (now the International Plant Genetic Resources Institute, IPGRI) throughout Latin America, southern Europe, and Asia got underway in 1975 (Reid and Konopka 1988). The Latin American samples from the IPGRI expeditions were deposited at NSSL; parts of the samples from Morocco, Uruguay, and Brazil were stored at CIMMYT. This IPGRI-related work continued through to 1985, by which time a further 1,500 samples had been added to the CIMMYT collection.

The CIMMYT holdings grew at a more rapid rate thereafter, to its present size of more than 17,000 accessions. This accelerated growth was largely a consequence of the Special Cooperative Agreement (SCA) to regenerate Latin American maize germplasm (USAID/USDA–NSSL and CIMMYT). The cooperative regeneration agreement involved 13 countries in 1992-96. By 1996 a total of 6,736 accessions had been regenerated, and backup samples were shipped to NSSL and CIMMYT for long-term storage. CIMMYT also recorded characterization data for the regenerated samples (Taba and Eberhart 1997). A second phase of the SCA regeneration project is currently under way with USDA–NSSL special project funding. In addition, the Latin American Maize Project (LAMP) funded by Pioneer Hi-Bred International and coordinated by USDA during 1987-96, evaluated about 12,000 Latin American accessions (Salhuana et al. 1998). CIMMYT used the evaluation data to obtain a core subset of 20 percent of the accessions to represent phenotypic diversity using multivariate classification analysis (Franco et al. 1998). The core subset is designated for further characterization by molecular fingerprinting and cross-breeding methods. Research to develop core subsets of CIMMYT bank accessions is also being pursued (Taba et al. 1998). Another major source of new genebank accessions is the CIMMYT maize-breeding program, from which samples of elite experimental varieties, source populations, and inbred lines are obtained.

Aside from *Zea mays* (cultivated maize), the CIMMYT collection includes two other species important to maize breeders. During 1989-92, CIMMYT collected 2,500 samples as cuttings from 158 populations of the perennial genus *Tripsacum* located throughout Mexico. About 150 of these samples have been established in a living base collection at the CIMMYT field station in Tlaltizapan, Morelos. This material is being used in a joint ORSTROM (France)–CIMMYT undertaking that applies new molecular tools to study the transfer of apomixis from *Tripsacum* to *Zea* maize (Berthaud et al. 1997).[5] CIMMYT also maintains a collection of *Teosinte*, the closest wild relative of maize. Because *Teosinte* outcrosses with maize or other *Teosinte* accessions, multiplication and preservation of these plants must occur in isolation from experimental plots, using open pollination among more than 100 plants if possible (Taba 1997). CIMMYT regenerates about four to five *Teosinte* accessions annually (some accessions dating to collections made in the 1960s), wherein the plants are sown in containers and tended by hand, a labor intensive operation. Since the mid-1980s, CIMMYT has also collaborated with the Instiuto Nacional de Investigaciones Forestales, Agícolas y Pecuaris (INIFAP) and the Instituto de Ciencia y Tecnología de Agrícola (ICTA) to periodically monitor wild populations of *Teosinte in situ* at various mid- to high-altitude

[5] Apomixis is a naturally occurring method of plant reproduction resulting in offspring that is genetically identical to the mother plant. It has the potential to revolutionize plant breeding, enabling any desired variety, including hybrids, to breed true. Thus, saved hybrid seed can be replanted by farmers with no change in the genetic makeup of the plant.

sites throughout Mexico and Guatemala. Table 1 summarizes the evolution and current status of the CIMMYT maize collection.[6]

2.2 THE WHEAT COLLECTION

During the late 1940s and early 1950s, Norman Borlaug—at that time a plant pathologist working in Mexico on the OSS team—assembled some 4,000 to 5,000 samples of wheat landraces from various regions of Mexico to assist in the OSS breeding program. This collection was classified into morphological types by a close collaborator of Borlaug's, Burt Bayles, from Oregon State University. During this time Bayles died unexpectedly from a heart attack at the Athens airport. Lacking the time and resources to work further with the collection and the facilities to store it properly, Borlaug selected representative samples of each morphotype and shipped them to the United States Department of Agriculture (USDA) Small Grains Collection, which is now housed at Aberdeen, Idaho. Borlaug's original Mexican collection was kept at ambient temperature and was eventually lost due to improper storage facilities.[7]

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[6] According to FAO (1996) estimates, the CIMMYT wheat collection is currently the world's largest, consolidated *ex situ* collection, and the institute's maize collection ranks fifth in the world based on the size of its holdings.

[7] Norman Borlaug, personal communication.

Table 1 CIMMYT genebank holdings, 1970-97

Crop/Type of accession	1970	1980[a]	1990	1997	Origin of 1997 holdings[c] From CIMMYT breeding program	Others
		(number of accessions)			*(percentage)*	
Wheat collection						
Bread wheat	na	4,505	42,881	71,171	60	40
Durum wheat	na	2,140	11,689	15,490	60	40
Triticale	na	2,240	8,576	15,200	85	15
Barley	na	2,096	7,918	9,084	75	25
Rye	na	-	33	202	25	75
Primitive and wild	na	-	3,934	11,794	0	100
Total	**na**	**10,981**	**75,031**	**122,941**	**-**	**-**
Maize collection						
Zea mays	4,612	9,869	10,364	17,000	4	96
Tripsacum	7	39[b]	39[b]	181[b]	100	0
Teosinte	36	124	130	162	100	0
Total	**4,655**	**10,032**	**10,533**	**17,343**	**-**	**-**

Source*:* FAO (1996) and CIMMYT genebank data files.
[a] Wheat data for 1980 are estimates.
[b] Additional collections are held by CIMMYT, but not formally as part of the bank inventory.
[c] Wheat data are approximate shares.

CIMMYT's present wheat collection was begun in about 1968 by the head of CIMMYT's international nurseries, Maximino Alcala, under the direction of Borlaug. Throughout the 1970s CIMMYT's wheat holdings were essentially a working collection, preserving the parental material used in, and the advanced lines coming from, the breeding program, including the material distributed through the international nursery system. There was no active acquisition program, nor any systematic efforts to regenerate the holdings.

Beginning in the mid-1980s, the growth in the wheat collection accelerated as a consequence of the increased political attention paid to (and hence resources made available for) the collection and conservation of plant genetic resources. From 1987 to 1997, the collection increased from 40,000 to 123,000 lines. The current wheat collection is a mixture of advanced breeding lines and parental germplasm from the CIMMYT breeding programs, landrace collections from various regions of the world (principally Turkey, Pakistan, Iran, and Mexico), and material provided from the collections or breeding programs of other research agencies in other countries (especially North America, Japan, Denmark, and the United Kingdom). The founding CIMMYT wheat collection contained mainly bread wheats, and was subsequently diversified through the addition of durum wheats, barley, and triticale. The collection now consists of wheats at all stages of enhancement, from various wild and weedy species, through landraces (cultivated varieties often collected from farmers' fields), obsolete wheat cultivars, to elite commercial cultivars.

The acquisition of varieties held in other *ex situ* collections is a significant means of growth in the collection. An example is a joint University of California, Davis–

CIMMYT project conducted during 1988-89 that rescued more than 3,000 triticale lines (i.e., wheat-rye crosses) from the collections of three prominent North American triticale breeders (Furman et al. 1997). Every year the collection also grows by the addition of advanced breeding lines from CIMMYT's crop-improvement program. Prominent among these are the sets of advanced wheat breeding lines (and improved barley varieties)[8] released for trials and evaluation around the world in CIMMYT's International Nurseries program.

In addition, field collection expeditions are undertaken by the CIMMYT genebank staff to acquire germplasm that may be endangered, deemed under-represented in the existing collection (or *ex situ* collections more generally), or of special interest for its breeding potential. During the period 1992-97, CIMMYT added about 10,000 rye and barley accessions (from about 300 locations throughout Mexico) to its holdings. These collection expeditions involved working with Mexican colleagues to assemble local landraces as part of a project supported by CONABIO, the Mexican Biodiversity and Genetic Resource Utilization Program (Skovmand et al. 1997). This material is now being characterized by CIMMYT, and a complete set of the collection has been repatriated to the national program.

The CONABIO project involved a modest additional cost for CIMMYT, around $20,000 of field expenses in addition to CIMMYT staff time. In contrast, a collection trip jointly undertaken by Agriculture Canada, ICARDA, and CIMMYT to Tibet in 1989-

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[8] The global CGIAR mandate for barley was transferred from CIMMYT to ICARDA in 1984 (CIMMYT 1985). Barley improvement research continues at CIMMYT under a collaborative arrangement with ICARDA, whereby an ICARDA barley breeder is stationed at CIMMYT.

90 cost $40,000 (of which the CIMMYT share was $4,000 to cover travel and related expenses, but not staff time). Accessions also continue to be added to the CIMMYT collection that duplicate endangered materials held in other collections. For example, there is a project presently underway to regenerate over 7,000 accessions from Iran; a two-year undertaking costing around $20,000 in travel and field costs. Table 1 summarizes the past changes and current status of the number and type of wheat accessions held at CIMMYT.

2.3 FACILITIES FOR STORING GERMPLASM

1966 to 1995

CIMMYT's early operations were geared almost exclusively to improving wheat and maize yields (or, more generally, increasing crop productivity) based largely on the development of improved varieties. The institute's germplasm holdings reflected that crop-breeding focus.

From 1966 to 1971, the CIMMYT maize collection (developed by regenerating material as part of the Inter-American Maize Program) was housed in refrigerated storage facilities in the basement of the soil science building at the National School of Agriculture, Chapingo. In 1971 a new, seed-storage facility was completed at CIMMYT in El Batan, Texcoco and the collection was subsequently transferred to it. The facility consisted of two, 145 cubic-meter, refrigerated chambers held at 0°C, but in 1984 was refitted to provide one chamber for the long-term storage of a base maize collection held at -18°C. The other chamber was retained for an active maize collection. By the late 1980s, the storage space set aside for the active collection was almost filled to capacity (10,920 maize accessions in 1988). The base collection vault was not full at that time, but it was necessary to store seed for distribution coming from the maize regeneration activities in a section of the medium-term storage facility used by the wheat program, and that space was now needed for storing the growing collection of wheat.

CIMMYT's wheat holdings were initially stored in small, paper packets held in freezer chests. In 1981 the wheat collection was moved to a newly constructed 1,500 square meter facility with four refrigerated chambers. Two chambers, with a combined capacity of 90,000 accessions, were maintained at 4-5°C for an active collection of germplasm, and two larger chambers, with a combined capacity of 180,000 accessions, were kept at about -2°C for medium-term storage of a base collection of CIMMYT's research products.[9] However, during the 1980s, CIMMYT's objectives gradually broadened to include germplasm conservation (specifically the development and maintenance of a comprehensive bread-wheat and triticale collection), and it became necessary to develop a suitable low-temperature, low-moisture facility to house this new base collection over the longer term. Expanding CIMMYT's storage capacity also enabled the institute to provide backup storage facilities for the ICARDA wheat collection.

Post-1995

In October 1995, construction of a new genebank facility financed by the Japanese government was commenced. The main construction phase was completed by May 1996 and refitting the ancillary offices was completed a few months later. Beginning in mid-1996, CIMMYT staff gradually began transferring maize and wheat seeds into the new facility. During this process the maize collection was checked for consistency with the genebank records and repacked into new containers in readiness for storage. Approximately 40,000 wheat accessions obtained from or regenerated in Karnal bunt-free areas were directly moved to the new facility. The process of regenerating the remaining 80,000 wheat accession began in 1996 and is expected to be completed by about 2002. For the first time in CIMMYT's history, the maize and wheat collections were consolidated into a single facility, with advanced technology for medium- and long-term storage.

The main structure of the new genebank facility consists of a two-storey, fortified-concrete bunker, built to withstand most conceivable natural or other disasters. The climate is controlled to precise temperature and humidity specifications, and the facility is equipped with alarms, security measures, and a backup power supply. The upper (ground) level of the storage rooms house the active collection, held at just below freezing point (-3°C) and 25 to 30 percent relative humidity. This constitutes the "working" part of the bank, from which seed requests by CIMMYT and other scientists are filled. The lower (below-ground) level consists of the base collection stored at -18°C, primarily for long-term storage. The seeds are stored on movable shelves to optimize use of the available space. Barcode labels are being applied to all the samples in the maize collection to facilitate the management of seed packs for distribution and inventory, but not at present to the wheat samples because of budget limitations.

The size of the seeds is an important source of distinction between the maize and wheat holdings, and is a distinction that has significant management and cost implications. A stored sample of wheat at CIMMYT is 250 grams in the working

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[9] At this temperature, acceptable seed viability is maintained for 40 to 50 years.

collection (about 7,000 seeds), and 100 grams in the base holdings (around 3,000 seeds). A working sample of maize is 3 kilograms (from 6,000 to 10,000 seeds) and a base-collection sample is about 1 to 1.5 kilograms (about 2,000 to 5,000 seeds). Wheat accessions are stored in aluminum-laminated bags about the size of a one-pound bag of coffee, while maize accessions are stored in one-gallon plastic containers in the active collection and laminated bags in the long-term collection. The new facility allocates 240 cubic meters of both medium- and long-term storage space to each program, sufficient to store 390,000 wheat accessions and 67,000 maize accessions in the long-term collection. If present rates of growth in the size of the respective collections persist, it will take 53 years to fill the space allocated to wheat and 50 years to fill the space set aside for maize.[10]

[10] These time-to-capacity calculations were based on projecting forward contemporary rates of growth in the numbers of maize and wheat accessions (about 1,000 and 5,000 per annum respectively).

3. THE SIMPLE ECONOMICS OF GENEBANKING

One surely narrow, but nevertheless instructive, approach to costing a genebank is to place the facility and the operations that surround it in a production economics framework. Inputs such as labor, land, buildings, energy, and acquired seeds are used to produce stored seeds and the information that accompanies them, and to disseminate seeds to breeders and others at CIMMYT and elsewhere. Properly stored seeds are options for genetic resources that can be exercised (repeatedly, if necessary) in future years.

Using the concepts and estimation procedures encompassed by production economics, it is useful to break down total costs into their variable, capital (or, more meaningfully, durable), and quasi-capital components and, relatedly, to calculate average and marginal costs.[11] This makes it possible to investigate the magnitude of possible economies of scale or size, and scope. Economies of scale or size, loosely speaking, refer to reductions in the unit costs of production that come with increases in the size of the operation (where "output" is in the form of stored or shipped seeds). The phenomenon reflects factors such as the decreasing relation of surface area to volume of the refrigerated facility, and specialization and the appropriate division of labor. Larger operations mean that comparatively well-paid geneticists or agronomists can be fully employed managing the genebank, rather than spending significant amounts of their time

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[11] Average annual storage costs can be calculated as the *total* costs of storage (in a given year) divided by the number of accessions in a collection. In this context, marginal costs are the *additional* costs (increase in total costs) incurred by adding an additional accession to the existing collection.

at less productive tasks such as sorting and classifying seed—tasks that can be carried out by less expensive technicians or temporary workers. Economies of scale or size are further exploited when the genebank facility is large enough to have and efficiently use other lumpy fixed factors—such as physical infrastructure and scientific expertise—as well as variable inputs such as hired labor and chemicals.

Economies of scope are cost savings resulting from diversifying the genebank operation, wherein inputs can be shared across different aspects of the operation.[12] Input sharing can also extend beyond the genebank. CIMMYT's genebank has ready access to field operations and maintenance crews, seed-health staff and facilities, and various other services (e.g., fundraising and management, publications, and computer support) conducted as part of the center's primary crop improvement mission. Thus, consolidating the wheat and maize collection in a shared facility run as part of a broader crop-research operation offers the prospects of significant cost savings compared with maintaining each crop collection in separate, geographically disbursed facilities.

As a practical matter, we identified three classes of costs: those that were sensitive to the scale of the operation (treated as variable costs), those that were not scale sensitive (fixed or capital costs), and a group of costs that were neither fixed nor variable, but lumpy nonetheless (quasi-fixed or quasi-capital costs). Some per-unit costs varied according to the size of the genebank facility; others varied according to the number of accessions stored in the genebank, which is related to but different from the size of the facility. Per-unit costs also varied according to the number of accessions processed (i.e.,

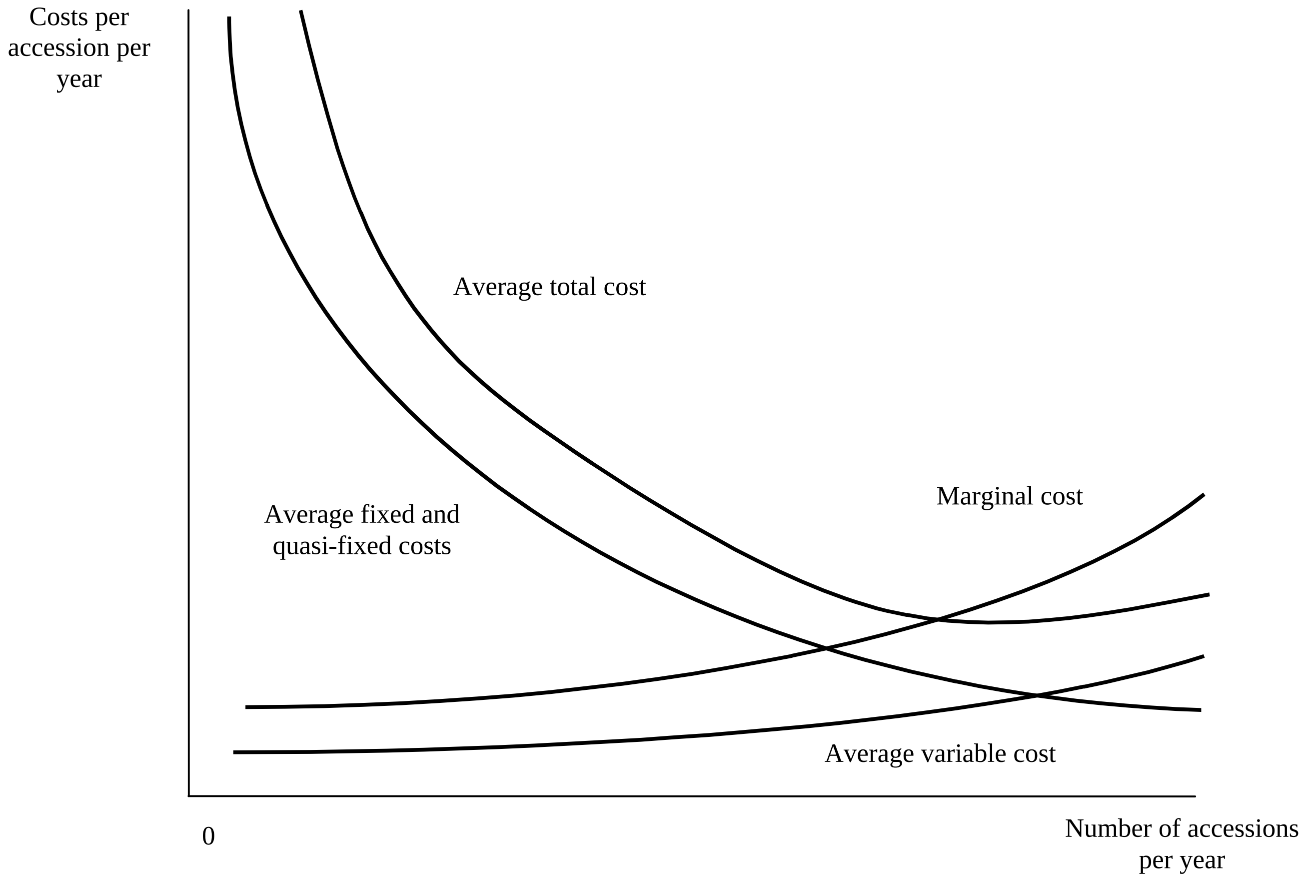
[12] Bailey and Friedlaender (1982) provide a rigorous yet intuitive review of economies of scope concepts. See Baumol, Panzar, and Willig (1988) for a more complete treatment of the topic.

the throughput) for germination testing, regeneration, and seed-health activities. The amount of throughput is linked to, but not directly determined by, the number of accessions held. It also depends on the various seed-management “protocols” that are in place, which are themselves affected by the specifics of each crop and the history of the operation. Finally, some elements of the cost profiles are sensitive to the number of accessions disseminated in a given year: again these costs are related to, but not necessarily determined by, the size of the genebank holding and also vary with the size and destination of the seed shipments.[13]

Figure 1 shows the typical changes in average and marginal costs to changes in the amount of output (for example, the number of stored seeds). Average fixed or quasi-fixed costs generally decline as output increases—as when a given fixed cost, such as the cost of the genebank facility, is charged against a greater amount of output, such as more stored seeds. Marginal costs are the addition to total costs from the addition of the last unit of output—commonly marginal costs eventually increase due to the law of diminishing marginal returns. In Figure 1 the number of accessions could equally refer to the number of accessions stored, regenerated, or disseminated in any particular year.

[13] This is a service function, whose costs are beyond the direct control of the genebank managers, however, who pays for seed-dissemination services is a decision made by CIMMYT and its genebank mangers. The present practice is for CIMMYT to bear all the costs of disseminating such seed, irrespective of who receives it and how much is sent.

Figure 1 Average and marginal cost curves for conserving seed



Note: The marginal cost equals the average total costs when the average total cost is at a minimum.

Costs are also affected by the allocative efficiencies of input use. As the relative prices of inputs such as labor, capital, and chemicals change, so should the mix of those inputs in the storage and distribution of seed. The sensitivity of the mix of inputs to changes in the relative prices of inputs is in turn dependent on the degree of substitutability and complementarity of the respective inputs. An increase in the price of labor over time, for instance, ought to spur a substitution of other inputs for labor—for example, electronic data processing, or improved refrigeration equipment that lengthens the storage life and thereby the regeneration cycle for stored seeds—resulting in a change in the mix of the respective inputs in the total costs of the genebank operations.

Changes in the technology of genebank operations will also affect the optimal amount, mix, and cost of inputs used in the longer run. As international seed distribution becomes quicker and cheaper due to improvements in express mail, it can substitute for duplicate conservation facilities in different regions of the world, if phytosanitary or other barriers are not unduly burdensome. Moreover, the direction and nature of the change in the technologies available may itself be driven by shifts in relative prices (the so-called "induced-innovation model" of technical change, see Hayami and Ruttan 1985). Over the longer run, technical changes will tend to reinforce the magnitude and direction of the shorter-term shifts in input mix brought about by the price changes.

Other cost aspects of a genebank are also amenable to economic evaluation, such as an analysis of the cost of searching in a genebank for particular traits.[14] Lack of adequate evaluation data for genebank materials is a common complaint of potential genebank users. Koo and Wright (1999) have addressed the economics of searching for disease-resistance traits from genebank accessions destined for use in crop-improvement research, and analyzed the timing of the provision of evaluation data.[15] They found that (a) pre-evaluation can be uneconomical for sufficiently rare diseases, (b) the value from pre-evaluation is greatest for traits with an intermediate rate of occurrence, all else being

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[14] This type of application is somewhat analogous to analysis of a bibliographic search in a library (see, for example, Cooper and DeWath 1976), if the accessions have been adequately characterized with respect to all potential traits.

[15] See also Gollin, Smale, and Skovmand (1998).

equal, and (c) cost decreases that might accrue from advances in biotechnology encourage pre-evaluation. Information on the costs of characterizing and disseminating germplasm along with details of the demand for stored seeds, as provided here, helps optimize the timing and type of genebank materials to be evaluated.

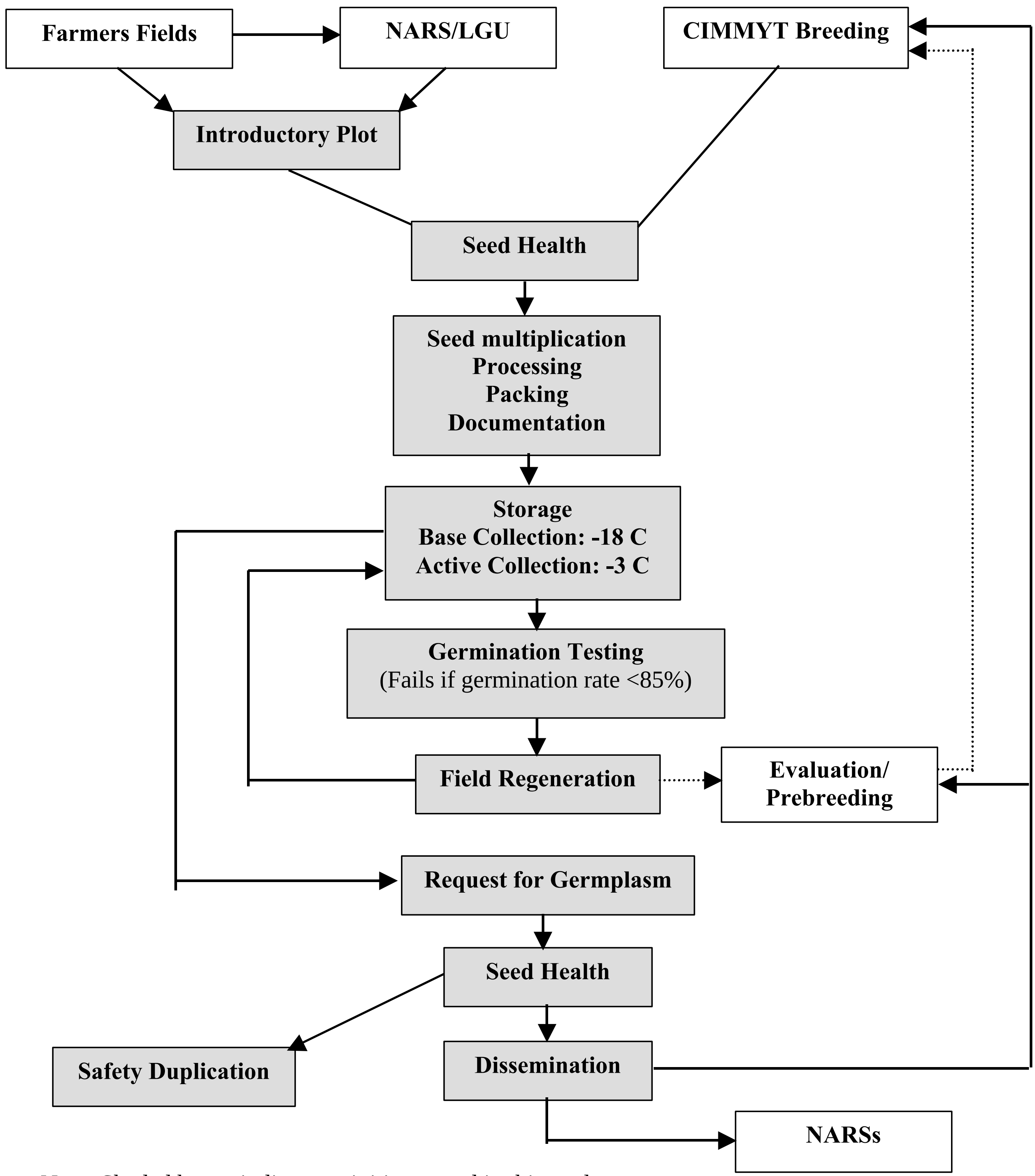
The principal objective of this study is to make a comprehensive costing of CIMMYT's genebank operation and to place those costs in an economic framework as a basis for thinking through various policy aspects related to the management of an *ex situ* genebank for thinking through various policy aspects related to the management of an *ex situ* genebank. This costing study also serves as a pilot case, enabling other genebank operations in the CGIAR (and elsewhere) to undertake a similar exercise as a means of developing meaningfully comparable cost estimates.

4. COSTING THE CIMMYT GENEBANK

One immediate issue was to delineate the nature and scope of the activities to be included in the costing exercise. Figure 2 provides a schema of the activities related to the collection, storage, and use of CIMMYT germplasm. A more comprehensive cost accounting of these germplasm activities would include an analysis of prebreeding, breeding, and crop-performance characteristics derived, for example, from multi-locational yield trials. Here we limit our attention to the introduction of new accessions, storage, regeneration (including germination testing), and seed-dissemination functions carried out as part of, or in conjunction with, the genebank operations.

Budgets overseen by the genebank managers represent only a fraction of the relevant costs, and so there are practical difficulties in tracking down all the relevant data. For instance, at CIMMYT, much of the seed-health costs associated with introducing new accessions to the genebank and shipping material to those who request it are borne by a seed-health unit whose management and budget fall outside the control of the genebank operations. Likewise, much of the genebank's capital and some of the relevant labor and fringe-benefit costs or general overhead expenses are not reflected in the genebank budgets.

Figure 2 Flow chart for *ex situ* germplasm at CIMMYT



Note: Shaded boxes indicate activities costed in this study.

4.1 COST OF DURABLE OR FIXED INPUTS

A breakdown of the capital costs related to the genebank facility and the costs of the equipment used in CIMMYT's genebank operation is provided in Table 2. Complementing the storage facility are rooms for cleaning, sorting, and packing seeds destined for storage at CIMMYT or shipment elsewhere, drying rooms, various work rooms, offices, and a seed laboratory used for germination testing that is shared between the maize and wheat programs. Much of this ancillary space involved renovating existing facilities, rather than erecting entirely new structures. However, they were included here (as are all other relevant capital items) on a current replacement cost, rather than an historical purchase-price basis. The genebank is also serviced by a backup power-generation unit. Much but not all of the backup power unit is dedicated to the genebank; about 80 percent of this cost was allocated to the genebank based on consultation with CIMMYT's plant managers. Costs that were common to storing the maize and wheat collections were allocated equally to each crop.

The building in which the seed holdings are stored is deemed impervious to ready destruction, and is likely to have a long service life; we took it to be 40 years (an estimate that is also in line with general CGIAR depreciation guidelines). The service life of the laboratory equipment and climate-control machinery was assumed variously to be 10 or 15 years. (Much of this equipment is in regular use and subject to wear and tear.)

Table 2 also lists the capital costs associated with seed-health operations, part of which are prorated to the genebank and the rest are appropriately charged to CIMMYT's breeding and international nursery-trials operation that is also serviced by the seed-health

Table 2 Capital input costs

Items	Service life	Common costs	Replacement cost: Wheat-specific costs	Replacement cost: Maize-specific costs	Annualized cost[a]: Wheat-specific costs	Annualized cost[a]: Maize-specific costs
	(years)		*(U.S. dollars)*		*(U.S. dollars per year)*	
Storage	**-**	**-**	**555,529**	**581,169**	**29,653**	**31,467**
Storage facility	40	921,204	460,602	460,602	22,376	22,376
Refrigeration equipment	15	102,914	51,457	51,457	4,450	4,450
Backup power equipment	30	32,821	16,410	16,410	913	913
Seed containers	20	-	27,060	52,700	1,915	3,729
Seed health	**-**	**-**	**16,999**	**16,327**	**1,888**	**1,808**
Seed health facility	40	3,641	1,820	1,820	88	88
Laboratory equipment	10	29,013	14,506	14,506	1,720	1,720
Jacuzzi equipment	10	-	672		80	
Germination testing	**-**	**-**	**12,000**	**6,000**	**1,423**	**711**
Germination chamber	10	-	6,000	6,000	711	711
Vernalizer	10	-	6,000	-	711	-
Regeneration	**-**	**-**	**144,310**	**56,450**	**17,108**	**6,692**
Screenhouse	10	-	112,000	-	13,277	-
Seed cleaning equipment	10	-	7,310	6,450	867	765
Drying chamber	10	-	25,000	50,000	2,964	5,927
General capital inputs	**-**	**-**	**109,834**	**126,979**	**13,238**	**17,658**
Ancillary buildings	40	-	59,548	55,268	2,893	2,685
Vehicles	5	-	44,993	66,418	9,718	14,345
Miscellaneous capital	10	-	5,294	5,294	628	628
Total capital cost	**-**	**-**	**838,672**	**786,926**	**63,310**	**58,337**

[a] Calculated using a 4 percent rate of interest and equation (5) from appendix C.

Note: See appendix A for details

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unit. Some custom-built Jacuzzi equipment is used to clean seed for Karnal bunt (*Tilletia indica*) disease that is shipped overseas as part of CIMMYT's international wheat-nursery program or in response to requests for seed from the genebank, and so its use was prorated accordingly (as discussed in more detail in Section 4.5 below).

While the purchase price of the capital items indicates the investments required to replicate the CIMMYT genebank facilities they are not directly useable for one of our primary purposes, namely to provide a representative *annual* cost of the CIMMYT genebank operations. To estimate an annualized "user cost" of outlays on lumpy capital items such as buildings and equipment, an appropriate and often convenient method is to treat commercial rental rates of the relevant capital items as an estimate of the annual user cost of capital.[16] Absent relevant rental rates, we directly estimated the annualized, present-value cost of capital based on information about the purchase price of each capital item, and assumptions about their respective service lives, and the real rate of interest. We assumed a "one-hoss-shay" depreciation profile; the capital good survives intact until the end of its life, and then disappears all at once. The algebra for these cost calculations is spelled out in appendix C. Annualized capital costs are shown in the two right-hand columns of Table 2, calculated using an interest rate of 4 percent.

[16] Smith (1987) discusses various aspects related to the user cost of capital.

4.2 STORING SEEDS

Maintaining the storage areas in the genebank at a precise, stable, low-temperature, low-moisture (i.e., low relative humidity) regime is a costly exercise.[17] The variable costs of controlling the climate in the CIMMYT facility include the cost of electricity to run the compressors, dehumidifiers, and fans, the costs of maintaining this equipment, and the related costs of operating an emergency backup power plant.[18] Allocating these types of costs to the germplasm facility is difficult as they represent only part of the overall costs involved in operating the institute's physical plant. To arrive at the estimates in Table 3, we directly costed the energy required to maintain the genebank

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[17] CIMMYT headquarters at El Batan, which experiences a seasonally dry and wet tropical highland climate, is more suitable for seed-conservation work than are tropical locations that experience all-year humid conditions.

[18] During the planning stages for the new genebank facility, CIMMYT staff evaluated the feasibility of using liquid nitrogen for long-term storage of the wheat collection, as is done at the U.S. National Seed Storage Laboratory in Fort Collins, Colorado. While it was technically feasible, the option was ruled out on cost grounds; currently, the price of liquid nitrogen in Mexico is about $1.50 per liter, compared with 11 cents per liter in Colorado and well above the break-even point between conventional and cryogenic storage (reportedly about 80 cents per liter for the CIMMYT facility). While cryogenic storage is also technically feasible for maize, it was also costly compared with more conventional alternatives.

Table 3 Storage and related costs

Items	Common variable costs		Wheat-specific costs				Maize-specific costs			
	Labor	Non-labor	Labor	Non-labor	**Subtotal**	**CAPITAL**	Labor	Non-labor	**Subtotal**	**Capital**
				(U.S. dollars per year)						
Storage	**-**	**-**	-	-	**22,404**	**29,653**	**-**	**-**	**22,404**	**31,467**
Temperature control	-	9,926	-	4,963	4,963	-	-	4,963	4,963	-
Humidity control	-	12,818	-	6,409	6,409	-	-	6,409	6,409	-
Alarm and monitoring	3,120	300	1,560	150	1,710	-	1,560	150	1,710	-
Backup power systems	-	125	-	63	63	-	-	63	63	-
Maintenance	10,400	-	5,200	-	5,200	-	5,200	-	5,200	-
Overhead	-	-	-	-	4,060	-	-	-	4,060	-
Information management	**-**	**-**	**-**	**-**	**22,898**	**-**	**-**	**-**	**26,437**	**-**
Maintaining database	-	-	14,280	-	14,280	-	15,528	-	15,528	-
Catalog management	-	-	4,469	-	4,469	-	6,118	-	6,118	-
Overhead			-	-	4,149	-	-	-	4,790	-
General management	**-**	**-**	**-**	**-**	**152,975**	**13,238**	**-**	**-**	**167,816**	**17,658**
Managerial staff	-	-	117,876	-	117,876	-	128,628	-	128,628	-
Computers	-	-	-	5,180	5,180	-	-	6,580	6,580	-
Miscellaneous expenses	-	-	-	2,200	2,200	-	-	2,200	2,200	-
Overhead	-	-	-	-	27,719	-	-	-	30,408	-
Total	**-**	**-**	**-**	**-**	**198,277**	**42,891**	**-**	**-**	**216,657**	**49,125**

Note: See appendix A for details

at its specified climate characteristics, and also estimated the costs of a routine schedule of maintenance on the climate-control equipment and the backup power-generation unit.

The information management costs in Table 3 (and discussed more fully in Section 4.7) represent the costs of creating, updating, and managing the various databases used in the genebank operation. This includes the cost of developing software by CIMMYT's computer- support staff, and so we removed this expense from the general CIMMYT overhead rate to avoid double counting. Table 3 reports a "general management" category, which includes the costs of the genebank managers and technical staff and other general genebank costs. The conservation of genetic resources is a primary rationale for maintaining a genebank separate from the working collections maintained by breeders. From this perspective these expenses represent a rather lumpy set of costs that were prorated among the various conservation and dissemination functions identified in the tables to follow.[19]

4.3 GERMINATION TESTING, REGENERATING, AND MULTIPLYING SEEDS

Stored seeds gradually lose their viability due to aging and so their germination rates must be checked periodically.[20] For wheat, the monitoring and regeneration procedures followed by CIMMYT begin with a germination test when processing introduced seed upon its first entry to the genebank or after its last regeneration. A

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[19] Although we did assign 20 percent of the cost of the genebank managers and principal technical staff to tasks (principally prebreeding, varietal characterization functions) not encompassed by this study.

[20] Even when stored at -18 °C, seed is biologically active, but at a much reduced rate, and thus subject to aging. When seeds are stored at very low temperatures, any associated pests and diseases are inactive.

sample of the seed from each accession is placed in a germination chamber for five days and checked to determine its viability: the accession undergoes a cycle of regeneration if its germination rate falls below 85 percent. If the sample satisfies the viability criterion it is retested at a later time. A computer program is used to sample from the active collection for germination testing, selecting a number of five-year old accessions, more ten-year old seeds, even more twenty-year old seeds, and so on. For now, the maize bank also samples from the active collection for germination testing (beginning with the oldest seed first and working forward), restoring both the active and base collection if the sample fails to germinate satisfactorily. Eventually, this procedure (rotating through the collection from the oldest to the youngest samples) will settle down to a five-year cycle.

A large share of the costs in assessing viability consists of the costs of the labor used to actually carry out the tests, but additional costs (including the costs of establishing and running a suitable laboratory with germination chambers) must be factored in as well. The operational costs associated with germination testing are reported in Table 4, along with the respective annualized capital cost from Table 2.

A principal challenge in managing the regeneration of an *ex situ* collection is to minimize the prospects of genetic drift, thereby maintaining a collection whose genetic makeup matches as closely as possible that of the original holdings. Genetic drift involves the loss of alleles (i.e., genetic content) from one regeneration cycle to another. This drift in genetic content is exacerbated when the number of seeds in a heterogeneous sample shrinks, thereby running the risk that the sample does not appropriately represent the underlying within-sample genetic variation. The frequency of regeneration cycles can be increased to maintain sample size, but the regenerative process itself must be carefully managed to minimize genetic drift. For example, in an open-pollinating crop like maize, if some seeds in an accession have the propensity for higher pollen production than others, hand pollination may be necessary to prevent drift towards the higher-pollen characteristic.[21] Moreover, genetic drift may be exacerbated if samples are regenerated under conditions of soil, chemical inputs, or daylight that differ markedly from the native ecology. This is generally more of a concern when regenerating wild relatives and some landraces specifically adapted to their growing environments than when regenerating more advanced breeding lines and improved cultivars.

As a general rule, the rates of genetic drift are much less for a self-pollinating crop like wheat than for an open-pollinating crop. The CIMMYT wheat bank regenerates an entire accession from its base collection, replacing both the active and base collections when the viability of the active collection falls below threshold levels. Once the base collection has been fully restored in the new genebank facility, the intent is to continue the cycle of germination tests (replacing both the active and base collections as appropriate), while servicing requests for seed from the active collection and replenishing seed when necessary by bulking up samples drawn from the base collection. Accessions are replenished when their sample size falls below a critical level (around 1,500 seeds for

[21] One of the significant advantages of the new genebank is that the long-term storage facility is held at -18°C, which should enable seeds to remain viable for up to 100 years (compared with up to 50 years for accessions stored at -2 °C), thereby reducing the rate of regeneration required due to loss of seed viability.

Table 4 Costs of maintaining genebank accessions

Items	Wheat				Maize			
	Variable costs				Variable costs			
	Labor	Non-labor	**Subtotal**	Capital costs	Labor	Non-labor	**Subtotal**	Capital costs
	(U.S. dollars per year)							
New introduction	**-**	**-**	**6,614**	**1,266**	**-**	**-**	**4,707**	**1,266**
Seed health testing	1,972	2,923	4,895	-	1,343	1,991	3,334	-
Seed handling	520	-	520	-	520	-	520	-
Overhead	-	-	1,198	-	-	-	853	-
(Number of accessions)	-	-	(5,800)	-	-	-	(1,580)	-
Germination testing	**-**	**-**	**3,488**	**1,423**	**-**	**-**	**1,392**	**711**
Germination testing	2,756	100	2,856	-	1,040	100	1,140	-
Overhead	-	-	632	-	-	-	252	-
(Number of accessions)	-	-	(12,000)	-	-	-	(3,400)	-
Regeneration	**-**	**-**	**66,947**	**17,108**	**-**	**-**	**89,457**	**6,692**
Screenhouse	3,692	242	3,934	13,277	-	-	-	-
Fields	18,794	6,111	24,905	-	27,070	15,569	42,639	-
Transport	-	4,018	4,018	-	-	550	550	-
Seed cleaning	7,280	-	7,280	867	9,360	3,500	12,860	765
Seed drying	1,248	8,591	9,839	2,964	2,080	15,020	17,100	5,927
Seed containers	-	4,840	4,840	-	-	98	98	-
Overhead	-	-	12,131	-	-	-	16,210	-
(Number of accessions)	-	-	(22,000)	-	-	-	(650)	-
Dissemination	**-**	**-**	**7,335**	**622**	**-**	**-**	**9,860**	**542**
Seed health testing	582	1,208	1,790	-	336	491	827	-
Packing and shipping	676	2,188	2,864	-	520	5,140	5,660	-
Phytosanitary certification	780	572	1,352	-	520	1,066	1,586	-
Overhead	-	-	1,329	-	-	-	1,787	-
(Number of accessions)	-	-	(14,220)	-	-	-	(3,680)	-
Duplication	**-**	**-**	**7,408**	**-**	**-**	**-**	**4,876**	**-**
Packing and shipping	1,820	4,246	6,066	-	580	3,413	3,993	-
Overhead	-	-	1,342	-	-	-	884	-
(Number of accessions)	-	-	(35,000)	-	-	-	(2,230)	-
Total	**-**	**-**	**91,792**	**20,419**	**-**	**-**	**110,291**	**9,211**

Note: See appendix A for details.

maize and 700 seeds for wheat). For maize this point is reached after about four to five calls on that holding. For wheat, CIMMYT ships about 100 seeds when servicing a request, and so about 65-70 requests can be filled before regeneration is required. This seed dissemination and replenishment strategy significantly lengthens the time between rounds of regeneration.

Wheat accessions are now normally regenerated in a screenhouse at El Batan or in Mexicali.[22] The screenhouse facility enables regeneration to proceed on a year-round basis under controlled and protected conditions, with up to three cycles per year at staggered times to spread the use of labor. In 1996, the sample year for this study, an exceptionally large number of accessions were regenerated to deal with potential Karnal bunt problems when transferring materials from the old to the new storage facility opened that year. Seed samples were first prepared in special plots at the El Batan field stations (and sprayed with fungicides every 10 days to prevent Karnal bunt infestation), then flown to Mexicali, in the state of Baja California Norte, where they were sown out in one-meter rows to scale up the size of the sample to 500 grams.[23] The peak labor

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[22] The Karnal bunt infestation, found in the regeneration fields (and surrounding region) used by the CIMMYT wheat program at Ciudad Obregon, Sonora, prompted the regeneration activities to be relocated from the CIMMYT field station to El Batan in 1987. The introduction plots and screenhouses at El Batan are free of Karnal bunt. The downside of this move is that high-quality seed for storage cannot be produced at El Batan because of the rainfall, which typically occurs during the grain filling period. Seed produced at Sonora maintains an excellent rate of viability over the long term (for example, seed samples multiplied at Sonora in 1980-81 still maintain their viability at greater than 98 percent).

[23] Seed is being multiplied at Mexicali because the screenhouse at El Batan does not have the capacity to regenerate the 60,000 accessions that are being cleaned of Karnal bunt. Once all accessions are from areas free of the disease, the screenhouse at El Batan (determined to be free of Karnal bunt by CIMMYT’s seed-health unit) will be capable of handling all the regeneration and multiplication requirements for wheat stored in the genebank.

requirements in the regeneration process occur at the time of harvest and during the completion of field books, wherein various morphological and physiological traits for each accession are recorded.

Most of CIMMYT's maize accessions obtained from tropical maize-growing areas of low and intermediate elevations are regenerated at Tlaltizapan, Morelos, while El Batan is used for germplasm obtained from the tropical highlands. Maize uses 2.5 hectares in Tlaltizapan for two cycles per year and 1.5 hectares in El Batan. A minimum of 16, five-meter rows are required to regenerate a maize accession, but we based our calculations on a 20-row standard to account for failed regeneration.[24] Since there are approximately 2,000 rows per hectare (100 accessions), it requires a total of 6.5 hectares to regenerate 650 maize accessions.

Appendix Tables B1 and B2 report the typical field costs for regenerating a hectare of maize or wheat seed at El Batan and hectare of maize seed at Tlaltizapan. The amount of inputs such as irrigation, agrochemicals (including fertilizers), and management time varies according to seasonal and other factors. Given that many of these costs are not explicitly itemized in CIMMYT's accounting system, we first estimated the typical quantity of each of the inputs used for preparing the land and then planting and harvesting the seed, priced each item accordingly, and then derived the corresponding costs. A shadow rental rate representing the user cost of land was also

[24] A first round of regeneration may not yield a sufficient quantity of seed, determined to be 100 usable ears. The first attempt usually gives acceptable results about 60 percent of the time; as a consequence, there is a second round of plantings to deal with the 40 percent of samples that fail to fully regenerate and are thus carried over from the first round. After hand harvesting, all ears deemed acceptable for storage are shelled and the seed is mixed to form a "balanced bulk" sample that is placed into storage.

included as part of the regeneration costs in Table 4.[25] The benchmark, field-related costs of regenerating seed at El Batan is $1,073 per hectare and $1,009 per hectare at Tlaltizapan. Recently, both the wheat and maize programs have out-sourced some of these regeneration and evaluation activities to other, non-CIMMYT field sites, which may help curtail or at least contain these costs in the future. At present, INIFAP charges CIMMYT $1,217 per hectare for such services at a location near Mexicali.[26]

We used these benchmark, per-hectare field costs to estimate the overall costs involved in regenerating an accession of wheat and one of maize, taking care to adjust these benchmark figures to reflect cost differentials that arise due to differences in the seed density, volume, and reproductive aspects of each crop. For instance, it takes at least 60 square meters to regenerate an accession of maize, while an accession of wheat typically requires only 0.75 square meters. Moreover, the labor costs for maize are much higher than wheat due to the hand pollination required for each plant. Regenerating maize also involves additional costs associated with the glassine and pollination bags used to control pollination.[27] Wheat uses a screenhouse, thereby pushing up the capital costs for this crop. Table 4 summarizes the annual costs of regenerating each crop.

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[25] Half the land at CIMMYT's El Batan headquarters is provided gratis by the Mexican government (the land on which the main building complex is located), the other half was purchased by CIMMYT in the early 1970s. The Toluca, Tlaltizapan, and Poca Rica stations are owned by CIMMYT. Land at Cd Obregon, Sonora, is made available free of charge by a farmer association in exchange for access to improved wheat cultivars. Land used at Mexicali is rented from a local farmer association.

[26] Personal communication with A. Amaya.

[27] In the regeneration process, a glassine bag is placed over the young ear of each plant to protect it from stray pollen, and a pollen tector bag is placed over each tassel to contain pollen. The pollen tector bag filled with pollen is taken from the tassel and then placed on the ear.

4.4 PROCESSING SEED ACCESSIONS FOR STORAGE

Prior to this study, the wheat program routinely regenerated incoming accessions before introduction to the genebank, whereas the maize program generally did not (especially regarding introductions via the SCA regeneration project discussed above and in more detail by Taba and Eberhardt 1997).[28] If regeneration is performed, processing a new introduction to the genebank is much like regenerating an existing accession, but involves certain additional treatments. The introduced seed is inspected thoroughly upon arrival to screen for any known or suspected seed health problems, which if found mean the seed is burned. Wheat and maize seeds are then deep frozen until planting out to kill any insects. The first regeneration is performed on specially quarantined introduction plots that maintain stringent pest-control procedures. The seed-health unit inspects the plants during this process as well as the resulting seed. After harvesting from the introduction plots, maize seeds are formed into bulk samples and added directly to the genebank—wheat seeds planted out at El Batan undergo a further round of regeneration in the screenhouse to improve the quality of the seed in readiness for storage. In addition to the seed-health aspects, various characterization and data-entry activities are performed before an accession is finally added to the collection.

[28] The wheat program changed its protocol on new introductions based on the preliminary results of this study. A significant number of new introductions comes from the CIMMYT breeding program. Many of these breeding lines are bulked up for distribution and testing in CIMMYT's international nursery trials. Past practice was to supply the CIMMYT genebank with about 10 grams of seeds per accession, which was bulked up as part of the genebank's regeneration activities for storage in the genebank. Now the incoming breeding lines are bulked up in one operation, with significant savings to the genebank: the marginal costs of bulking up some additional seed for storing in the genebank as part of the multiplication activities for the international nursery trials is about 10 percent of the average cost of regenerating the seed in a "stand alone" operation run by the genebank.

It typically takes much more time to manually clean, sort, and inspect maize seeds than it does wheat seeds: each ear of maize must be sorted individually by hand to remove broken or diseased seed. Although wheat seeds are intrinsically easier to handle, they do require comparatively more attention to aspects of seed health, as discussed above and in more detail below. Both maize and wheat accessions require a similar amount of labor to record relevant data in field books, but the higher planting density for (and smaller growth habit of) wheat affords it some efficiencies (time savings) compared with maize.

Each wheat and maize accession is stored at CIMMYT headquarters in two sets of containers—one goes to the active collection, the other for long-term storage in the base collection. Each wheat accession is stored in an aluminum bag both for the active and long-term collections at a cost of 11 cents per bag; each maize accession held in the active collection is sealed in a plastic bucket costing $2.80 each, while each accession stored in the base collection is placed in two aluminum bags costing 15 cents each (the bags used for maize are the same type, but bigger than the bags used for wheat). In addition, a sample of each accession (10 grams of wheat seed and 1.5 kilograms of maize seed) is prepared for backup storage in the U.S. National Seed Storage Laboratory (NSSL) in Colorado.

Before placing them in storage, all seeds are dried to reduce their moisture content after harvesting and cleaning. The maize bank harvests and dries seed at two locations (El Batan and Tlaltizapan), using a two-step drying procedure. At both locations, the harvested ears are dried in a hot air-forced dryer (33°C) to reduce the seed moisture content to 12-15 percent. The ears are then shelled and “balanced bulk samples” are made by mixing seed from the ears of different plants from the same accession. The seed samples from Tlaltizapan are shipped to El Batan where all the seeds are cool dried in a dryer of two metric tonnes capacity held at 10°C and 25 percent relative humidity. Over a period of 2-3 months the moisture content of the seed is reduced to 6 to 8 percent, at which point the seed is placed in the storage facility.

When harvested, wheat samples are immediately placed under refrigeration until they can be cleaned, dried, and packed for storage. Wheat arrives at the bank with approximately 12 percent moisture. The seed is cool dried (the dryer is held at around 10 percent humidity and 10 °C) to effect a gentle drying. It takes about 6 to 7 weeks to dry the samples from 12 down to 6-7 percent moisture.[29] There could be further benefits (in terms of extended storage life) of further drying to 3 to 4 percent moisture, but then special techniques must be used to germinate the seed. The costs of operating and maintaining the dryers was included in Table 4, along with the annualized costs of the dryers from Table 2.

4.5 SEED HEALTH

All newly introduced material is subject to seed-health checks before being included in the genebank. The health of all out-going seed must also be certified and our cost schedules reflect that aspect. However we took care not to double count health

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[29] The drying facilities for the wheat program are located in El Batan, and prior to this study had been a significant bottleneck to the genebank operations. The old drying facilities had a capacity of 2,000 kilograms, which, when combined with an average sample size of 0.5 kilograms and a drying time of 12 weeks, meant a drying capacity of 16,000 accessions per annum. The new dryer (installed during the course of this study) has the same capacity as the current piece of equipment but reduces the drying time to around 7 weeks, increasing the throughput to 24,000 accessions per year.

costs—in all but exceptional cases the checks done at the time of introducing or regenerating maize seed suffice for subsequent shipments made from the collection. Wheat seeds are checked when first introduced and again at the time samples are packaged for shipment. At CIMMYT, most of the relevant seed-health activity and the associated costs are the responsibility of CIMMYT's seed-health unit. The capital costs incurred by these activities are identified in Table 2, and the labor and other operational costs for the genebank operation are included in Table 4 as parts of new introduction and dissemination costs—recognizing that only part of the seed- health operation relates to accessions coming into and being shipped from the genebank, and so only part of the overall seed health costs are included here.

Some seed-health costs are incurred directly by the genebank. The general operation of a well-managed seed bank involves periodic checking for ambient (air-borne) spores, monitoring the cleanliness of the machinery used in processing the seed, and precautionary measures to eliminate possible vectors, which at CIMMYT involves the daily washing, with bleach, of all walls and floors in areas where seeds are processed. The efforts to deal with Karnal bunt have also had cost consequences for the genebank. Karnal bunt is not a particularly virulent or economically important disease for wheat, but its presence does limit the acceptability of seed that is infected or contaminated by the fungus by numerous national quarantine agencies (Fuentes-Davila 1996, Beattie and Biggerstaff 1999).

CIMMYT's troubles with this disease stem from an infestation of Karnal bunt in the CIMMYT fields at Ciudad Obregon, Sonora, that were routinely used by the genebank prior to 1987. Although the Sonora fields are ideal in many respects for regenerating seeds, they are no longer used due to the Karnal bunt problem. Instead, wheat seeds are now multiplied in clean plots at El Batan, checked for spores in bulked samples after passing through chlorine disinfection, regenerated at Mexicali, and shipped back to El Batan in sealed containers. To facilitate large-scale disinfestation for Karnal bunt, as mentioned above, a "Jacuzzi-like" system for cleaning wheat seeds was developed.[30] The seeds are placed in plastic baskets with metal mesh bottoms and suspended for three minutes in a one-percent solution of chlorine bleach while agitated by air bubbles. This system has proved most effective in eliminating any Karnal bunt teliospores, and has enabled the wheat germplasm bank and the International Nurseries System to continue operating effectively. The costs of dealing with the contamination involve additional regeneration costs, specialized shipping procedures, and related phytosanitary certification costs, increased chemical applications, and increased seed-health monitoring costs. These costs are incorporated into the estimates provided in Table 4.

[30] The development of this treatment regime was triggered to a great extent by the desire to protect the viability of CIMMYT's International Nursery System against phytosanitary restrictions on internationally disseminated samples. For the past several years only about 4 percent of the seed treated in the Jacuzzi involve material coming from the genebank.

4.6 SEED DISSEMINATION AND DUPLICATION[31]

Seed Dissemination

Distribution from the genebank takes various forms. Some material is used by genebank personnel for characterization or evaluation purposes, such as the efforts by the wheat bank manager to screen for resistance to Russian wheat aphid, and the ongoing activities by the maize bank manager to characterize the new incoming material from the LAMP project and elsewhere for development of heterotic populations of various categories of maturity, adaptation, and seed color. Other material is distributed in response to individual request from breeders, plant pathologists, and others at CIMMYT or elsewhere. Seed is also sent to other genebank facilities, often in the context of CIMMYT's joint collection and conservation work with developing-country NARSs (e.g., sharing of material collected as part of the recent LAMP project is an example of this type of exchange). The cost of responding to such a diverse set of seed requests includes determining which seeds are most suitable to fill the request, and then assembling, treating, and packaging the samples to be sent, as well as the associated shipping costs. These costs are sensitive to the amount and range of seed shipped.

Another set of costs is sensitive to the number of shipments made (as distinct from the number of accessions shipped), as well as the size and destination of each shipment. Relatedly, each shipment outside Mexico is subject to phytosanitary controls

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[31] CIMMYT plays an important, if not pivotal, role in the international dissemination of seed for breeding. The major part comes from the CIMMYT breeding program, in the case of wheat in standard sets prepared for use by members of the International Nursery System. These dissemination activities are managed by the respective breeding programs: only the dissemination activities directly linked to the genebank are included in this study.

and this certification process is a reasonably time-intensive and costly undertaking. Aside from the cost of the certificates themselves (payable to the Mexican government), it draws on the time of staff in CIMMYT's seed-health unit and the genebank to prepare the necessary documentation and arrange for the shipment itself. In addition, shipments of seed from CIMMYT must be accompanied by a Material Transfer Agreement that assigns use rights to the seed and this documentation must be developed, tracked, and logged. Table 5 summarizes the shipments made from the genebank since 1987.

Table 5 Number of accessions and shipments sent from CIMMYT genebank

Year	CIMMYT[a]	Rest-of-the-world: Developing countries	Rest-of-the-world: Developed countries	Rest-of-the-world: Total	Total	CIMMYT	Rest-of-the-world: Developing countries	Rest-of-the-world: Developed Countries	Rest-of-the-world: Total	Total
	(Number of accessions)					(Number of shipments)				
Wheat										
1987	2,764	9,287	195	9,482	12,246	21	25	12	37	58
1988	1,690	288	92	380	2,070	23	13	11	24	47
1989	4,928	2,547	2,269	4,816	9,744	41	28	10	38	79
1990	940	680	490	1,170	2,110	38	12	6	18	56
1991	4,042	324	21	345	4,387	19	5	5	10	29
1992	2,278	561	115	676	2,954	18	12	6	18	36
1993	6,333	584	1,160	1,744	8,077	14	2	3	5	19
1994	1,026	3,793	703	4,696	5,722	8	10	14	24	32
1995	2,944	229	101	330	3,274	7	2	4	6	13
1996	12,890	133	1,200	1,333	14,223	9	14	8	22	31
1997	8,624	542	1,822	2,364	10,988	11	12	11	23	34
1998	2,652	11,601	1,003	12,604	15,256	24	16	13	29	53
Maize										
1987	2,400	1,667	447	2,114	4,514	27	32	19	51	78
1988	4,341	1,489	587	2,076	6,417	48	20	29	49	97
1989	5,093	1,238	1,378	2,616	7,709	47	48	17	65	112
1990	3,450	1,103	687	2,090	5,540	46	21	20	41	87
1991	2,231	508	117	625	2,856	27	22	16	38	65
1992	1,970	536	710	1,246	3,216	25	25	15	40	65
1993	3,740	818	1,813	2,631	6,371	37	22	21	43	80
1995	3,039	717	637	1,354	4,393	39	23	18	41	80
1995	2,542	264	532	796	3,338	34	17	13	30	64
1996	2,776(2,607)	803	106	909	3,685	28	28	13	41	69
1997	1,678(1,574)	686	234	920	2,598	26	30	19	49	75
1998	1,599(883)	3,109	354	3,463	5,062	28	50	16	66	94

Source: CIMMYT maize and wheat genebank files.

[a] The number of accessions shipped from the CIMMYT genebank to CIMMYT include material sent to breeders, plant pathologists, and so on involved in the Center's crop-improvement program as well as material destined for evaluation trials run by genebank personnel. The figures in brackets indicate the number of maize accessions shipped to genebank personnel for evaluation purposes. About 75 percent of the CIMMYT wheat shipments go to the crop-improvement program and about 25 percent for evaluation activities managed by the genebank program. Shipments from the genebank to the rest of the world are made on request, and so can vary substantially from year to year. For instance, the exceptionally large wheat shipments in 1987 reflected significant requests from India to aid their efforts to find resistance to Karnal bunt, the large developing-country shipments in 1998 were due to the repatriation of material (9,811 accessions in total) collected throughout Mexico to the national program.

The structure of maize and wheat shipments is similar in some respects but quite different in others. Averaging since 1996, there were substantially more accessions of wheat (13,489 per year) than maize (3,782 per year) shipped from the genebank. In both cases more than half the accessions were internal shipments within CIMMYT (nearly 60 percent in the case of wheat, 53 percent for maize). And, a significant share of these internal shipments involved transfers from the genebank to the genebank managers for prebreeding, varietal characterization purposes—about 25 percent of the wheat accessions and nearly 84 percent of the internally distributed maize accessions—with the respective residual shares going to CIMMYT breeders and other scientists. The remainder of the accessions were shipped to collaborators worldwide: an average of 5,444 accessions of wheat per year and 1,764 accessions of maize over the past three years. Thus in recent years, about 40 percent of the wheat seeds disseminated each year from the genebank go to agencies and individuals outside CIMMYT, and 47 percent of the maize seed is so distributed. The preponderance of these overseas shipments were to developing countries (75 percent of the externally shipped wheat accessions and 87 percent of the maize accessions).

Table 5 also provides information on the number of shipments, as distinct from the number of accessions shipped. More wheat than maize accessions are shipped abroad and there are fewer wheat shipments per year: thus the average number of accessions per shipment is 220 in the case of wheat compared with just 34 for maize.

Duplicate Holdings

The new storage facilities at CIMMYT are designed to withstand major natural catastrophes, and backup power generation, climate control, and general operating procedures are also in place to minimize the chance of damage to or loss of the collection. As an additional safety precaution, much of the CIMMYT wheat and maize collections are held in duplicate form in other locations. By 1997, about four-fifths of the base maize collection and approximately one-half of the base collection for wheat were held at the U.S. National Seed Storage Laboratory (NSSL) in Fort Collins, Colorado.

The backup collections for wheat are shipped and stored in a "black-box" fashion. A 10-gram (around 350 seeds) sample of each wheat accession is prepared, labeled, and packed in aluminum foil bags and then put into cardboard boxes, each containing up to 400 accessions. The boxes are airfreighted to the backup facility where they are stored. The expense of preparing the samples and packing each black box are included in the costing calculations: freight costs from El Batan to Fort Collins for the last shipment of black boxes in 1996 totaled $342 for 35,000 duplicates. Wheat duplicates are cumulated and shipped on a periodic basis to save shipping costs, with the next shipment of over 30,000 accessions planned for fall 1999.

The idea behind a black box approach is that the box is packed once at CIMMYT and then never opened, thereby minimizing the chance of contamination of the collection while keeping handling costs to a minimum. Moving a box full of plant seeds through customs and quarantine facilities (both exiting Mexico and entering the recipient country) is becoming increasingly difficult and is a significant barrier to the choice of location at which to back up a collection. Ensuring the duplicate collection is safely housed in a well-managed facility, and can be repatriated without undue bureaucratic or political delays if needed, are other important considerations.

At present the Fort Collins facility does not charge for storing the duplicate collection, but that could change in the future. CIMMYT has formal agreements for the storage of a duplicate collection with NSSL in Fort Collins for both maize and wheat and with ICARDA for wheat.[32] Parts of the collection are also backed up in less formal fashion at other sites. The National Institute of Agrobiological Resources (NIAR) in Japan, and the AWCC (Australian Winter Cereals Collection) hold significant parts of the CIMMYT wheat collection. However, each of these national facilities follows its own coding and documentation practices, so efforts to restore an appropriately documented CIMMYT collection from these various other holdings could be costly. Nonetheless, their existence does provide a "fail safe" option for recovering much of the CIMMYT genebank material, should that be lost.

The Mexican national agricultural research agency (INIFAP) has duplicated about 70 percent of its maize collection in the CIMMYT maize holdings. CIMMYT's maize holdings are duplicated and stored as an integral part of the NSSL collection, rather than in black-box fashion as is the case for wheat. All new introductions and regenerated accessions are shipped to NSSL on an annual basis, and about 80 percent of the CIMMYT maize collection was backed up at NSSL by 1996. Between 1,500 and 2,000

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[32] CIMMYT and ICARDA signed an agreement in February 1991 to provide duplicate storage for each center's seed holdings. Most of ICARDA's cereal collection is now backed up at CIMMYT. Unfortunately, a complete shipment of wheat seeds to ICARDA (made as part of CIMMYT's International Nursery Systems program) was burned on entry to Syria by the local authorities. For this reason no duplicate genebank storage has been done at ICARDA, and the feasibility of that site as a viable backup option for CIMMYT's wheat holdings in the near future remains questionable.

accessions are shipped each year in cheesecloth bags after the regenerated seed is dried.[33] The NSSL repack and store the accessions in aluminum bags. CIMMYT identity numbers are entered into their data management system, along with information on the amount of seed in storage and its germination status. This more active means of duplicating holdings, in which genebank sites reciprocally monitor and share seed preservation information, offers the prospects for more secure, accessible, and, possibly, more cost-effective means of duplication.

Data and Information Management

Fundamental to the genebank is the management of the information that describes each accession. However, operationally (and for costing purposes) it is difficult to separate data and information used in the effective management of genebanks from the data that is generated by and facilitates the breeding program at CIMMYT and elsewhere in the world. Some of the data serve multiple purposes. Standardizing accession ID numbers, common protocols for recording and reporting performance evaluation data (whether it be data collected as part of the genebank regeneration efforts or as part of the international evaluation trials), and compatible software procedures for recording, storing, retrieving, and analyzing such data can yield significant benefits in the use of this information for both seed conservation and breeding purposes.

The routine operations of the genebank include the entry of “passport” data (detailing the source and origin of the seed) at the time the accession first enters the collection, the processing of field book observations collected as part of a trial conducted

[33] In 1996, a further 2,629 accessions regenerated as part of the LAMP project were shipped to Fort Collins.

when the accession is new to the collection and at all subsequent regenerations, as well as the maintenance of a database that tracks the storage location, time in storage, seed viability history, and stock levels of each accession. Barcode labeling of each maize accession in the genebank is being introduced to streamline this process.

The wheat genebank operation internally contracts for the services of a data entry team employed by CIMMYT's wheat program, and is currently in the process of digitizing all of its old field books. The maize bank commits 1.75 years of its own staff to managing documentation of information including regeneration, new introductions, seed monitoring, and evaluation. These data are not only geared to the internal management needs of the CIMMYT genebank, they are also made available to others, on demand. Catalogs in the form of CD-ROM or web-based searchable databases are gradually replacing printed publications.

The genebank management systems are part of a broader effort at CIMMYT to improve the information base concerning the Center's extensive maize and wheat holdings. The past several years have seen the creation of the Genetic Resources Information Package (GRIP) with a combination of Australian project-funding and CIMMYT core-funding, and the incorporation of that information into the CG Systemwide Information Network for Genetic Resources (SINGER). The Wheat Genebank Management System has been recently incorporated into the International Wheat Information System (IWIS), a computer database system that integrates information from nursery trials through to pedigree information and is able to trace lineages of advanced breeding lines. The wheat-bank director estimates that 40 percent of his time was dedicated to database issues in 1996, the baseline survey year for this study.

The Maize Germplasm Bank Management System (MZBANK) has recently been updated through participation in the SINGER project. The Latin American Maize Project (LAMP) has produced a CD-ROM containing passport information for all of the CIMMYT maize-bank accessions, including the original collection and the regenerations from the ongoing LAMP collaboration. The maize bank has begun scanning a picture of each ear of corn, for eventual incorporation into the database.

5. CONSERVATION COSTS

5.1 A REPRESENTATIVE SNAPSHOT

In 1996, CIMMYT's genebank operation had a budget of around $435,000—$185,000 for the wheat bank and $250,000 for the maize bank. Treating this *budget* as indicative of the *annual cost* of maintaining the wheat and maize collections at CIMMYT is grossly misleading, as we shall now demonstrate. On the one hand the budget omits the cost of essential genebank functions such as seed-health testing, some of the relevant labor costs, and overhead expenses that cover the cost of providing general institutional and administrative support to the genebank. In addition many of the relevant capital costs are also missing and those capital expenses that are included represent the purchase of durable inputs that remain in use for a number of years; inputs that would be better costed on an annualized, not lump-sum, basis (and especially so if the annual costs are to be properly placed in a longer-run context).

On the other hand, the budget supports activities such as the prebreeding, varietal-characterization work directly supervised by the managers of both banks. While this work is vital for the effective use of the genebank collection, it is not essential for the conservation function of a genebank (and not explicitly costed as part of this study). Similarly, the genebank pays for distributing seed worldwide to those who request it—again, an important service function, but not one that directly contributes to the conservation of the collection, and so represents a class of costs that for some purposes are best treated separately as we have done here.

Table 6 draws together data presented in the previous tables, providing an overview of the total variable and capital costs listed by various activities or cost components along with the corresponding average cost per accession. The first column reports the number of treated or stored accessions that is implicit in each of the capital, quasi-capital, and variable cost totals listed in columns 2, 3, and 4 respectively. Taking these figures at face value, the total cost of conserving CIMMYT's wheat and maize collection in 1996 (excluding the costs incurred in disseminating seeds from the genebank) is $586,631—$282,385 for wheat and $304,246 for the maize part of the collection. This is substantially more than the total genebank budget for this year, but for various reasons (some described above) the comparison is spurious and the totals are not representative of a typical year.

Table 6: Annual average costs of conserving and disseminating accessions

Items	Number of accessions	TCC	TQCC	TVC	Current capacity ACC	Current capacity AQCC	Current capacity AVC	Full capacity[a] ACC	Full capacity[a] AQCC	Full capacity[a] AVC
		(U.S. dollars per year)			(U.S. dollars per accession per year)					
Wheat										
Conservation Costs	-	**58,276**	**95,974**	**128,135**	**1.76**	**4.35**	**5.83**	**1.57**	**4.08**	**5.83**
Storage costs	123,000	**34,066**	**47,987**	**33,041**	**0.28**	**0.39**	**0.27**	**0.09**	**0.12**	**0.27**
Storage	-	29,653	47,987	22,404	-	-	-	-	-	-
Management	-	4,413	-	10,637	-	-	-	-	-	-
Maintenance costs		**24,210**	**47,987**	**95,094**	**1.48**	**3.96**	**5.56**	**1.48**	**3.96**	**5.56**
New introduction	5,800	2,369	11,997	9,273	0.41	2.07	1.60	0.41	2.07	1.60
Germination testing	12,000	2,526	11,997	6,147	0.21	1.00	0.51	0.21	1.00	0.51
Regeneration	22,000	18,211	11,997	69,606	0.83	0.55	3.16	0.83	0.55	3.16
Duplication	35,000	1,103	11,997	10,067	0.03	0.34	0.29	0.03	0.34	0.29
(Management)	-	(4,413)	-	(10,637)	-	-	-	-	-	-
Dissemination Costs	14,200	**5,035**	**47,987**	**17,972**	**0.35**	**3.38**	**1.27**	**0.35**	**3.38**	**1.27**
Dissemination	-	622	47,987	7,335	-	-	-	-	-	-
Management	-	4,413	-	10,637	-	-	-	-	-	-
Maize										
Conservation Costs	**-**	**51,908**	**104,728**	**147,610**	**17.79**	**41.23**	**154.27**	**16.15**	**38.93**	**154.27**
Storage costs	17,000	**37,353**	**52,364**	**34,791**	**2.20**	**3.08**	**2.05**	**0.56**	**0.78**	**2.05**
Storage	-	31,467	52,364	22,404	-	-	-	-	-	-
Management	-	5,886	-	12,387	-	-	-	-	-	-
Maintenance costs	**-**	**14,555**	**52,364**	**112,819**	**15.59**	**38.15**	**152.22**	**15.59**	**38.15**	**152.22**
New introduction	1,580	2,738	13,091	7,804	1.73	8.29	4.94	1.73	8.29	4.94
Germination testing	3,400	2,183	13,091	4,489	0.64	3.85	1.32	0.64	3.85	1.32
Regeneration	650	8,164	13,091	92,554	12.56	20.14	142.39	12.56	20.14	142.39
Duplication	2,230	1,472	13,091	7,973	0.66	5.87	3.58	0.66	5.87	3.58
(Management)	-	(5,886)	-	(12,387)	-	-	-	-	-	-
Dissemination Costs	3,680	**6,428**	**52,364**	**22,247**	**1.75**	**14.23**	**6.05**	**1.75**	**14.23**	**6.05**
Dissemination	-	542	52,364	9,860	-	-	-	-	-	-
Management	-	5,886	-	12,387	-	-	-	-	-	-

Note: Total quasi-capital cost (TQCC) includes the cost of senior scientific and technical staff ($143,962 for wheat and $157,093 for maize, both including overhead costs). We allocated these quasi-capital costs and the associated management costs (general and information management) equally to the storage, maintenance, and dissemination categories. The management cost component of maintenance costs was allocated equally to each of the sub-activities listed in this cost category (i.e. new introduction, germination testing, etc.).

[a] Full capacities for wheat and maize are 390,000 and 67,000 accessions, respectively.

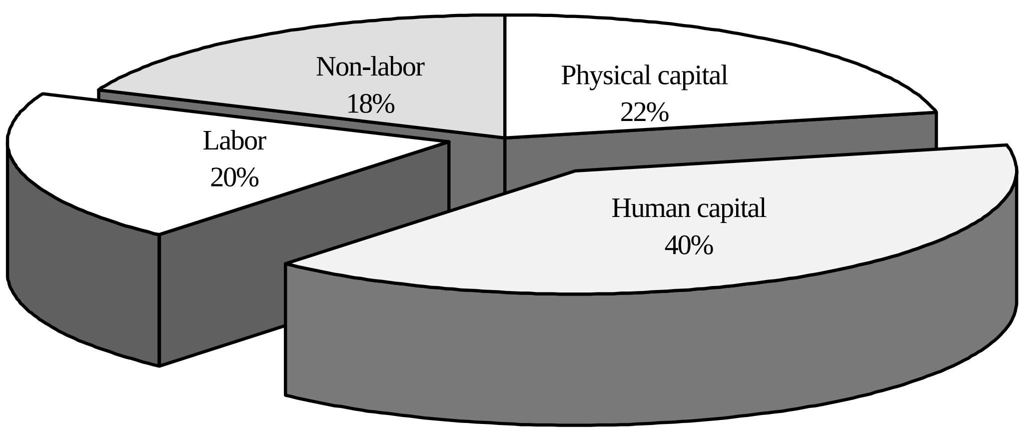
To give a more realistic and representative comparison we made several adjustments to the budget and cost totals. We scaled down the annual total budget of CIMMYT's genebank by 20 percent, our conservative estimate of the time spent during the survey year by genebank managers on varietal characterization and other activities not included in our costing exercise. We also removed the dissemination activities from the budget total, to focus the comparison on conservation activities per se. Because the cost totals for some genebank functions represented an atypical level of activity during the survey year, we used a more typical set of accession numbers involved in these functions in conjunction with the per-accession figures reported in columns 5 through 7 of Table 6 to derive a more representative estimate of the annual cost totals.[34] Figure 2 gives the adjusted annual conservation cost of $498,821 broken down into various cost classes.[35] The comparable budget total of $229,680 is around 45 percent of the estimated annual cost of maintaining CIMMYT's present genebank collection, including the annualized

[34] For example, in 1996 an exceptionally large number of wheat accessions (22,000) were regenerated in the process of moving material from the old to the new genebank facility while insuring the introductions to the new facility were free of Karnal bunt. An exceptionally large number of wheat accessions (35,000 in total) were also duplicated that year for backup storage purposes. We took the average number of accessions processed or stored over the past few years as our representative accession totals. For rescaling the new introductions estimates we used 5,000 wheat accessions (and 1,000 maize accessions), germination testing was 6,000 wheat (4,000 maize), regeneration was 6,000 wheat (500 maize), dissemination was 13,500 wheat (3,800 maize), and duplication was 11,600 wheat (1,500 maize).

35 Our decision to not round off the estimates presented in this section should not be construed as implying an false precision. It was done to facilitate cross referencing with the tables and their accompanying notes in appendix A.

cost of the capital used by the genebank.[36] Excluding these capital costs, the budget still fell well short of the $388,637 variable plus lumpy labor costs spent on conserving CIMMYT's genebank collection in a typical year.

Figure 3 Representative annual cost of CIMMYT germplasm conservation activities ($498,821)



[36] This gross budget total of $435,000 was scaled down by 48 percent to net out the prebreeding activities of the genebank managers and the costs of disseminating seeds that are not captured in the *conservation* cost total reported in Figure 3. Adding the dissemination costs to the conservation costs gives a total of $650,669, well in excess of the comparable budget total of $348,000 (estimates as 80 percent of the $435,000 budget figure reported by CIMMYT).

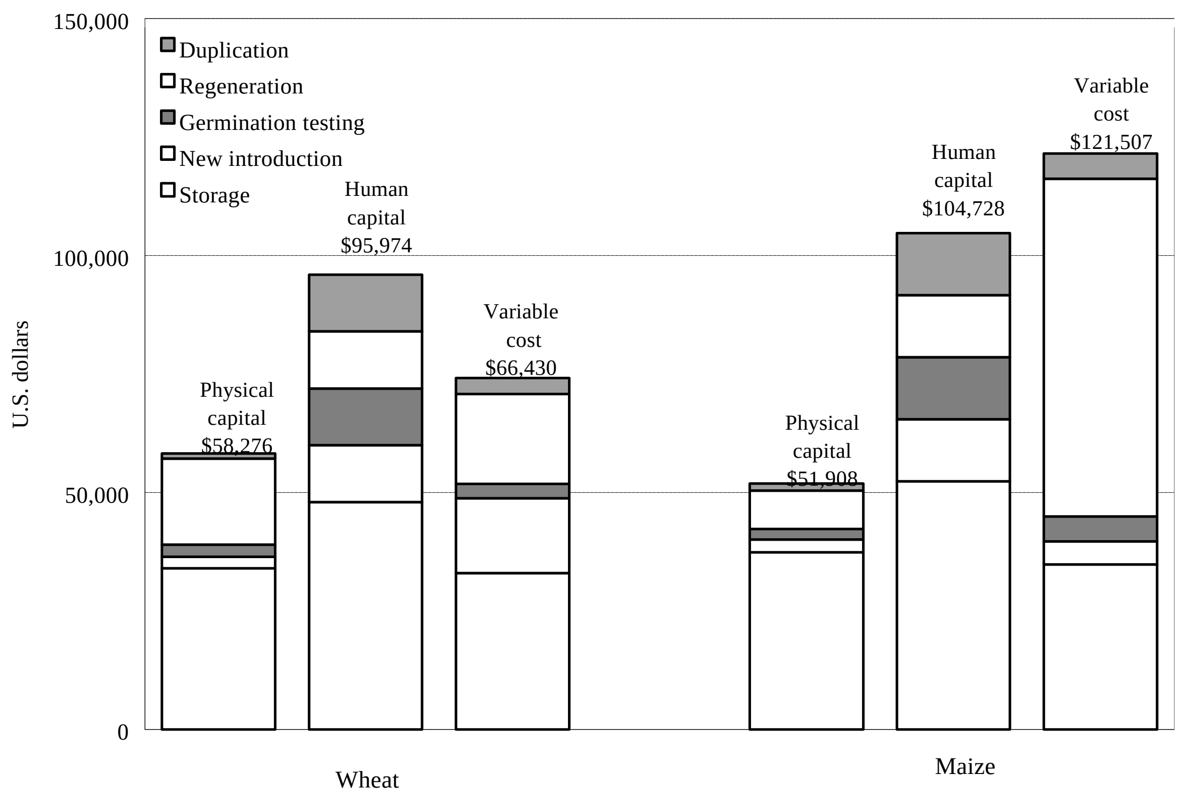
Figure 3 shows that about 60 percent of the annual cost of the genebank operation involve labor (and human-capital) inputs, with the remaining costs divided about equally between operational costs and the annualized cost of capital. For those who have visited a genebank facility with its rows of storage shelves, extensive refrigeration equipment, and so on, it is natural to think the operation is quite capital intensive. Our estimates belie this notion. To be sure, the more than $1.6 million invested in the CIMMYT genebank facility and its associated plant and equipment (columns 2 and 3, Table 2) represents a significant investment in capital. However, when expressed in annualized terms these capital costs represent 22 percent of the cost of running the CIMMYT genebank, not especially suggestive of a capital-intensive operation. Indeed, like the crop-improvement research it supports, maintaining a genebank is a labor-intensive undertaking and carries with it a big, recurrent, "overhead" cost in the labor required to manage the bank as well as regenerate and otherwise maintain the viability of the collection. In this regard saving seeds in a genebank is not like storing books in a library or maintaining a museum of history or antiquities—in cost-share terms, a genebank is perhaps more akin to keeping animals in a zoo or maintaining a botanical garden. About two-thirds of these labor costs (representing the cost of the senior scientific and technical staff) are lumpy in nature and best treated as a quasi-fixed input. [37]

Figure 4 identifies the structure of the costs separately for wheat and maize. We divide costs into their fixed-, quasi fixed-, and variable-cost components (where variable

[37] It is usual to think of labor as a variable, not fixed, cost. Here, we treat this part of labor as a fixed (or more properly, quasi-fixed) input—the genebank mangers and core technical staff are hired on multiyear contracts and their total labor input does not vary with variations in the size of the genebank holding. What does change somewhat from year to year is the allocation of this labor among various genebank activities.

costs represent expenses that are sensitive to the scale of operation such as electricity, chemicals, and hired labor, fixed costs are insensitive to the size, scale, or scope of the undertaking, and quasi-fixed costs fall between these two extremes, but generally more to the fixed end of the cost spectrum.) Here the cost of physical capital such as the buildings, plant, and equipment were treated as fixed; the cost of the human capital embodied in the senior scientific staff and genebank technicians were taken to be quasi-fixed.

Figure 4 Annual costs of conserving wheat and maize germplasm



The annualized cost of the physical capital used to maintain CIMMYT's present wheat and maize holdings are quite similar, although anticipating the discussion below, notably about seven times more wheat than maize accessions are currently stored at CIMMYT. Perhaps not surprisingly, the storage component accounts for the majority of these capital costs: over 65 percent for both crops. About 25 percent of the capital expenses are incurred in regenerating the seed. The spending each year for lumpy labor services is a little more for maize ($104,728) than for wheat ($95,974). In fact, it is the cost of senior scientific and technical staff that constitutes the biggest share of the fixed or quasi-fixed costs for both crops (62 percent for wheat, 67 percent for maize).

While there is little difference between CIMMYT's wheat and maize operations in the annual cost of physical capital inputs (and, to a lesser extent, the cost of lumpy labor inputs), Figure 4 highlights the substantial differences in the structure of their variable costs. The maize program spends considerably more each year than the wheat program on regenerating its holdings. Indeed, regenerating seed accounts for 58 percent of the variable costs for maize and only 28 percent for wheat. These differences are largely attributable to the substantially higher amount of labor required to regenerate maize while minimizing genetic drift in this heterogeneous, out-crossing plant.

5.2 ECONOMIC ANALYSES OF GENEBANK COSTS

Costs on the Margin

Given the genebank is operating well below capacity, the average costs per accession detailed in Table 7 provide upper-bound estimates of the corresponding marginal costs. It is these marginal costs that are central to assessing the economics of changes to the genebank operations on the margin or over the short run. For example, what is the cost of storing an existing accession for one more year, or, equivalently, what is the benefit in terms of cost savings from eliminating a duplicate accession from the genebank? The answer depends, obviously, on the crop in question, and perhaps less obviously on the state of the sample, including its time in storage, time to last regeneration or germination test, and such like. If the sample is known to be viable it costs little to hold over an accession of either crop for one more year—just 27 cents for each accession of wheat and $2.05 for an accession of maize. However, if the viability of the seed needs to be checked and then the sample regenerated because it failed the test, the cost of keeping it for another year jumps dramatically to $3.94 for each wheat accession and $145.76 for each sample of maize. Clearly there can be substantial cost savings from eliminating duplicate accessions. In fact it would be economic to spend upwards of $140 to ascertain if a maize accession was duplicated in the CIMMYT holdings (or, perhaps, for that matter held in collections at other sites, given the cost of shipping in seed, if needed, is comparatively low and falling).

Table 7 Marginal costs of conserving an accession for one year

Items	Existing accession		Introduced accession	
	No regeneration	Regeneration	No regeneration	Regeneration
	(U.S. dollars per accession per year)			
Wheat				
Storage costs	0.27	0.27	0.27	0.27
New introduction costs				
Containers[a]	-	-	0.22	0.22
New introduction	-	-	1.60	1.60
Duplication	-	-	0.29	0.29
Maintenance costs				
Germination testing	-	0.51	-	0.51
Regeneration	-	3.16	-	3.16
Total conservation costs	**0.27**	**3.94**	**2.38**	**6.05**
Maize				
Storage costs	2.05	2.05	2.05	2.05
New introduction costs				
Containers	-	-	3.10	3.10
New introduction	-	-	4.94	4.94
Duplication	-	-	3.58	3.58
Maintenance costs				
Germination testing	-	1.32	-	1.32
Regeneration	-	142.39	-	142.39
Total conservation costs	**2.05**	**145.76**	**13.67**	**157.38**

A second policy question relates to the first: what is the cost of introducing a new accession into the genebank, given the decision to store it is revisited after one year? The answer also depends on the protocol for new introductions of a specific crop as well as the size and state of the sample. CIMMYT's standard procedure is to check the health status of virtually all incoming accessions.[38] The sample size should be sufficient for storage in the genebank as well as provide enough seed for a backup sample stored in an off-site facility. If a new accession is viable and of sufficient size to negate the need to bulk up the sample, the cost to CIMMYT of incorporating this new accession in its genebank and storing it for one year is $2.38 per accession for wheat and $13.67 for maize. However, if for any reason the sample requires regenerating at the time of its introduction, this cost increases to $6.05 per accession for wheat and soars to $157.38 for maize.

We can also answer the question: does it cost CIMMYT less to keep an accession for another year or, alternatively, discard the holding if the same accession can be introduced to the collection, as need, from elsewhere? According to our estimates, it is clearly cheaper to hold on to an existing accession of wheat and maize *for one more year* than to introduce that same sample from elsewhere, providing the existing accession needs no regeneration. If the existing accession needs regenerating because, for example, the sample size is too small then the story is not as clear-cut. For wheat, it pays to rollover the existing accession for another year if the introduced accession is regenerated

[38] Wheat seed originating in Mexico is not subject to a seed-health check at the time of introduction, but is checked when shipped to a location outside of Mexico.

(as is often required with the small samples commonly shipped by other genebanks)—there is little cost difference if the introduction is not regenerated. For maize, it is definitely cheaper to introduce an accession that requires no regeneration: moreover, the cost differential is relatively small even if the new introduction needs regenerating.

This type of cost calculus, and its implied management responses, are even more complex if we allow for the interplay of time and costs. The dissemination data in Table 5 suggests that many genebank accessions sit untouched for many years. Indeed, it is the option value of these accessions rather than their more immediate use value that is the justification commonly cited for establishing and maintaining a genebank. However, that option value can only be realized if at some future date the sample is called upon for breeding or other research purposes. Rather than compare the cost differentials of holding on to an existing accession versus introducing that same accession *in the current year*, a more subtle but perhaps even more relevant question is the following: if an accession will be first utilized n years from now, how long must that delay n be before it is economic to rely on introductions from elsewhere rather than to maintain an existing holding?[39]

Figures in Table 7 indicate that regeneration costs are high, especially for maize. If an existing maize accession requires regeneration and the same accession is known to

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[39] This break-even year, t^*, is found by solving $C^{t^*}/(1+r)^{t^*} = \sum_{t=0}^{t^*} K_t/(1+r)^t$, where C^{t^*} is the cost of introducing an accession in year t^* (with or without regeneration), K_t is the annual cost of holding over an accession until year t^* (with or without regeneration in the first year), and r is the real rate of interest. When the uncertainty of n is recognized, the calculation becomes more complex.

be stored elsewhere, it may be more economic to discard the accession from the genebank unless it is utilized within 2-3 years (presuming interest rates fall in the 2-6 percent range). The cutoff period for wheat under the same situation is 7-10 years. Since the costs of introducing a wheat accession to the collection are large compared with the costs of storage, it is more economic to conserve existing accessions deemed useful in the near future. In the case where regeneration is not required, the cutoff period for wheat is 7-10 years, and 5-6 years for maize. In general, if accessions are unlikely to be used within a decade or so, it is better to store those accessions in a single facility and distribute them to local genebanks when requested, assuming transportation costs and other quarantine barriers are not prohibitive.

Underlying all the cost comparisons discussed above is the understanding that CIMMYT receives its incoming accessions gratis—they are not charged for the seed or the costs of shipping it to El Batan. This is the current common practice for publicly funded genebanks the world over; they generally provide seed free of charge to those who request it. Presuming CIMMYT's cost structure is typical (or at least a lower bound) of the costs incurred by other genebanks, these data give some indication of the willingness of others to pay should a market for stored seeds emerge and CIMMYT opts to charge for access to its accessions. Abstracting from any intrinsic value of the seed itself, the costs of carrying over an existing accession is the maximum others with current access to free seeds would be prepared to pay for access to seed from CIMMYT at time n (thereby avoiding the cost of storing the seed themselves). As we have seen, these costs are time dependent—the cost of carrying over accessions for one period or to distant future periods can vary markedly.

Costs in the Very Long Run

Most of the figures above refer to the costs of conserving an accession for one more year, with the notion that decisions taken now can be revisited the following year. However, genebanks may well want, or be required, to guarantee safekeeping of samples in perpetuity; for example those accessions held in trust by the CGIAR centers by way of their commitments to the United Nations Food and Agriculture Organization (FAO). The cost of such a guarantee obviously depends on the state of future technology, input costs (including the rate of interest), storage capacity, and regeneration intervals.

Table 8 shows the average costs of conserving wheat and maize accessions *in perpetuity*, assuming costs are constant over time in real (inflation-adjusted) terms. We considered the present values of the costs of conserving an existing accession and a newly introduced accession with different regeneration intervals and different real rates of interest (2, 4, and 6 percent per annum, which were deemed to span the relevant range). Testing for the viability of seed samples was assumed to begin 10 years after introducing a new accession to the collection, with retesting every five years thereafter.[40]

[40] More detailed information on these cost components is included in Appendix Table D1.

Table 8 Present values of conserving accessions in perpetuity

Items	Existing accession						Introduced accession					
	No initial regeneration			Initial regeneration			No initial regeneration			Initial regeneration		
	2%	4%	6%	2%	4%	6%	2%	4%	6%	2%	4%	6%
	(U.S. dollars per accession)											
Wheat												
Storage costs												
Storage	13.77	7.02	4.77	13.77	7.02	4.77	13.77	7.02	4.77	13.77	7.02	4.77
New introduction costs												
Containers	-	-	-	-	-	-	0.22	0.22	0.22	0.22	0.22	0.22
New introduction	-	-	-	-	-	-	1.60	1.60	1.60	1.60	1.60	1.60
Maintenance costs												
Germination testing [a]	4.44	1.93	1.13	4.95	2.44	1.64	4.44	1.93	1.13	4.44	1.93	1.13
Regeneration/duplication [b]												
25 years (w/o ini. reg.)	5.39	2.07	1.05	8.84	5.52	4.50	5.39	2.07	1.05	8.84	5.52	4.50
50 years (w/o ini. reg.)	2.04	0.56	0.20	5.49	4.01	3.65	2.04	0.56	0.20	5.49	4.01	3.65
100 years (w/o ini. reg.)	0.55	0.07	0.01	4.00	3.52	3.46	0.55	0.07	0.01	4.00	3.52	3.46
Conservation costs (25 yrs)	**23.60**	**11.02**	**6.95**	**27.56**	**14.98**	**10.91**	**25.42**	**12.84**	**8.77**	**28.87**	**16.29**	**12.22**
Conservation costs (50 yrs)	**20.25**	**9.51**	**6.10**	**24.21**	**13.47**	**10.06**	**22.07**	**11.33**	**7.92**	**25.52**	**14.78**	**11.37**
Conservation costs (100 yrs)	**18.76**	**9.02**	**5.91**	**22.72**	**12.98**	**9.87**	**20.58**	**10.84**	**7.73**	**24.03**	**14.29**	**11.18**
Maize												
Storage costs												
Storage	104.55	53.30	36.22	104.55	53.30	36.22	104.55	53.30	36.22	104.55	53.30	36.22
New introduction costs												
Containers	-	-	-	-	-	-	3.10	3.10	3.10	3.10	3.10	3.10
New introduction	-	-	-	-	-	-	4.94	4.94	4.94	4.94	4.94	4.94
Maintenance costs												
Germination testing	11.49	5.01	2.92	12.81	6.33	4.24	11.49	5.01	2.92	11.49	5.01	2.92
Regeneration/duplication												
25 years (w/o ini. reg.)	227.86	87.63	44.34	373.83	233.60	190.31	227.86	87.63	44.34	373.83	233.60	190.31
50 years (w/o ini. reg.)	86.29	23.90	8.38	232.26	169.87	154.35	86.29	23.90	8.38	232.26	169.87	154.35
100 years (w/o ini. reg.)	23.38	2.95	0.43	169.35	148.92	146.40	23.38	2.95	0.43	169.35	148.92	146.40
Conservation costs (25 yrs)	**343.90**	**145.94**	**83.48**	**491.19**	**293.23**	**230.77**	**351.94**	**153.98**	**91.52**	**497.91**	**299.95**	**237.49**
Conservation costs (50 yrs)	**202.33**	**82.21**	**47.52**	**349.62**	**229.50**	**194.81**	**210.37**	**90.25**	**55.56**	**356.34**	**236.22**	**201.53**
Conservation costs (100 yrs)	**139.42**	**61.26**	**39.57**	**286.71**	**208.55**	**186.86**	**147.46**	**69.30**	**47.61**	**293.43**	**215.27**	**193.58**

Note: The data in this table came from appendix D1.
[a] The germination testing was assumed to start in the 10th year and then every 5 years thereafter, except for existing accessions which start immediately.
[b] Here we assume seed samples are duplicated for back-up purposes at the time of introduction and again during each regeneration cycle.

The average cost of conserving an existing accession of wheat in perpetuity ranges from $6.10 to $20.25 when a 50-year cycle of regeneration begins in 50 years, and from $10.06 to $24.21 when the 50-year cycle begins in year zero (i.e., there is an initial round of regeneration). The present values of conservation are more sensitive to changes in the rate of interest than they are to changes in initial regeneration protocols: lower rates of interest result in higher present values of these costs streams. But the interest cost of securing this long-term commitment falls proportionally when interest rates are low. For maize, the comparable costs range from $47.52 to $202.33 per accession, absent an initial regeneration, and from $194.81 to $349.62 with an initial round of regeneration. Regeneration costs constitute a significantly larger share of the overall costs of conservation for maize than wheat, and so there are correspondingly larger cost consequences from changes in the initial regeneration protocol in maize, especially at higher rates of interest. For example, at an interest rate of 6 percent, conserving a sample of maize seed in perpetuity costs $47.52 without an initial round of regeneration and $194.81 with initial regeneration (more than a 300 percent increase in costs), compared with $6.10 and $10.06 respectively for an accession of wheat (about a 65 percent increase in costs).

These estimates are based on a 50-year cycle of regeneration in perpetuity. In fact, the longevity of seed in the new CIMMYT genebank is uncertain: 50 years seems a reasonable bet now, but (for some samples perhaps) it may be only 25 years or seeds could well remain viable for a 100 years. If the conservation objective can be achieved with a regeneration cycle of 100 years and absent an initial regeneration, the present value of an in-perpetuity commitment to conserve seed is only $9.02 per accession for wheat and $61.26 for maize at a 4 percent rate of interest. Reducing the regeneration interval to 25 years increases the costs to $11.02 for a sample of wheat and $145.94 for maize. These types of data can be used to assess the benefits from upgrading a genebank facility and thereby increasing the storage life of the seed. Lengthening the regeneration cycle from 25 to 100 years reduces the present-value average cost of conserving an accession of maize by $84.68 (i.e., 145.94 – 61.26), and by $2.00 (i.e., 11.02 – 9.02) for an accession of wheat. The cost savings from this aspect alone total $1,439,560 for the 17,000 accessions of maize and $246,000 for the 123,000 wheat accessions currently housed at the El Batan facility—more than enough to justify the funds spent on building the new CIMMYT genebank. Moreover, these savings in cost are a lower-bound estimate of the benefits from improved seed storage. They abstract from the benefits derived from increasing the safety of the collection and lowering the rates of genetic drift that resulted from moving the collection to this new facility.

Above we considered costs at either end of the conservation spectrum—the marginal costs of conserving an accession for one more year versus the average total costs of conserving an accession in perpetuity. Both types of costs are useful for different types of conservation and investment decisions. Rather than commit to conserving the collection in perpetuity, another possibility is to keep the collection for the life of the genebank—taken here to be 40 years—and then revisit the decision, considering options to abandon the holding, rebuild and perhaps extend the facility, or ship the seeds for storage elsewhere. This is a weaker type of commitment, and correspondingly the present values of the respective costs are generally lower than the costs incurred in storing the collection in perpetuity. Table 9 is identical in format to Table 8, but provides cost data tailored to a 40-year conservation profile (see appendix D2 for a more detailed breakdown of the same data). Once again, the present value of variable and capital costs is sensitive to the rate of interest: the cost savings from committing to store seeds for 40 years instead of an infinite number of years are more modest as the rate of interest increases. For example, comparing the corresponding estimates in Tables 8 and 9, the cost of conserving an accession of wheat for 40 years versus forever is reduced by more than 50 percent (from $20.25 in Table 8 to $9.52 per accession from Table 9) at a 2 percent rate of interest, compared with less than a 15 percent reduction in costs (from $6.10 to $5.24) at a 6 percent interest rate. As the interest rate increases, the discounted costs of storage beyond 40 years have smaller weight in the total cost.

Table 9 Present values of conserving accessions for the life of a genebank (40 years)

Items	Existing accession						Introduced accession					
	No initial regeneration			Initial regeneration			No initial regeneration			Initial regeneration		
	2%	4%	6%	2%	4%	6%	2%	4%	6%	2%	4%	6%
	(U.S. dollars per accession)											
Wheat												
Storage costs												
Storage	7.53	5.56	4.31	7.53	5.56	4.31	7.53	5.56	4.31	7.53	5.56	4.31
New introduction costs												
Containers	-	-	-	-	-	-	0.22	0.22	0.22	0.22	0.22	0.22
New introduction	-	-	-	-	-	-	1.69	1.60	1.60	1.60	1.60	1.60
Maintenance costs												
Germination testing	1.99	1.34	0.93	2.50	1.85	1.44	1.99	1.34	0.93	1.99	1.34	0.93
Regeneration/duplication												
25 years (w/o ini. reg.)	2.10	1.29	0.80	5.55	4.74	4.25	2.10	1.29	0.80	5.55	4.74	4.25
50 years (w/o ini. reg.)	0.00	0.00	0.00	3.45	3.45	3.45	0.00	0.00	0.00	3.45	3.45	3.45
Conservation costs (25 yrs)	**11.62**	**8.19**	**6.04**	**15.58**	**12.15**	**10.00**	**13.44**	**10.01**	**7.86**	**16.89**	**13.46**	**11.31**
Conservation costs (50 yrs)	**9.52**	**6.90**	**5.24**	**13.48**	**10.86**	**9.20**	**11.34**	**8.72**	**7.06**	**14.79**	**12.17**	**10.51**
Maize												
Storage costs												
Storage	57.20	42.20	32.70	57.20	42.20	32.70	57.20	42.20	32.70	57.20	42.20	32.70
New introduction costs												
Containers	-	-	-	-	-	-	3.10	3.10	3.10	3.10	3.10	3.10
New introduction	-	-	-	-	-	-	4.94	4.94	4.94	4.94	4.94	4.94
Maintenance costs												
Germination testing	5.15	3.46	2.41	6.47	4.78	3.73	5.15	3.46	2.41	5.15	3.46	2.41
Regeneration/duplication												
25 years (w/o ini. reg.)	88.97	54.76	34.01	234.94	200.73	179.98	88.97	54.76	34.01	234.94	200.73	179.98
50 years (w/o ini. reg.)	0.00	0.00	0.00	145.97	145.97	145.97	0.00	0.00	0.00	145.97	145.97	145.97
Conservation costs (25 yrs)	**151.32**	**100.42**	**69.12**	**298.61**	**247.71**	**216.41**	**159.36**	**108.46**	**77.16**	**305.33**	**254.43**	**223.13**
Conservation costs (50 yrs)	**62.35**	**45.66**	**35.11**	**209.64**	**192.95**	**182.40**	**70.39**	**53.70**	**43.15**	**216.36**	**199.67**	**189.12**

Note: The data in this table came from Appendix D2.

Total Costs in the Short and Long Runs

Table 10 illustrates the total costs of conserving seeds over different time horizons. Abstracting from the costs of characterizing, disseminating, or documenting seeds the *marginal variable costs* of storing the existing accessions of maize and wheat for one year are modest indeed—only $33,210 for wheat and $34,850 for maize. These marginal costs cover the cost of maintaining and operating storage equipment: they take as given, and thereby exclude fixed costs in the form of physical capital and lumpy labor inputs (defined here, as the overhead of labor in the form of management staff). Including annualized fixed costs (including a prorated overhead labor component) provides an estimate of the *average costs* of one year of storage of all accessions—for wheat the costs are $115,620, for maize they are $124,610.

A commitment to conserve the accessions for the longer run naturally carries with it a higher price tag, where the costs of conservation are taken to include the cost of storing and maintaining the viability of a collection. In present-value terms, the *total costs* of conserving CIMMYT's present maize holdings for the life of the genebank (under baseline assumptions) are $2,788,686 for the wheat collection and $3,486,180 for the maize collection, a total of $6,274,866. Committing to conserve the seeds in perpetuity costs a total of $7,953,857; $3,530,092 for the wheat collection and $4,423,765 for maize. For management and various policy and investment purposes it is useful to break out the capital costs from the other expenses. According to our estimates, the present-value equivalent of $1,807,705 is needed to underwrite the capital costs of conserving CIMMYT's current maize and wheat holdings for the life of the genebank—a

Table 10 The total costs of conserving accessions in the short and long run[a]

Items	Costs per accession				Total cost			
	Storage	Conservation	Dissemination	Total	Storage	Conservation	Dissemination	Total
				(U.S. dollars per accession)				
Wheat (123,000 accessions)								
One year	**0.94**	**7.86**	**5.00**	**12.86**	**115,620**	**160,836**	**67,500**	**228,336**
Variable	0.27	4.23	5.50	5.77	33,210	58,594	75,739	108,949
Quasi-capital	0.39	2.28	5.66	6.05	47,970	61,214	106,844	154,814
Capital	0.28	1.35	1.70	1.98	34,440	41,028	45,753	80,193
40 years	**19.29**	**81.43**	**81.13**	**162.56**	**2,372,670**	**2,788,686**	**1,095,255**	**3,883,941**
Variable	5.56	6.90	11.28	16.84	683,880	691,920	751,050	1,434,930
Quasi-capital	8.03	46.90	116.36	124.39	987,690	1,260,446	2,198,156	3,185,846
Capital	5.70	27.63	34.92	40.62	701,100	836,320	934,735	1,635,835
In perpetuity	**24.36**	**103.93**	**102.81**	**206.74**	**2,996,280**	**3,530,092**	**1,387,935**	**4,918,027**
Variable	7.02	9.81	15.67	22.69	863,460	882,104	961,214	1,824,674
Quasi-capital	10.14	59.22	146.96	157.10	1,247,220	1,591,596	2,776,086	4,023,306
Capital	7.20	34.90	44.11	51.31	885,600	1,056,392	1,180,727	2,066,327
Maize (17,000 accessions)								
One year	**7.33**	**198.34**	**22.03**	**220.37**	**124,610**	**250,560**	**83,714**	**334,274**
Variable	2.05	149.34	155.39	157.44	34,850	116,695	139,685	174,535
Quasi-capital	3.08	32.94	47.17	50.25	52,360	86,635	140,709	193,069
Capital	2.20	16.06	17.81	20.01	37,400	47,230	53,880	91,280
40 years	**150.84**	**1,054.9**	**349.71**	**1,404.00**	**2,564,280**	**3,486,180**	**1,328,898**	**4,815,078**
Variable	42.20	45.66	66.51	108.71	717,400	731,240	810,470	1,527,870
Quasi-capital	63.41	678.08	970.98	1,034.39	1,077,970	1,783,555	2,896,575	3,974,545
Capital	45.23	330.55	366.51	411.74	768,910	971,385	1,108,033	1,876,943
In perpetuity	**190.52**	**1,359.8**	**443.30**	**1,803.08**	**3,238,840**	**4,423,765**	**1,684,540**	**6,108,305**
Variable	53.30	85.79	113.71	167.01	906,100	944,050	1,050,146	1,956,246
Quasi-capital	80.09	856.47	1,226.43	1,306.52	1,361,530	2,252,735	3,658,583	5,020,113
Capital	57.13	417.52	462.94	520.07	971,210	1,226,980	1,399,576	2,370,786

[a] Presuming a 50 year regeneration cycle (without initial regeneration) and a 4 percent rate of interest.

total of $2,238,372 if the seeds are conserved in perpetuity and the genebank facility and other capital items are replaced on a recurring basis as needed.

Setting aside the cost of capital, it takes $4,467,161 in total labor (including the labor of senior scientific staff) and operating costs to conserve the entire wheat and maize holdings for 40 years, $5,670,485 if the seeds are saved in perpetuity. This figure includes much more than the labor and operational costs required to simply store the seeds in the genebank. It factors in the costs of checking the viability of the seeds, periodically regenerating the samples (here, the regeneration cycle was presumed to be 50 years, although a certain share of seed is regenerated each year, reflecting the varying time in storage and the respective regeneration histories of each accession), plus the data-management costs required to manage the collection.

Separate from these costs are the costs of disseminating the seeds, usually on request to breeders and others outside of CIMMYT, although a sizable share is taken from the genebank by the managers themselves for prebreeding characterization purposes and for backup storage at an off-site facility. If the genebank continued to distribute seed at the rate typical of the past few years, this dissemination function alone would cost about $2,424,153 in present-value terms over a 40 year time horizon, and $3,072,475 in perpetuity.

Bundling all these costs together (i.e., including the seed storage, regeneration, duplication, information management, and dissemination activities) we estimate that the capital, labor, and operational costs combined would total $8,699,019 over the life of the genebank and $11,026,332 in perpetuity. This represents the amount of money that would need to be set aside (at a 4 percent real rate of interest) to underwrite genebank activities at their current levels over the longer run, a sizable but not an especially large sum of money.

Economies of Size, Scale, and Scope

In addition to the 600,000 accessions held in the 11 genebanks maintained by the CGIAR, there are at present about 5.6 million accessions stored in 1,308 genebanks worldwide (FAO 1998). Is there any economic gain to be had from consolidating these holdings into fewer facilities? A sense of the size of the gains from consolidating the world's wheat and maize collections can be had from the CIMMYT data. By world standards, the CIMMYT holding is large, but not the largest. The Institute of Crop Germplasm in China has a total of about 300,000 accessions in long-term storage while the National Seed Storage Laboratory in the United States holds 268,000 seed samples in its collection (FAO 1998).

Returning to Table 6, the right-hand set of columns gives the average annual cost of conserving the CIMMYT collection presuming the genebank were full to capacity—specifically storing 390,000 wheat accessions (compared with 123,000 presently) and 67,000 maize accessions (17,000 now). Operating the genebank at full capacity and allowing for savings through size and scale economies would involve an estimated annual cost of storage (net of regeneration and other expenses) of $414,420, compared with the annual storage costs of the facility at its current capacity of $240,230 (table 6). However, if the genebank at full capacity were operating with the cost structure at current capacity, the annual storage costs would be $857,710. This constitutes an annual saving in costs of $443,290 ($179,247 for the wheat holding and $264,043 for maize) compared with storing the same number of seeds, say, in two separate facilities at the average per accession costs currently experienced by the CIMMYT genebank. These savings come from significantly increasing the size of the holding but with no corresponding increase in the annual fixed and quasi-fixed costs of storage.

Our calculations imply some sizeable economies to centralizing storage of all cultivars of a crop and avoiding excessive duplication of storage facilities. Given the relatively modest cost of black-box or other forms of safety duplication, conservation economics and security imperatives can be jointly satisfied with one central genebank and duplicates held in other different parts of the world. One possible scenario is to set up one central genebank for long-term conservation and various local genebanks for active collections. However, the best scenario depends on transport and communication costs, on the relative conservation costs of active collections and long-term collections, as well as on the different effects of the environment on different crops, issues for further study. At least one duplicate set should be at a location in which the prospect of political embargoes, military actions, or terrorism that could disrupt international access is extremely remote.

We find that the investments in the facility and its equipment are dominated by the quasi-fixed labor inputs and the variable costs, especially those operating costs (such as the costs incurred with new seed introductions, germination testing, and regeneration) that are not directly determined by the total number of accessions held in storage. The current excess capacity of the genebank facility does not necessarily mean that the facility was built too large: within certain ranges, many of the physical capital costs are probably not highly sensitive to size, and the surface-to-volume ratio declines with size so storage costs increase less than proportionally to the size of the facility as we have illustrated. By our estimates, the annualized cost of storing seed is about 58 percent of the total cost conserving CIMMYT's wheat and maize collection. The capital-intensive, well-insulated storage facility helps economizes on refrigeration costs and facilitates long cycle-times between costly regenerations. Thus the high, upfront investment in durable inputs is the price paid for subsequently lower variable costs of conserving the seeds.

The above issue on economies of scale in which possible benefits arise from consolidating of a specific crop (say, wheat) in a single facility, can be extended to the issue of economies of scope in which benefit may arise from aggregating different crops in a single facility. At CIMMYT, the quite distinct needs of wheat (and related small grains) and maize are met by one facility with provisions for both. Economies of scope appear to be significant, and anecdotal evidence suggests that advantages of joint learning also appear to be significant. Moreover, these scope economies extend beyond the genebank per se to include cost savings from linking various genebank functions (such as seed health testing and regeneration activities) with the CIMMYT breeding program. These scope economies, and the likely spillovers of tacit knowledge between breeders and genebank managers, mitigate against consolidating genebank accessions in a central location distant from associated crop-improvement activities.

Conserving Seeds Versus Conserving Biodiversity

The large differences in average and marginal costs between wheat and maize accessions should be interpreted with care. The conservation cost per accession is not the same as the conservation cost per unit of genetic diversity. Wheat accessions are typically highly homogenous so that the diversity in wheat collections is mainly between rather than within accessions. Open-pollinated crops such as maize, on the other hand, are highly heterogeneous, and each accession contains a wealth of genetic diversity. Indeed, the high cost of regeneration for maize accessions is related to the care that must be taken to maintain this diversity through several cycles of regeneration over coming centuries. Thus, though the conservation cost per unit of accession for maize is significantly larger than the cost for wheat, the cost per “unit of diversity” for maize is not necessarily higher than that for wheat. A simple comparison of the costs per accession among different crops is likely to be hazardous.

5.3 RELATION TO OTHER GENEBANK COST STUDIES

The evaluation of the costs of the maize and wheat genebanks in the common CIMMYT facility shows clearly that comparison of per-accession costs across different crop species is likely to be misleading as an indicator of the costs of conservation of genetic diversity. But discussion of different crops helps illustrate the variety of considerations that affect genebank management and evaluation. We are fortunate in having two other case studies to consider, one for the costs of a cassava genebank at Centro Internacional de Agricultura Tropical (CIAT) in Colombia, by Epperson, Pachico, and Guevara (1996), and one for a sweet potato genebank in Georgia, United States, by Jarret and Florkowski (1990).

Cassava and sweet potatoes are very different crops from wheat or maize. Being clones, the amount of diversity conserved per accession is also quite different. In addition, the technical setting of a field genebank is quite different. As in CIMMYT's *Tripsacum* field genebank mentioned above, regeneration problems do not arise. On the other hand, the annual replanting of these crops leaves room for errors of identification and confusion of adjacent plots, attack by field pests, and so on. Cassava is traditionally conserved in a field genebank, in which the crop is maintained by replanting year after year. The average total cost (Epperson et al., Table 3) was calculated at $17.09 per accession. Due to the labor-intensive nature of operating a cassava field genebank, the share of variable costs is greater than that of fixed cost: $10.50 versus $6.59. Maintaining a field bank for cassava involves activities that are similar to regenerating accessions held in *ex situ* collections like those of wheat and maize.

Focusing on the regeneration activities in Table 6, the comparable breakdown of costs are $3.16 and $1.38 of variable and fixed costs respectively for wheat and $142.39 and $32.70 for maize. Clearly variable costs are also the predominant share of total costs in the CIMMYT genebank, although the total cost per accession and their respective variable-fixed cost shares differ markedly for each crop. However, direct comparison of these figures is misleading, not least since Epperson et al. included characterization and evaluation activities in their cost estimates, whereas our conservation cost estimates, by design, do not.

A more instructive comparison drawn by Epperson et al. is the cost difference between the cassava field genebank just discussed and the *in vitro* cassava genebank. At CIAT, some of the facilities necessary for *in vitro* conservation are also used for virus cleaning, an operation required for worldwide distribution of germplasm from either genebank. In addition, the specialized labor and structures required for the *in vitro* genebank had excess capacity at current levels of operation, and were therefore treated as fixed costs. This means that although the average total cost, at $26.22 per accession per year, was higher than the field genebank ($17.09 per accession per year), the average variable cost at $1.85 per accession, is less than 20 percent of the equivalent figure for the field genebank ($10.50). Taking the average variable cost to be an upper bound of the corresponding marginal cost, the cost of placing an additional accession in each genebank is dramatically different, though the average total costs are quite similar. Thus the benefit of using modern methods to detect duplication of cassava accessions is dramatically higher if the accessions are duplicates in the field rather than *in vitro*. However, plants stored *in vitro* must be replanted in the field at regular intervals to maintain vigor, and so the optimum system would require that some portion of the accessions be located in a field genebank at any time.

Another earlier comparison of field and *in vitro* genebanks is the study by Jarret and Florkowski of the conservation of sweet potato (*Ipomoea batatas*) in Georgia. Though their study contains a wealth of informative detail about the two conservation methods, the discussion of the actual costs of operating a genebank is very limited. The study reports only the average annual cost of machinery and equipment at $28 per accession for field conservation (p. 143) and $22 for *in vitro* conservation (p.144), without considering more substantial costing elements such as labor, other facilities, chemical costs, and so on. Inclusion of the costs of labor and other building facilities may substantially increase the average cost for both types of conservation to several hundred dollars, given the small number of accessions conserved (1,000 samples) and the comparatively high cost of U.S. labor.

Meaningfully comparing the data from these two studies with the cost evidence assembled for this study is fraught with difficulties. Aside from substantial differences in the span of inputs and conservation activities considered and the classification of cost into their fixed and variable components, neither of these two studies sought to distinguish between costs in the short versus long run. The *raison d être* for a genebank is as a repository to guarantee continued availability of seeds for future generations. Thus properly dealing with the long-run structure of the costs of these operations, with the repeated rounds of regeneration and the replacement of capital required to maintain the viability of the collection over the long haul, is central to an economic assessment of a genebank.

6. CONCLUSION

The first lesson to be learned from this study is that genebank budgets give a poor account of the costs of conserving germplasm. In CIMMYT's case, the budgets controlled by the genebank managers represent about 45 percent of the total annual costs of conserving the collection, including the costs of storing, regenerating, and duplicating the seed. Second, the marginal variable costs of holding on to an accession for one more year are substantially lower than the average total costs of conservation and the costs are highly sensitive to the crop being considered. Generally the per-accession costs (but not necessarily the cost per unit of genetic diversity) are much higher for maize than wheat, reflecting differences in the size of the seeds, the growth habit of the plant, and the demands placed on careful conservers striving to minimize the incidence of genetic drift when regenerating a heterogeneous, out-crossing crop like maize.

We estimate the marginal variable cost of conserving an accession of wheat for one more year is just 27 cents, and for maize is $2.05. This cost includes the costs of the electricity and labor for operating the storage plant and equipment, but not the corresponding capital costs, nor the costs of replenishing, germination testing, or regenerating a holding. The average total costs for holding on to an accession for an additional year (i.e., including all the variable costs and the annualized cost of capital) is 94 cents per accession for wheat and $7.33 for maize if the seed samples are viable and need no regeneration. If regeneration is required the average cost per accession rises to $4.61 for wheat and $151.04 for maize.

Advances in technology have eliminated much of the location-specificity of *ex situ* genebanks. Complete climate control means independence from local weather when storing the seed, and advances in communications mean the bank should in principle be accessible worldwide if it is served by modern telecommunications and express mail facilities. Regeneration requirements may place a premium on location, but decisions as to where to physically store the seed and where to regenerate it are separable. Thus, if questions of security and freedom from phytosanitary controls and political interference in access can be satisfactorily resolved (and presuming the benefits in knowledge spillovers among breeders and genebank managers working in close proximity are negligible), the argument for consolidating the holdings of crops held in genebanks worldwide in just one site seems economically compelling. By way of example, we estimate that the costs of storing seed in the CIMMYT facility operating at full capacity (i.e., 390,000 wheat accessions and 67,000 accessions of maize) would annually save $443,290 through size and scale economies alone, compared with the annual costs of storing the same amount of seed, say, in two facilities with cost structures equivalent to the CIMMYT facility operating at its current capacity (123,000 wheat and 17,000 maize accessions). In present value terms this would generate a cost saving in the order of $9.12 million over the 40-year life of the genebank (assuming a 4 percent rate of interest). The physical security problem seems solvable by present black-box or other off-site arrangements for storing duplicates. If the political and phytosanitary risks are not eliminated, perhaps a second, long-term, world-conservation facility may be necessary. In any event, failure to consolidate holdings (at least among the CGIAR genebanks) carries with it a hefty price tag in terms of foregone cost savings.

Genebanks are generally seen as a means of conserving seeds for the long run. Taking this idea at face value, we estimated the costs of conservation over various time horizons stretching from one year to forever. Keeping CIMMYT's present collection intact for the life of the genebank would cost a total of $6.27 million in present-value terms under baseline assumptions about the rate of interest and various regeneration and other conservation protocols—$2.79 million for the wheat collection and $3.48 million for the maize collection. This includes the costs of the genebank facility, the periodic replacement of equipment as it wears out, and the annual costs of the labor and materials required to store, germinate test, and regenerate seed as necessary. Holding the collection in perpetuity (with periodic capital replacement) would up the total cost to $7.95 million.

Common wisdom would suggest that conserving seeds is a capital-intensive affair. Our figures show this is not the case. While CIMMYT's facility represents a sizeable investment in buildings, plant, and equipment totaling about $1.62 million, the annualized cost of capital represent 22 percent of the annual costs of the operation compared with 60 percent going to labor expenses. Other operational costs make up the remaining 18 percent. In fact it is the lumpy labor costs of senior scientific and technical staff (at 40 percent of the annual costs) that are the largest fixed or quasi-fixed component of the genebank costs. Taking a long-run perspective, it would require an endowment of $2.28 million earning 4 percent rate of interest to underwrite the capital costs for the CIMMYT genebank into perpetuity (including the periodic replacement of the genebank buildings and related equipment). To underwrite *all* the conservation and dissemination costs of the CIMMYT genebank at its present scale of activity into perpetuity would involve an endowment totaling $11.03 million ($7.95 million for conservation and $3.08 million for dissemination). Given the importance of the conservation of germplasm into the next millennium, such an endowment appears to be a bargain as an investment on behalf of coming generations.

APPENDIX A

Notes for Tables 2-4

All costs are in 1996/97 U.S. dollars. Peso denominated costs were converted to U.S. dollars at the rate of $1.00 = 7.8 pesos.

Table 2: Capital Input Costs

All capital costs represent the current purchase (i.e., replacement) cost of the items involved. Some costs were not attributable to the wheat or maize operations. They are reported ascommon costs" and allocated on a 50-50 basis between the two programs. Annualized costs presented in the two right-hand columns were calculated by multiplying the replacement costs by the appropriate discount factors. The discount factors were derived by using equation (5) in appendix C, a 4 percent rate of interest, and the respective service lives. For example, the discount factors for 5, 10, 15, 20, 30, and 40 years of service life are 0.216, 0.118, 0.865, 0.708, 0.055, and 0.048, respectively.

Storage

Storage facility. Costs of constructing the active and long-term storage facility were taken from consolidated costing figures developed by GAO consultants and provided by CIMMYT's finance office. Major cost elements include $351,034 for construction material and labor, $225,000 for shelving, and $93,237 for thermal panels.

Refrigeration equipment. Costs of purchasing and installing pumps, compressors, fans, ducting, and so on in the new genebank facility.

Backup power equipment. This equipment is used mainly, but not exclusively, as a backup power option for the genebank facility in the event of a power grid failure. The figure reported here is 80 percent of the total cost of the equipment (based on advice from

CIMMYT facilities personnel as to the appropriate share of these costs allocable to the genebank).

Seed containers. Wheat uses aluminum bags for active and long-term storage, and maize uses a plastic container for active storage and two aluminum bags per accession for long-term storage. For wheat, 11 cents per aluminum bag x 123,000 accessions x 2 bags per accession (active and long-term storage). For maize, $2.80 per one-gallon plastic bucket x 17,000 accessions for active storage, plus 15 cents per bag x 2 bags per accession x 17,000 accessions for long-term storage.

Seed Health

Seed health facility. Total area of the buildings occupied by the seed-health unit is 45.51 sq. m., and the construction cost per square meter is $400. Twenty percent of this cost was attributed to the genebank operations—in 1998 the seed health unit processed a total of 51,170 accessions, including 9,620 accessions for the genebank.

Laboratory equipment. Based on a detailed, item-by-item accounting of the laboratory equipment in the seed-health unit, we estimated the replacement cost of this equipment totaled $145,064, of which 20 percent was assigned to the genebank operations.

Jacuzzi equipment. Cost of this custom-built piece of equipment and associated compressors totaled $16,794 (pool $3,717; trays $8,076; and compressor $5,000). This gear is used for treating wheat accessions shipped from the genebank as well as seed samples distributed via the international wheat nursery system. Based on the average weight and deployment of seed during 1997 and part of 1999, we estimated that about 4 percent of the accessions treated each year are from the genebank, and so this share was used to prorate the total cost.

Germination testing

Germination chamber. Used to maintain a controlled temperature regime for the germination of seeds. Maize and wheat each have one germination chamber costing $6,000 per unit.

Vernalizer. Used by the wheat program to hold seeds at the low temperatures required to replicate the cold-weather period necessary for germinating some varieties of wheat (cost is $6,000).

Regeneration

Screenhouse. Cost of a single, stand-alone, plastic-fabric-on-metal-frame structure at El Batan, measuring about 2,000 sq. m.

Seed cleaning equipment. Includes a seed scale ($1,985) for maize and wheat, a seed counter for wheat ($5,325), and a sheller ($4,465) for maize.

Drying chamber. Includes one seed dryer ($25,000 each) for wheat located at El Batan and two seed dryers for maize (one at El Batan, the other at Tlaltizapan).

General capital inputs

Ancillary genebank structures. Wheat includes 3 offices (total 46.23 sq. m.), 3 work rooms (83.55 sq. m.), 1 secretarial office shared with maize (7.68 sq. m.), and one seed laboratory shared with maize (30.5 sq. m.)—a total of 148.87 sq. m. Maize includes 3 offices (46.25 sq. m.) and 4 work rooms (72.83 sq. m)—a total of 138.17 sq. m. All costed at $400 per square meter.

Vehicles. Two vehicles for wheat and three for maize, plus 20 percent of one vehicle used by the seed health unit allocated equally to each crop ($21,425 per vehicle).

Miscellaneous capital. Includes furniture and fixtures (shelving etc.) for office and work rooms of the CIMMYT genebank. We also included 20 percent of the replacement cost of the office equipment used by the seed-health unit (0.2 x $2,938). Computers were costed on an annual rental basis in line with CIMMYT's present charge-back procedures, and so were directly included in Table 3 on an annual, rental-cost-equivalent basis.

Table 3: Storage and Related Costs

Representative labor costs used in our calculations are the following—internationally recruited scientist: $124,600 per annum ($70,000 plus 78 percent fringe benefits such as pension, health benefits, home leave allowances, etc.); locally recruited specialist: $19,200 per annum ($12,000 plus 60 percent fringe benefits); secretary: $16,000 per annum ($10,000 plus 60 percent on-cost); assistant labor: $520 per month ($325 per month plus 60 percent fringe benefits); unskilled daily labor: $260 per month ($200 per month plus 30 percent fringe benefits).

Overhead

The genebank facility is part of a more general CIMMYT operation, and thereby draws benefit from this association. Thus our cost calculations include the genebank's appropriate share of the common oroverhead" costs incurred by CIMMYT. In 1998, CIMMYT's audited overhead rate was 30 percent (calculated as a loading on CIMMYT'soperational" not total budget). With help from CIMMYT's director of research we removed or reduced those cost categories included in the center's general overhead rate that would lead to an implicit double counting by dint of us having direct costed some of these elements. The remaining elements in the adjusted overhead rate of 22.13 percent used for this study are research support (systems and computing services, 1.12 percent; biometrics, 0.76 percent; hardware maintenance, 0.01 percent; soils and plant laboratory, 0.11 percent; El Batan station, 1.32 percent), information services (external relations, 1.02 percent; donor relations office, 0.24 percent; publications, 1.65 percent; library, 1.04 percent), and administration (administration finance, purchasing, human resources, visitor services, 10.68 percent; plant operation, 3.03 percent) and depreciation, 1.15 percent (one quarter of the 5.77 percent general depreciation allowance, representing the residual share of general depreciation charges attributable to the genebank).

Storage

Nonlabor costs of storage ($9,926 for temperature control, $12,818 for humidity control, and $300 for alarms and security) represent the electricity costs for running the respective equipment, calculated by estimating the number of kilowatt hours per annum for each piece of equipment x 6.7 cents per kilowatt hour in consultation with CIMMYT facilities personnel.

Labor costs of $3,120 for alarms and security represent the cost of a security guard for one year. The costs for maintenance includes refrigeration ($3,120; 1 unskilled daily laborer for 1 year), electricity ($6,240; 2 daily laborers each for one year), and cleaning ($1,040; 4 months of daily labor).

Information and Data Management

Costs incurred for the data entry and analysis involved in the upkeep and maintenance of genebank data records.

Labor cost of maintaining database for maize ($15,528) includes 1.75 assistant years (21 months) at $520 per month plus 24 percent of specialist labor (0.24 x $19,200). The cost for wheat includes 6 months of data entry ($3,120) and 3 months of data processing ($1,560) by assistant labor and 6 months of management by a specialist ($9,600 = $1,600 per month x 6 months), which at the time of this study were all drawn from staff in the CIMMYT wheat improvement program.

Catalog management costs for additional software and database development involve services rendered by CIMMYT's computer programming staff (3.19 programmer months for maize and 2.33 months for wheat charged at a rate of $1,918 per programmer month).

General Management

Managerial staff. Includes labor costs of genebank staff not elsewhere included in Tables 3 and 4. Core staff for the wheat program include an internationally recruited scientist, 3 locally hired assistants (high school diplomas or equivalent), and a secretary (shared on a 50-50 basis with maize), all based at El Batan. The maize program includes an internationally recruited scientist, a locally hired specialist, and 3 locally hired assistants based at El Batan, plus an assistant based at Tlaltizapan. All relevant costs of assistants are directly charged to the various activities detailed in Tables 3 and 4. Eighty percent of managerial staff time was charged against the activities included in this study. The managerial cost for wheat is $107,680 ($124,600 for internationally recruited scientist x 80 percent, plus half a secretary $8,000). The cost for maize includes 80 percent of internationally recruited scientist ($99,680), plus half a secretary ($8,000), plus 56 percent of a specialist ($10,752). Twenty percent of the cost of managerial staff for the seed health unit was also allocated equally among the two crops. This includes 60 percent of an internationally recruited manager ($74,760), one local specialist ($19,200), and half a secretary ($8,000).

Computers. Wheat program includes 3 computers and the maize program includes 4 computers, plus a computer shared between the two programs @ $1,400 per computer per year (as per CIMMYT's internal charge-back rate). Twenty percent of the two computers used by the seed-health unit that are attributed to the genebank operation.

Miscellaneous expenses. Includes office-related expenses, telephone bills, etc.

Table 4: Costs of Maintaining Genebank Accessions

The costs included in this table are sensitive to the number of accessions being treated, a number that fluctuates from year to year. Our approach was to compile these costs and the corresponding number of accessions (as indicated in brackets below) for the primary survey year 1996 (except the seed health costs and associated accession numbers which are for 1998) as a basis for estimating a per accession cost. Some subsequent calculations in this paper use an annual average accession figure (typically an average for the three years 1996-98) to scale up these per unit costs. The base costs are net of overheads and so the adjusted overhead rate of 22.13 percent was applied to each of the implicit subtotals of the respective cost categories.

New Introduction

(5,800 accessions of wheat and 1,580 accessions of maize in the survey year)

Seed-health testing. Includes costs for testing incoming accessions incurred by the seed-health unit. In 1998, the seed-health unit tested a total of 20,000 incoming accessions (12,750 wheat and 7,250 maize) and 31,170 outgoing accessions (29,360 wheat and 1,810 maize), including accessions destined for the genebank as well as the movement of seed in conjunction with the breeding program. The annual labor cost was $28,480 (one technician, $16,000 and two assistants, $6,240 x 2), and the non-labor costs were $42,000. In general, over the longer run, about 70 percent of these costs relate to the testing of incoming accessions and 30 percent pertain to outgoing accessions (and there is thought to be little, if any, difference in determining the seed-health status of a wheat or a maize accession). However, based on the total number of accessions tested by the seed-health unit in 1998 (i.e., 20,000 incoming accessions and 31,170 outgoing accessions), we opted to assign 60 percent of the 1998 seed-health costs to screening incomings and 40 percent for outgoings. Based on this breakdown for this year, the labor costs for screening an incoming accession are estimated to be 85 cents (0.6 x $28,480 ÷ 20,000 accessions) and 37 cents for each outgoing accession (0.4 x $28,480 ÷ 31,170 accessions). The corresponding non-labor costs are $1.26 for each incoming accession and 54 cents for each outgoing accession.

From the total number of wheat accessions introduced in the sample year (5,800), about 40 percent (2,320 accessions) were obtained from outside Mexico and were therefore subject to seed health checks. Thus for wheat the total labor costs are $1,972 (85 cents x 2,320 accessions) and the non-labor costs are $2,923 ($1.26 x 2,320 accessions). For maize the total labor costs are $1,343 (85 cents x 1,580 accessions) and $1,991 ($1.26 x 1,580 accessions) for non-labor.

Seed handling. Includes activities such as drying, packing, and storing seed when new samples are not regenerated. One month of assistant labor is required for each crop.

Germination testing

(12,000 accessions of wheat and 3,400 accessions of maize in the survey year)

Labor. Labor costs for wheat represent 3.8 months of an assistant laborer @ $520 per month plus 3 months of an unskilled laborer @ $260 per month. The cost for maize includes 2 months of an assistant.

Nonlabor. Includes chemicals and other testing supplies.

Regeneration

22,000 accessions for wheat—an exceptionally high rate of regeneration due to dealing with Karnal bunt problems when transferring material from the old to the new genebank facility—and 650 accessions for maize in the survey year

Screenhouse. Labor cost for wheat includes 5.1 assistant labor months ($520 x 5.1) plus 4 unskilled daily labor months ($260 x 4). Nonlabor cost includes costs of fertilizer, plastic, and irrigation water.

Field. Field cost estimates were developed by first calculating arepresentative" per hectare cost for preparing, planting, and managing a crop. As outlined in appendix Tables B1 and B2, summing across these cost components gave a total of $1,073 per hectare for El Batan (where both wheat and maize are regenerated) and $1,009 per hectare for Tlaltizapan (where some of the maize holdings are regenerated). The corresponding figure for Mexicali was $1,217 per hectare where only a total cost figure was available. These costs include the cost of herbicides, insecticides, fertilizers, equipment use, as well as field labor and various other materials costs. The labor component of these cost estimates was $333 per hectare for El Batan, $426 for Tlaltizapan, and $450 for Mexicali. To this was added an imputed land rental rate of $256 per hectare obtained from CIMMYT's field station manager. To regenerate 22,000 accessions, wheat used 4 hectares in Mexicali and 2 hectares in El Batan. The 650 accessions of maize were regenerated over 2 cycles of 2.5 hectares per cycle at Tlaltizapan and one cycle of 1.5 hectares in El Batan.

In addition to the hired field labor included in the per hectare costs detailed in appendices B1 and B2, there are additional labor inputs from genebank staff to manage the crop. Wheat used 40 months of unskilled daily labor ($10,400) plus 11.4 months of assistant labor ($5,928). Inclusive of the field labor costs of $2,466 (calculated as 4 hectares @ $450 per hectare in Mexicali plus 2 hectares @ $333 per hectare in El Batan), the total labor cost for wheat is $15,986. Maize used 36 months of unskilled daily labor ($9,360) and 8 months of assistant labor ($4,160) in Tlaltizapan, and 32 months of unskilled daily labor ($8,320) and 5 months of assistant labor ($2,600) in El Batan. Inclusive of the field labor cost of $2,630 (calculated as 5 hectares @ $426 per hectare in Tlaltizapan plus 1.5 hectares @ $333 per hectare in El Batan), the total labor cost for maize is $27,070.

The nonlabor field cost for wheat is $4,548 (4 hectares @ $767 per hectare in Mexicali plus 2 hectares @ $740 per hectare in El Batan), and imputed land cost is $1,536 (6 hectares @ $256 per hectare). Nonlabor field cost for maize is $4,025 (5 hectares @ $583 per hectare in Tlaltizapan plus 1.5 hectares @ $740 per hectare in El

Batan), and land cost is $1,664 (6.5 hectares @ $256 per hectare). To control cross pollination, maize also used a glassine bag (3 cents per bag) and a pollen tector bag (0.8 cents per bag) for each plant. Since 40,000 plants are established per hectare, the cost of these bags per hectare is $1,520 (3.8 cents x 40,000). The total non-labor cost for maize is $15,569 ($4,025 for nonlabor field costs, $1,664 for land rental, plus $1,520 per hectare for bags x 6.5 hectares).

Transport. Nonlabor costs for wheat include $897 to air freight seed from El Batan to Mexicali, plus $1,410 to haul regenerated seed by truck back to El Batan, plus $1,711 for travel and related costs of El Batan staff working at the Mexicali site ($600 on plane tickets, $150 on return travel costs, and $961 for per diems). The cost for maize ($550) is for shipment of seed from Tlaltizapan to El Batan

Seed cleaning. Labor cost for wheat includes 8 assistant months plus 12 unskilled daily labor months, totaling $7,280. Labor cost for maize is 4 assistant months plus 16 unskilled daily labor months in Tlaltizapan, totaling $6,240; and 2 assistant months plus 8 unskilled daily labor months in El Batan, totaling $3,120. Nonlabor cost for maize includes bags, envelopes, and fungicides.

Seed drying. Labor cost for wheat includes 1.4 assistant month plus 2 unskilled labor months, a total of $1,248. Labor cost for maize includes 2 assistant months and 4 unskilled labor months, a total of $2,080. Non-labor costs for both wheat and maize represent electricity costs for running the dryers: $8,591 for wheat and $7,510 x 2 dryers for maize.

Seed containers. The container cost for wheat is $4,840 (22,000 accessions x 2 bags @ 11 cents per bag for active and long-term storage), and the cost for maize is $98

(650 accessions @ 15 cents per accession for long-term storage only, since maize reuses plastic buckets for seed stored in the active part of the collection).

Dissemination

(14,220 accessions and 31 shipments for wheat and 3,680 accessions and 69 shipments for maize.)

Seed health. The average labor cost for an outgoing accession is 37 cents and 54 cents of nonlabor expenses (see New Introduction category above). From a total of 14,220 wheat accessions distributed by the genebank, only 1,330 accessions were screened by the health unit and sent outside of CIMMYT. Thus the seed-health costs for wheat are $492 (37 cents x 1,330 accessions) for labor and $718 (54 cents x 1,330 accessions) for nonlabor. There were 910 out-of-CIMMYT maize accessions distributed, and the corresponding figures are $336 (37 cents x 910 accessions) and $491 (54 cents x 910 accessions). The Jacuzzi treatment is only applicable for outgoing wheat accessions. The total annual costs for treating seed in the Jacuzzi equipment was $2,240 for labor and $12,253 for nonlabor, of which only 4 percent ($90 and $490 respectively) were attributable to the genebank operation based on the quantity and disposition of seed treated in 1997 and part of 1999.

Packing and shipping. 1.3 assistant labor month is required for wheat and 1 assistant labor months for maize. Nonlabor costs are material costs totaling $188 for wheat (1 cent per bag x 14,220 accessions + $1.50 per box x 31 shipments) and $140 for maize (1 cent per bag x 3,680 accessions + $1.50 per box x 69 shipments). Shipping costs were $2,000 for wheat and $5,000 for maize.

Phytosanitary certification. Labor includes time of CIMMYT staff spent filling out paperwork and arranging shipments (1.5 assistant month for wheat and 1 month for maize). Nonlabor represents $26 per shipment for phytosanitary certificate (payable to the Mexican authorities). Wheat had 22 shipments out of Mexico in 1996, and maize had 41 shipments.

Duplication

(35,000 accessions for wheat and 2,230 accessions for maize.)

Labor. One assistant can process 500 wheat accessions per day (70 days @ $26 per day = $1,820), and 100 maize accessions per day (22.3 days @ $26 per day = $580).

Nonlabor cost for wheat includes the cost of the storage bags (35,000 accessions @ 11 cents per bag = $3,850), the cost of the shipping containers (36 boxes @ $1.50 per box = $54), plus shipping costs of $342. Maize costs include the cost of the storage bags (2,230 accessions @ 56 cents per bag = $1,249), the shipping containers (110 boxes @ $1.50 per box = $165), plus shipping costs of $2,000.

APPENDIX B1

Table B1 Field costs for regenerating wheat and maize accessions at El Batan

Activities	Labor	Non-labor	Total
	(U.S. dollars per hectare)		
Initial land preparation			
Clearing	7	19	26
Rake	10	28	38
Ripping	11	27	38
Fertilizer	16	148	164
Rows	5	14	19
Incorporating fertilizer			
Making beds	5	14	19
Sewing	11	27	38
Irrigation	-	15	15
Labor	51	-	51
Pest control (initial application)			
Brominal	-	38	38
Topik	-	109	109
Estarene	-	46	46
Basgaran	-	40	40
Lorsban	-	32	32
Weeding			
Cultivation	11	27	38
Irrigation	-	46	46
Labor	78	-	78
Pest control (at harvesting)			
Folicur	-	52	52
Tilt	-	58	58
Labor	128	-	128
Total	**333**	**740**	**1,073**

APPENDIX B2

Table B2 Field costs for regenerating maize accessions at Tlaltizapan

Activities	Labor	Non-labor	Total
		(U.S. dollars per hectare)	
Initial land preparation			
Chop and incorporate residues	17	39	56
Disk and plow	7	33	40
N fertilizer	-	94	94
P fertilizer	-	27	27
Incorporation	2	5	7
Planting			
Making beds	6	5	11
Seed covering	7	3	10
Pre-emergent herbicide	-	73	73
Irrigation	12	21	33
Birdman	287	-	287
Insecticide			
Ambush	-	31	31
Pounce	-	46	46
Lorsban	-	26	26
Application	36	5	41
Post-seeding			
Irrigation	30	75	105
Cultivation	13	2	15
Fertilizer	-	93	93
Incorporation	9	5	14
Total	**426**	**583**	**1,009**

APPENDIX C

The Annuity Cost of Capital Purchased with Replacement

The present value of outlays on a capital item with life *n* purchased at time zero for *X* dollars and repurchased every *n* years is given by:

$$PV_0^n = X + \frac{X}{(1+r)^n} + \frac{X}{(1+r)^{2n}} + \frac{X}{(1+r)^{3n}} + \ldots$$
$$= X\left[1 + \frac{1}{(1+r)^n} + \frac{1}{(1+r)^{2n}} + \frac{1}{(1+r)^{3n}} + \ldots\right]$$

$$PV_0^n = \left[\frac{1}{1-a^n}\right]X \qquad \text{where } a \equiv \frac{1}{1+r} < 0 \tag{1}$$

The present value of a capital item with life *n* purchased at time *n* for *X* dollars and repurchased every *n* years is given by:

$$PV_n^n = \frac{X}{(1+r)^n} + \frac{X}{(1+r)^{2n}} + \frac{X}{(1+r)^{3n}} + \ldots$$
$$= \frac{X}{(1+r)^n}\left[1 + \frac{1}{(1+r)^n} + \frac{1}{(1+r)^{2n}} + \frac{1}{(1+r)^{3n}} + \ldots\right] = a^n X\left[\frac{1}{1-a^n}\right]$$

$$PV_n^n = \left[\frac{a^n}{1-a^n}\right]X \tag{2}$$

The present value of outlays on a capital item purchased at time *k* for *X* dollars and repurchased every *n* years is given by:

$$PV_k^n = \frac{X}{(1+r)^k} + \frac{X}{(1+r)^{k+n}} + \frac{X}{(1+r)^{k+2n}} + \frac{X}{(1+r)^{k+3n}} + \ldots$$
$$= \frac{X}{(1+r)^k}\left[1 + \frac{1}{(1+r)^n} + \frac{1}{(1+r)^{2n}} + \frac{1}{(1+r)^{3n}} + \ldots\right]$$

$$PV_k^n = \left[\frac{a^k}{1-a^n}\right]X \tag{3}$$

For example, the present value of an outlay of $10,000 (X = 10,000) beginning in the 10th year (k = 10) and then every 5 years (n = 5) thereafter is $37,937 with a 4 percent rate of interest (r = 0.04).

Similarly, the present value of a capital item costing *Y* dollars purchased every year (annuity) from time 0 is given by:

$$PV_0^1 = \left[\frac{1}{1-a}\right]Y \qquad (4)$$

To calculate the annualized user cost *Y* of a capital item costing *X* dollars purchased every *n* years, we need to set $PV_0^1 = PV_o^n$ and solve for *Y* in terms of *X*.

$$PV_0^1 = PV_o^n \qquad \Rightarrow \qquad \left[\frac{1}{1-a}\right]Y = \left[\frac{1}{1-a^n}\right]X$$

$$Y = \left[\frac{1-a}{1-a^n}\right]X \qquad (5)$$

For example, the annualized user cost of an item costing $1 million (X = 1,000,000), repurchased every 40 years (n = 40) is $48,578 with a 4 percent rate of interest (r = 0.04).

APPENDIX D1

Table D1 Present values of average costs of conservation and dissemination in perpetuity

	Present value of ACC			Present value of AQCC			Present value of AVC		
	2%	4%	6%	2%	4%	6%	2%	4%	6%
Wheat									
Conservation costs									
Storage cost	**11.11**	**7.20**	**6.04**	**19.90**	**10.14**	**6.89**	**13.77**	**7.02**	**4.77**
Maintenance costs									
New introduction	18.99	10.62	7.89	105.49	53.78	36.54	1.60	1.60	1.60
Germination testing	9.84	5.47	4.04	50.99	25.99	17.66	4.44	1.93	1.13
Regeneration/duplication	40.31	22.23	16.43	45.29	23.09	15.69			
50 years; w/o initial reg.							2.33	0.85	0.49
50 years; w/ initial reg.							5.49	4.01	3.65
25 years; w/o initial reg.							5.68	2.36	1.34
100 years; w/o initial reg.							0.84	0.36	0.30
Dissemination costs	**16.47**	**9.21**	**6.84**	**172.11**	**87.74**	**59.62**	**12.20**	**5.86**	**3.75**
Maize									
Conservation costs									
Storage costs	**89.31**	**57.13**	**47.47**	**157.09**	**80.09**	**54.42**	**104.55**	**53.30**	**36.22**
Maintenance costs									
New introduction	81.29	45.05	33.17	422.56	215.42	146.38	4.94	4.94	4.94
Germination testing	30.29	16.69	12.23	196.37	100.11	68.02	11.49	5.01	2.92
Regeneration/duplication	621.66	343.70	252.30	1326.53	676.27	459.52			
50 years; w/o initial reg.							89.87	27.48	11.96
50 years; w/ initial reg.							232.26	169.87	154.35
25 years; w/o initial reg.							231.44	91.21	47.92
100 years; w/o initial reg.							26.96	6.53	4.01
Dissemination costs	**82.50**	**45.42**	**33.28**	**725.70**	**369.96**	**251.39**	**58.13**	**27.92**	**17.89**

Note: The following equations in appendix C were used to calculate the present values of each activity. Germination testing, equation (3); Storage costs, equation (4); Regeneration/duplication (w/o initial reg.), equation (2); Regeneration (w/initial reg.), equation (1).

APPENDIX D2

Table D2 Present values of average costs of conservation and dissemination for the life of a genebank

	Present value of ACC			Present value of AQCC			Present value of AVC		
	2%	4%	6%	2%	4%	6%	2%	4%	6%
Wheat									
Conservation costs									
Storage costs	**6.08**	**5.70**	**5.45**	**10.89**	**8.03**	**6.22**	**7.53**	**5.56**	**4.31**
Maintenance costs									
New introduction	10.39	8.41	7.12	57.72	42.58	32.99	1.60	1.60	1.60
Germination testing	5.38	4.33	3.65	27.90	20.58	15.95	1.99	1.34	0.93
Regeneration/duplication	22.05	17.60	14.84	24.78	18.29	14.17			
50 years; w/o initial reg.							0.29	0.29	0.29
50 years; w/ initial reg.							3.45	3.45	3.45
25 years; w/o initial reg.							2.39	1.58	1.09
Dissemination costs	**9.01**	**7.29**	**6.18**	**94.16**	**69.46**	**53.82**	**6.10**	**4.38**	**3.27**
Maize									
Conservation costs									
Storage costs	**48.86**	**45.23**	**42.85**	**85.95**	**63.41**	**49.13**	**57.20**	**42.20**	**32.70**
Maintenance costs									
New introduction	44.47	35.66	29.95	231.19	170.55	132.15	4.94	4.94	4.94
Germination testing	16.57	13.21	11.04	107.43	79.26	61.41	5.15	3.46	2.41
Regeneration/duplication	340.12	272.11	227.77	725.76	535.41	414.84			
50 years; w/o initial reg.							3.58	3.58	3.58
50 years; w/ initial reg.							145.97	145.97	145.97
25 years; w/o initial reg.							92.55	58.34	37.59
Dissemination costs	**45.13**	**35.96**	**30.04**	**397.04**	**292.90**	**226.94**	**29.06**	**20.85**	**15.56**

Note: See notes to Appendix Table D1.

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